GIS Applications and Spatio-Temporal Change

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1. INTRODUCTION

This paper was done as a part of the Human Responses and Contributions to Environmental Change in Africa (HRAC) project, coordinated by Paul Sinclair. The project has three research themes focusing on environmental change in the research areas, the relation between environmental change and settlement systems, and the impact of resource utilisation on the environment. The present study is a part joint teamwork in Anosy in the far south-east of Madagascar. The field team includes archaeologists Jean-Aimé Rakotoarisoa and Chantal Radimilahy and agronomist Amelie Berger who is studying past cultivation systems. The starting point for ongoing research in the area was the thesis of Jean-Aimé Rakotoarisoa who summed up the archaeological investigations from the 1980's and 1990's.

My part of the project followed three aims: Firstly to digitise coverages and to establish a map of land systems. Secondly to establish a phase by phase time series data set of archaeological sites. Thirdly to buffer the archaeological sites against the land systems maps. GIS-applications were used to implement these aims and assess spatio-temporal change in the location of settlements in the Anosy area from c. 900 to 1800 AD.

2. INTELLECTUAL BACKGROUND

2.1 Theoretical framework

To comprehend spatio-temporal change in human-modified landscapes two notions are regarded as fundamental in this paper – the relationship between human and environment, and the concept of evolution. McGlade has approached these questions in a model of ecodynamics (McGlade 1995). The ideas put forward by McGlade are followed, although on an implicit level. He argues that previous archaeological research concerning the interaction human and environment relied on a framework derived from human ecology and ecological anthropology. In these disciplines functional methods have predominated within an economic perspective. Evolutionary concepts, principally adaptation and equilibrium, were absorbed in the archaeological field and articulated in the processual paradigm (McGlade 1995:115-116).

The idea prevailed that the cultural system works to maintain stability and that major perturbations can only be caused by external factors. Inherent was a sense of mechanism and predictability. Alternative lines of research have developed in post-processual contributions. There has been a tendency to conceptualise the landscape with regard to perception, experience and symbolic attributes (McGlade 1995:113). In consequence 'meaning' has become observer-dependant and perceptually relativistic. In the crititics opinion the social is emphasised, while the natural is lost (McGlade 1995:113).

In recent years it has been widely recognised that environment and society can not be regarded as two separate and independent entities. To overcome this duality McGlade has put forward a model called ecodynamics (1995). One objective is to trace the different temporal rhythms inherent in natural and social processes. The contraction between these rhythms is regarded to be crucial for an understanding of the human and environmental relationship (McGlade 1995:117-118). A pluralistic view is adopted and the human-modified environment is thought to be confined to a set of complex social and cultural interdependencies. One of the consequences with the ecodynamics is a replacement of the traditional evolutionary paradigm by a principle of self-organisation. The ideas of adaptation and equilibrium, often implicit, are rejected. Inspiration is sought in recent developments in the natural sciences regarding non-linear phenomena, as opposed to the linear and deterministic conditions. In a non-linear system order emerges in complex systems through unstable transitions.

One aspect that is accentuated in the model is that in a spatio-temporal analysis the environmental scale needs to be considered. This has been realised in the case of Zimbabwe - depending on the scale different patterns become apparent (Sinclair 1987). At the macro-level it seems as clusters of settlements correspond in a significant way to the macroscale environmental units. At the micro-level however, the location of individual settlements are due to movement of central authority, according to collateral chiefly succession.

2.2 Method and GIS-applications

The present paper primarily concerns an analysis based on GIS-applications and comprises three steps. In the first step the coverages needed for the creation of land systems maps were produced including topography, hydrography and two geological maps (of scale 1:100000 and 1:200000). In the second step these maps were used to delineate land systems according to the definitions of Larsson and Strömquist (1991). For comparison two land systems maps were produced. In the third step the archaeological sites were buffered against the land systems maps, with catchment circles of 0,5 km and 1 km radius. From the buffered maps the areas of each land unit within the buffers were calculated in percentage, phase by phase. Further analysis is planned as part of the ongoing HRAC program.

All the maps included in the paper were digitised on the screen in MFworks (Thinkspace Inc.) from TIFF images, creating rasterised maps of high resolution (each cell 7,5x7,5 m). The reasons to apply this sharpness were two-fold. Firstly it is a quick approach to get a detailed representation of uniform areas. Secondly it is possible to change the cell size according to the needs of the analysis, by using the MFworks respace operation. Thus it is not necessary to choose one pixel size used for all GIS-applications from the beginning. For example it would be possible to fit the resolution of the land systems maps with field data registered on spreadsheets in low resolution. The final step of the analysis was carried out in ArcView GIS (ESRI), because of the option to combine vectorised and rasterised spatial data in the analysis, by the extension Spatial Analyst. Site co-ordinates could be imported from a data base file and then buffered against the land systems maps. By using the TIFF export facility in MFworks all coverages produced in the program could be transformed to a format readable in ArcView GIS. Thus the two programs became compatible.

2.3 The research area

The research area essentially comprises the Efaho river valley, a part of Anosy located in the far south-east coast of Madagascar (see fig. 1). This is an area where extensive archaeological research has been carried out during the 1980’s and 1990’s. A survey program was undertaken with the methods developed for the central highlands, including air photograph studies combined with field surveys in promising areas (see fig. 2 for the surveyed areas in relation the research area). Information was also obtained through conversation with local residents. The investigations resulted in a thesis written by Jean-Aimé Rakotoarisoa (1994). The study was supplemented with ethnographic data, taking advantage of the unique set of documents preserved from the 16th century and onwards. The earliest written accounts coincide with the arrival of the first Europeans in the 16th century. Of special value is the vivid records written down by the 17th century French governor Flacourt, who spent many years in the French colony Fort Dauphin. His observations, primarily from Anosy, are reproduced in ‘Histoire de la Grande Isle de Madagascar’, which includes detailed descriptions of customs, plants and various aspects of the region. In this study a map with the fortified sites of the time registered in relation to the topography and rivers is of interest (see fig.3).

As is evident in fig. 3 the research area is larger than the territory than has actually been archaeologically investigated. There are three reasons for this. Firstly the size has been adjusted to correspond to the scale of the spatial analysis, including buffering of the archaeological sites. As a consequence edge effects are avoided. Secondly the larger frame corresponds to the limits of the agronomical data, collected by Amelie Berger in the field and which are subject of ongoing GIS analysis. Thirdly there are good prospects for future archaeological work in areas not yet surveyed by Rakotoarisoa.

2.4 Research trends in Madagascar

Early on, archaeological research in Madagascar was focused on the initial peopling of the island. Now both the African bantu and south-east Asian elements have been recognised and dates for the first colonisation varies around the middle of the first millennium AD (Sinclair 1993, Radimilahy 1998). Among the first archaeological discoveries belonged the spotting of the coastal site Vohémar and accords with a general interest for coastal sites at the time. The archaeological remains included elaborate objects such as jewellery and chlorite schist vessels. During the 1960’s archaeology was established as a scientific discipline in Madagascar. Vérin, who collaborated with geographers and followed French research tendencies, was the driving force. A comprehensive archaeological survey program was conducted with the objective to establish a relative chronology for the settlements. Complementary dates were assessed through radiocarbon measurements, which also contributed to the realisation of the early origin of for example Talaky in the southeastern coast. Much attention was still given to the coastal sites, in part due to the association of datable foreign artefacts.

In response to the French cultural historical work, alternative lines of research have been developed. Processual approaches have been used to analyse cultural change from ceramic sequences. Other works have followed structural approaches in application of symbolic meanings on intra-site and inter-site relations. Surveys continue to provide new archaeological material and through air photograph studies more than 16000 hillforts have been registered in the central highlands. The findings have contributed to the foundation of a chronological sequence and a basic idea of settlement systems. Thus they provide information about the formation of the Merina State, which controlled large areas of Madagascar in the 18th and 19th century. Tendencies apparent during the 15th century, including development of hierarchical clusters of settlements with fortified major centres, located on hilltops and controlling surrounding small villages, were enforced during the following periods. A structural change in the settlement pattern is evident during the 18th century in connection with the forging of the Merina State (Wright & Rakotoarisoa 1989).

In Mahilaka in the north-west of Madagascar the development of urbanism has been examined on the site level (Radimilahy 1998). Series of investigations, including more than 600 drill cores, augering, phosphate analysis, electroresistivity survey and excavations, have been conducted in order to encompass the spatial organisation of the site through time. It has been assessed that the site possessed an advanced economic position, both with regard to the hinterland of north-west Madagascar and the trade network of the western Indian Ocean. The site dates back to end of first millennium and grew to a considerable town, extending to 70 ha during its peak. Stone structures have been revealed as well as a plenitude of both imported and locally produced objects. In the study of urbanisation in Madagascar the definition of a town currently has shifted to follow principles adequate for East African conditions, rather than European.

2.5 Previous archaeological research in Anosy

In this section the principal results from the thesis of Rakotorisoa (1994) are summarised. Altogether 53 sites are included in the research area, which have been studied according to their environmental context, including factors such as topography, distance to the coast, vegetation, geological features etc. Three large groups of sites were distinguished – coastal, inland and refugee. The coastal sites were located in proximity to a hoba, which is a bay allowing small boats to embark. No defensive structures were associated to these settlements. The inland sites were located on small hills, between the coast and the mountains. The refugee sites were small in extent and their locations were strategic on mountain spurs, resembling a defensive system called kizo.

Four archaeological phases have been assessed with reference to ceramics, each phase given the name after the most representative site from respective phase. The four phases are in chronological order Maliovola (10th to 13th century), Ambinanibe (14th to 15th century), Tranovato (16th to 17th century) and Hoala (18th to 19th century). During Maliovola the food procurement diversified and there is evidence for fishing and cattle raising. Furthermore, in Mokala bone remains from lemures have been found. The flottation tests have at this point revealed no crop remains. However, the location of Maliovola close to a present rice field implies that some cultivation occurred. It is supposed that the people mostly relied on tubers. This is a phenomenon still visible in small villages in Anosy and neighbouring areas. The sites were few and small, less than 0,5 ha, although larger sites may not yet have been found. The settlements had a seasonal and temporary character and were part of a simple economic system. The trade was limited and a piece of chlorite schist found in Mokala is one of the few examples of imported goods.

During the following phase, Ambinanibe, the sites were still few, although larger. The food procurement activities seem to have developed and the sites were located in small sandy hills along the river courses in areas suitable for cultivation of sweet potato, bageda. There are indications of some specialisation in the subsidence practises – agriculture in Efangitse, fishing in Ambinanibe and cattle raising in Tsiandrora. Iron working was present already during the first phase but was further developed during Ambinanibe. The trade increased and became more far-reaching, according to the finds of chlorite schist and celadon.

During the Tranovato phase many of the developments that were initiated during the earlier phases culminated in connection with the arrival of new people, Zafiraminia, which seized the power. They brought with them a strict socio-hierarchical system, which was associated to the ancestors. The settlements grew in size and some sites extended more than five ha. They also became fortified with defensive structures of ditches and palisades of wood. Iron working and the long-distance trade was enforced. Objects from China, Portugal, England and France now reached the region. Riziculture and cattle raising were the principal food procurement activities. The conditions changed with the French colonisation of Anosy in the 17th century and Fort Dauphin became a new European power centre. The French challenged the established power of the Zafiraminia, a fact which is historically attested. The Hoala phase is marked by recurrent disturbances and the Zafiraminia tried to regain their previous status, but without success. The size and the number of sites decreased and some areas were deserted, although they were later reoccupied by other people. New crops were introduced and there were still abundant of imported goods, Chinese in particular.

2.6 Chronostratigraphic framework

The chronology of Anosy was established through the ceramics, confirmed by radiocarbon dates and in coherence with Wright's classification in the central highlands (Rakotoarisoa 1994:46). The ceramic assemblages also define the archaeological phase. The results are summarised in this chapter, as they are the basis for the observations of spatio-temporal change. The ceramics were classified according to three principal characteristics: surface, texture of the clay and firing technique. The pottery was also analysed with regard to the form comprising three categories: rim, body and base. Elaboration of the rim seems to have been a recurrent feature, observed in other parts of Madagascar as well. This fact has proven to be useful for the purpose of further division, resulting in seven groups of rims.

Based on the granularity of the clay, two groups of pottery can be distinguished for the first archaeological period. The first category comprises pottery made in fine clay. The production includes shallow open vessels provided with a red-brownish coating, some of them decorated on the inside of the rim with a few channels. Pottery made of coarse sandy clay constitutes the second category. This material was preferred for large open vessels with flat bases and with thick and flattened rims. Horizontal and crossed incisions were used for decoration on the inside. The former motif is related to some pieces of chlorite shists, rare in this region. In Mokala some confusing pottery have been found. They are decorated with motifs that reappear during Tranovato. The reason for this coincidence is uncertain, but has been explained as a survival, innovation or intrusion. Pottery found in Maliovola seems to share some characteristics with neighbouring regions. This is evident in coarse ceramics from both Andranasoa and Talaky.

During Ambinanibe the pottery changes in quality and becomes coarser with inclusions of sand and quartz. Closed vessels with incised decoration predominate. Among the few finds of open vessels belongs a copy of a celadon. The variations in decoration occur basically along two trajectories. Firstly parallel lines, either oblique or separated vertical and horizontal, in certain cases provided with applicated lines in corresponding angle. Secondly oblique incised lines are combined in a zigzag pattern. A difference has also been noted between Ambinanibe and Efangitse in the breadth of the incised lines. The reason could be either chronological or technological. Efangitse is furthermore the only representation of an open type of pottery with eversed rims carrying simple incised decorations. The date is suggested to be of late Ambinanibe, which accords with the two plausible explanations that have been put forward. In the first one, the divergence reflects a continuation of occupation from late Ambinanibe to early Tranovato. According to the second theory, the Tranovato people maintained the production of Ambinanibe ceramics. Flacourt's description of a new people conquering the ancient settlements supports this theory.

Two features in particular have been used to distinguish the Tranovato phase from the former – the decoration and the thickness of the rim. The pottery during Tranovato shows diverse qualities, both in the clay and the decoration. The coarse clay used during Ambinanibe continued to be employed. The finer clay was restricted to the open vessels. These were covered by graphite and decorated with triangular punctates typical for the rest of the Madagascar during the 15th century. The shape follows various hemispheric forms. One more open form, with flat influences, resembles the shape of the celadon. There are also examples of carinated forms, which frequently were covered by graphite. The most common decoration for the open vessels is triangular impressions on the outside. During Hoala this kind of decoration is instead placed on the inside of the rim. Occasionally these forms are found in small Tranovato sites. One interpretation suggests a technological continuation initiated during Tranovato. In that case they could be the remains of some peripheral villages that managed to survive after Flacourt's destruction 1651. The sherds could also be the result of farmer's agricultural activities during the 18th and 19th century. The restricted vessels from the Tranovato phase have a spherical shape and are simply decorated. Besides triangular impressions other motifs similar to examples from the Ambinanibe phase also occur. The distribution of the restricted vessels varies according to the decoration, where triangular motifs are only found on the larger sites, while combed motifs predominate in the smaller sites.

Triangular motifs continued to be a common decoration during Hoala. But as stated above, they are instead placed on the inside of the rim and some simple lines are added. Some sherds indicate a partiality for combining several motifs, including vertical incisions. Another difference is seen in that the bowls with eversed and thickened rims gain a deeper form. These vessels are manufactured in medium to fine clay. Spherical pots of the type occurring during Tranovato are confined to some few examples found in Fenoarivobe. In time they appear to have been replaced by cooking pots made in iron.

3. PHYSICAL ENVIRONMENT

3.1 Topography and geology

The Anosyan ranges cover large parts of the research area, which is reflected in both the geology and the climate. The extension of the mountains roughly follows the 100 m altitude line (see fig. 4). Another typical feature of the region is the undulating hills of the hinterland, extending from the mountains to the coast. Together with the seasonal rivers the hills forms a broken landscape (which is indicated in fig. 4), with an altitude ranging from about 25 to 50 m.

Crystalline rock and sediment deposits largely constitute the geomorphology of Anosy. The composition of these follows the physiography, both in the crystalline mountains, the eroded hinterland and the low-lying of coast. The Anosyan ranges belong to the ancient precambrian basement and obtained its shape during a series of tectonic movements. The sediments are of recent date and are both of marine and continental origin (Rakotoarisoa 1994:14). The marine sediments are concentrated to the coast and rest directly on the crystalline rock. Three successive periods of transgressions during the Quaternary era have formed the landscape of the coast, leaving areas of sand dunes and grey calcareous. Furthermore Karimbolian sand formations, resulting from lagoonal deposits, elongate to the interior. Further inland, both continental and marine deposits are prevalent. Alluvial deposits, both ancient and recent, surround the estuary of Efaho and are also found in the upper river valleys and in some cases in the interior.

3.2 Hydrography

The lagoons and permanent rivers of Anosy are represented in fig.5. Evident is the Efaho River, and its branches, dominating position, running from the mountains in the north along the valley to the ocean in the south. The relative high precipitation in combination with the mountains provides a well-developed hydrography. Besides the permanent rivers abundant of seasonal rivers penetrate the landscape. In fact owing to the large numbers of seasonal rivers it didn't seem reasonable to represent them. However a change is discernible in the pattern in the coastal area, which is dominated by the lagoons. In times of inland inundation, streams occasionally find their ways through the dunal ridges, separating the coast from the hinterland, and supply the lagoons with water.

3.3 Vegetation

Basically three vegetation types are found in Anosy: forests, grasslands and plantations. The forest is rapidly diminishing and the primary forests today are confined to the mountain ranges and some patches along the coast. The primary forests belong to the humid tropical forest in the east and shows high ecological diversity, offering plentiful resources for humans. Forest fires are rare in this humid environment and human impact has been far more devastating, often resulting in a degraded form of vegetation called 'savoka'. This is compact foliage with scant species, often limited to some heliophilous species. Efforts have been made to compensate for the lost forests, by introducing Eucalyptus and fig trees (Rakotoarisoa 1994). The lasting effects have been limited and are found in some urban areas, as for example in Fanjahira and Mandena. Some idea of the original vegetation of the coastal area cab obtained from the reserve forest in the south central part of the research area.

The destruction of forest has profound repercussions for the food production. Promotion of erosion in the mountain slopes has resulted in that rice fields along the rivers have been silted. Furthermore the ecosystems have been disturbed and destroyed the natural habitat for the primeval fauna. The forests have been replaced by savannahs, suitable for cattle.

3.4 Climate

Located on the south-east extremity of Madagascar, Anosy shares the characteristics of the east humid climate. However, the region is also influenced by the semi-arid climate in the south, extending from the Anosyan ranges and to the west. The mountains close to the ocean together with the trade wind give rise to a humid climate. Typical features are high precipitation and temperature, although declining in southern latitudes. Furthermore the trade wind substantiates high atmospheric humidity and brings water-vaporised air from the Indian Ocean. This in turn annotates seasonal variations in temperature (Donque 1972:116-117). The rain period begins in October and ends in April. Rainfall is not unusual during the dry season and July even accounts for the highest amount of rain during the year. During this period systems of bad weather prevail, due to the strength of the trade wind. In January and February tropical cyclones are frequent.

With the mountain ranges in proximity to the ocean, Anosy has a diverse climate. Sub-regional climates can be distinguished depending on distance to the ocean, altitude and winds (Rakotoarisoa 1994:20). The humid zones are those of higher altitudes with mountain slopes facing the wind coming from south-east. There the annual precipitation exceeds 2000 mm, comparing with the Anosyan average of 1500-1600 mm. Mountain slopes on the lee of the wind, on the other hand, are relatively dry. Although the humid climate predominates, semi-arid elements are recognised. The driest areas are found in the coastal plains in the south and south-west, with annual precipitation of 750 mm.

4. THE LAND SYSTEMS APPROACH

4.1 The method

One aim of the present work was to first create a platform for various aspects of analysis, performed in several steps. A method was sought for that could relate spatio-temporal change, within an archaeological perspective, to various physical features according to simple principles. The land systems approach (Larsson & Strömquist 1991) was chosen, as it seemed promising in fulfilling these requirements. The method is a technique to delineate and define environmental units of uniform character. It was developed for rapid reconaissance mapping of air photographs and satellite images. Inherent in the procedure is the way to survey several environmental factors simultaneously, creating an integrated map. There are some variations in the employment of mapping units, but in this case the land system and the land facet are used as they are defined according to Larsson and Strömquist (1991):

- The land system is an area of recurring pattern of topography, soils and vegetation, and with a relatively uniform climate.
- The land facet is an area within which, for most practical purposes, environmental conditions are uniform.

The procedure in this paper differs from the described as neither air photographs or satellite images were available. Instead a topographical map (with the scale 1:100 000) and two geological maps (with the scales 1:100 000 and 1:200 000) were used. There were three reasons for this: Firstly it is a cheap way to map the research area. Secondly it is a quick way to map large areas, avoiding the time consuming work of georeferencing a lot of air photographs. Thirdly the outset was to focus on geomorphological and topographical features with the objective to create a map which has been relative unchangeable during the last during thousand years, the time scope of study. Vegetation being a highly time sensitive factor was thus excluded from the mapping.

Considering the stated principles two land systems maps were created. The applicability of the both will be assessed in the analysis.

4.2 Land systems alternative 1

The first land systems map was in principal created from a geological coverage overlayed with a topographical coverage (see fig. 4). First the land systems were grouped according to recurrent geomorphological features giving four land systems – crystalline land, alluvial land, dunal land and ocean (see fig. 6).

The crystalline land system comprises all areas, which have a basic crystalline character, excluding minor variations. Further division was made with regard to altitude resulting in three land facets (0 to 25 m, 25 to 100 m and above 100 m).
In the dunal land system sand dunes and recent dunes were grouped together. Considered was also altitude and proximity to the ocean. The limit between the coast and the inland was set to the dunal ridges running parallel to the littoral and forming a natural border. All together five land facets were included in the land system – coastal dunes 0 to 25 m, coastal dunes 25 to 100m, inland dunes 0 to 25 m, inland dunes 25 to 100 m and recent dunes.

In the alluvial land system all areas with aquatic character or alluvial deposits, both ancient and recent, were included. For the reason of further division were marshes, lagoons, rivers and alluvia separated. Consideration was also taken to differences between location along the coast and in the interior. The result was six land facets: rivers, lagoons, coastal alluvia, inland alluvia, coastal marshes and inland marshes.

4.3 Land systems alternative 2

Although the first land system seemed to provide suitable information of the physical environment, two questions lead to the decision to create a second land systems map for comparison. Firstly, would it be possible to create a varied map, which considered topographical influences without the use of artificial altitude lines and thus create natural borders? Secondly, would it be possible to use the natural division of the landscape in the three units – coast, inland and mountains – proposed by Rakotoarisoa? Support for these ideas were found in the second available geological map of the area (see fig. 7), where there seemed to be a correspondence between geological and topographical features. These factors were considered in the mapping and resulted in seven land systems (see fig. 8) – riverine alluvia, mountains, ferralitic inland, ferralitic slopes, dunes, coastal alluvia and ocean. In the descriptions below each land system has been provided with Roman numerals and each land facet with a letter.

I Riverine alluvia. This land system includes all permanent rivers and alluvial deposits connected to them. Two land facets are distinguished – rivers (Ia) and alluvia (Ib).

II Mountains. This land system forms continuous areas of high altitude and generally exceeds 100 m. The bedrock character is pronounced, either of granite or gneiss. Two land facets are separated within the system – granite (IIa) and gneiss (IIb). The latter are smaller units than the former and are located within other land systems.

III Ferralitic inland. The area is an undulating landscape of small hills and the soil is ferralitic, even though differences can be distinguished in the composition, which is reflected in the two land facets – sandy (IIIa) and sandy with influences of dunes and ancient alluvia (IIIb).

IV Ferralitic slopes. These areas are linked to the topography and the hydrograpy of the mountains and the soil is both ferralitic and hydromorph. Two land facets are separated within the system: hydromorphic soils below the mountains (IVa) and hydromorphic soils in eroded slopes (IVb).

V Dunes. This land system comprises areas of dunal character, found along the coast. The system comprises three land facets: stabilised dunes (Va), dunes on granite (Vb) and active dunes (Vc).

VI Coastal alluvia. This land system includes marshes, lake deposits, lagoons and alluvia within the coastal area. Three different land facets are accounted for – lake deposits (VIa), lagoons (VIb) and alluvia (VIc)

VII Ocean.

Both of the land systems maps seem relevant for the analysis at this point and will therefor be used for further evaluation in land use assessment. The second land systems alternative may be increased to a larger frame (using the geological map of scale 1:200 000) for comparison to neighbouring areas.

5. SPATIAL ANALYSIS

In the spatial analysis the sites were buffered against the two alternative land systems maps, phase by phase, with catchment circles of 0,5 and 1km radius (see fig. 9 to 16). The results of this analysis can be seen in table one and two. It is important to note that the statistics for the earlier phases are more uncertain than the later phases, which are represented by more sites. The results of the spatial analysis are briefly outlined below, according to both of the land systems alternatives.

Land system alternative 1.

During the Maliovola phase the crystalline areas account for the largest portion of the land systems within the buffers. The coastal dunes form another large group, which together with the relative high percentage of ocean indicates that coastal site locations were favoured. In the following Ambinanibe phase there is a significant rise in the percentage of inland alluvia within the site buffers. The coastal land facets are still pronounced, although a shift can be observed from the ocean to the lagoons. During the Tranovato phase high percentage of inland alluvia is still evident. There is a marked shift from the coastal dunes to the crystalline areas of lower altitude. During the final phase the move to the crystalline land system was clearly shown and also from the inland alluvia and the rivers further inland towards higher altitudes.

Land system alternative 2.

Site buffers are dominated by dunal elements during the Maliovola phase, stabilised dunes in particular. Coastal site locations are also preferred. Another land facet is the sandy ferralitic inland shown in a single buffer. During the Ambinanibe phase there is an increase of the riverine alluvia within the site buffers. The coastal areas are still highly represented, but there is a shift from the dunes and the ocean to the lagoons. In the following period a move occurs from the dunes and the lagoons to the ferralitic inland. The riverine alluvia is a significant part, a situation that changes during the Hoala phase with sites located further from the rivers and the riverine alluvia to the ferralitic inland in proximity to mountains and ferralitic slopes.

	Maliovola		Ambinanibe		Tranovato		Hoala	
	0.5 km	1km	0.5 km	1 km	0.5 km	1 km	0.5 km	1 km
Ocean	9.7	10.6	0.6	6.5	6.7	7.0	2.8	3.3
Dunal land								
Inland d. 0 - 25 m		3.5		0.6	0.5	2.3	1.4	2.8
Inland d. 25 - 100 m					0.7	2.3	1.5	1.4
Coastal d. 0 - 25 m	23.4	22.6	21.9	15.9		0.3	1.7	
Coastal d. 25 - 100 m	2.3	1.1	6.9	6.3				
Recent dunes	2.8	2.2		0.4			0.1	
Alluvial land								
Inland alluvia	3.8	7.5	24.3	21.5	20.2	16.8	6.2	7.3
Coastal alluvia								
Rivers	12.5	8.0	12.8	8.3	7.8	6.3	2.3	1.8
Inland marshes					1.7	2.3	0.3	0.3
Coastal marshes	0.3	1.9	0.3	1.8				
Lagoons	0.3	6.0	8.2	8.7			0.3	0.3
Crystalline land								
0 - 25 m	36.7	21.6	25.0	29.6	51.9	51.0	61.6	59.5
25 - 100 m	8.1	14.4		0.4	10.5	11.0	20.4	18.6
>100 m		0.6				0.7	1.3	3.1

Table 1. Land system alternative 1, buffer areas by land facets (%).

	Maliovola		Ambinanibe		Tranovato		Hoala	
	0.5 km	1km	0.5 km	1 km	0.5 km	1 km	0.5 km	1 km
Ocean	9.8	15.5		3.4	6.9	7.3	3.7	4.1
Riverine alluvia								
Ia	10.0	9.3	13.3	10.2	7.8	6.8	2.2	2.1
Ib	5.9	6.8	19.0	17.2	19.2	16.9	4.3	5.9
Mountains								
IIa							2.8	3.5
IIb	3.4	5.7			1.4	2.5		
Ferralitic inland								
IIIa	23.4	19.6	26.0	29.6	60.3	61.0	45.5	43.7
IIIb		0.7	6.1	5.3	2.2	2.9	35.3	32.5
Ferralitic slopes								
IVa								
IVb		0.9			1.4	2.5	4.0	6.2
Dunal areas								
Va	30.7	21.2	21.4	15.4			0.6	0.4
Vb		0.5						
Vc	15.3	14.5	9.2	8.1		0.7		
Coastal alluvia								
VIa	1.5	3.1	5.0	8.7				
VIb								
VIc		2.0		2.0	2.2	1.8	1.6	1.7

Table 2. Land system alternative 2, buffer areas by land facets (%).

6. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Observations in spatio-temporal change were achieved by creating land systems maps and establishing a time series data set. Two different land systems maps were produced which were compared in the buffer analysis. Similar trends were observed, phase by phase, for both of the alternatives. In the Maliovola phase the sites are concentrated to the coast in dunal areas. During the Ambinanibe phase the sites are centred towards the flood plains, while the coastal settlements were to the lagoons rather than the ocean. In the Tranovato phase a shift occurs from the dunes in the coast to the crystalline areas/ferralitic inland. In the final phase, a time of recurrent conflicts initiated by the French in the previous phase, the orientation to crystalline land/ferralitic inland is further pronounced, with a move from the floodplains and the rivers further inland towards the mountains.

According to the above shifts were discerned in settlement location in relation to the land systems. It was for example observed that the portion of inland areas increased through time. However it should be noted that the inland areas roughly correspond to the surveyed areas. The picture might be altered in future research as is indicated in the map provided by Flacourt in the 17th century (see fig. 3). Future archaeological work is recommended for these areas.

LIST OF ABBREVATIONS

ESRI - Environmental Systems Research Institute, Inc.

TIFF - Tagged Image File Format

Human Responses and Contributions to Environmental Change in Africa

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ILLUSTRATIONS

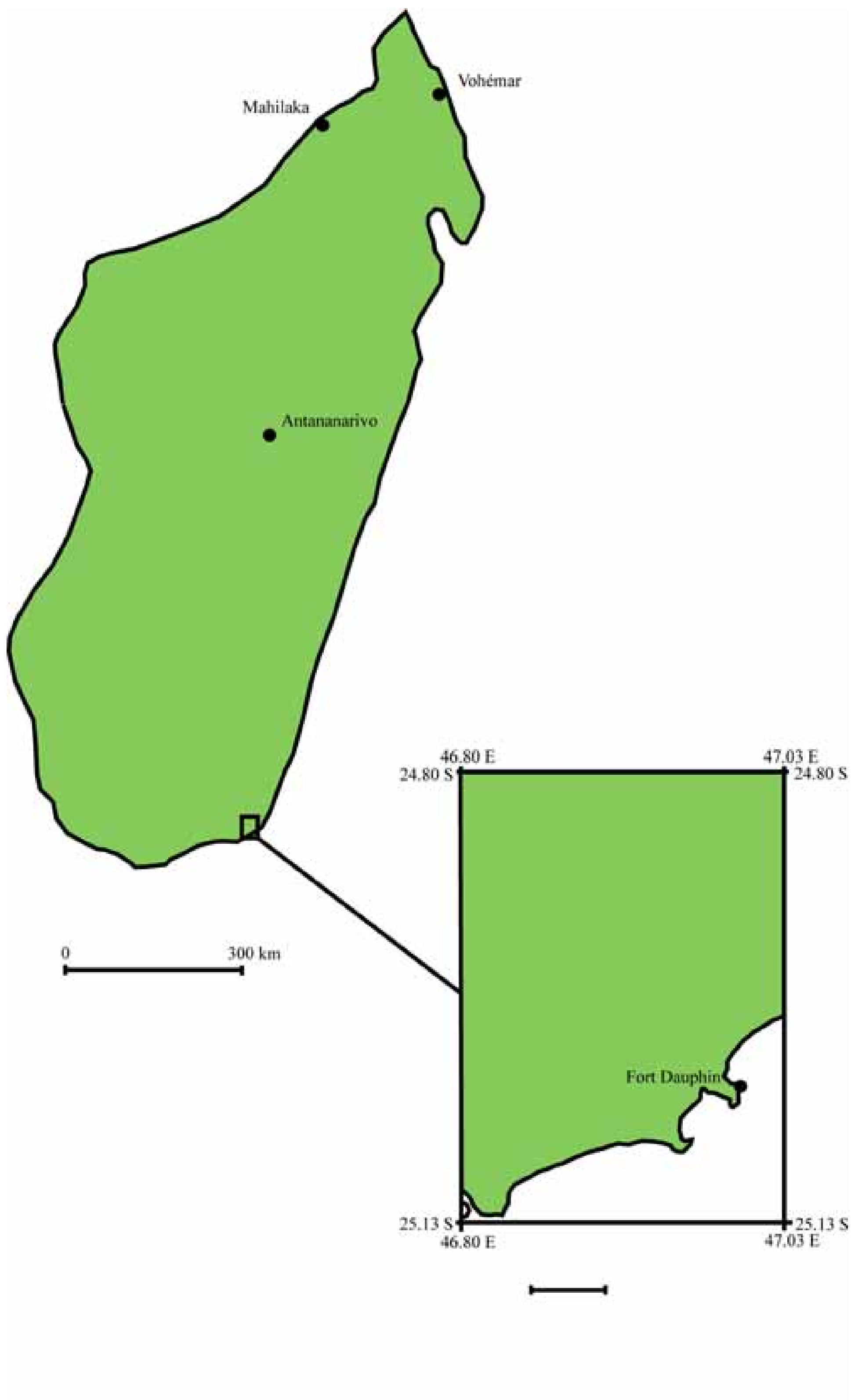

Fig.1 The research area in relation to Madagascar (with co-ordinates for fig. 2 to 16)

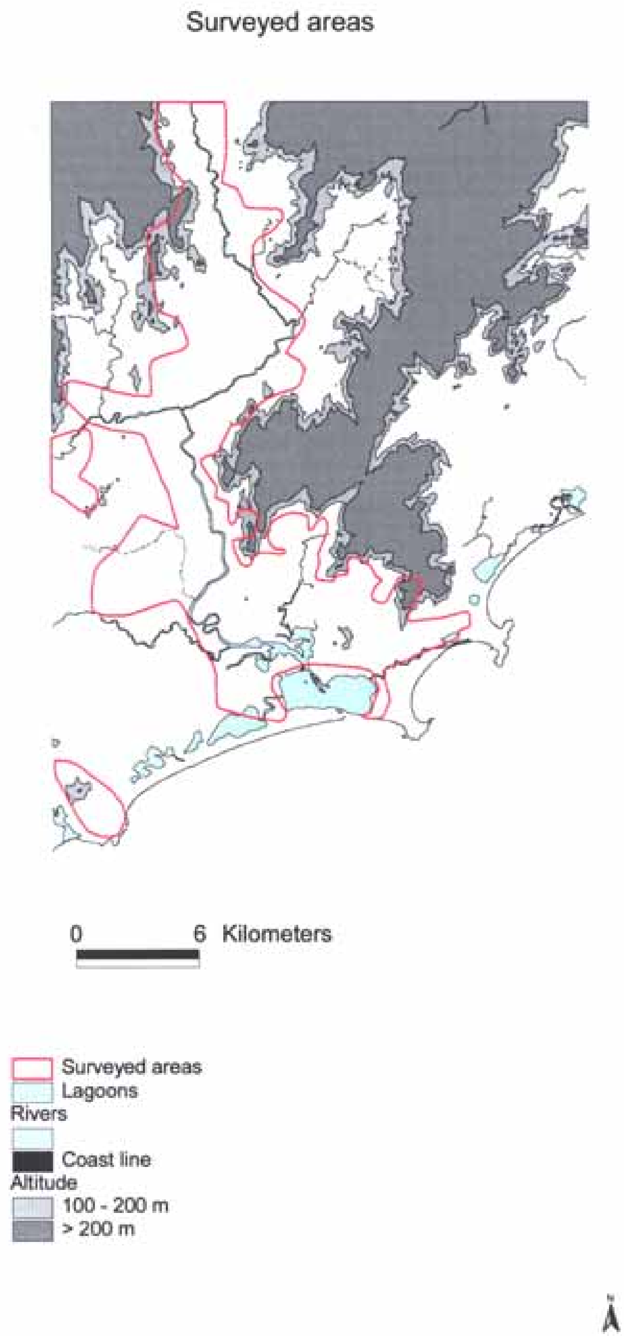

Fig. 2 The Anosy area showing bounded survey areas

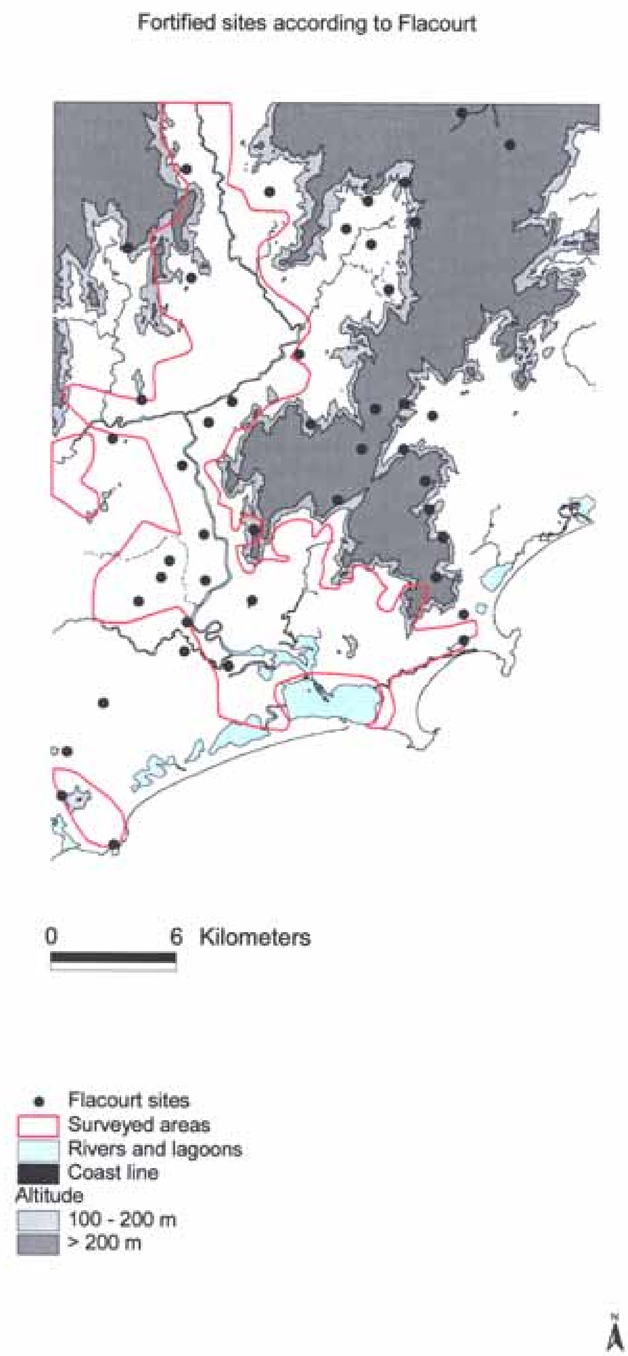

Fig. 3 Fortified sites registered by Flacourt (in the middle of the 17th century)

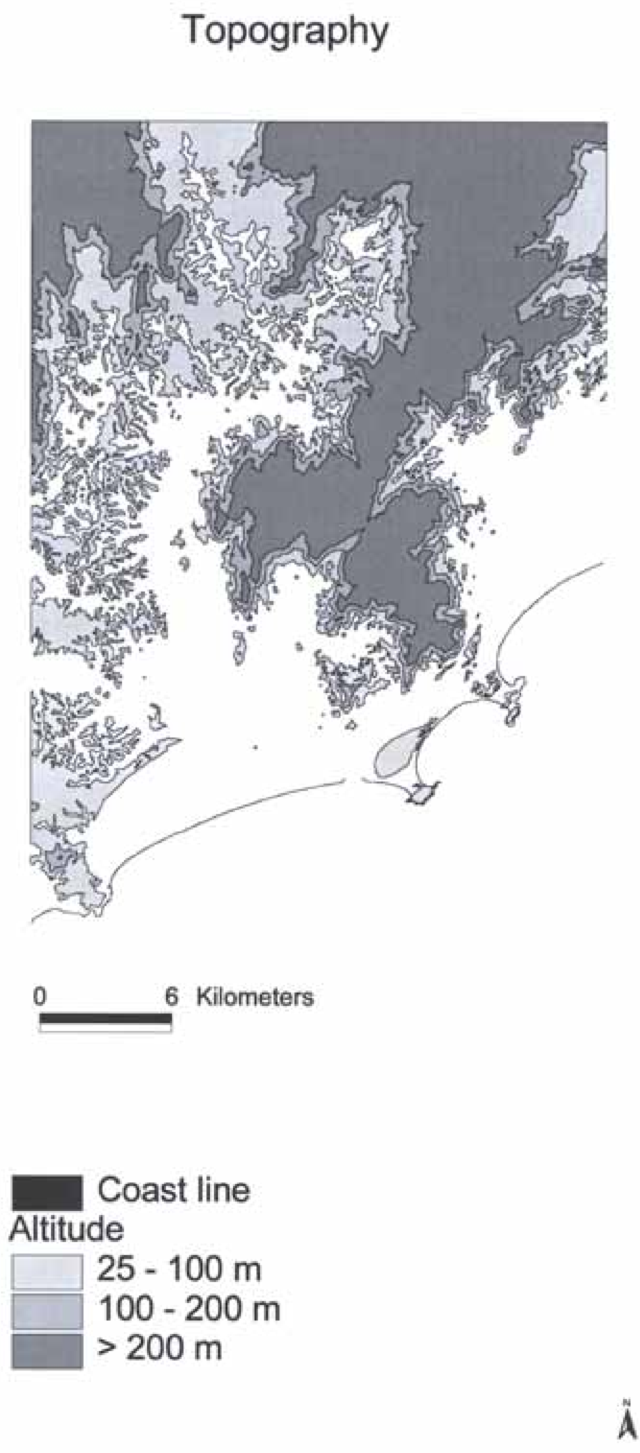

Fig. 4 Detailed topography of the research area

Hydrography

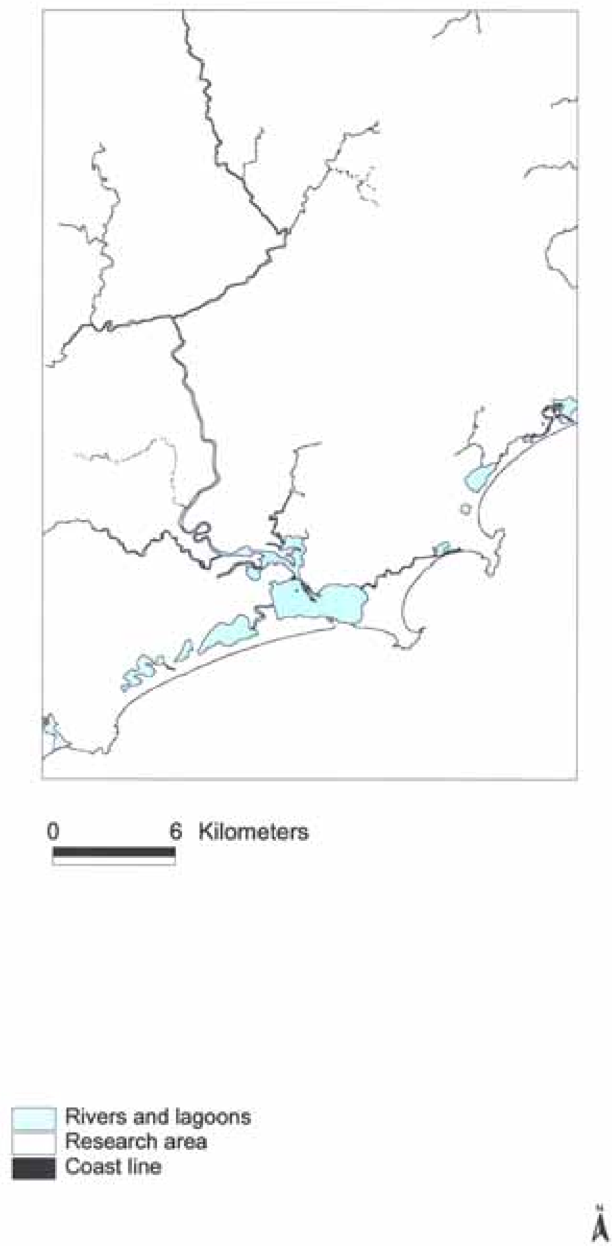

Fig. 5 Hydrography of the research area

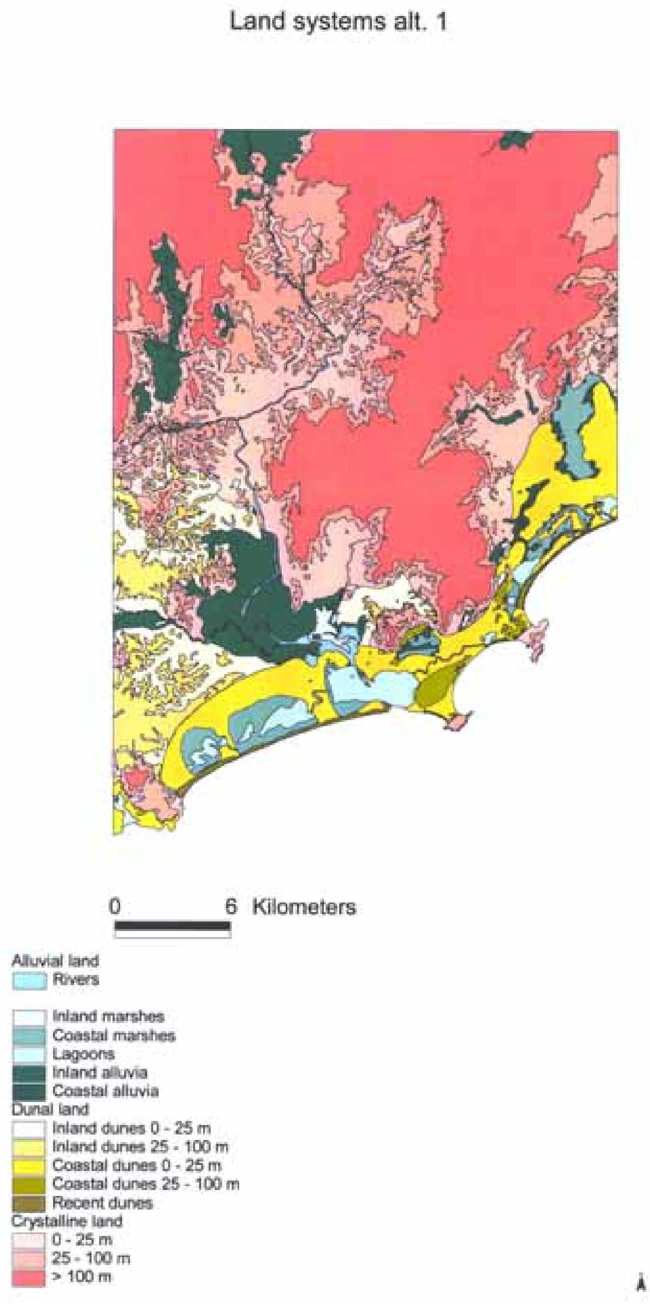

Fig. 6 Land systems alternative 1

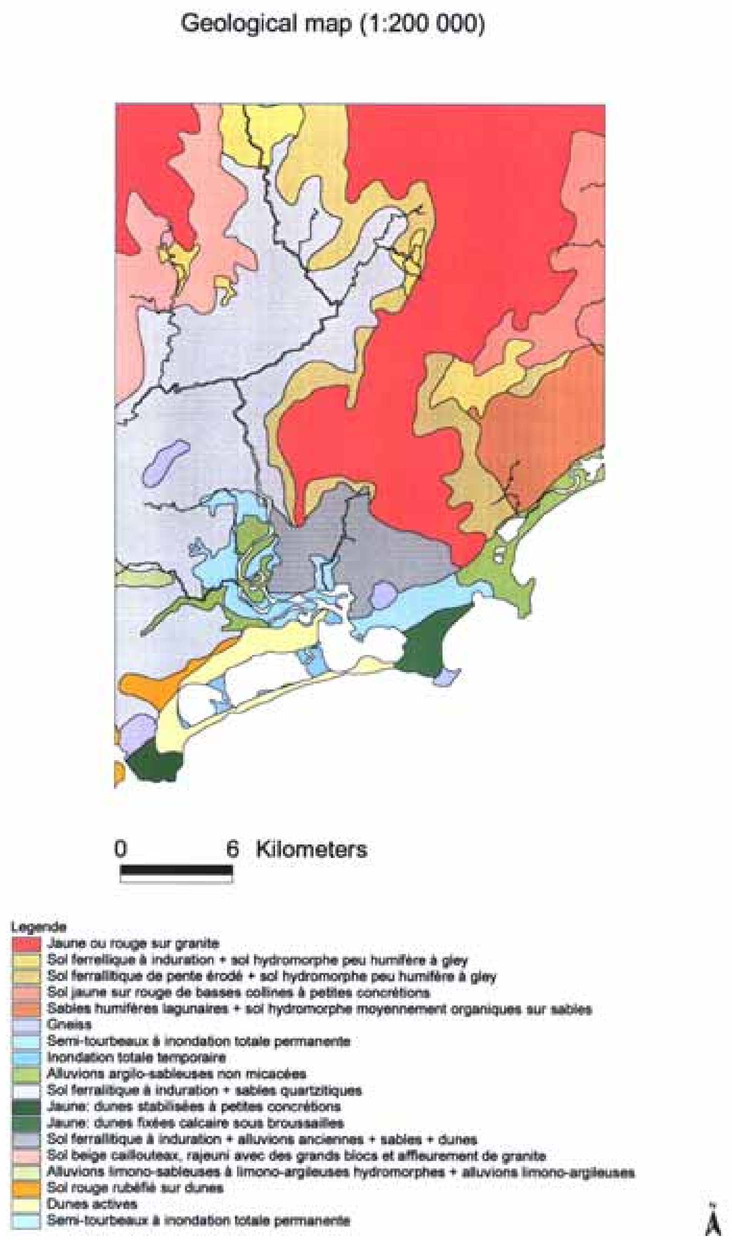

Fig. 7 Geological map of the research area (scale 1:200 000)

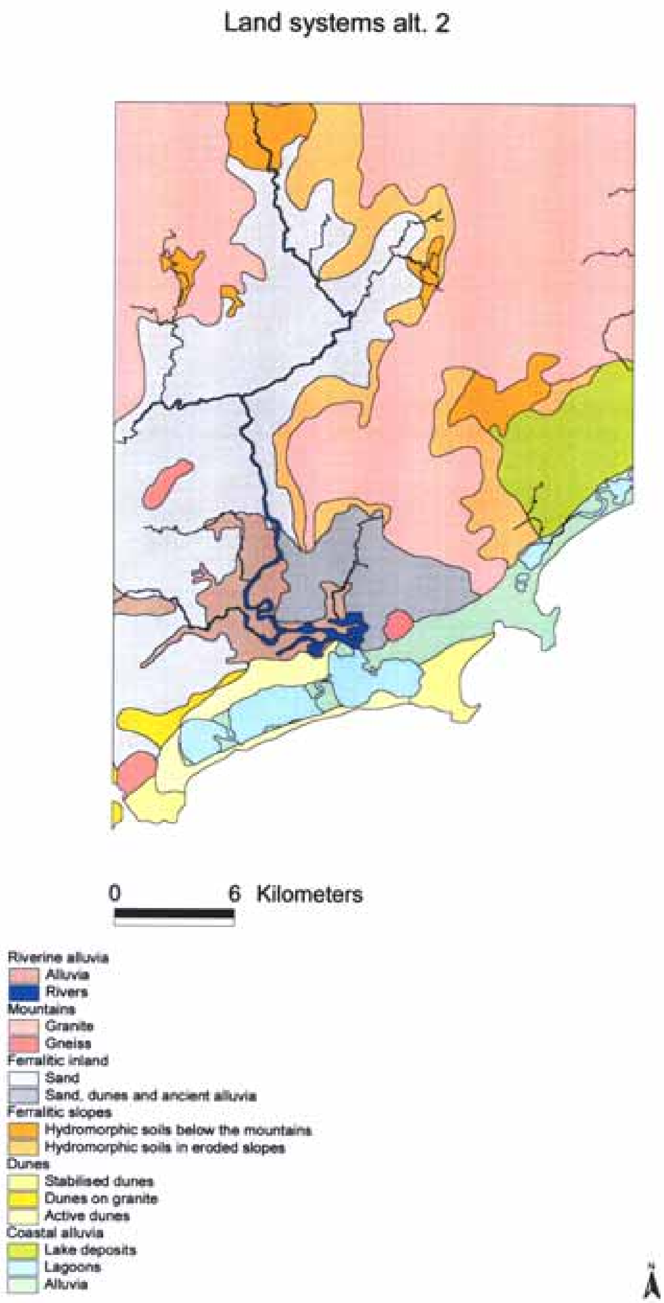

Fig. 8 Land systems alternative 2

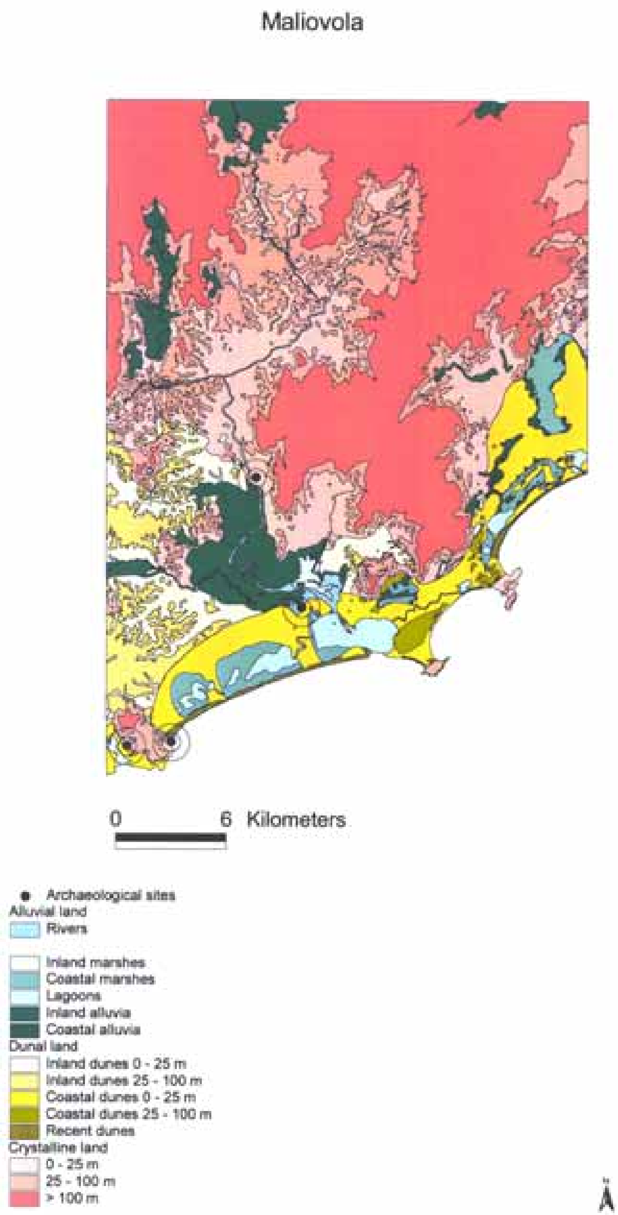

Fig. 9 Land systems alternative 1 with buf fered sites from the Maliovola phase (10th to 13th century)

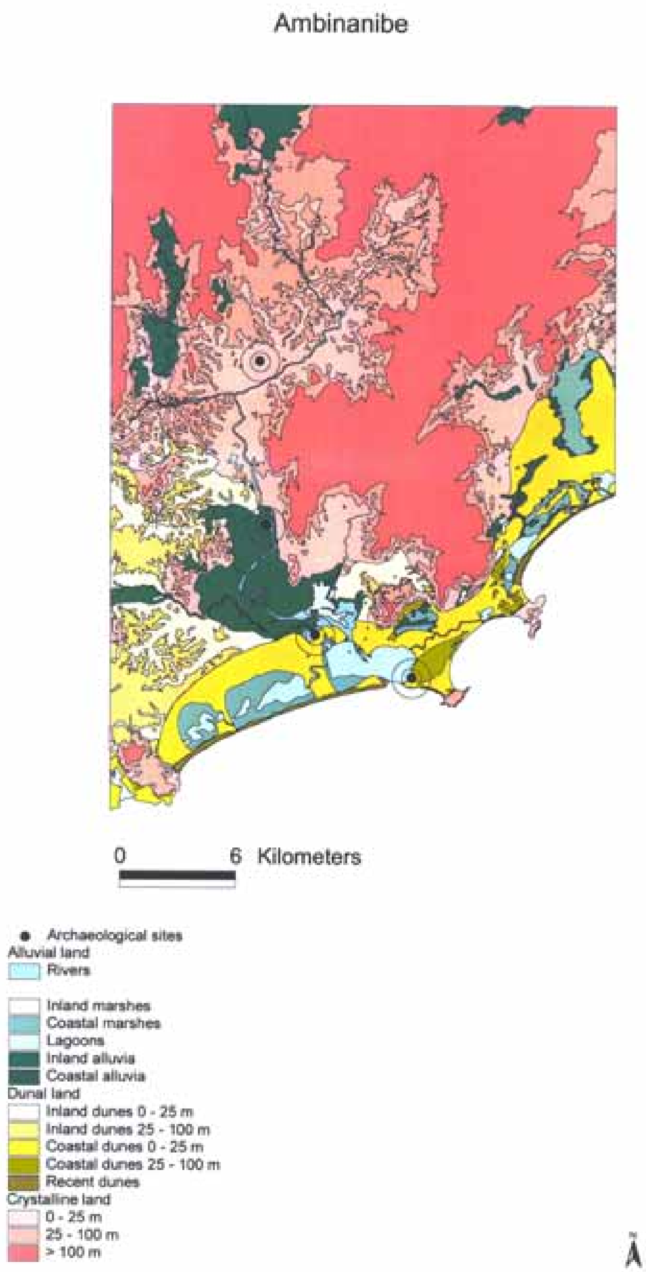

Fig. 10 Land systems alternative 1 with buf fered sites from the Ambinanibe phase (14th to 15th century)

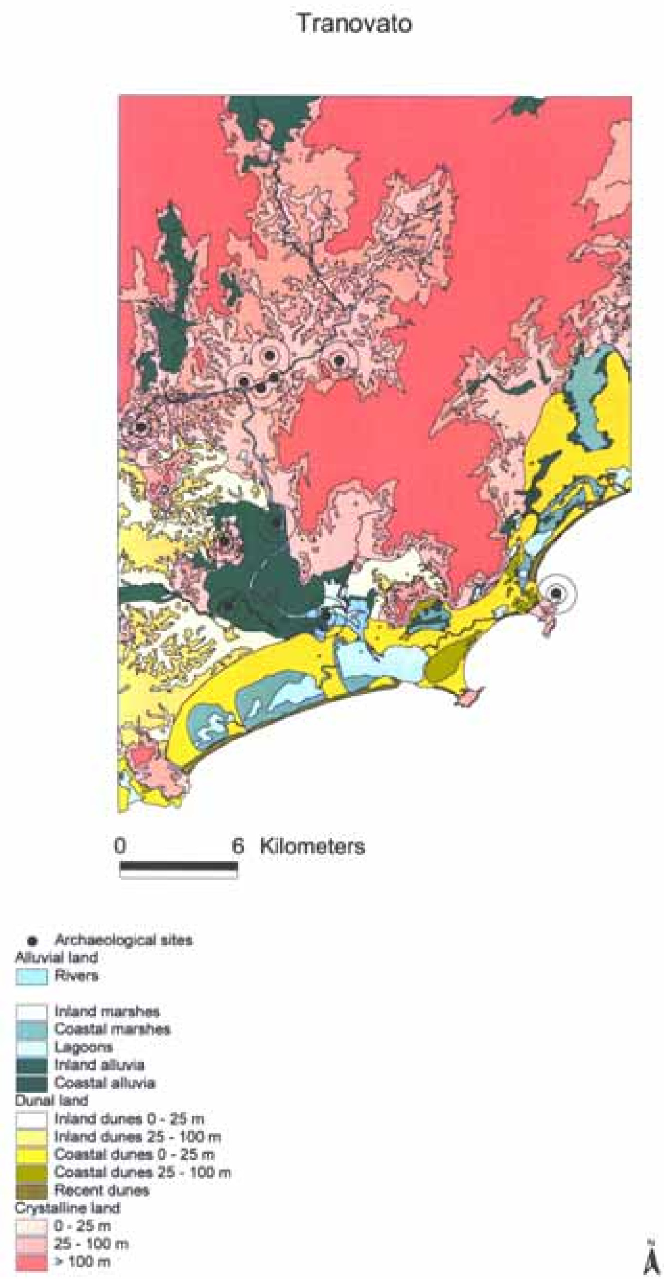

Fig. 11 Land systems alternative 1 with buf fered sites from the Tranovato phase (16th to 17th century)

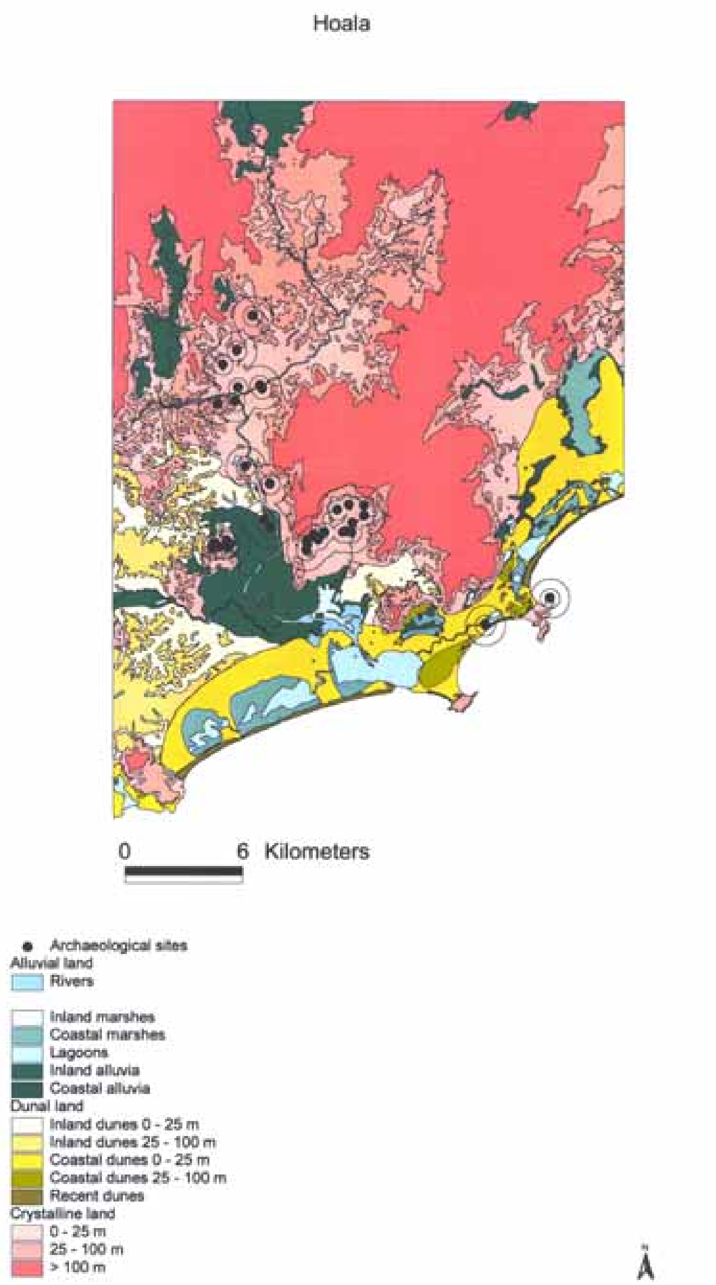

Fig. 12 Land systems alternative 1 with buf fered sites from the Hoala phase (18th to 19th century)

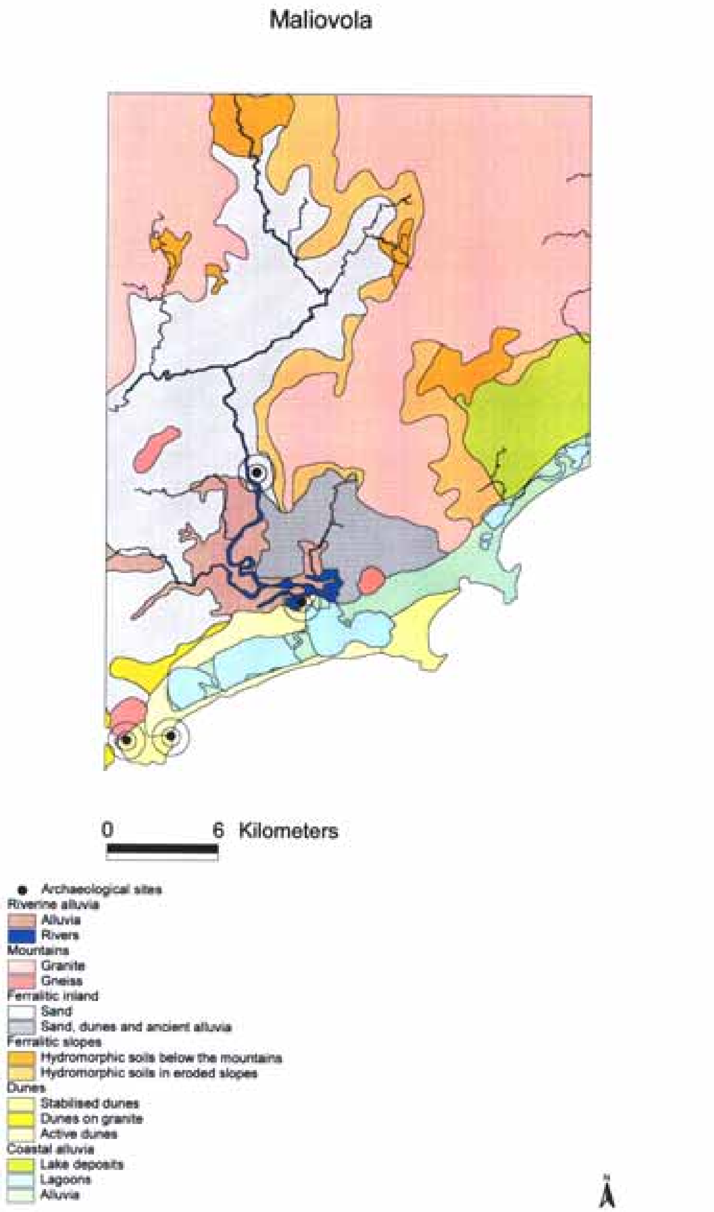

Fig. 13 Land systems alternative 2 with buf fered sites from the Maliovola phase (10th to 13th century)

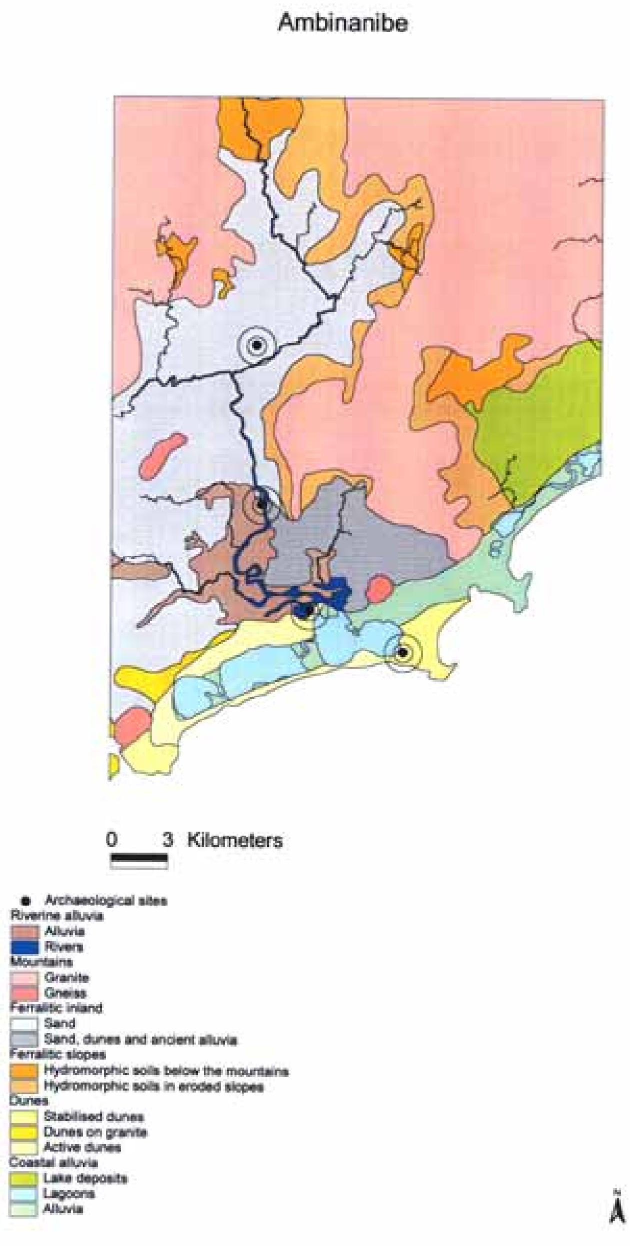

Fig. 14 Land systems alternative 2 with buffered sites from the Ambinanibe phase (14th to 15th century)

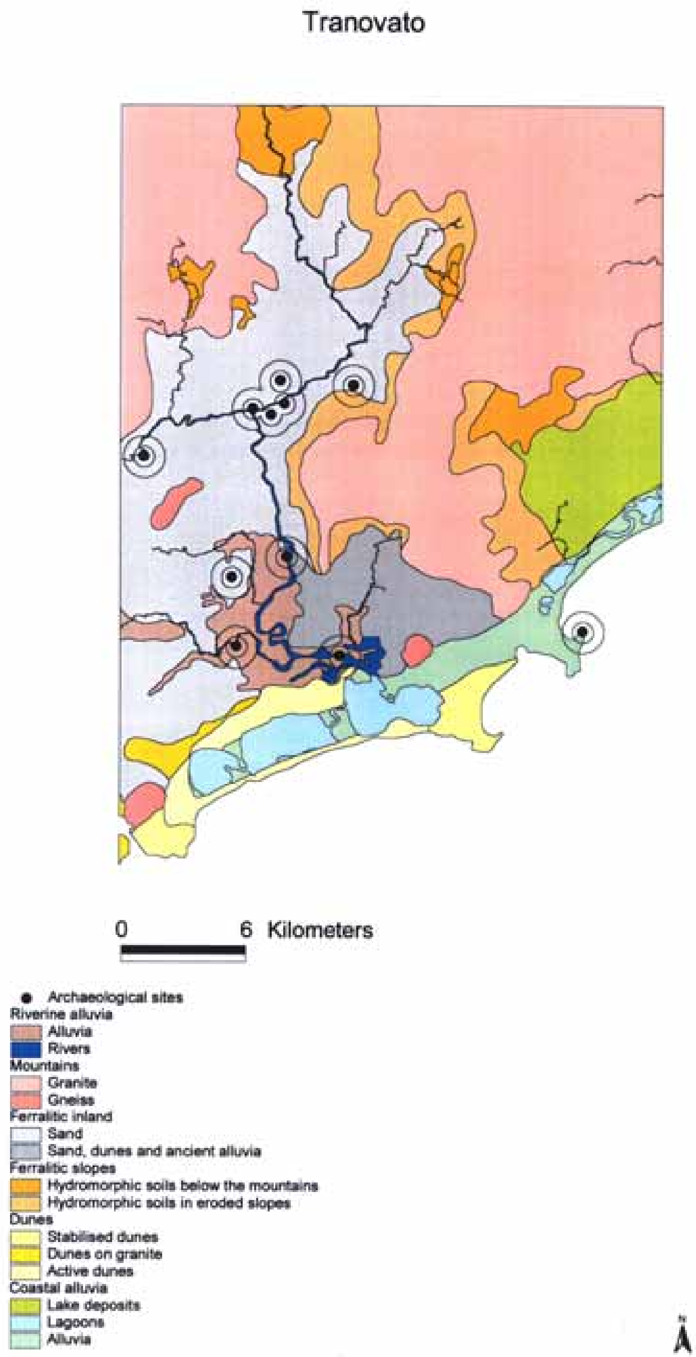

Fig. 15 Land systems alternative 2 with buffered sites from the Tranovato phase (16th to 17th century)

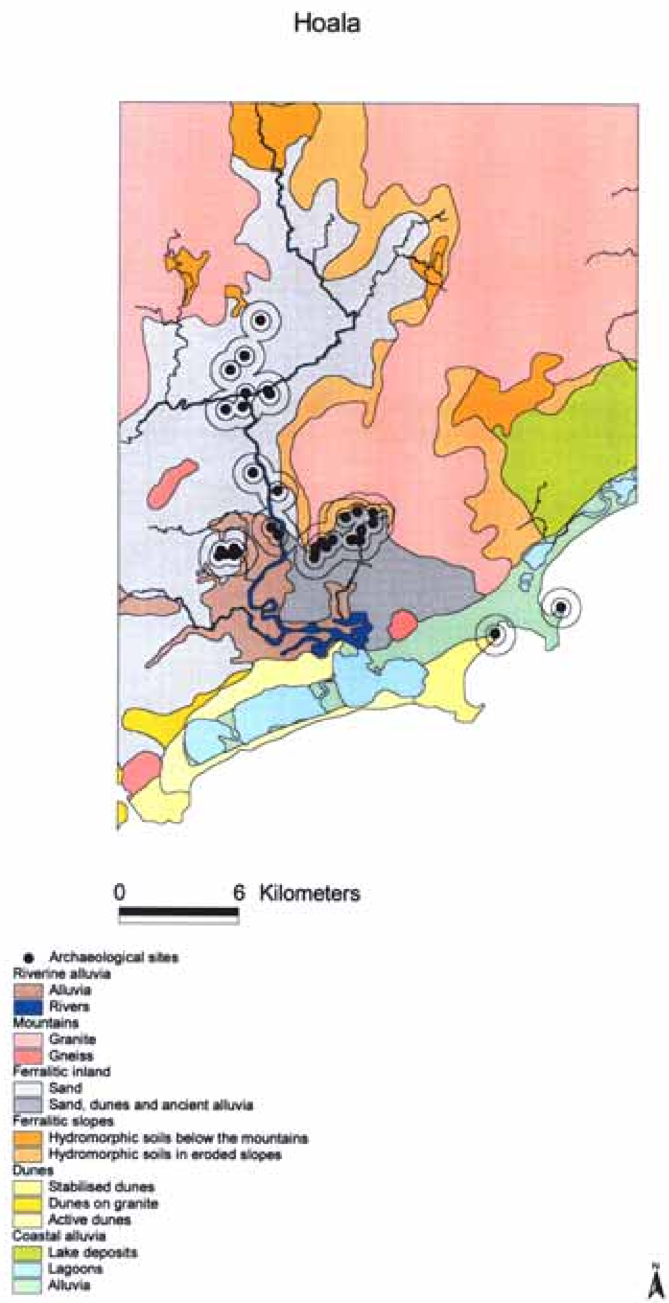

Fig. 16 Land systems alternative 2 with buf fered sites from the Hoala phase (18th to 19th century)