Technology

David Lopez Cornelio

Modeling land use sustainability in Fiji Islands

Research Paper (postgraduate)

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PREFACE

Fiji islands are among the most dynamic economies in the South Pacific, with rapid changes on infrastructure and industrial developments, tourism and commercial agriculture; even though they often come alongside environmental impacts on endemic biota and ecosystems that are not well understood, not much is invested on research to plan a sustainable use of land. Parallel unsolved concerns are land tenure issues in which ancestral community ownership coexists with modern markets; tensions over land leases between ethnical groups and high population growth trigger land use intensification, and rise of emigrations, of landlessness, of unemployment and finally of poverty. Therefore, it is of a national interest to asses these trends for long term sustainable land use planning; even nearly 3500 years ago a record of regulations aimed to achieve sustainability and equality: **3** … for six years you may plant crops in your fields, prune your vineyards, and gather what they produce. **4** But during the seventh year, you must let the land rest. **8** Count seven of these years seven times for a total of 49 years... during that time there will be seven ·years of rest **9** and proclaim liberty to everyone living in the land... everyone is to return to their own property (Leviticus 25).

In this document, the first chapter is a synopsis of land use in the rural areas of Fiji islands, its evolution, types, problems and alternatives, the second chapter is a review of some common free gis packages available in the internet useful for forestry and land use evaluations, their number and degrees of sophistication are ever growing; the last two chapters are applications, first on detecting the severity of land use intensity in relation to other socioeconomic parameters, and second on the planning of the best places for planting trees of economic or ecological importance. The articles were presented at international conferences, they are in no way a comprehensive treatise on the subject; my main purpose is to ignite the interest of students and staff working in the forestry field to try on and propose projects of various types, scales and complexity, with just a standard PC and access to internet and library resources. Thank you very much,

David Lopez Cornelio

CONTENTS

A synthesis on land use changes and agroforestry in Fiji Islands

Abstract

Agricultural development has a long history in Fiji Islands, since colonial times it evolved around sugarcane plantations; currently it is diverse, expanding and intensifying according to market demands and opportunities; with collateral environmental impacts such as soil erosion on hilly regions, unchecked agrochemicals usage and soil and water pollution. Agroforestry provides one of the best alternatives to increase yields on hilly terrain, diversify land production, maintain ecological systems and sustain other rural industries; however, its broad practice is still limited in the islands. Strategic long term planning and well implemented and integrated programs that combines traditional and new technologies are therefore necessary.

1.0 Introduction

Agroforestry is defined as the deliberate incorporation of trees into, or protection of trees within, an agro ecosystem in order to ensure its short and long term productivity, cultural utility, and ecological stability (Thaman and Clarke 1990). Agroforestry systems incorporate new economic opportunities with different benefits, markets, and production risks than commodity farming (Gold *et al.* 2004), serving as a model for integrative land use management systems currently being developed in response to global concerns. The prospects for regular availability of tree products can also reduce farmers' risk in the event of crop failures. Forty years ago they started to be promoted by western aid organizations working on marginal lands, a decade later low intensity indigenous cultivation systems were adopted and new criteria were identified for successful land use management strategies after decades of environmental damage (Turner 1980). Today, sustainability, stability and equality are as important as efficiency on agricultural production and yield optimization of timber different products and uses (Garret and McGraw 2000). Future concerns focus on fossil fuels substitution. The article discusses the historical, geographical and socioeconomic background of Fiji Islands to recommend directions on research and development of agroforestry systems.

2.0 Geography and land use evolution

Almost 70% of the land area of Viti Levu and Vanua Levu islands (87% of total Fiji Islands area) is steep mountainous terrain (Ushman 1984) (Figure 1). Viti Levu covers over half the total land area of the islands and is home to roughly three quarters of the population. Both islands are steep and volcanic with a rainy, tropical climate; the wet areas being in the south, the east and center are covered with dense vegetation and forest, while the drier west is savannah grassland. Mangrove forests dominate the coasts. Only 16% of the land is used for arable farming in valleys, river deltas and coastal plains. Patterns of crop planting are determined by variations in rainfall. Mean monthly temperature ranges from 23^{0}C in July and August to 27°C in January. The humid southeastern shorelines of the big islands get 3,000 to 5,000mm per year (FMS 2015).

The islands have formed from volcanic materials and sedimentary rocks, deposited towards the eastern margin of an ancient massive oceanic plate or platform. Extensive volcanic eruptions in Rotuma, Koro, and Taveuni islands raised limestone reef and alluvial terraces (Leslie 1997).

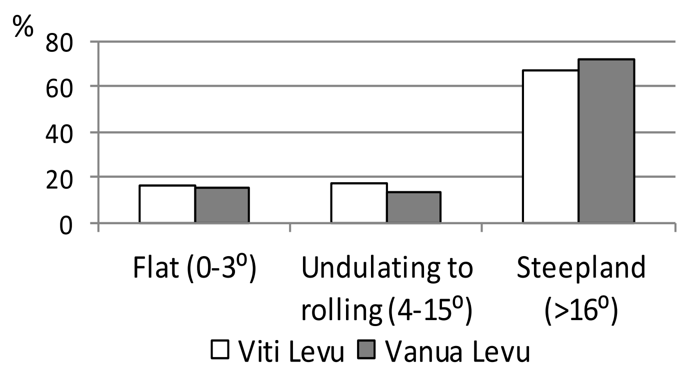

Figure 1. Slope and LUC classes. Source: Twyford and Wright (1965).

Nine of the eleven soil orders are represented in Fiji Islands (Leslie 1997); they are histosols (saturated or peaty soils), andisols (young, from volcanic parent materials), oxisols (oxides or Fe and Al, strongly weathered), vertisols (clayey soils), ultisols (strong weathered with an argillic horizon), mollisols (dark coloured surface horizon, high in organic matter and bases), alfisols (weak to moderately leached with an argillic horizon, low organic matter in the topsoil), inceptisols (weakly altered from parent material by leaching and weathering), and entisols (very young soils with little development of soil horizons). Coastal soils are young and sandy, developed soils are on flat and stable remnants of old plains and terraces. Soils from non-acidic rocks have deep red mottled profiles and iron oxide concretions in the upper horizons. Profiles from acid rocks are high in wet areas, tend to be yellow, mottled red, clayey and not well drained. Crops are exposed to nutrient deficiencies, coarse textured shallow soils in low atolls have low capacity to retain water or nutrients and the availability of trace elements is also low due to soil alkalinity. Potassium (K) deficiency is widespread in the islands, others reported are on nitrogen (N), phosphorus (P), calcium (Ca), sulfur (S), sodium (Na), iron (Fe), copper (Cu), zinc (Zn), manganese (Mn), boron (B), molybdenum (Mo) and cobalt (Co) (Asghar *et al.* 1986).

Class I soils covers only 355,902ha (19.4%), 22% in Viti Levu and 15% in Vanua Levu; they are first class soils suitable for cocoa, mango, dalo and sugar cane without modification. Class II soils comprehend 193,277ha (10.5% of Fiji total area), of which 8% are in Viti Levu, 13%, in Vanua Levu and 43% in Taveuni, they require minor soil conservation works. Class III soils group 587,002 ha, 42% in Vanua Levu and 29% in Viti Levu (figure 2). The largest class (IV) comprises 702,391ha (38.25% of Fiji), considered unsuitable for agriculture (Leslie and Ratukalou 2002).

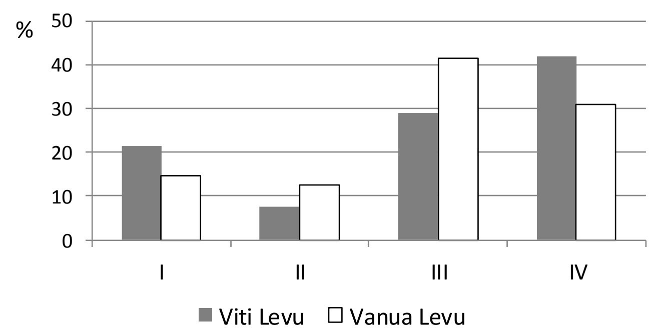

Figure 2. Major land utilization classes (%). Source: Twyford and Wright (1965).

First occupants arriving from Australia and New Guinea domesticated sago, Colocasia taro, Canarium nut, a kind of banana, Saccharum edule (duruka), kava, Pandanus, Burckella and Pometia, including the management of coconut, 2-3 species of pandanus, Inocarpus fagifer (tahitian chesnut), Canarium indicum, Spondias dulcis, Pometia, Pangium, Terminalia, Burckella, Calophyllum, and hardwood trees for handicrafts around 4000 years ago (Clarke 1993 and Kirch 1984). As cultivation of sago moved from New Guinea to the Solomons and Vanuatu, Metroxylon sagu shifted to M. salomonense, and the epidemic M. vitiense in western Polynesia and Micronesia emerged. Common wild vegetation is a mixture of introduced mission grass (Pennisetum polystachyon), wire grass (Sporobolus spp.), and thickets of guava scrub (Psidium guajava), with remnant trees of ironwood (Casuarina equisetifolia) and vadra or screw-pine (Pandanus tectorius). Typical trees in the range 150-365masl include baka (Ficus oblique), vau (Hibiscus tiliaceus), koka (Bischofia javanica), ivi (Inocarpus edulis), vesi (Intsia bijuga) and vaivai (Serianthes vitiensis) (Kuhlen 1994). The traditional multiple uses of Cocos nucifera (Coconut palm), Hibiscus tiliaceus (Beach hibiscus) and Mangifera indica (Mango) and a comprehensive list of useful trees according to main characteristics and tolerances, origin, main products and main uses were described in detail by Thaman *et al* (2010). After the first settlements were well-established, there was a period of indigenous agroforestry enrichment and deforestation that lasted tens of thousands of years in Papua New Guinea, and 800-3000 years for most of the islands of Melanesia, Polynesia and Micronesia (Thaman *et al*, 2010). In the early 1800s most of the land area was under forest (Leslie and Ratukalou 2002). Large fires were reported in the 19th century, burning for as long as a week. Ecosystems were modified by tillage, mounding, permanent clearance of forest, control of fallow cover, drainage, irrigation, ponding, exclusion of livestock, weeding, prevention of erosion, and deliberate fertilization. Currently a complex mosaic comprising fern lands, open grassland, reed grass and largely man-induced savannah revert to forest cover in a slow and steady succession process if the land is under fallow. Fire-maintained fern-grass savannas are common on infertile, eroded, or truncated red soils (*talasiga*) with few casuarina and pandanus trees. The *talasiga* grasslands are considered by most to be artificially induced by slash and burn practices, however Nunn (2003) points to nature-induced fires and the temperatures and sea levels rise during 750CE–AD1300, increasing aridity, decreasing food supply by 80% and leading to the formation of larger human settlements. The construction of Ring-Ditch fortifications of at least 350m diameter demanded 11,000man days of labour, the movement of over a million cubic feet of soil, and the use of 6000 posts, 11000 lenghts of bamboo, and 6000 plantains to place between the posts (Parry 1977). Intensive, highly productive and sustainable systems developed in pre-colonial times provided techniques and basic principles for farming difficult environments (Denevan 2001). Yams, more consumed in the past, were planted on terraces facing the tradewind, enforced with bamboo shoots to retard soil erosion (Twyford and Wright 1965). Traces of them are dispersed in 39 localities in the Sigatoka valley (Parry 1987) with sizes of 0.5-50ha range, and of 4-10m range width. Aerial photos verify the once intricate hydrological system of nineteen century terraced gardens in the Rewa and Navua deltas, now largely abandoned. In the Nakauvadra valley, streamside elevated terraced gardens are stone-faced, some walls are of over two meters in height and over a meter of fill beneath the garden soil (Kulhken 1994). Before colonization land supplied all family needs, although the gardens were of larger size than today, the actual cultivated areas were limited by the tools available, and the administrative units were also smaller than today.

3.0 Land tenure and agricultural development

A large quantity and variety of traditional food crops grown in Fiji (figure 3) are a “hidden strength” in the economy (ADB 1996). The Pacific islands in general have some of the highest rates of nutritional disorders and nutrition-related non communicable diseases in the world (Thaman *et al*, 2010). Farmed areas are larger in Western and Northern regions, these two regions also hold the largest remaining areas of native forests and tree plantations (figure 4). The agricultural industry had a growth of 3.4% in 2013 driven by increases in sugarcane, yaqona, taro, and coconut production. Sugarcane output increase of 25.8% was due to improved supply and milling efficiency (Reserve Bank of Fiji 2015); it recovered from a decline by 26.2% in 2012 year (Reserve Bank of Fiji

2013). Sugar is mainly grown in the drier north eastern side of the islands by around 22,500 farmers, each cultivating 4-5ha on average producing up to 400,000 tons per year (Reddy 2003). The state Fiji Sugar Corporation manages the sugar industry making contracts with growers and processing sugar cane at four mills.

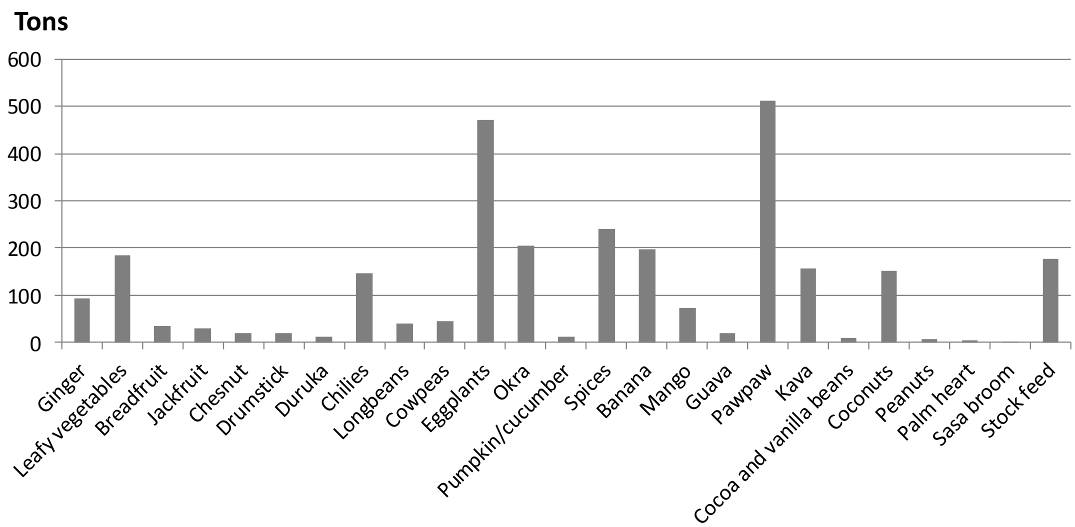

Figure 3. Volume of agricultural exports (tons). Source: MAPI (2007). Root crops (not included in graphic) comprised a total of 11,929 tons.

Since the mid-1990s squatter settlements in Fiji expanded rapidly largely due to a halt on agricultural land leases (Thorton 2009), a problem that may fuel deforestation since one of the most visible ways to fix ownership in developing countries is by land clearing, even if the opened space is not used productively (Smith *et al* 1995). Eighty four percent of the land is hold under customary ownership, 38% of it is leased, only 85 of the total land area is of freehold and 3.8% belongs to the State (Walsh 2006). Customary tenure that provided in the past for elements of taxation as contribution in labor, food or service to the community, is now ineffective due to the patterns of inheritance, the increasing distances to the farms (Crocombe 2001), and its inability to provide permanent use rights to farms larger than 3ha (IBRD 1965) which constitute 40% of the total farms in Fiji Islands. A second factor is related to sugar cane production decline by 42% once the land reverted to Fijian ownership, with consequent delays on planting and poor cultivation practices (Prasad 1984). However, most native Fijians do not have real access to land (Crocombe 2001). Although the predominant view is that long term leases encourage the buildup of permanent structures and planting of perennial crops (Ushman 1984), some argue that they are not necessarily essential for first-best investment incentives, and that rental markets are hardly ever pro-poor (Ciamarra 2004). The common view is that future strategies will have to enhance production in accordance to the land capability and assist on downstream production and marketing (Leslie and Rokatuvalou 2002).

Most Fijian rural households include a wage earner, they produce both food and cash crops, many earn additional income from fishing. Wet areas produce coconuts, ginger, cassava, taro, kava, bananas and breadfruit; areas with intermediate rainfall produce vegetables, cocoa, passion-fruit and maize, and in minor scale sorghum, tobacco, sweet and Irish potatoes and turmeric. Dry areas produce upland and irrigated rice, mung beans, pigeon peas, yams, citrus fruit, pineapples and mangoes. Over 40,000 households rely mainly on coconut sales (copra) (Thaman *et al.* 1993). Breadfruit tree is used for making canoes, bamboo for fishing poles, housing and rafts; other native trees with high demand for woodworking and handicrafts industry are vesi (Intsia bijuga), nawanawa (Cordia subcordata), and mulomulo (Thespesia populnea). The plantation sector groups twenty five coconut estates, often with beef cattle and dairy farms with over 50 cows. The government has several large farms for livestock research and breeding stock distribution (Leslie and Ratukalou 2002). Other common livestock are poultry, goats, and pigs.

Sixty nine per cent of the population resides on Viti Levu island while 20% and 10% in Vanua Levu and Taveuni islands respectively. Ethnic Fijians reside in nuclear villages, the households are normally economically inter-dependent (Chandra 1983). The fijian word for land (*vanua)* includes the people attached to it. Indo-Fijians households by contrast show no economic inter-dependence. Farm size varies as follows: 2.81ha at Western, 2.54ha at Central, 11.29ha at Northern and 3.09ha at Eastern Districts (Macfarlane 2008). Smallholder systems, in some cases with several households per farm, can be of subsistence, semi-commercial or highly commercial. A source of inequality in farm size is the demographic differentiation, as households appear, grow and mature, the changes in land holdings reflect the fluctuations in the demand for land associated with each stage, resulting in a successive subdivision of land (Chayanov 1966).

The country implemented a framework for evaluating sustainable land management (FESLM) and a decision support system (DSS) to assist on organizing land use in accordance to its real capability at farm, village, watershed, and regional scales by integrating socioeconomic and biophysical data with indigenous knowledge (Rais *et al*. 1997). FESLM aims to enhance production, reduce the level of production risk, protect the natural resources, be economically viable, and socially acceptable (FAO 1993). Its performance is monitored by checking crop yields, nutrients balance, forest regeneration capacity, soil cover maintenance, soil and water quality and quantity, net farm profitability, and participation.

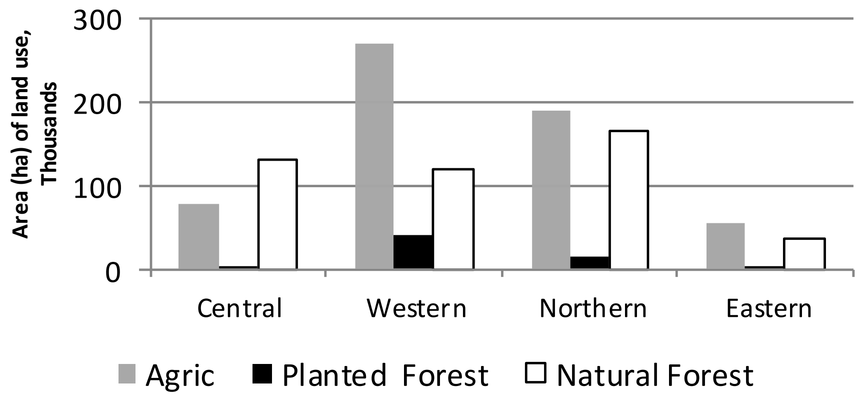

Figure 4. Main types of land use per division in Fiji Islands. MAFFA (1992).

4.0 Agroforestry systems: current situation and future

Contour hedgerow is the principal agroforestry method of soil conservation with annual crops to reduce run-off, increase infiltration and reduce soil loss through the effect of the barrier, maintain soil organic matter through leaves and root residues, and lead to a progressive development of terraces by accumulation of soil upslope of hedgerows and stabilization of rivers by stems and roots (Young 1997). Trees or perennial crops are planted as a barrier along the contours of a slope, and agricultural crops are planted between them (McDonald *et al.* 1997). Major interactions in hedgerow intercropping that affect crop yields are related to soil fertility, competition, weed control, and soil conservation particularly on sloping lands. Hedgerow intercropping might increase the yield of the closest crop rows on the sheltered side (Huxley *et al.* 1994) and in short periods of time (Banda *et al*. 1994), control soil erosion (Kiepe and Rao 1994), and reduce soil evaporation when pruning are applied as mulch (Tian *et al*. 1993).

Depending on the specie, trees improve soil fertility and modify the microclimate under their canopy. The magnitude of change depends on canopy and root characteristics, age, size and trees density. Boundary plantings generally reduce crop yields but the effect extends over a relatively small area. The productivity of an agroforestry system depends on: (1) the complementary of resource use by the components, (2) the efficiency of nutrients cycling, and (3) the net value of harvested tree products relative to the net value of crop products (Rao *et al*. 1998). Tree desirable characteristics include a supply of viable seed, fast growth, nitrogen fixation and copious biomass production for use as mulch, fodder, and fuel wood. Selected shrubs and tree should: i) be adapted to the local soil and climate conditions, ii) have low demand for nutrients and be nitrogen fixing, iii) contribute to soil conservation and biodiversity, iv) be culturally accepted by farmers and v) provide economic products. For this, some areas that need research are the study of litter fall and associated processes, net primary productivity, carbon sequestration, microbial competition, root competition, albedo-reflectance changes at the landscape level, silvopastoral systems, economics, pharmaceutical products and conservation biology (Gordon *et al.* 1997).

In the mid-1970s the Native Land Trust Board identified land growing cane as “arable”, irrespective of local slopes (Leslie and Rotukalou 2002). The land use section of the Ministry of Agriculture developed a farming model for steep slopes in which three hedgerows (*kava, pigeon pea*, pineapple, *vetiver* grass) are placed 20m apart. *Vetiver* grass hedges are more effective on controlling soil erosion than pineapple barriers or traditional farming (figure 5). The grass is also traditionally used in thatch making and handicrafts but hedgerows established in sugar cane farms 40-50 years ago were removed to prevent its uncontrolled propagation (Craswell *et al.* 1998). Areas growing sugar and ginger at slopes over 8^0 are prone to high soil erosion, the same with broad burnt areas of cane trash, native forests and pine plantations (Galletly and Swartz 1974). Sustainably or not, the forestry sector based on pine and mahogany production increased by 10.9% (FBoS 2014).

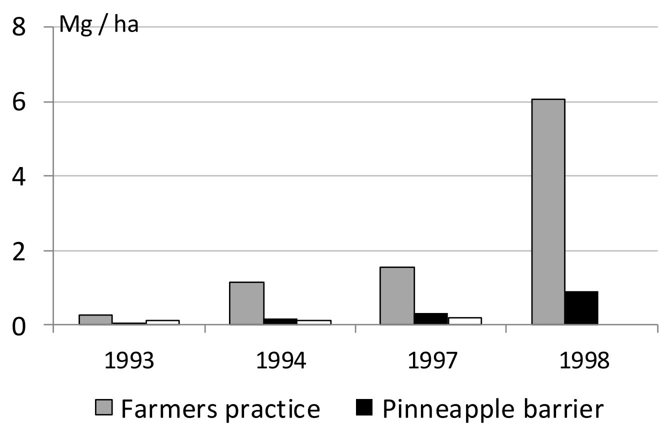

Figure 5. Soil erosion rates at Waibau plots, Fiji with a slope range of $24\text{-}29^0$. All treatments were cropped with cassava. Source: IBSRAM (1996) and Ratukalou (1998).

Alternatives to tree hedgerows are rows of pit pit (*Saccharum edule*), valangur (*Polyscias grandiflora*), gaga (*Heliconia bihai*) and banana (Craswell *et al.* 1998). The benefits of the hedgerow treatments at early stages after establishment do not outweigh the costs to the farmer, unless the specie planted on the contour is a cash crop such as pineapple (Pratap *et al. 1*996). The sloping agriculture land technology (SALT) is a form of alley farming in which annual and perennial crops are grown in bands 4-5m wide between rows of legume trees and shrubs. In a *line planting system*, trees are planted in lines at 10x1m or 15x1m spacing at east-west direction to maximize sunlight intake, with interplanted crops between lines.

Silvopastoril systems are intensively managed production systems. Their commercial viability is influenced by land ownership patterns, soil conditions, climatic factors, proximity to timber and livestock markets, and transportation infrastructure (Sharrow *et al*. 1996). They may outperform pastures and forests as carbon sinks. Sharrow and Fletcher (1994) found that Douglas Fir trees associated with pastures in Western Oregon accumulated approximately 740 kg $ha^{-1}yr^{-1}$ more carbon than forest, and 520 $ha^{-1}yr^{-1}$ more than pastures during the 11 years after planting. Increased tree growth of 5 to 10% can be achieved when proper timing, intensity, duration, and class and type of livestock are applied to young conifer forests where palatable understory grasses or shrubs are competing with trees (Sharrow *et al*. 1996). Plants that can be shaped into hedges are cassava, gliricidia and *Erythrina* tree species). Live stakes are also used to support climbing plants such as black pepper, betel, vanilla and yams (Verheij and Waaijenberg 2008). Economic risks decrease because livestock and forest components require different inputs, share few common diseases and pests, and sell into different markets; in addition, trees can have a climate-stabilizing effect on livestock, resulting in less energy consumption and lower mortality.

Recent tree introductions with increased importance in Pacific islands agroforestry systems are Albizzia sp., Cassia sp., Gliricidia sepium, a range of eucalyptus or gum trees, caribean pine (Pinus caribaea), big-leaf mahogany (Swietenia macrophylla) and jambolan (Syzygium cumini) (Thaman 1994). Leaves and pods from Leucaena leucocephala, Gliricidia maculata, Erythrina species (drala) and Calliandra calothyrsus contain high amounts of crude protein, ideal as animal feed in dry seasons (Singh 2001). When intercropped with coconut palms, they control weeds, improve soil structure and copra yields. Fodder is obtained by cutting at 50-150cm height every two months, and fuelwood by pruning every 3-4 months (Rosa 1993). Casuarina equisetifolia, australian kauri (Agathis robusta) or mahogany (Swietenia macrophylla) are planted in a few rows along the perimeter or along the roadside border of the allotment, or sometimes as a small woodlot on part of the allotment (Thaman *et al.* 2010). Kellas *et al* (1995) recorded higher pasture production at 10.5m and 18m distance from the tree line than in open pasture systems, although production tended to decrease when tree density increases. Mahogany (Swietenia mahogani L.) is large, fast growing timber specie that does not fully utilize solar energy and soils at early stages of the life cycle. Datta and Dey (2009) successfully transplanted five weeks old chilli seedlings into four years mahogany plantation at 5x3.5m spacing. In Labasa turmeric is intercropped with cocoa plants, and tissue cultured bananas and sweet potatoes with Mahogany, Vesi, and Dakua trees at the farm borders (http://agroforestrypacific.blogspot.com), and turmeric is with cocoa plants. *Santalum yasi*, a semiparasitic oil producing shrub with high demand, was observed with 16 host trees in Viti Levu farms (Goswami and Singh 2014). Widely studied but hardly associated with crop farms in Fiji, coniferous trees are of easy site adaptability and rapid response to intensive management, their conical crowns allow more light to reach the forest floor and are less likely to be browsed by livestock (Sharrow and Fletcher 1994).

5.0 Discussion and conclusions

Fiji Islands are undergoing increasing pressure to increase cropping areas and shorten fallow periods between crops, resulting on severe cases of soil erosion and nutrients deficiencies. The slow conversion of mono cropping into agroforestry systems brings economic and ecological benefits in the medium and long term; however most farmers are still driven by short term decision making due to land tenancy insecurity and misinformation on sustainable land use practices. It corresponds to the government to establish policies that specify a minimum number of trees per hectare that should be planted by the tenant, and to provide simple technical guidelines for intercropping with different crops. These guidelines can be based on latest tested trials and on ancient traditional practices widespread in the South Pacific, incorporating both fijian and indo-fijian interests and culture in the market. Agroforestry systems provide ways to manage scarce natural resources that balances environmental stewardship, financial feasibility and social responsibility. Although the islands have great potential to develop them enhancing agricultural yields, controlling soil losses, and mitigating climate change effects; basic research on their socioeconomic impacts, species ecology, symbiotic and allelopathic relationships, appropriate low cost down streaming techniques and marketing are needed. Unsolved land tenure issues discourage long term investments on land development; however, planting delays and/or overextended fallows ultimately restitutes soil fertility. The re-establishment and intensification of appropriate time-tested systems of tubers (or others) cultivation like irrigated terraces, and forest taro production are recommended in hilly areas. Ambitious agricultural plans like the ones described in the national 2020 agriculture sector policy agenda need to stress the importance of research and extension, the opening of new markets for organic products, prices stability, and transparent land rights that will prevent both land misuse and overuse, and encourage long term investments. Future land reformation plans will have to be implemented step by step according to local conditions, facilitate productivity, overcome the legacy of colonial tenures, and reestablish a more effective organizational structure within groups of joint landholders.

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Alternatives on GIS&RS for forestry applications in the Pacific Islands

Abstract

Land scarcity and global warming in the Pacific Islands demand the monitoring of changes in real time and at different scales, and the implementation of systems of land use allocation for sustainable agricultural production, conservation and development expansion. Although open source software (OSS) for GIS and remote sensing are rapidly expanding worldwide and improving, there has been uncertainty at higher education institutions regarding the selection of appropriate software for teaching and research purposes. The paper briefly describes the characteristics of some mature OSS and discusses their main capabilities, advantages and disadvantages. Their adoption in a forestry curriculum may be advantageous in the long term, considering issues of learning curve steepness, versatility, affordability, effectiveness, and documentation available on them.

Keywords

Open source software, GIS and remote sensing software, forest mapping

1. Introduction

Geographic information systems (GIS), a key technology for developing countries, is defined as a system of software components that maintain a spatially aware database, provides analytical tools that enable spatial queries of the database, allows the association of locations with imported graphical data, and provides graphical and tabular outputs. Of particular interest is the adoption of OSS for GIS in developing countries as a means of reducing licensing costs and of promoting indigenous technological development, by avoiding being hostage to proprietary software (United Nations 2004), and by assisting the setting up of an information economy (Weerawarana and Weeratunga 2004). The open source components are distinguished depending on the project (Bivand 2011) by the availability of open source software licenses, by access to bug trackers, mailing lists, and by the documentation of external dependencies in the build and install system (figure 1). Large scale environmental and socio-economic applications compel OSS to include significant spatial analysis capacities to meet the needs of end-users (Goodchild 2003) in areas such as spatio-temporal data models (Erwig *et al.* 1999), geographical ontologies (Fonseca *et al.* 2002), spatial statistics and spatial econometrics (Anselin 1999), cellular automata (Couclelis 1997), and environmental modeling (Burrough 1999). The article describes some OSS for GIS of potential utility on forestry training in the Pacific islands.

2. Assets and challenges for GIS Implementation in the Pacific islands

Most undergraduate students acknowledge the usefulness of maps and basic surveying tools they may use when employed by either the ministry of forestry, NGOs, logging companies or private projects, with the challenge to solve practical problems in remote areas. Most of them are also financially able to purchase a personal computer, have intermediate computer skills, and can access the internet. Besides the high acquisition cost of latest digital data, most areas in the islands are of difficult access, and inter institutional cooperation to implement programs related to climate change adaptation, rural poverty alleviation or biodiversity conservation is still weak. Most training institutions count with insufficient number of PCs equipped in most cases with commercial software with licenses that have to be yearly renewed. In Fiji a general unit on GIS has to be completed in 11 weeks after one on forest survey and mapping. Other inconveniences are unstable power supply, narrow internet bandwidth connection, low graduates continuity rate on GIS projects (less than 10% of them) and budget shortage to upgrade labs and equipment.

2. Causes of software dependence

Advantages of open source software such as cost savings, vendor independence, and open standards, are more known than the disadvantages such as knowledge barriers, legacy integration, forking, sunk costs and technology immaturity (Nagy *et al* 2010). Most users are concerned about the long-term maintenance of their files and applications, on the sustainability of OSS projects (with different data model and user interfaces), and on the costs of data conversion (commercial GIS products use proprietary data formats) even though the algorithms of commercial software cannot be examined neither distributed (the original software is required to run the model) (Brent 2008). Unlike their proprietary counterparts, OSS web mapping technologies range from internet map server applications (MapServer) and spatial database management systems (PostGIS) to desktop GIS for data editing and analysis (QGIS, SAGA). The term ‘free software’ is not used in the sense of ‘free-of-cost software’ (Neteler and Mitasova 2008), it rather addresses the freedoms of the user to use, study, modify, and distribute software. An approach that mitigates several software development problems is their modularization by making several logical parts independent from each other (components or libraries), an advantage when direct communication among developers located worldwide is sometimes difficult and time consuming. This model results in one or several core libraries that contain the most important functions (e.g. data input and output, geometry and feature model, user interface classes, etc.) and additional libraries built on top of them that allows the distribution of a basic application with core GIS functions (figure 6); whereas advanced or special GIS functionality can be delivered via so-called plug-ins and extensions, which is the case of GRASS, QGIS, MapWindow, gvSIG, uDig and OpenJUMP projects; resulting in a flexible OSS GIS user community that chooses the best software for each task to accomplish (Neteler and Mitasova 2008). The Open Source Geospatial Foundation (http://osgeo.org) bundles several OSS projects, including GRASS.

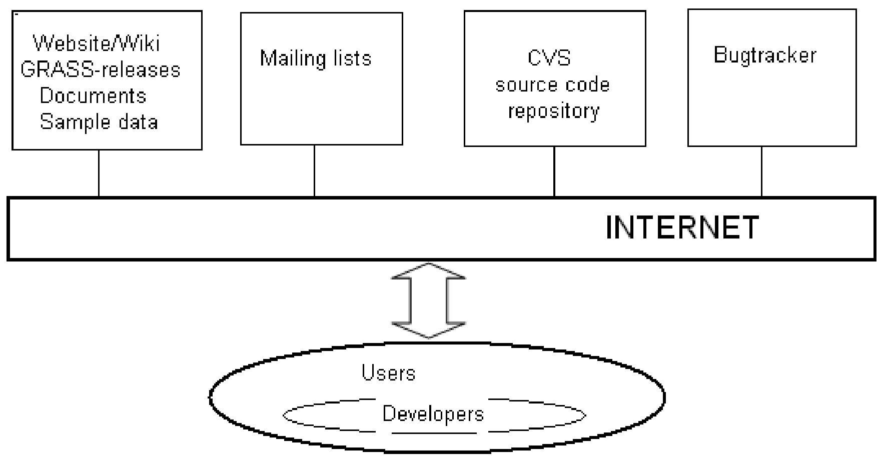

Figure 1. Development Model: Developers' and users' interaction with semi-automated development tools over the internet.

4. Open source GIS and RS projects

New projects are appearing in the internet with enhanced capabilities and new applications with different levels of complexity (figure 2). A robust Open Source GIS software is achieved when: (i) quality algorithms due to public peer review, (ii) facilitation of customization, and (iii) good and fast support via email lists and Web forums (Steiniger and Hay 2009).

4.1. The Geographic Resources Analysis Support System (GRASS)

Released in the 1980s by the US Construction Engineering Research Laboratory (CERL) for military applications, it evolved into one of the most comprehensive, general purpose OSS. GRASS (http://grass.osgeo.org) is a raster/vector GIS combined with integrated image processing and data visualization subsystems. It includes more than 350 modules integrated in pull down menus for management, processing, analysis and visualization of geo-referenced, spatial data, using both an intuitive graphical user interface and command line syntax for ease of operations (Neteler and Mitasova 2008). Whenever a new project (LOCATION in GRASS terminology) is created, the projection and coordinate system must be defined. The map projection definition is stored in an internal file within the given LOCATION which can have several MAPSETs (LOCATION subdirectories) used to subdivide the project into different topics, sub regions, or as workspaces for individual team members. Besides access to his own MAPSET, each user can also read maps in other users' MAPSETs, but he can modify or remove only the maps in his own MAPSET (Neteler and Mitasova 2008). All MAPSETs include a WIND file that stores the current boundary coordinate values and the currently selected raster resolution. When creating a new LOCATION, GRASS automatically creates a special MAPSET called PERMANENT designed to store the core data for the project, its default spatial extent in the DEFAULT_WIND file and coordinate system definitions. GRASS can be linked directly to several software applications including Quantum GIS, Sextante (an analytical extension for gvSIG), statistical and geostatistical support (R Statistical Computing Environment, gstat, MATLAB), and rendering and multi-dimensional visualization software (Furlanello *et al.* 2003; Bivand *et al* 2008; Neteler *et al* 2008). In the field of ecology, Garzon *et al* (2006) built a modeling framework for predicting forest areas by integrating a machine learning extension of R within GRASS for predictive habitat modeling of pinus silvestris on the Iberian peninsula. The ISAMUD system for wildlife management integrates spatial databases with GRASS, using it to compute spatial statistics on locations, trajectories and home ranges from GPS collar wildlife data based on their environmental attributes (Cagnacci and Urbano 2008). Ortigosa *et al* (2000) integrated a tool for habitat suitability assessment with GRASS.

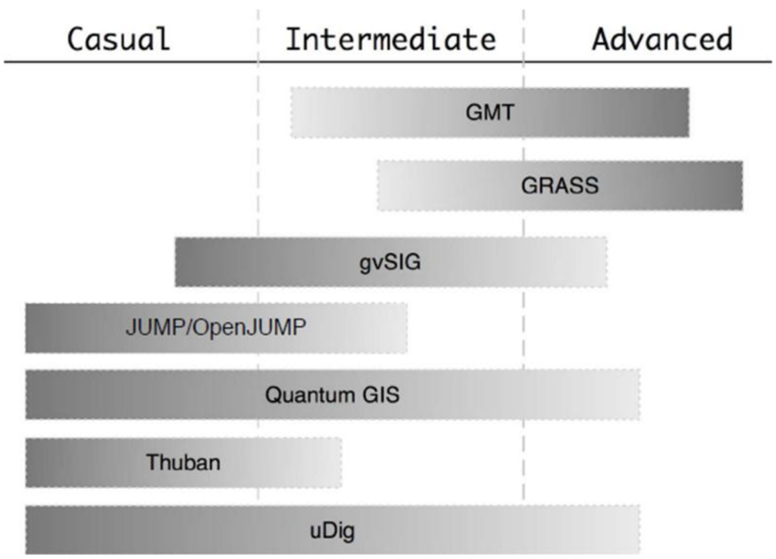

Figure 2. Functionalities complexity of some OSS projects. Source: Sherman (2008).

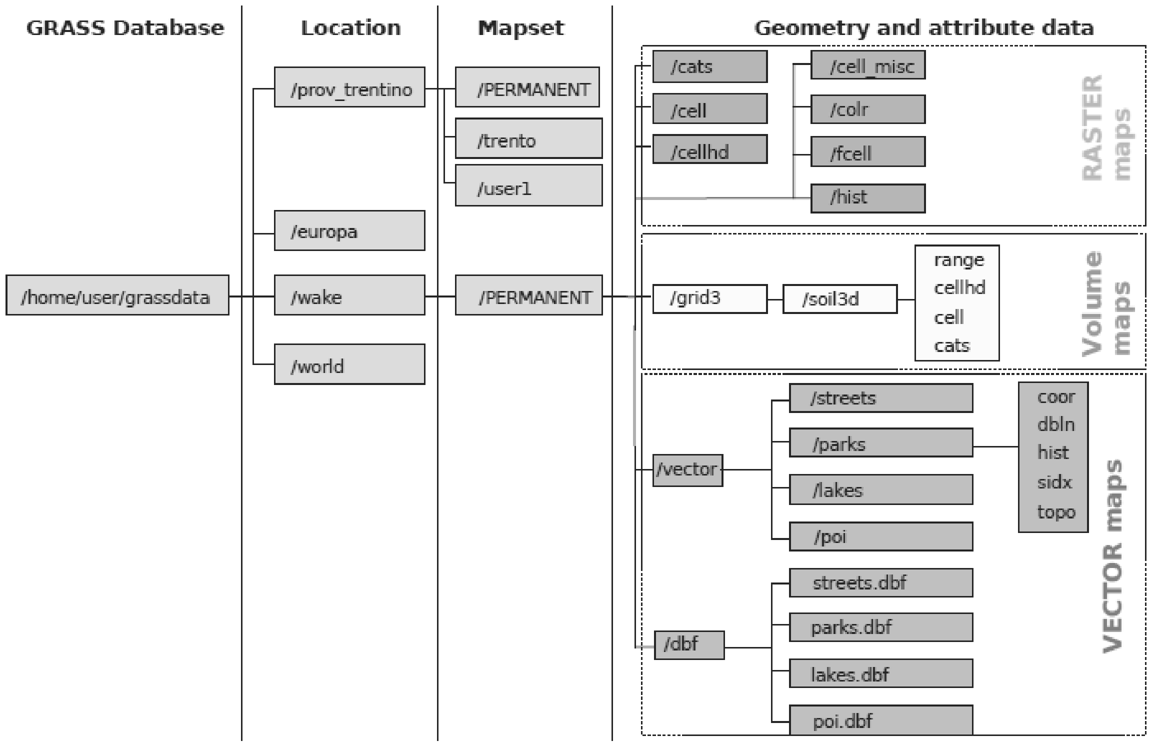

Figure 3. Organization of GRASS data directory, LOCATIONs, MAPSETs, vector and raster maps. Source: Neteler and Mitasova (2008).

4.2. Quantum GIS (Qgis)

Conceived by Gary Sherman in C++ and Python (Sherman, 2008), is the preferred visualization environment for GRASS users providing a modern user interface and map element symbology editor. The software provides useful GIS tools in spatial analysis, geoprocessing, geometry, and data management tasks (Ming-Hsiang and Smith 2011). The current version of QGIS contains a graphical interface to most GRASS tools, a graphical data catalogue, and a native vector digitizer. Javagrass (http://www.jgrass.org) is an alternative user interface which includes 3D visualization. Qgis provides tools in spatial analysis, geoprocessing, geometry and data management with special focus on hydrological and geomophological analysis. The integration of a WMS and WFS server into QGIS allows a seamless crossover from desktop to the web. The Web Map Service (WMS) provides a simple HTTP interface for requesting geo-registered map images from one or more distributed geospatial databases; whereas the Web Feature Service Interface Standard (WFS) defines web interface operations for querying and editing vector geographic features, such as roads or lake outlines. The fusion with the uDig software project is ongoing, adding 3D visualization and further GIS analytical capabilities to uDig. There are over 100,000 Qgis users worldwide (Sherman 2008).

4.3. MapServer

The best-known web map servers are (UMN) MapServer (Kropla 2005) and GeoServer (Erle *et al* 2005). Both solutions are comparable to similar proprietary solutions with respect to functionality and performance (Aime and McKenna 2009). They offer vector and raster support, and conform to a number of OGC web mapping standards including WMS, WFS, WCS, GML, and SLD. MapServer runs as a Common Gateway Interface (CGI) application within the Apache web server environment. The platform was originally developed at the University of Minnesota in 1994 with NASA funding. It creates map images from spatial information stored in digital format, handles both vector and raster data rendering over 20 vector data formats, including shapefiles, PostGIS and ArcSDE geometries, OPeNDAP, Arc/Info coverages, and Census TIGER files (Kropla 2005). MapServer is template based; when first executed in response to a web request, it reads a configuration file (mapfile) that describes the layers and other components of the map, then draws and saves the map. Next, it reads one or more HTML template files that are identified in the mapfile; each template consists of conventional HTML markup tags and special MapServer substitution strings that specify the paths to the created map image, identify which layers are to be rendered, and their zoom level and direction. MapServer substitutes current values for these strings and then sends the data stream to the web server, which then forwards it to the browser. The .map file is the basic configuration file for data access and styling for MapServer, it is an ASCII text file made up of different objects, each with a variety of parameters documented in the mapfile reference. MapServer has the ability to create maps as part of a larger application so that images are written to a writable directory and referenced in templates, or it can act as a map engine and return an appropriate mime-type and binary stream directly to the client browser. The latter is a useful feature for embedding links to dynamically created maps using a simple HTML image tag. MapServer supports the automatic generation of components a user would normally find on a map including legends, scale bars and reference or key maps. It also contains powerful feature query capability. When returning a set of query results, MapServer uses one or more templates to present what can be a complex and diverse set of information (Kropla 2005). A result set can contain one or more features for one or more layers. A series of header and footer templates can be (optionally) used to frame individual feature information.

4.4. The Integrated Land and Water Information System (Ilwis)

Initially developed and distributed by ITC Enschede (International Institute for Geo-Information Science and Earth Observation) in the Netherlands (ITC 2015), it has been distributed under the terms of the GNU General Public License since 2007. The current version (3.8.1) is similar to GRASS GIS in several ways and is one of the most user-friendly integrated vector and raster software programs currently available only on Microsoft windows; although a Linux wine manual has been released for Linux users that wish to run windows programs. Features available for vector data include digitizing, display, interpolation and calculations. For raster data, the functions include creation of digital elevation models, slope, aspect, and distance calculation, besides common image processing capabilities such as statistics, filters, mosaic, georeferencing, classifications and histograms (Ming-Hsiang and Smith 2011). Figure 4 shows a study case in which Ilwis was used for cyclone hazard zonation in the south of Chittagong, Bangladesh, using data of the April 1991 cyclone. The project produced several maps of the expected number of casualties per village and population category caused by cyclone flood events with return periods of 5, 10, 20 and 50 years. Prior to this, maps of the flood depth per return period, population density and population vulnerability to flooding have to be made. To calculate flood depths a DTM and a linear flood-decay model were used.

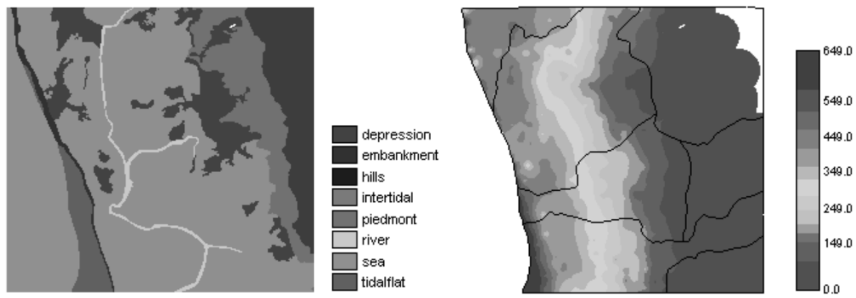

Figure 4. Overview of study area and hazard map for a surge depth of 650cm. Source: (Damen and Westen 2008).

4.5. PostGIS

PostGIS (http://postgis.refractions.net/) is the most popular open source GIS database engine built upon the PostgreSQL object-relational database. Many developers consider that PostGIS challenges several commercial GIS databases, such as Oracle Spatial and Microsoft SQL Server Spatial (Ming-Hsiang and Smith 2011). It allows location queries run in the simple features of SQL specification from the Open Geospatial Consortium (OGC) (SVN 2016). Most of the OGC standards depend on a generalized architecture captured in a set of documents collectively called the Abstract Specification, which describes a basic data model for representing geographic features, on top of which a growing number of specifications or standards have been developed to serve specific needs. The sequence to use PostGIS layers are: 1. Open the PostGIS dialog box by clicking the Add a PostGIS Layer tool, 2. Select the connection to use or create a PostGIS connection to the database, 3. Connect to the database, 4. Select the layer(s) wished to be added to the map, 5. Optionally specify a query to limit the features returned, 6. Optionally set the encoding, 7. Add the layer(s) to the map canvas by clicking the Add button (SVN 2015).

4.6 uDig

The User Friendly Desktop (uDig) Java-based desktop GIS, designed by Refractions Framework Research (http://udig.refractions.net) is a frequent framework for building other GIS platforms and applications like DIVA-GIS, and the Distant Early Warning System for Tsunamis (DEWS). It offers strong capabilities to integrate web mapping technologies, such as WMS, WFS, remote ArcSDE, WCS, GeoRSS and KML. The uDig website includes good tutorials and walkthrough documents for first-time users (Ming-

Hsiang and Smith 2011). It provides viewing and editing for a variety of data formats, including the usual file-based layers (shapefiles and rasters), PostGIS layers, WMS, WFS, Oracle Spatial, and DB2 that cover most of common data needs (figure 5). It is written in Java and released under GNU Lesser General Public License, it has a walkthrough in Flash and quick start directions for those who wish to complete a full version build to write plug-ins or contribute to the main build. It can use GRASS for complex vector operations and embedded JGRASS and specialized hydrology tools from the Horton Machine. It supports shapefiles, PostGIS, WMS and many other data sources natively, and is used by several well known companies such as Spatial Systems Consulting Company (Canada), LISAsoft (Australia), CampToCamp (Switzerland and France), HydroloGIS (Italy), and Axios (Spain) (Eichar *et al.* 2015).

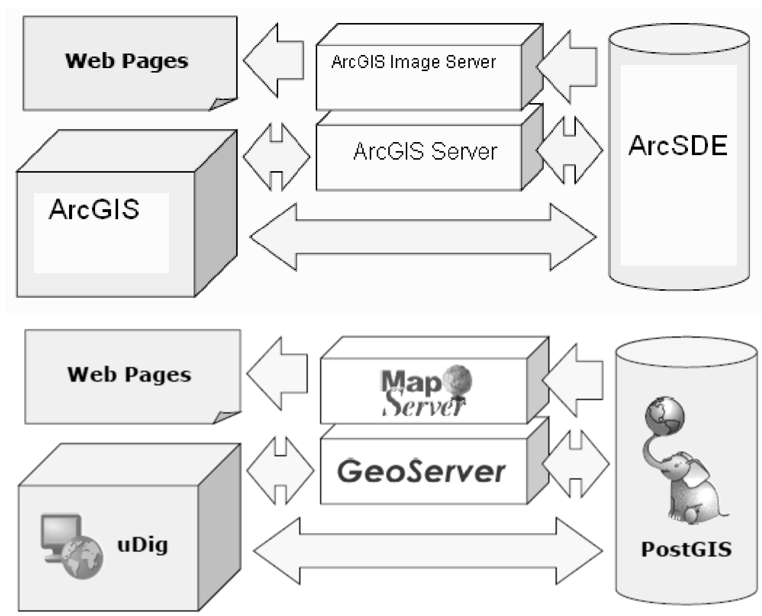

Figure 5. ESRI and Open Source Geospatial architectures comparison. Source: Eichar *et al* (2015).

4.8 The Generic Mapping Tools (GMT)

An open-source collection of computer software tools for processing and displaying xy and xyz datasets, including rasterization, filtering and other image processing operations, and various kinds of map projections. Written in C, It was originally developed in 1988 by Paul Wessel and Walter Smith and is currently hosted at the University of Hawaii. The letters GMT originally stand for Gravity, Magnetism and Topography, the three basic types of geophysical data as most of its users are geoscientists. Besides its strong support for the visualization of geographic data sets, the software includes tools for processing and manipulating multi-dimensional datasets. It has 60 specialized map making commands with output to publication-quality PostScript format making possible to fill the gap in hard copy map production that has troubled GRASS users for long (Wessel *et al.* 2013). Although several attempts have been made to integrate GRASS and GMT (Beaudette 2007), most are based on the “loosely coupled” approach of using intermediate files. Recent developments in the GDAL library, maturation of the Python/SWIG API, and planned Python integration in GMT 5.0 suggest that a more generalized and coherent fusion of GRASS and GMT will be possible in the near future. GMT stores 2-D grids as COARDS-compliant netCDF files and comes with a comprehensive collection of free GIS data, such as coast lines, rivers, political borders and coordinates of other geographic objects. Users convert further data (like satellite imagery and digital elevation models) from other sources and import them. GMT stores the resulting maps and diagrams in PostScript (PS) or Encapsulated PostScript (EPS) format. Users operate the system from the command line enabling scripting and the automation of routine tasks. More or less comprehensive graphic user interfaces are available from third parties, as well as web applications, bringing the system's functionality online.

4.9 Spring

It was designed to meet Brazil’s challenges on natural resources monitoring. It operates as a seamless geographical data base with a large volume of data, without being limited by tiling schemes, scale and projection (Camara *et al* 1996). It supports both raster and vector data geometries, with functions for image processing, digital terrain modeling, spatial analysis and data base query and manipulation. Achieves full scalability (from desktop PCs running Windows or OS/2 to high-performance UNIX workstations), and provides an easy-to-use, yet powerful environment, with a combination of menu driven applications and spatial algebra language.

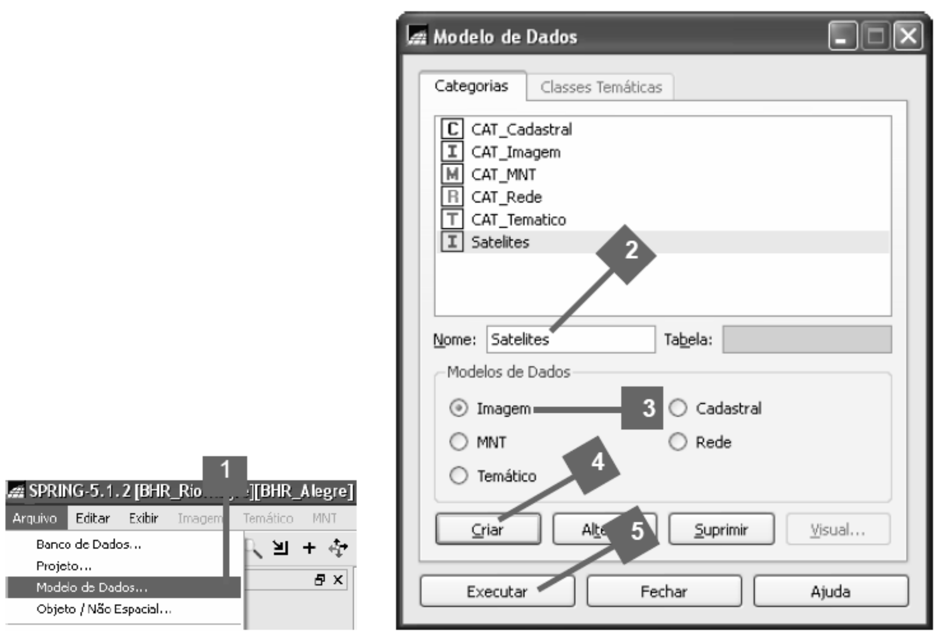

Figure 6. A data model must be defined in the active database before importing data into SPRING.

4.10 Terra Lib

TerraLib is an open source GIS software library, written in C++, which allows a collaborative environment and its use for the development of multiple GIS tools; its source code is available at www.terralib.org. Software libraries can only be used by coupling them to a host application, i.e., a desktop GIS or a GIS server (Steininger and Hunter 2012), they do not offer a graphical or command-line user interface that allows direct use of the functions to perform cartographic projections, enable reading and writing of different data formats, or provide geographical analysis algorithms. TerraLib provides functions to decode geographical data, spatial analysis algorithms and a conceptual model for a geographical database (Camara *et al.* 1996). A central module called kernel contains the spatio-temporal data structures, support to cartographical projections, spatial operators and the interface to store and retrieve spatio-temporal data in object relational databases. The generic interface for storage and retrieving contains the routines to decode geographical data to and from a set of open and proprietary formats and some mechanisms to control visualization. The supported multi scale spatial models are of different extent and resolution (Carneiro 2006). The spatial analysis functions are implemented using the data structures of the Kernel. Different interfaces to the components of TerraLib can be built using different programming environments (Java, COM, C++) on top of the base modules.

The design goal for TerraLib is to support large-scale applications using socio-economic and environmental data using spatial databases, and stores data in different database management systems including MySQL and PostgreSQL. Its vector data model complies with Open Geospatial Consortium (OGC) standards. It handles spatio-temporal data types (events, moving objects, cell spaces, modifiable objects) and allows spatial, temporal, and attribute queries on the database (Camara *et al.* 1996). The developments are shown in figure7.

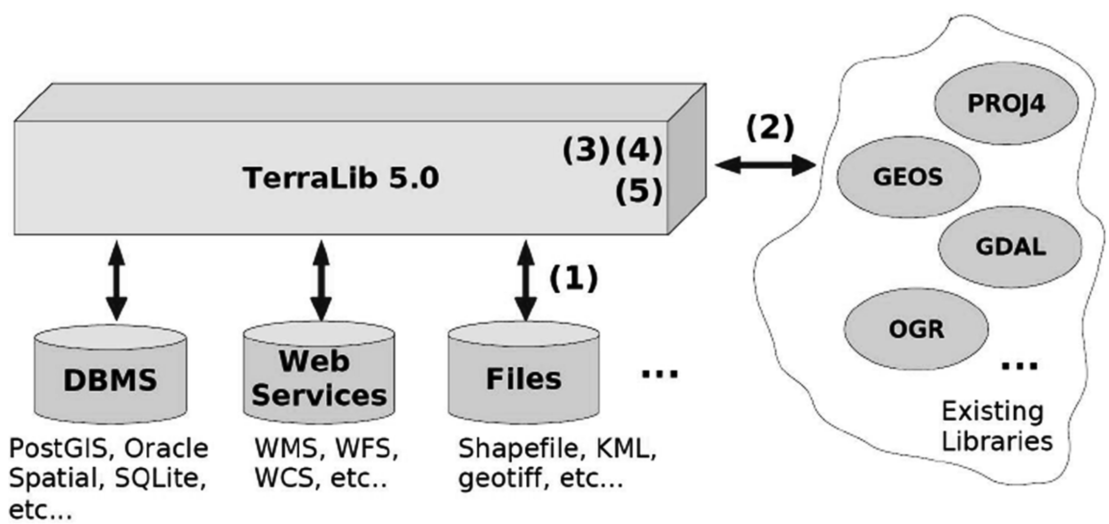

Figure 7. Envisioned developments in TerraLib 5: (1) Support to different kinds of data sources; (2) Extensive use of existing libraries; (3) More modular, simpler and more

easily extensible architecture; (4) OGC compliant (SFS-SQL, OGC Web Service, etc.); (5) Represent and query spatio-temporal data (adapted from Bivand 2011).

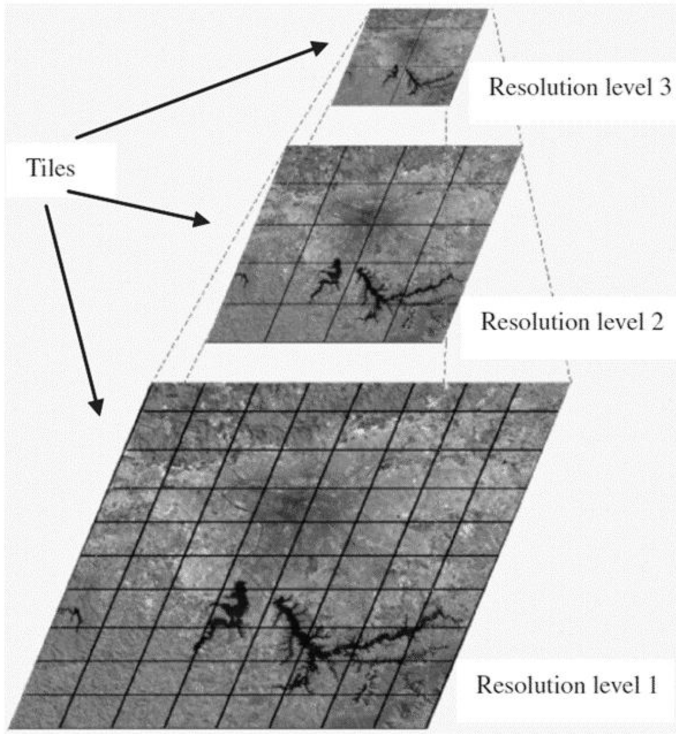

Figure 8. The library has drivers for storing raster data in different DBMS using indexing and compression (Camara *et al.* 1996).

4.11 Terra Amazon

Is a GIS tool designed to be a multi-user editor of geographic vectorial data stored in a TerraLib model database to assist on rainforest monitoring programs. It engages land use and land cover classification tools as well as spatial operations between vector data, allowing transitions analysis among other applications. TerraAmazon keeps work time records for project control. It´s functionalities are extensible through plugins, such as TerraImage (PDI) and TerraPrint (plotting). The assignment of a date to this geometry establishes the creation of a scenario. Many scenarios can be created for the same geometry by assigning different dates to it. TerraAmazon has two user levels: Administrator and Operator (Ribeiro and Queiroz 2007), only the Administrator has full access to all the menus, and user groups (each with a cryptographic password) can access different system functionalities. TerraAmazon only accepts vector files in shapefile (.shp) format and raster files as geotiff files (.tiff), jpg files (.jpg), Spring Grid files (.spr), binary RAW files (.raw) and ESRI ASCII Grid files (.txt).

4.12 System for Automated Geoscientific Analyses (SAGA)

A GIS originally developed at Goettingen University in Germany and currently maintained at the University of Hamburg, Germany. Version 2.0 in 2007 was the second major release of the SAGA program. The interim version 2.0.5, July 2010, is an upgrade. SAGA is a hybrid GIS with emphasis on grid (raster) functions. Vector data layers (and Point Cloud data layers) are shapes data layers. The shapes format is a non-topological vector format developed by the Environmental Systems Research Institute (ESRI) that allows their use in noncommercial software. The Application Programming Interface (API) and module libraries are Dynamic Link Libraries (DLL) not independent executables, accessed through a front end program. The Graphical User Interface (GUI) shown in figure 9 is a Windows-like implementation that controls the system (Cimmery 2007). Modules can also be executed by a second front end, the command line interpreter tool (CMD), which has the advantage that it can be executed from batch script files, which in turn enables a further automation of complex work flows and the routine processing of mass data. Several modules focus on digital elevation models and terrain analysis, like analytical hill shading, visibility analysis, local geomorphometry and geomorphographic classifications, terrain parameters related to hydrology, channel network and watershed basin extraction, and the creation of profiles and cross section diagrams. The parameter dialog of the modules is split into a Data Objects section (further subdivided into grids, shapes and tables) for input and output datasets and an Options section with further parameters required by the module (Köthe and Bock 2006). The system of the Data Object section is displayed as:

Symbol	Meaning
>>	mandatory input dataset
>	optional input dataset
<<	mandatory output dataset
<	optional output dataset

Several modules exist for manipulation and analysis of vector data, like merging of layers, selection of shapes, attribute table manipulation, type conversion and automated document creation. Standard operations on vector data are polygon layer intersections and vector data creation from raster data, e.g. creation of contour lines. Raster (or gridded) data can be created from point using nearest neighbor, triangulation and other interpolation techniques. Modules for the construction and preparation of raster data, allow the resampling, closing of gaps and the manipulation of value by user defined rules. The raster calculator is a very flexible standard tool, where a user defined formula is used to combine an arbitrary number of raster layers. Other standard operations are skeletonisations and grid based buffering.

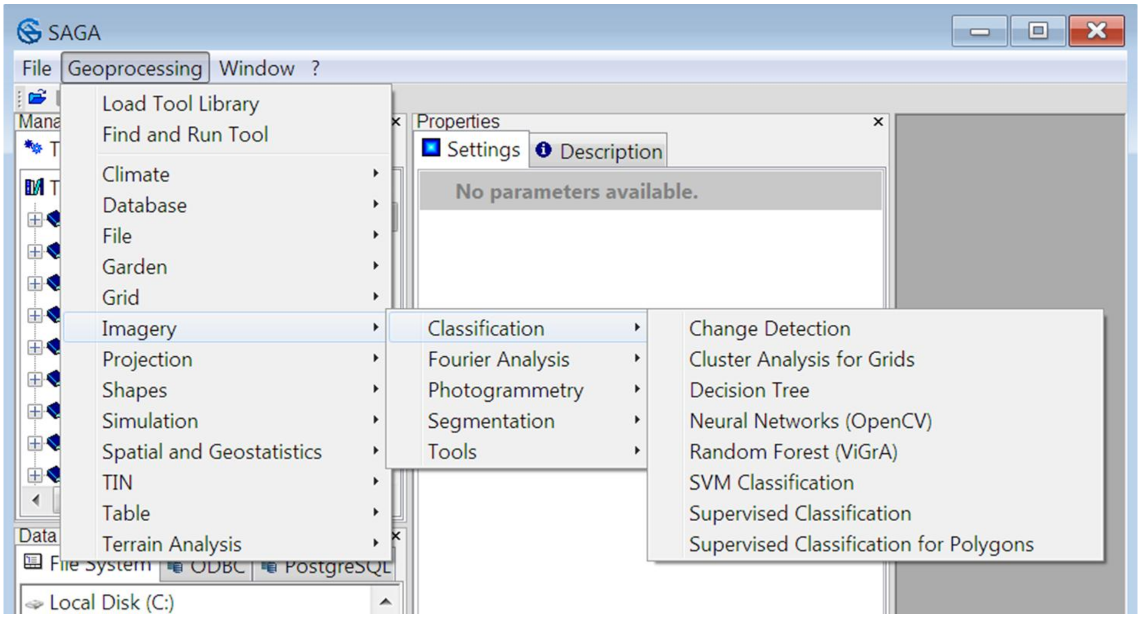

Figure 9. SAGA modules.

A project is a SAGA entity for associating one or more grid systems, grid data layers, shapes data layers and tables that you want linked together. It is possible to load the project rather than each individual data layer when a group of related data layers into the work session is desired. One or more projects can be loaded for a work session. Project files can be saved in any folder with a file format suffix .sprj. The “native” saga format for raster data is the DiGeM file format (Olaya 2004).

Figure 10 shows the results of an object oriented image classification process in which first an airborne CIR image is coarsely segmented, and then, within an enclosed rectangle, a finer segmentation is performed. The level of generalization defined by the user, can go from coarse (deciduous and coniferous trees) to fine (detection of single trees) depending on the image resolution. To determine the species or even the condition of the delineated tree object, it is possible to analyze the distribution of values of single or many spectral channels inside the object with statistical tools of special SAGA modules.

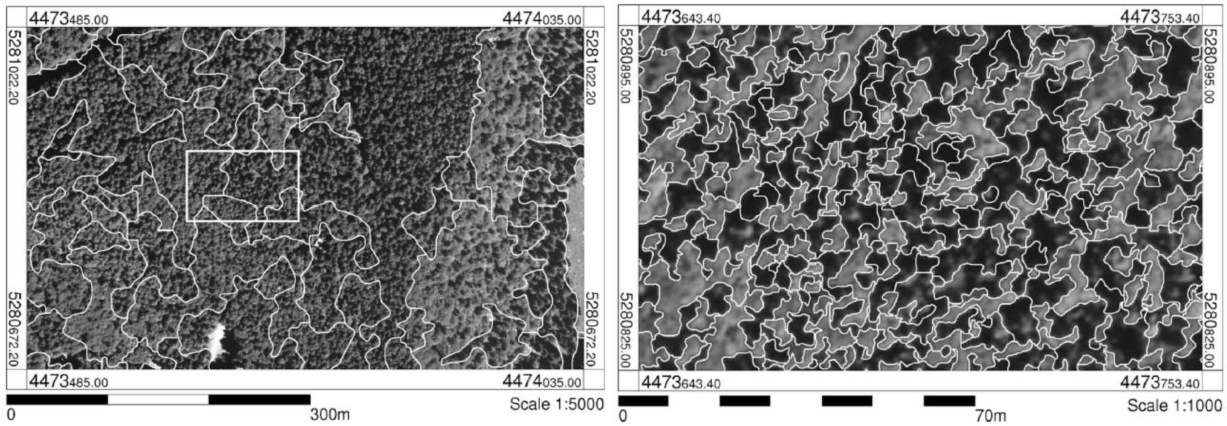

Figure 10. Results of the object oriented image classification. Source: (Köthe and Bock 2006).

The development objectives for the SAGA program are to provide geo-scientists an effective and user friendly tool for the implementation of geoscientific methods. The source code written in C++ is readily available.

5. Conclusions

The article provides an overview of some important OSS projects, several not well known and not fully documented; it is expected that the reader may decide and study in depth those most suitable to his/her needs. Open source software can be integrated into geospatial education to encourage a culture of openness, clearly differentiate between science and software and enable greater reproducibility in science. Whereas the geodatabese is the target, a GIS program is a tool. In the same token, a GIS program is not a 'silver bullet'; for selecting it the principle IIWUI ("If It Works Use It") applies since the ones described here reached a level of maturity and are robust. The adoption of a "multi-GIS use strategy" may untangle the general concepts of geospatial analytics from software-specific features and issues; which needs knowledge of "GIS concepts" and not of "software buttons". A multi-GIS strategy demands the familiarization with several tools, and the transfer of data between the tools. Two units (instead of one) on GIS and remote sensing are advisable in a forestry undergraduate curricula, focusing on the fundamentals of digital cartography and secondly, on forestry related practical applications. The inclusion of a programming introductory unit (Python, C++ or Java) in the BSc curricula of forestry is a plus.

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Socioeconomic drivers of shifting cultivation in Fiji Islands: a geographical approach

Abstract

Shifting cultivation is a common agricultural practice in the Pacific Islands and tropics in general; it is a sustainable practice only when the fallow periods are long. The intensification of land use respond to the need of more profits in the short term, market demands, smaller inherited farms, uncertain land tenure and population growth among others. Official statistical data and maps were utilized to build up chloropleth maps indicating the areas of high land use intensity according to farm size ranges and socioeconomic parameters (treatments) for the country. Critical maps built by Boolean operations displayed areas in which both the land use and the socioeconomic driver were simultaneously ranked as high or very high. Treatments showed significant differences ($p<0.05$), being the most influential those related to human demography; therefore it is recommended to enforce policies that will des-accelerate the rates of land use, such as the facilitation of land ownership over farms of bigger sizes, the gradual replacement of mono cropping by agroforestry systems, and the creation of more employment opportunities in the industry, tourism and services sectors.

Keywords: Land use intensification, shifting cultivation, GIS models.

1.0 Introduction

Shifting cultivation can be defined as "a system in which relatively short periods of continuous cultivation are followed by relatively long periods of fallow" (FAO 1982). It is probably one of the most misunderstood and thus controversial forms of land use; they comprehend a wide range of cropping systems, having in common: 1. The removal of the natural vegetation (usually forest or shrub land), in most cases by cutting and subsequent burning 2. A cycle of short cultivation and long forest fallows., and 3. The cyclical shifting of fields (AIPP and IWGIA 2014). They are an important and extensive strategy among agriculturalists in Oceania (Roos *et al.* 2016) where tropical rainforests perceived as pristine were either former settlements or cleared areas for irrigated or swidden agriculture (Bayliss-Smith *et al.* 2003). Early swidden depended on relatively short fallow periods until mobility no longer became a viable option, shifting unto strategies that avoided the use of fire such as reliance on irrigated pond fields or arboriculture (Rolett 2008).

Controversies persist on the impact of shifting cultivation on forest dynamics (Ziegler *et al.* 2011; Lawrence *et al.* 2010). Both fallow age and intensity of previous use influence the recovery of species composition and diversity after shifting cultivation (Mukul 2015). Some authors reason a balance between degradation and conservation, as low rainfall and small land area predispose islands to deforestation, while high, mountainous terrain and proximity to sources of volcanic ash help maintain forest cover (Rolett and Diamond 2004). The relationship between crop yields and fallow period is not clear though it is widely perceived that shorter fallows contribute to yield reduction (Kafle 2011); an exception was recorded in Bellona Island, Solomon Islands, where shifting cultivation is still maintained in the traditional way, and fallow lengths increased despite population growth due to redistribution of the cultivated area, induced migrations and changes in crops; therefore, land productivity remains high although there are indications of soil degradation in the center of the island (Mertz *et al.* 2012).

Currently the distribution of the major commercial crops in Fiji is not determined primarily by the physical environment. Coconuts and bananas are more related to the absence of alternative cash crops in the relevant areas than to their particular climatic or locational suitability. Rice depends on the distribution of Indian farmers rather than on the particular suitability of the soil and climate of the present producing areas. As the degree of commercialization increases and the range of cash crops widens, the degree of areal specialization will probably increase (Ward 1965). In the same token; as households begin, grow, and mature, changes in land holdings reflect the fluctuations in the demand for land associated with each stage (Chayanov 1966). A young household forms and expands acquiring land to meet needs. The pressure decline and the holding area may contract as children mature and leave the household. An increasing population combined with inheritance result in a successive subdivision of land at the death of the owner. This process leads to environmental degradation and subsequent rural poverty (figure 1). The main hypothesis in this paper is that there are not significant differences between current socioeconomic parameters on the intensification of land use in Fiji Islands.

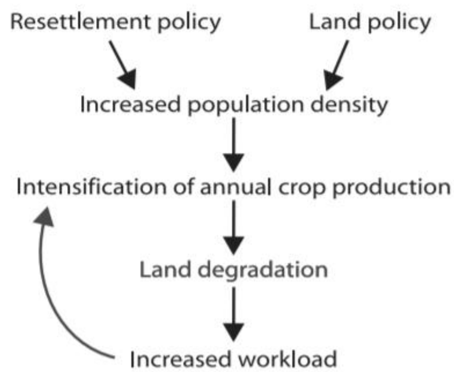


Figure 1. The policy, population and degradation cycle. With a limited amount of agricultural land available, and decreasing land yields, farmers use their only available resource, labor, to try to grow enough food for their households (IWMI 2015).

2.0 Materials and methods

Maps from the Fiji encyclopedic atlas and statistics from the 2009 national agricultural census were the main data utilized. Walsh (2006) compiled them after statistical analysis of the 1970 and 1990 national censuses, and printed them with ArcMap. After selection of sixteen of them, they were scanned, imported into Ilwis and georeferenced with WGS84 projection and corner coordinates 15°43'31.29"S, 176°29'04.38"E (top left) and 19°28'03.47"S, 178°25'58.51"W (bottom right), and 5.6 seconds pixel size. The maps were then digitized to delineate tikina (district) boundaries, converted into polygon format and rasterized. As per this process sixteen socioeconomic maps (figures 3-10), and eight maps showing land use intensity per province according to farm size range (less than 1ha, 1-3ha, 3-5ha, 5-10ha, 10-20ha, 20-50ha, 50-100ha, and over 100ha) were produced. To make uniform measurement units and numerical differences of value ranges between maps, they were re categorized into very low, low, intermediate, high and very high ranks. The land use intensity index was calculated as LUI = Total crops area/(total crops area + fallows area). To answer the question on how are the socioeconomic drivers (maps) related to land use intensity, critical maps were built displaying areas in which both the land use and the socioeconomic driver were simultaneously ranked as high or very high, according to the following script: Critical map = IFF (((‘LUI map’=“very high”) OR (‘LUI map’=“high”)) AND ((‘Land available map’=“very high”) OR (‘Land available map’=“high”)), “related”, “unrelated”). The script was run 160 times, produced 160 maps, and their pixel numbers were tabulated on a table, statistically tested and interpreted.

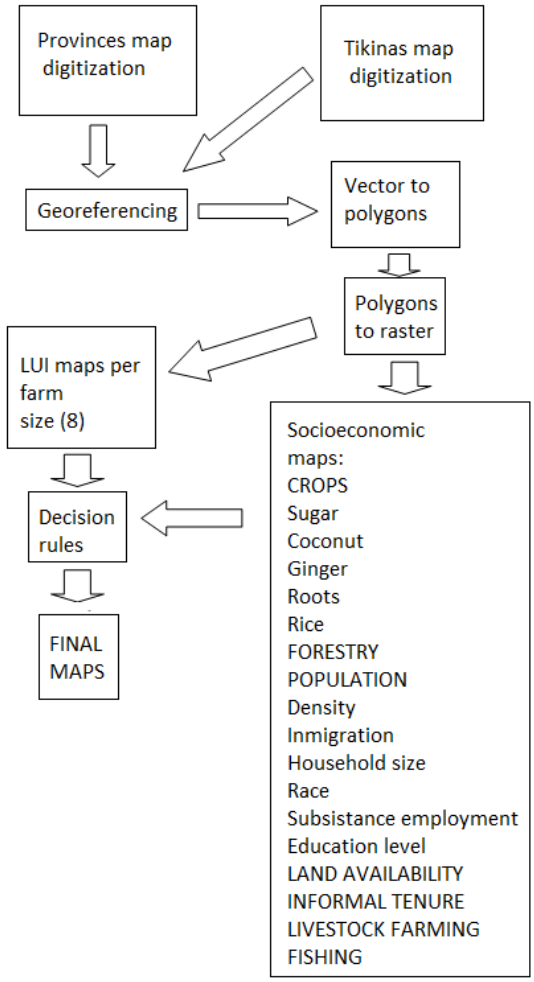
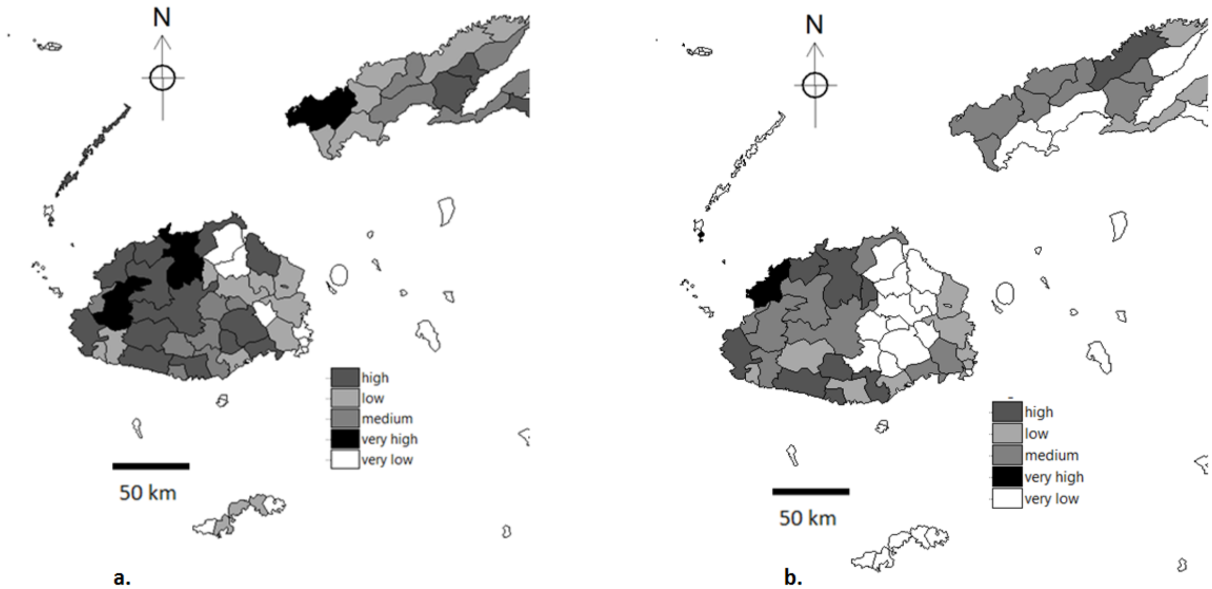


Figure 2. Flowchart of method

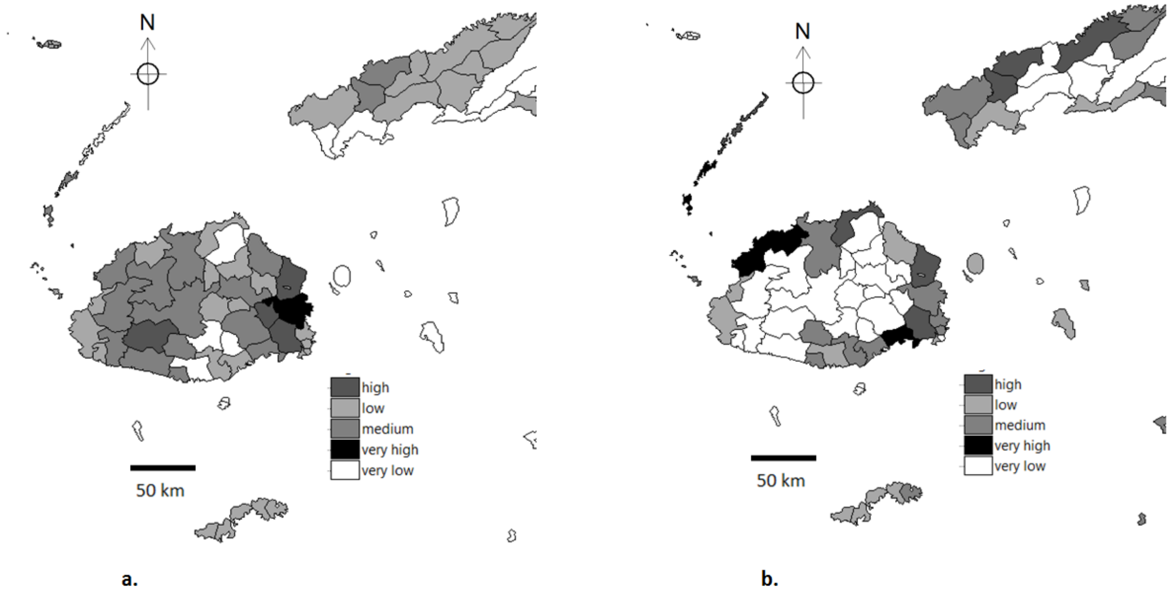
3.0 Results and conclusions

Numerical results were compiled on table 1 showing the number of pixels (and percentage) in which both the socioeconomic activity and the intensity of land use were high or very high. The socioeconomic activities, considered here as potential shifting cultivation drivers, are displayed on figures 3-10, they all were georeferenced and converted to the raster format in order to proceed with map calculation as given by the script mentioned before. Farms between 3-50ha are mostly covered by forests (natural or planted), grasslands or fallows of over 1year; shorter fallows are common in smaller farms (figure 18). Land use is intense on farms of under 3ha and very intense when they are of less than a hectare; the intensification diminishes on parcels from 3 to 50ha, and again intensifies when the farms are of over 50ha. In farms of less than 3ha size land use is intense when (in order of importance) indo-Fijian population, household size, and land availability values are high. In farms of 3-10ha size land use is intense when the values of (in order of importance) household size, subsistence employment, coconut farming, land availability, Fijian population, and population change are high. In farms of

10-20ha size land use is intense when the values of (in order of importance) household size, population change, subsistence employment and Fijian population are high. In farms of 20-50ha size land use is intense when the values of (in order of importance) higher education, fishing, forestry, in-migration, population density and population distribution are also high. In farms of 20-50ha size land use is intense when the values of (in order of importance) population change, Indo-fijian population, land availability, fishing and sugar farming are also high.



Figures 3a. Fiji islands map showing degrees of land availability per tikina. Range: Less than 5 to 40 km^2 of land "available" per average village or settlement; and 3b. The country's map showing degrees of forestry employment per tikina Range: 0 to 247 workers. The total forest area is of about 860,000ha. Wood industries are Fiji's fifth most important export satisfying the domestic demands (Walsh and Crosbie 2006).



Figures 4a. Fiji islands map showing degrees of livestock farming per tikina. Range: 0 to 63 workers. All of Fiji's livestock production is used locally, even though the government invested heavily, little changed from 1989 to 2004 (Walsh and Crosbie 2006). Figure 4b. The country's map showing degrees of fishing activity per tikina. Range: 0 to 247 workers. Fishing at $85million was Fiji's third largest export after garments and sugar.

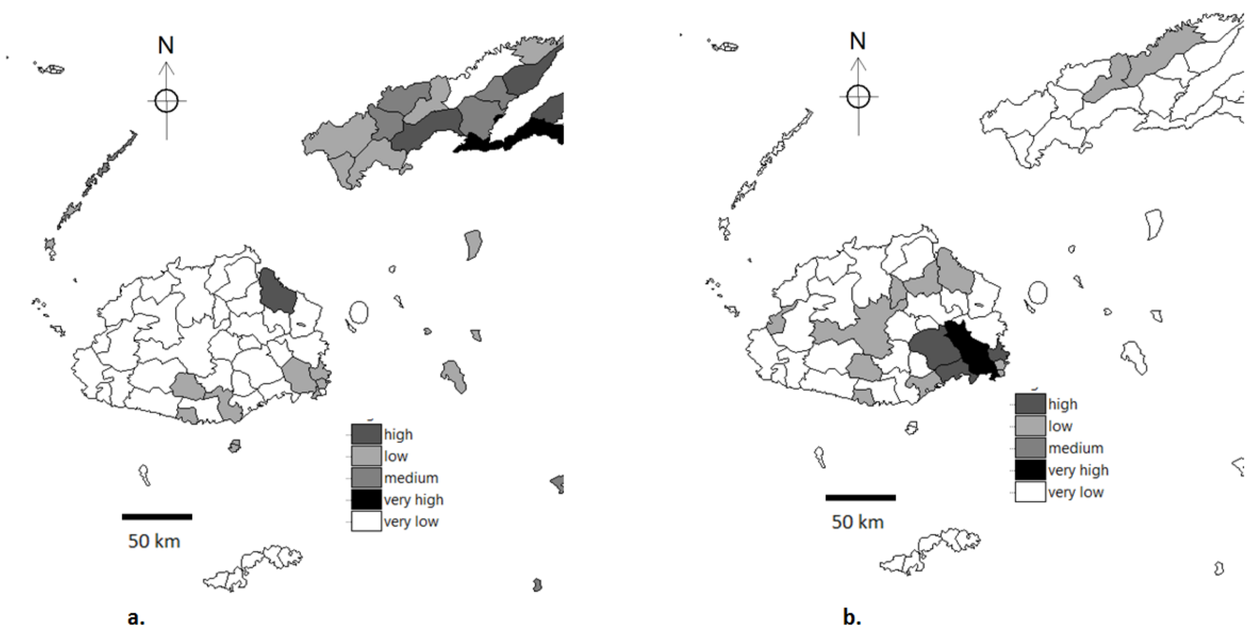


Figure 5a. Fiji islands map showing degrees of coconut farming per tikina. Range: 0 to 247 farmers. Over half of the production comes from Cakaudrove and 5b. The country's map showing number of ginger farmers per tikina. Range: 0 to 107 workers employed.

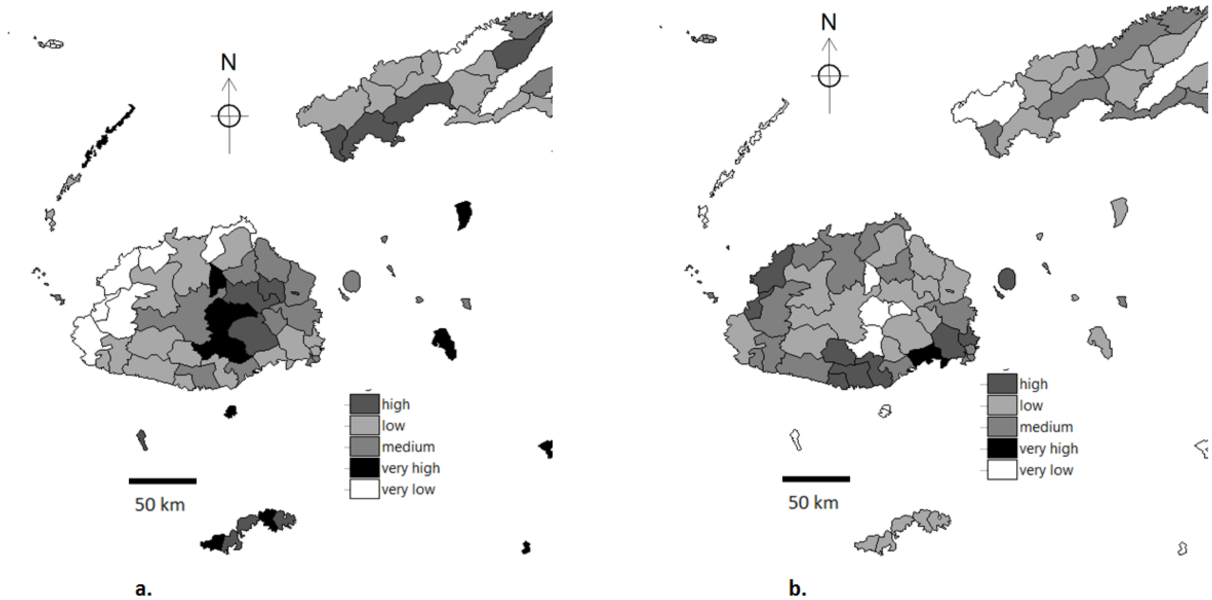
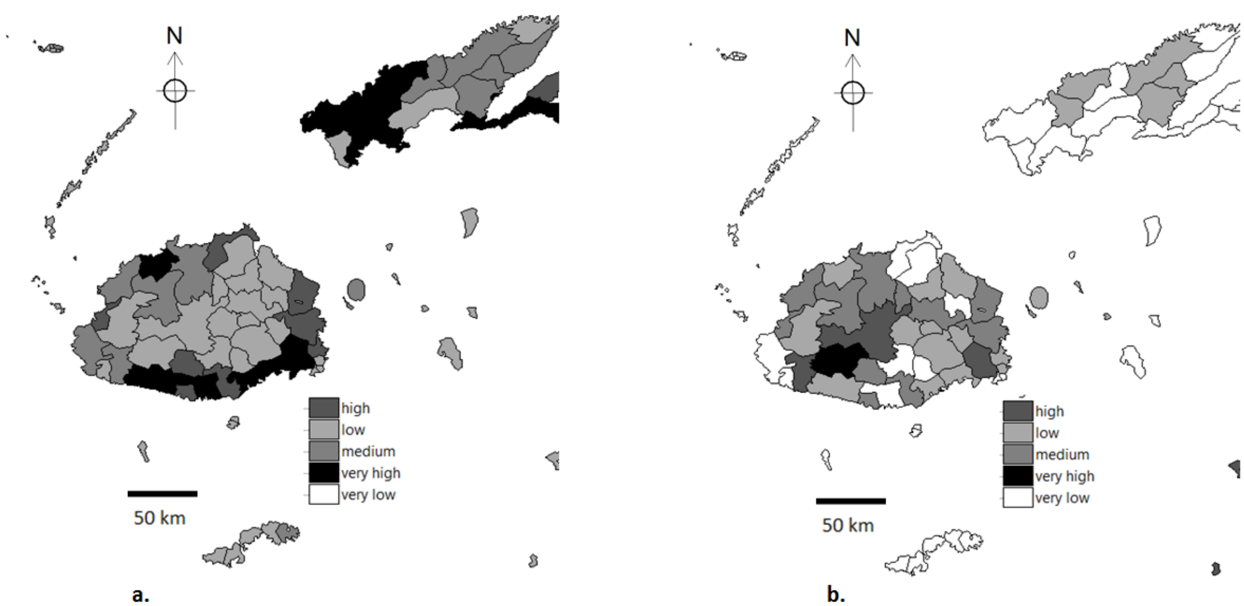
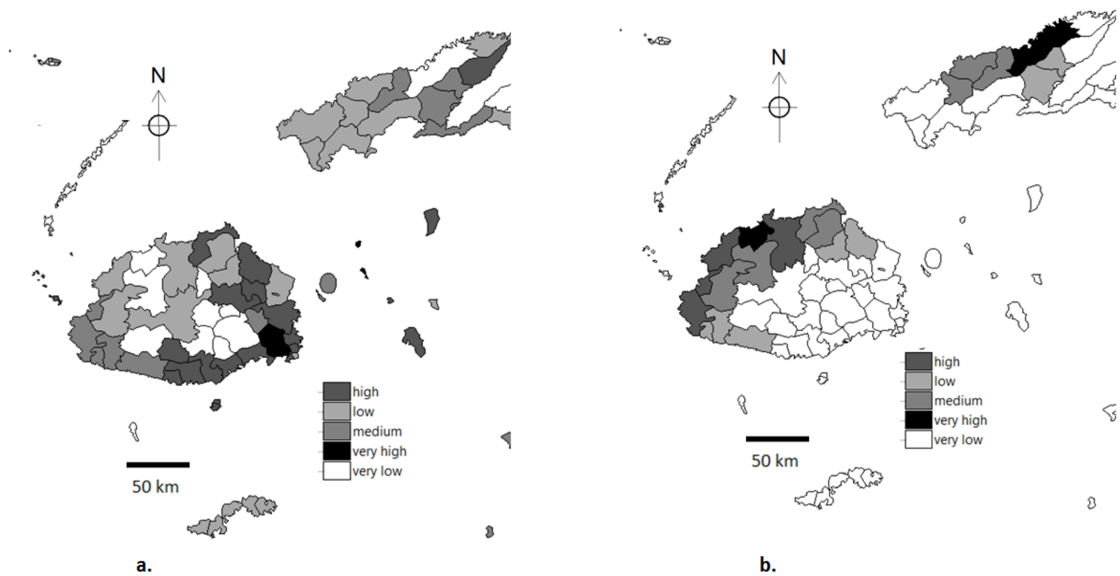


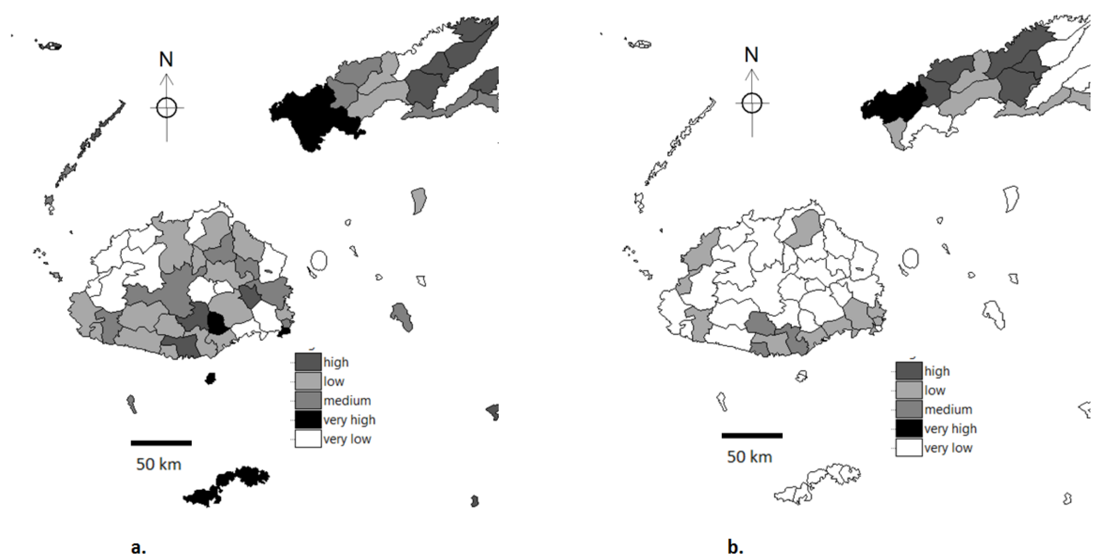
Figure 6a. Fiji islands map showing degrees of Fijian population per tikina. Range: Less than 45 to 99%; and 6b. The country's map showing degrees of tertiary education per tikina*.* Range: 0 to 21%.



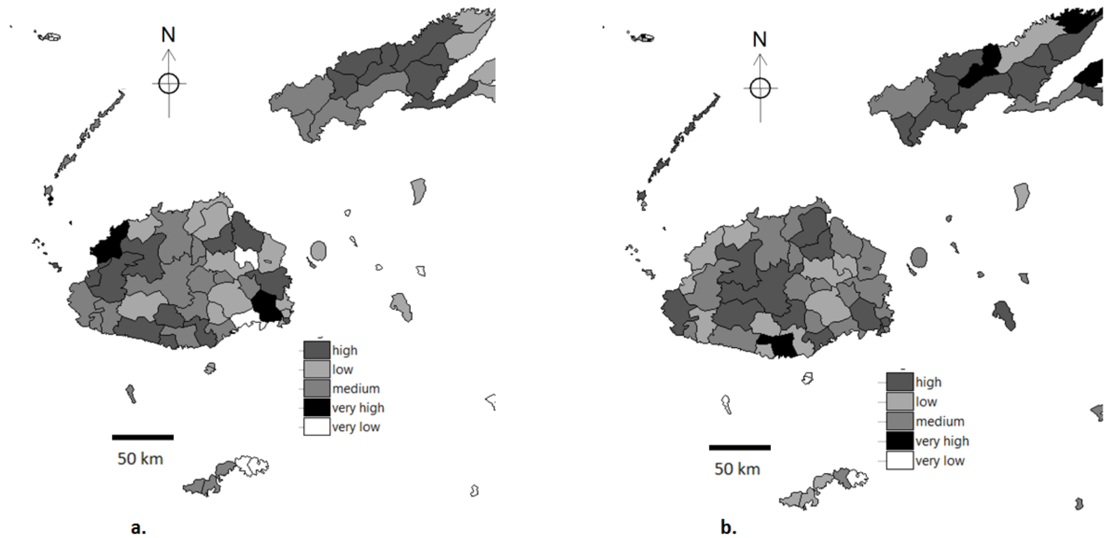
Figures 7a. Fiji islands map showing degrees of informal tenure on freehold land per tikina. Range: 0 to 8.4%. They occur in Ba, Nadi, Rakiraki, Bua, Wainunu, Macuata, Tunuloa and Cakaudrove *tikina*. Informal tenure on state or freehold land was more common in urban areas and among Indo-Fijians (Walsh and Crosbie 2006). Figure 7b. The country's map showing the numbers of vegetable farmers per tikina. Range: 0 to 624 farmers. They are widely grown across Fiji for local consumption, especially along the Sigatoka river and around Suva.



Figures 8a. Fiji islands map showing degrees of in migration per tikina as percentage of population (Fiji mean=31.2). Nationwide, migrants accounted for nearly one-third of tikina populations, the greatest concentrations were in Naitasiri tikina (over 60%), Namosi and Serua tikina and in Rakiraki. Figure 8b, The country's map showing the number of sugarcane farmers per tikina*.* Range: 0 to 7486 farmers.



Figures 9a. Fiji islands map showing degrees of subsistence employment per tikina. Range: 0 to 74.7% of labor force. Subsistence activities employed the half of the labour force in 1996 with a value of nearly 6% of the GDP (Walsh and Crosbie 2006). Figure 9b. The country's map showing the number of rice farmers per tikina*.* Range: 0 to 158 farmers. Sugar was Fiji's main export until 1988, currently employs a quarter of the active labour force (Walsh and Crosbie 2006).



Figures 10a. Fiji islands map showing the percentage of population change per tikina between 1946 and 1996. Range: below 35 to over 431; and 10b. The country's map showing degrees of household size per tikina. Range: Less than 4.78 to 6.56 members per household. After 1950 the population grew 3% which would have seen the population doubling every 23 to 34 years; however birth rates continued to fall, and emigration increased (Walsh and Crosbie 2006). The last three censuses showeda decline in the average number of people per household from 5.97 (1976), to 5.71 in 1986, and 5.32 in 1996.

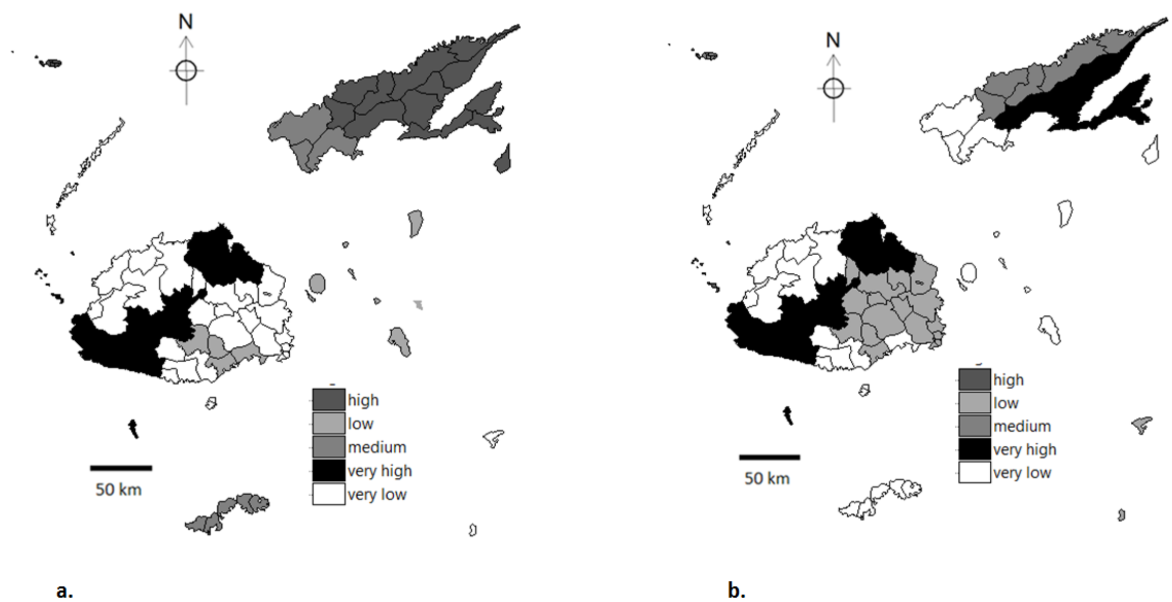


Figure 11. LUI of farms of less than 1ha (a) and 1-3ha (b) farm size ranges.

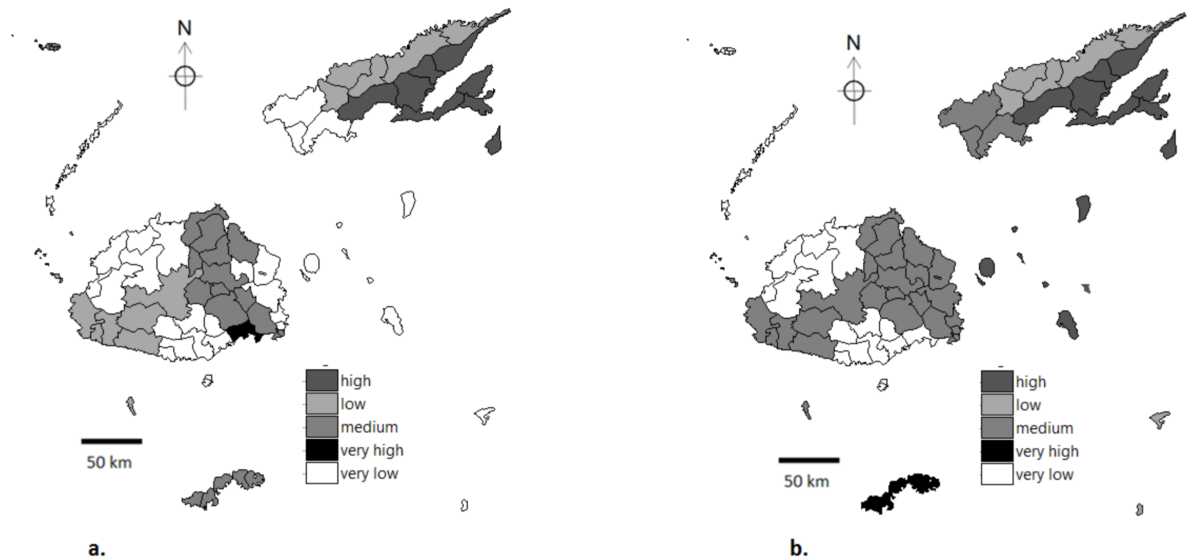


Figure 12. LUI of farms of 3-5ha (a) and 5-10ha (b) farm size ranges.

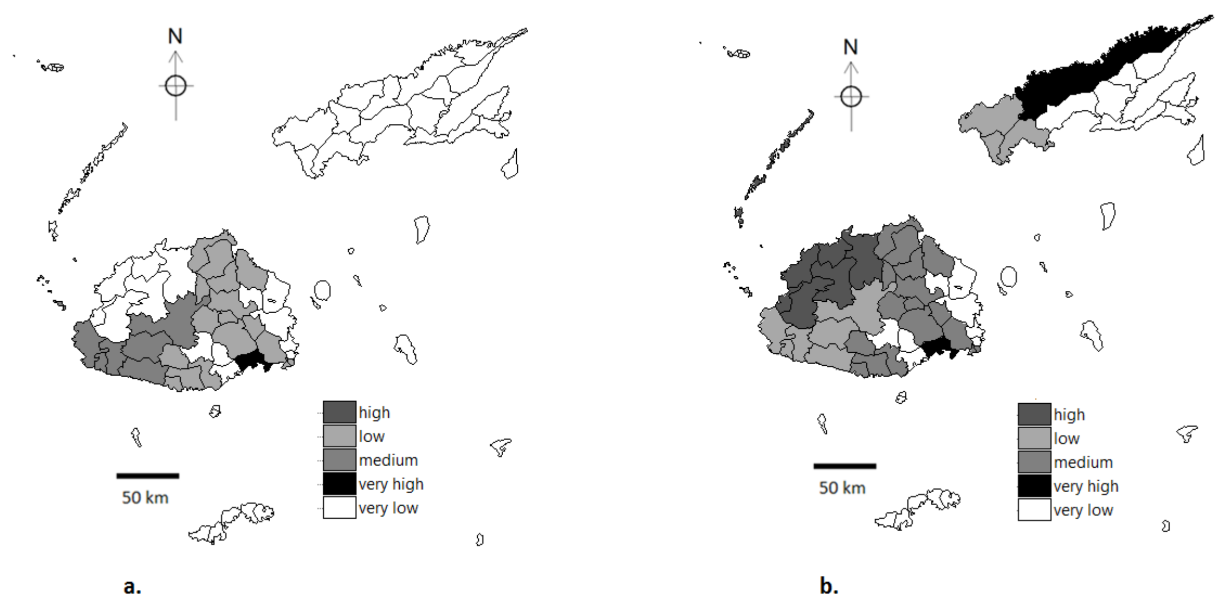


Figure 13. LUI of farms of 20-50ha (a) and 50-100ha (b) farm size ranges.

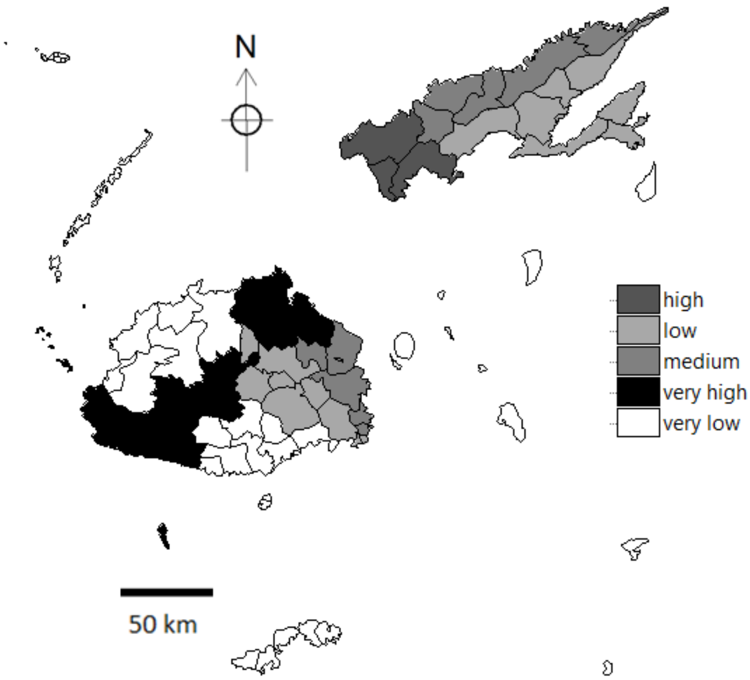


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Figure 14. LUI on farms of more than 100ha.

Table 1. Critical areas (in pixels and percentage) that reflect high or very high values for the socioeconomic driver and land use intensity simultaneously.

	Less 1 Ha		1 to 3 Ha		3 to 5 Ha		5 to 10 Ha		10 to 20 Ha		20 to 50 Ha		50 to 100 Ha		More than 100 Ha	
	pixels	%	pixels	%	pixels	%	pixels	%	pixels	%	pixels	%	pixels	%	pixels	%
Coconut farming	76756	25.81	55000	18.91	60000	63.81	60000	52.40	0	0.00	0	0.00	0	0.00	13000	7.22
Fijian pop.	34588	11.89	34588	15.99	35000	35.00	60000	52.40	47770	44.34	0	0.00	3345	1.96	23584	13.14
Education	0	0.00	0	0.00	7000	7.00	4000	3.49	0	0.00	6356	100.00	25000	14.62	0	0.00
Fishing	10025	3.45	10025	4.64	7000	7.00	0	0.00	0	0.00	6356	100.00	75000	43.85	10000	5.56
Forestry	49780	17.11	26908	12.44	0	0.00	0	0.00	0	0.00	0	0.00	6356	3.72	30000	16.67
Ginger farming	0	0.00	0	0.00	8000	8.00	0	0.00	0	0.00	6356	100.00	6356	3.72	0	0.00
Indofijian pop.	155255	53.37	210000	72.19	0	0.00	0	0.00	0	0.00	0	0.00	115115	67.30	35000	19.44
Vegetable crops	55557	19.10	55557	25.69	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	50000	27.78
Informal tenure	52023	17.88	52023	24.05	8000	8.00	15426	13.09	15000	13.92	0	0.00	20000	11.69	42000	23.33
Land availability	130166	44.74	126416	58.44	40000	40.00	33824	28.70	39042	36.24	6356	100.00	96761	56.57	121011	67.23
Livestock farming	15860	5.46	15860	7.33	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	15860	8.81
People per household	204426	70.37	153999	71.20	80000	85.08	80639	68.42	90591	84.08	0	0.00	75000	43.85	104456	58.03
Pop. Change 1986-96	55897	19.21	55524	25.67	55000	58.49	55059	46.72	70000	64.97	0	0.00	4500	2.63	7500	4.17
Pop. Change 1946-96	0	0.00	71852	33.22	0	0.00	40000	33.94	36000	33.41	0	0.00	125000	73.08	40000	22.29
Pop. Density	800	0.28	858	0.40	6356	6.76	0	0.00	0	0.00	6356	100.00	35000	20.46	900	0.50
Pop. Distribution	858	0.30	0	0.00	0	0.00	0	0.00	0	0.00	6356	100.00	50000	29.23	0	0.00
Rice farming	23759	13.77	23759	10.98	25000	26.59	23759	20.16	23759	22.05	0	0.00	45000	26.31	25000	13.89
Subsistance employm.	60000	20.63	48000	22.19	49000	52.11	75000	63.64	65000	60.33	0	0.00	16000	9.35	50000	27.86
Sugar farming	45000	15.47	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	72179	42.20	15000	8.36
Tikina immigration	38482	13.75	38482	17.79	22000	23.40	24400	20.70	20487	19.02	6356	100.00	6356	3.72	25000	13.89

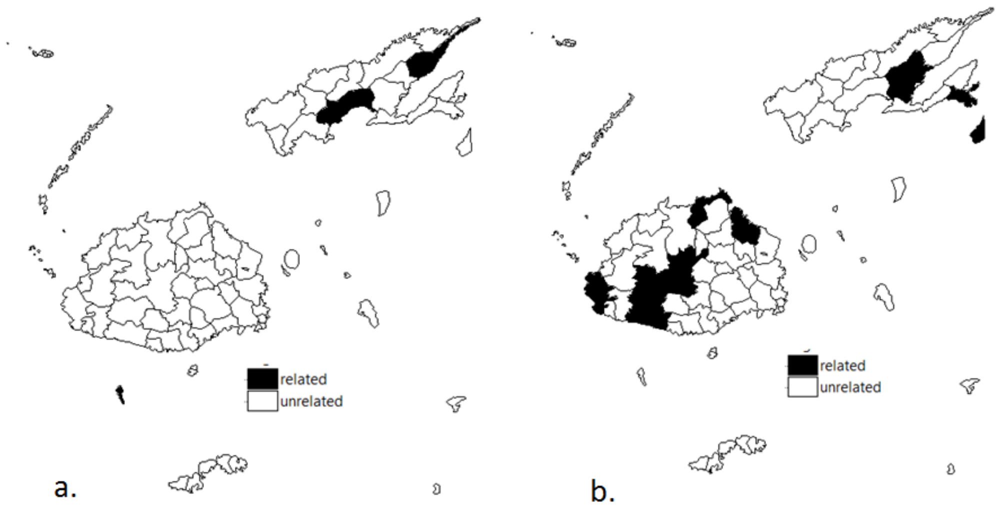

Figure 15. Critical maps for farms under 1ha showing areas with high or very high values of Fijian population and of land use intensity (a) and high or very high values of land availability and of land use intensity (b).

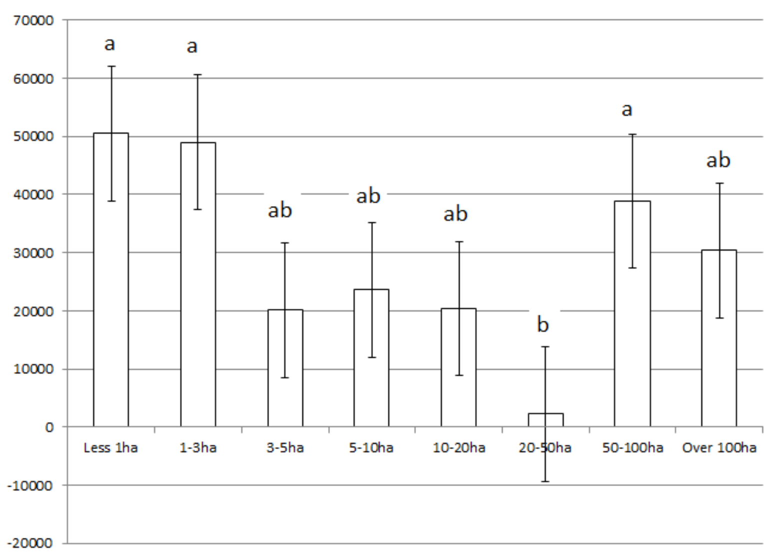

Figure 16. Total of pixels of areas with high or very high values of land use intensity index per farm size range. *Means that share the same letter represent not significant differences between them (p<0.05).

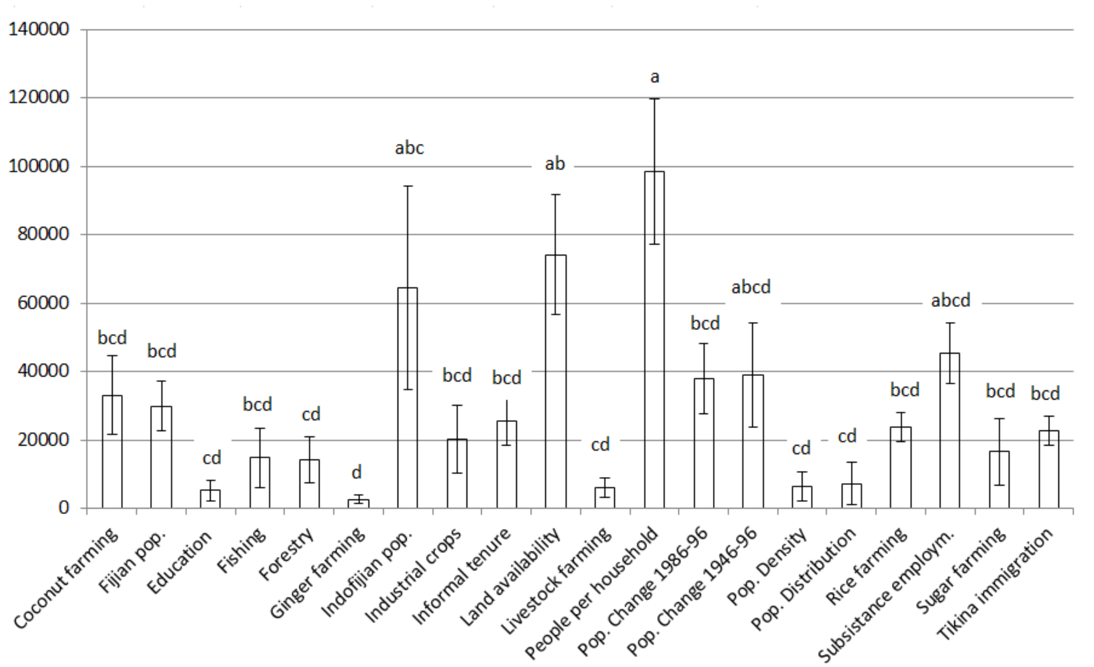

Figure 17. Total of pixels of areas with high or very high values of LUI per socio economic parameter. *Means that share the same letter represent not significant differences between them (p<0.05).

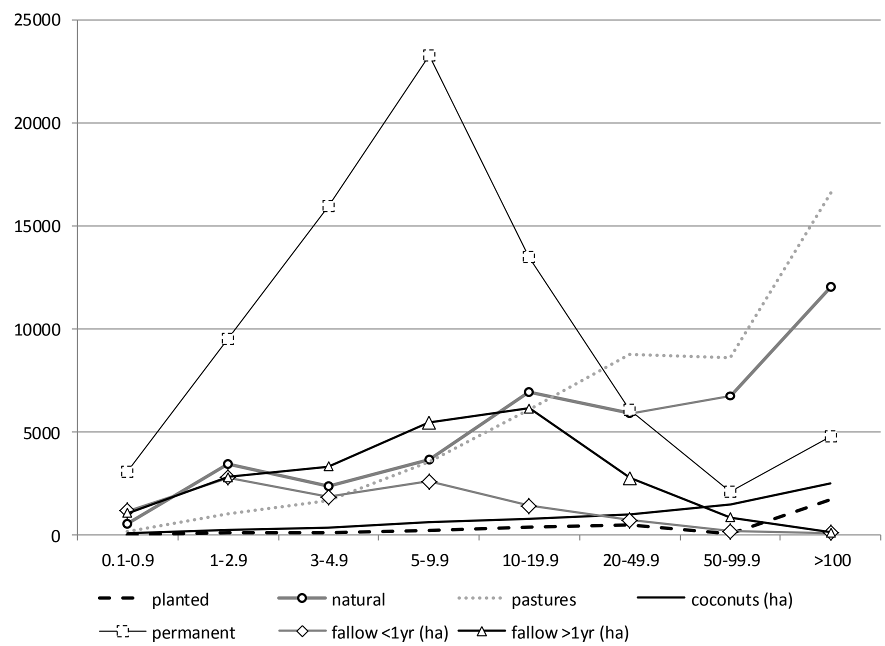

Figure 18. Total area (ha) of different land use types in Fiji Islands according to farm size range (ha). Source: Ministry of Agriculture (2009).

4.0 Recommendations

Reformulate policies that will des accelerate the rates of land use to control the high demographic growth and migrations, restrict farming on annual leases, expand areas under strict conservation status, promote access to land ownership over farms of more than 3ha, replace mono cropping by agroforestry systems, and create more jobs in the industry, tourism and services in the country.

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Land suitability for the plantation of important tree species in Vitilevu Island, Fiji

Abstract

Significant landscape changes in Fiji Islands lead to soil degradation, loss of native species, many of them endemic and pollution. The plantation of native and exotic trees is an alternative of sustainable use with ecological and economic advantages in the long run. Spatial models for plantations based on the ecological requirements of tree species can facilitate decision making, planning, and risks prevention. A land suitability analysis with open gis was carried out to identify areas in Vitilevu island for the planting of eleven native and exotic tree species. Altitudes, rainfall and forest cover maps were used as discriminating factors in boolean operations. The paper identifies and demarcates potential areas for planting eleven tree species. Tectona grandis, Syzygium decussatum, Gliricidia sepium and Intsia bijuga are the most promising species to plant in the island in order of importance. The model is robust but can be improved by adding other thematic layers.

Key words: Suitability analysis, tree plantation, GIS modeling, Fiji Islands.

1.0 Introduction

Over the last 20 years irrational logging of natural tropical forests worldwide shifted into sustainable management plans and plantations (Evans 1992) of varied composition, scale, complexity, and purpose. They are reported to halt deforestation, increase timber production, and improve soil and water quality and wildlife habitat (Nambiar 1996); furthermore, the Kyoto Protocol opened up new markets for tree plantations (IPCC 2006). According to figure1 the forested area in Viti Levu island covers almost 50% of its 10,389 km^2, of which 5-6% are planted (Leslie and Tuinivanua 2010).

Other aim of planting native trees is to support biodiversity conservation. Although in Fiji islands more than 200 villages established community-based management measures on a total of area of 10800km^2 of sea and land (Watling and Chape 1992); global warming prevents them to suffice for the long term preservation of species with unknown genetic plasticity (CBD 2009), signifying that many reserves still need to be created, resized or relocated. Land-use changes, human-induced fragmentation, and invasive species are main threats to biodiversity conservation in small and remote islands (Martins 1993). Palaeoecological records revealed declines of forest taxa, including palms, and a rapid invasion of introduced weed species (Prebble and Dowe 2008). In Easter Island (Chile) for example, flora decimation was almost complete after human colonization (Hunt and Lipo 2006). The natural rehabilitation of exposed areas is often slow, in Fiji islands the changes on vegetation structure and composition respond to differences in temperature and rainfall (Walther *et al.* 2002). The clearing of large areas for the planting of sugar-cane, coconuts and cotton resulted on soil losses of up to 90t/ha/year in the Island (Clarke and Morrison 1987), being the acceptable level for tropical regions of 13.5 t/ha/year (Hudson 1971).

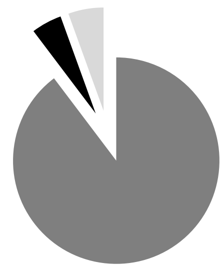


Figure 1**.** Forest cover distribution over land area in Fiji Islands (Leslie and Tuinivanua 2009).

1.2 Planning tree plantations with GIS

GIS forestry applications mainly focused on resource inventory (including monitoring and analysis) and modeling to support decision making (McKendry and Eastman 1991) specially on forest growth (Riano *et al.* 2004) and hydrological issues (Ticehurst *et al.* 2003); however the planning of reforestation projects at local, regional and national levels can be improved by (1) constructing geographical databases of land suitability for tree species, (2) assessing the land suitability, and (3) selecting possible land areas for new plantations. The areas in the database can be classified on the basis of discontinuities in climate, geology (Mackey *et al.* 2008), biota (Clifford and Stephenson 1975) or on their integration.

Land evaluations, traditionally based on soil surveys, predict land performance over time according to specific types of land use (Rossiter 1996). Carver (1991) applied a multiple-criterion evaluation (MCE) that identifies and map locations for the plantation of eucalyptus and pine according to variations on mean annual rainfall, rainfall regime, dry season length, mean maximum temperature of the hottest month, mean minimum temperature of the coldest month and mean annual temperature. The information that goes into the system determines suitability as incompatible (zero) or ideal (one) for each point of the area per vegetation type. The value of suitability depends on a set of physical and biological factors that favor or limit the growth of a tree species for decision-making (Felicisimo *et al.* 2002). The approach has been demonstrated at global and continental scales. In Finland, Kangas (1993) applied multi-criteria discrete methods to a reforestation plan by defining a three-level structure with three objectives: timber production, amenity, and impact on water. Nousiainen *et al.* (1998) added scenic values in a two-stage forest management application. In this paper I hypothesize that precipitation and altitude differences can determine potential areas for tree planting at large scale in Vitilevu island.

2.0 Materials and methods

Maps of forests, elevations and rainfall for Vitilevu island were downloaded from the internet, their original file formats converted into TIFF and imported into Ilwis Open by geospatial data abstraction library. They were georeferenced by corner points used a 1451-meter grid cell size in the elevations map, a 1355-meter grid cell size in the rainfall map, and a 460-meter grid cell size in the forests cover map rainfall map with resulting root mean square errors (RMSE) of less than 0.6 in all cases. A vector map was digitized for each of the maps (figure 3), the corners of the maps were 17°02'26.10"S,176°23'43.94"E top left and 18°44'41.40"S,178°47'38.72"E bottom right. Contour maps (rainfall and elevation maps) were linearly interpolated, by rasterizing them and then calculating values for pixels that were not covered by segments. The georeferenced forest cover raster map was converted first into a binary map (0 and 1 values), then into a points format map to capture forested areas, and finally reconverted to raster format for further processing. The pixels of the resulting three raster maps were resampled to a common georeference of 966 m^2 pixel size by bicubic interpolation, which determines the XY-coordinate of each pixel in the output map and calculates an interpolated value for each pixel using the 16 surrounding pixels of the input map. Areas to be planted with tree species listed on table 1 were found by applying decision rules. In a boolean operation the IF statement performs different things depending on a certain condition in the logical expression. The general syntax is *'If a then b [else c]'*, where *a* is a boolean expression, and *b* and *c* are either a single or a compound statement. For example, areas to be planted with Pine will be calculated by: Pinus = IFF (('Alt'>460) AND ('Alt'<760) AND ('rainfall'>600) AND ('rainfall'<1000) AND ('land cover'=1),1,0); where land cover=1 are areas without forests. In the case of the palm trees (sago and balaka) they need to be planted under cover so land cover =1 in their equations. The results were compiled on table 2. Figure 2 is a simplified example of a map calculation process to solve OutMap1 = IFF ((Landuse="Coffee") AND (DEM>=20), 50, 10):

Landuse

C	C	G
F	F	?
G	C	C

DEM

45	40	30
?	15	10
10	15	30

OutMap1

50	50	10
10	10	10
10	10	50

Figure 2. Map reclassification with conditional function (Ilwis 2016).

Table 1. Ranges of ecological requirements per specie (AFT 2016).

Specie	Altitude range (masl)	Rainfall range (mm)
Pinus caribaea	460-760	>600
Tectona grandis	0-1300	1250-3750
Leucaena leucocephala	0-500	<2500
Sesbania grandiflora	1000-2500	0 - 800
Metroxylon vitiense	2000 - 2500	0 - 700
Balaka microcarpa	> 4000	50 - 300
Intsia bijuga	0-600	2000-3000
Syzygium decussatum	0-2000	1500-6000
Agathis macrophylla	0-480	4000-5000
Swietenia macrophylla	0-500	1000-2000
Gliricidia sepium	650 - 3500	5 - 1500

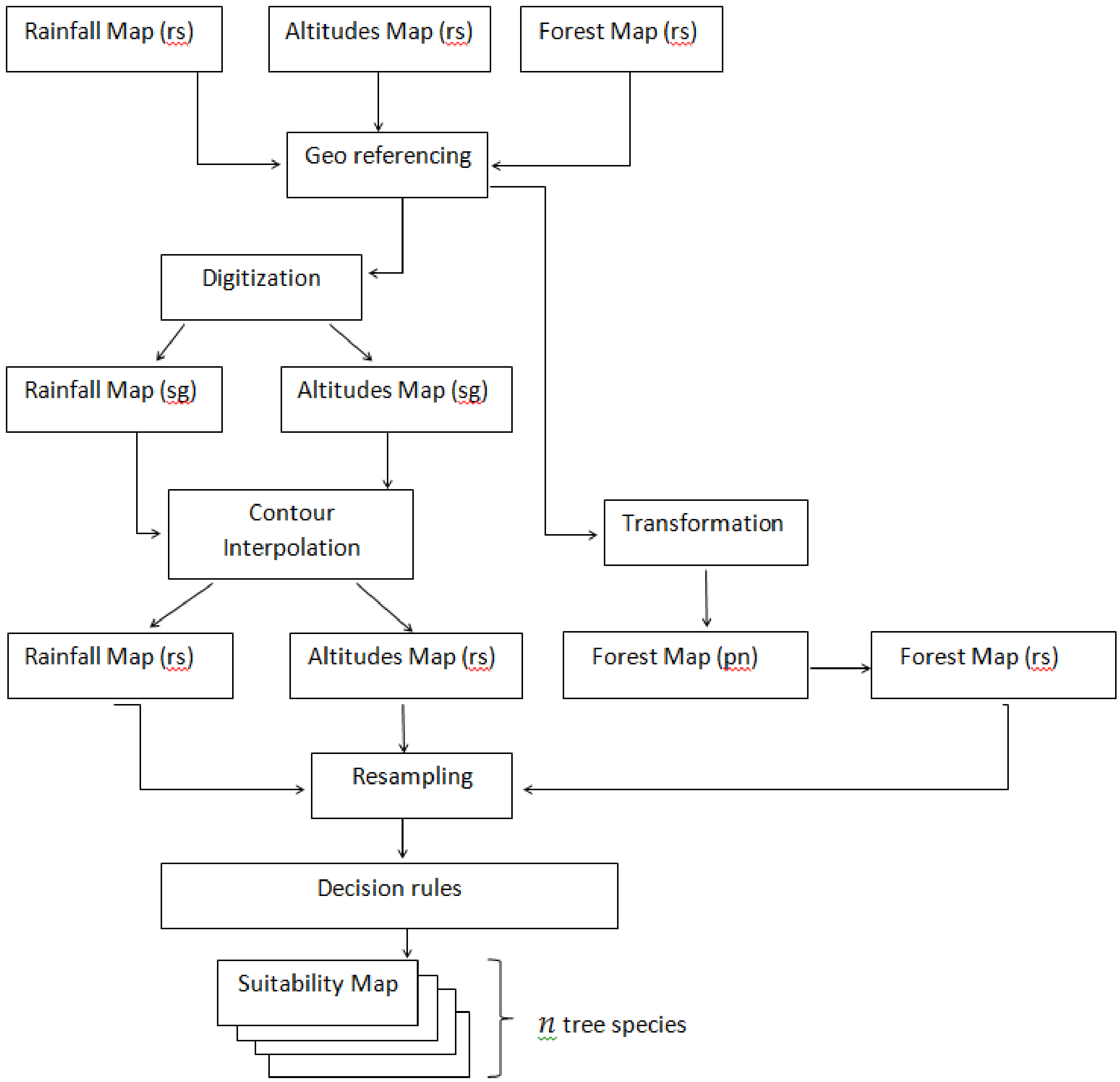


Figure 3. Flowchart of method. Maps used were in the raster (rs), segment (sg) and points (pn) formats.

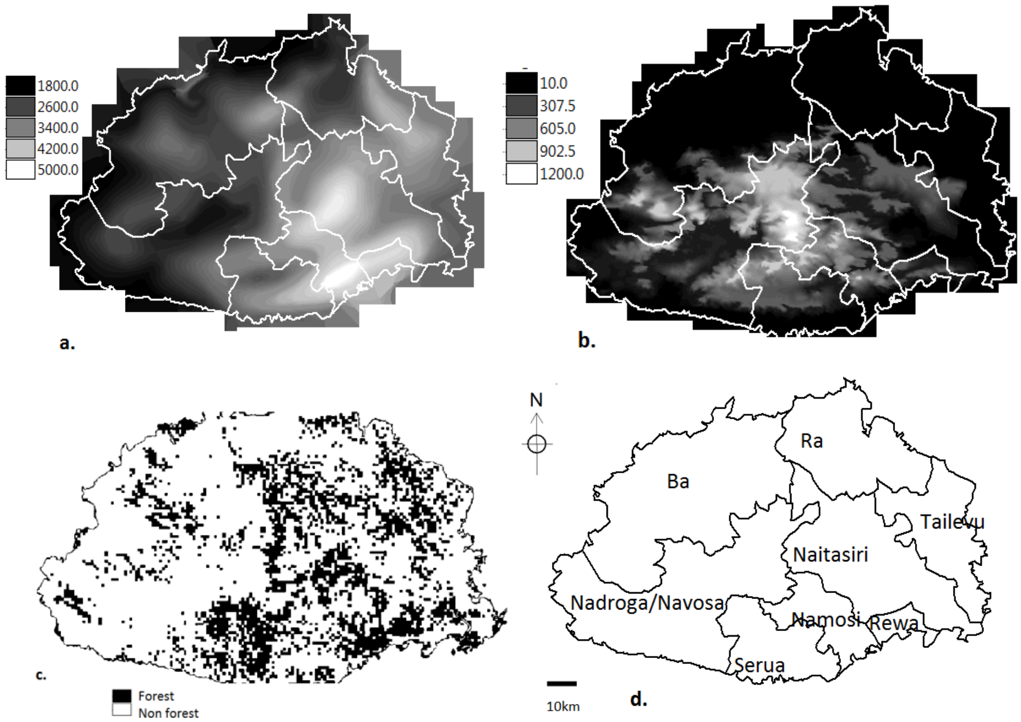
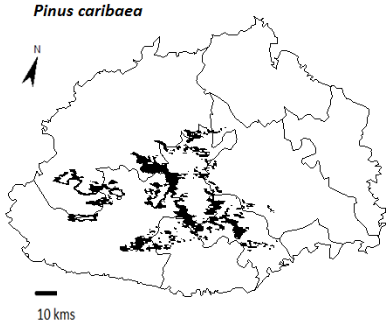


Figure 4. Rainfall (a), elevation (b), forest cover (c) and political (d) maps for Vitilevu Island.

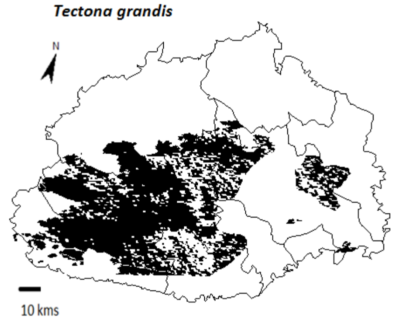
Table 2. Number of pixels and resulting areas to be planted per specie.

Specie	Family	Common name	Status	Pixels number of optimum areas	Area (ha)	Percentage
Pinus caribaea Morelet	Pinaceae	Pine	Commercial	66668	118802.4	6.16
Tectona grandis L. f.	Lamiaceae	Teak	Commercial	225118	401160.3	20.80
Leucaena leucocephala (Lam.) De wit	Leguminosae	Vaivai	Common	71234	126939.0	6.58
Sesbania grandiflora Pink	Fabaceae	Bean tree	Common	86636	154385.4	8.00
Metroxylon vitiense	Palmae	Fiji sago palm	Threatened	215132	383365.2	19.88
Balaka microcarpa	Palmae	Balaka	Threatened	9548	17014.5	0.88
Hydriastele boumae	Palmae	Niuniu	Threatened	7918	14109.9	0.73
Intsia bijuga (Colebr.) Kuntze	Fabaceae	Vesi	Threatened, commercial	101404	180701.9	9.37
Syzygium decussatum	Myrtaceae	Yasiyayi	Commercial	266908	475630.1	24.66
Agathis macrophylla	Araucariaceae	Dakua	Threatened, commercial	14021	24985.4	1.30
Swietenia macrophylla King	Meliaceae	Mahogany	Commercial	17703	31546.7	1.64
				Vitilevu total	**1928640.8**	**100.00**
			(110X162m)			
			(=17820m^2)			
			(=1.782ha)			

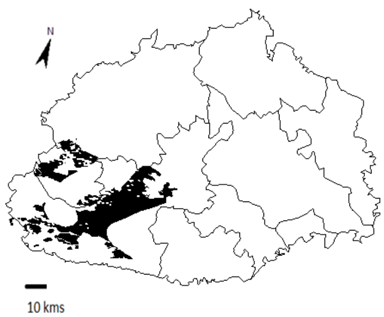
Pinus caribaea



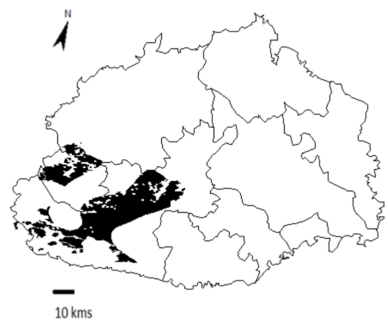
Tectona grandis



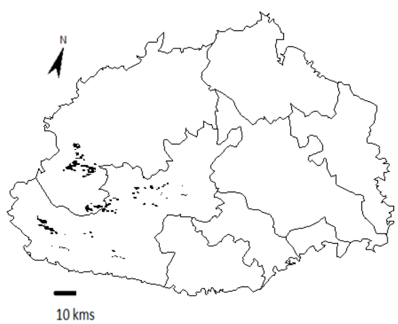
Leucaena leucocephala



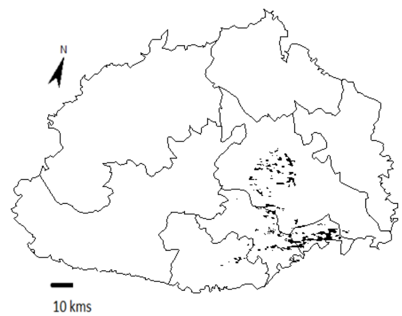
Sesbania grandiflora



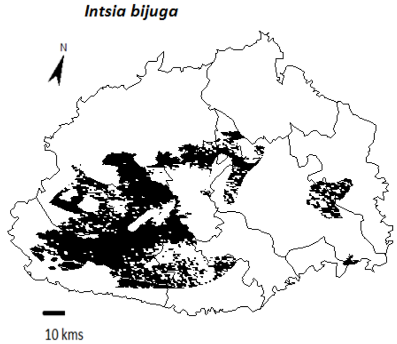
Metroxylon vitiense



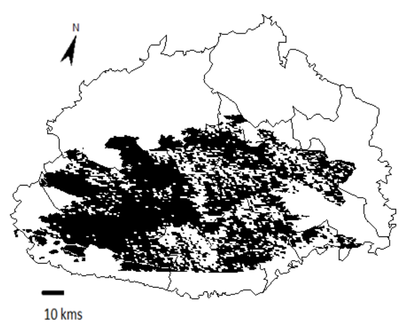
Balaka microcarpa



Intsia bijuga



Syzygium deccusatum



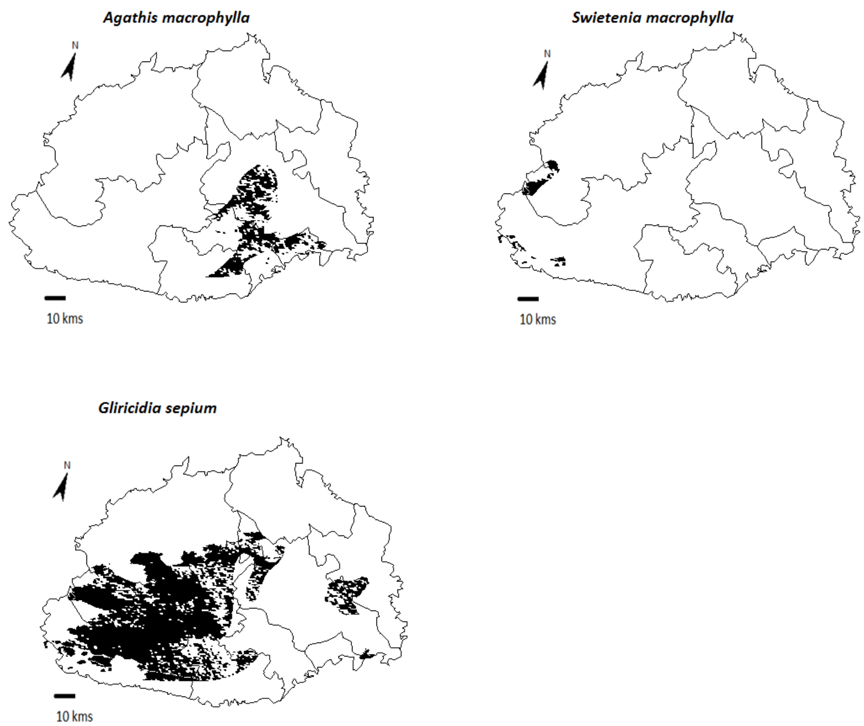


Figure 5. Maps displaying potential areas to be planted per specie.

Table 3. Potential areas in hectares to be planted by specie and by province.

Province	Agathis	Balaka	Gliricidia	Intsia	Leucaena	Mahogany	Pinus	Metroxylon	Sesbania	Syzigium	Teak
Nadroga-Navosa	1.124	0	138642.309	108605.38	54011	2231.421	27540.25	3452.366	60346.998	145275.033	96310.783
Serua	3832.559	429.649	15443.479	14397.878	0	0	3021.312	0	0	24020.442	41153.012
Namosi	11852.018	2402.27	1007.666	727.509	0	0	10270.83	0	0	29747.222	48525.89
Naitasiri	22203.215	4300.71	18687.624	18686.781	0	0	2289.588	0	0	66201.633	136872.29
Rewa	4884.623	3318.89	308.257	308.257	0	0	0	0	0	5557.337	17519.226
Ba	0	0	57695.763	45244.091	15453.9	5207.492	12398.56	3591.461	18282.984	57695.763	106621.52
Ra	0	0	22.199	22.199	0	0	0	0	0	22.199	29989.444
Tailevu	0	0	4139.13	4139.13	0	0	0	0	0	6670.378	82696.614

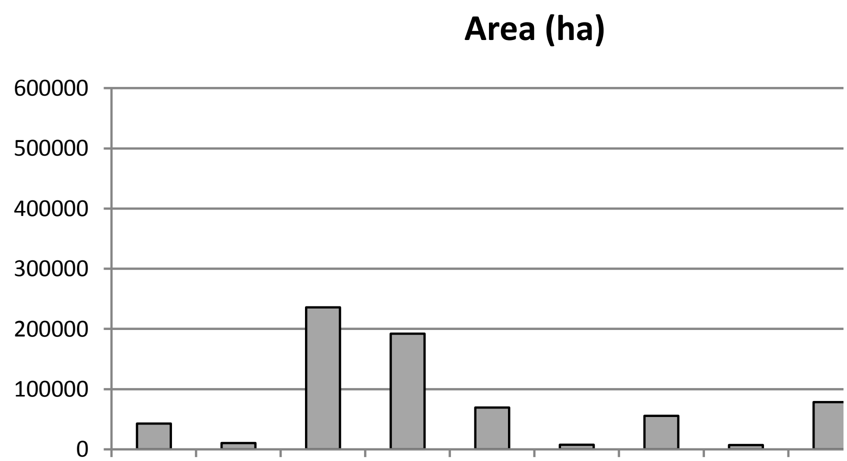


Figure 6. Total potential areas to be planted in Vitilevu island per specie.

3.0 Results and conclusions

According to figure 6 Tectona grandis, Syzygium decussatum, Gliricidia sepium and Intsia bijuga are the most promising species to plant in the island in order of importance (figure7). Pinus caribaea is more apt to be planted in Nadroga Navosa province (27540.248ha) followed by Ba (12398.563ha) and Namosi provinces (10270.831ha). Tectona grandis has high prospects on Ba (106621.516ha), Nadroga-Navosa (96310.783ha), Naitasiri (136872.29ha) and Tailevu (82696.614ha) provinces, Leucaena leucocephala in Nadroga-Navosa (54011.01ha) and Ba 15453.876ha) provinces, Sesbania grandiflora in Nadroga-Navosa (60346.998ha) and Ba provinces (18282.984ha), Metroxylon vitiense on Ba (3591.461ha) and Nadroga-Navosa (3452.366ha), Balaka microcarpa on Naitasiri (4300.705ha), Rewa (3318.891ha), Namosi (2402.269ha) and Serua (429.649ha) provinces, Intsia bijuga on Nadroga-Navosa (108605.376ha), Ba (45244.091ha), Naitasiri (18686.781ha) and Serua (14397.878ha) provinces, Syzygium decussatum in Nadroga-Navosa (145275.033ha), Naitasiri (66201.633ha), Ba (57695.763ha), Namosi (29747.222ha), and Serua (24020.442ha) provinces, Agathis macrophylla in Naitasiri (22203.215ha), Namosi (11852.018ha), Rewa (4884.623ha), and Serua (3832.559ha) provinces, and Swietenia macrophylla in Ba (5207.492ha) and Nadroga-Navosa (2231.421ha) provinces.

The genus Syzygium (Myrtaceae) comprises about 1200 species (Chen and Craven 2015), most are evergreen trees and shrubs. Several species are grown as ornamental plants for their attractive glossy foliage, few produce edible fruits. Gliricidia sp. is a multipurpose tree that can be planted by cuttings or seedlings year round (Ratukalou 1998). Intsia is one of the most valued trees in the Pacific and Tectona grandis is an important tropical hardwood with an MAI of 4-17m^3/ha/year (Pandey and Brown 2000). At this stage this work provides planners and investors with a firsthand report of land potential for the planting of endangered tree species or of high commercial value in the island. The proposed simple model is robust but can be improved by the addition of other thematic layers (soil fertility, land tenure, accessibility, and conservation areas), and by field checking for calibration.

4.0 References

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ANNEX: Photos of the rural landscape in Vitilevu island (the author 2016).

Figure 1. Subsistence family farm near Nadi city with cassava intercropped with papaya trees, the mature native trees in the background reveal that the area was formerly a natural forest.

Figure 2. Sugar cane being transported to the mill near Nadi city.

Figure 3. Small scale timber industries around Nadi city based on Pinus plantations. Most of the local enterprises are owned by Indofijians and most of the plantations belong to the Fijian communities.

Figure 4. Coconut trees are also common in the cities, the arrow indicates an *African tulip* (Spathodea campanulata) tree, an exotic aggressive invasive of degraded lands and plantations. After a failed attempt to eradicate it, alternative industrial uses are sought like woodchips production. The specie may also have a misunderstood ecological value as a colonizer in a forest succession by conditioning degraded soils.

Figure 5. Twenty years old *mahogany* (Swietenia macrophylla) plantation near Koronivia Research Station in Suva. The country's massive mahogany plantation started during the British rule, they reached maturity and are being exported. The specie regenerates well and its pests free, a problem that deters its planting in the areas of origin (courtesy from Dr. Chen Chien-Chih).

Figure 6. *Pandanus* palm tree growing amidst a mangrove at Tailevu coast. The specie is of high economic and cultural importance in Fijian villages. It provides material for roofings, carpets and handicrafts making. The fruits are edible and are increasingly used in agroforestry systems.

Figure 7. Farm cleared on a hill to expand a cassava plantation in Tailevu. Soil conservation practices are missing, therefore erosion risks are high. Tractor tilling was not done in contours but along the slope.

Figure 8. *Mangrove* forest at Tailevu coast. Their original areas dramatically decreased due to infrastructure development. They have a very important role on coastal protection against sea waves, and as a source of nutrients to coral reefs ecosystems.

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