Land cover changes on the West-African coastline from the Saloum Delta (Senegal) to Rio Geba (Guinea-Bissau) between 1979 and 2015

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ABSTRACT
To map vegetation and land cover changes on the West-African coastline using LANDSAT TM scenes taken at different dates, we applied a stacking of undirected classifications. The first step consists in interpreting the radiometric classes obtained via undirected classification so as to form the classes of the thematic nomenclature. The classification is subsequently improved by increasing radiometric contrasts within each of the classes. To do so, a Principal Component Analysis is applied to the LANDSAT channel. Then, a second classification within the classes enables to reallocate correctly those pixels that were wrongly classified previously. Cross-analysing the 2015 LANDSAT images and maps from earlier decades revealed that between the end of the years 1970 and the mid-2010s, wooded areas increased by 2% for the mangrove and 3.5% for dry land. This positive result is the outcome of significant regressions of woodlands compensated by even more significant progressions. It is in the mangrove that progression prevails over regression, especially in the last fifteen years. Finally, an opposition between particularly stable sectors and particularly changing sectors was observed, given that areas having gone through two changes or more are larger than those having gone through one change only in 36 years.

Introduction
For tropical forests (1.7 billion hectares) alone, the annual loss is estimated at 6 million hectares between 2005 and 2015, whereas this rate was 10 million in the years 1990 (FAO Global Forest Resources Assessment, 2015). Most of the loss in forest cover in the tropics is due to agricultural clearing (Singer, 2015). In west Africa, the problem of the impact of drought since the end of the years 1960 added to deforestation (Chappell & Agnew, 2004; Dai et al., 2005; Hulme, Doherty, Ngara, New, & Lister, 2001; Nicholson, 2000). It is necessary to map the changes occurred in the vegetation cover, and more specifically in the distribution of woodlands, to get a better knowledge of landscape dynamics, hence manage these resources better (Walker, 2004).

The coastline being studied here is an ensemble of deltas and estuaries comprising a wide variety of vegetation formations. In the Saloum and in Gambia, there are savannahs and cereals fields (an alternation of millet and groundnuts in the Groundnut Basin), and mangroves are accompanied with mudflats, expanses of mud unsuitable to the development of mangrove because of the soil salinity and acidity. For years, the Saloum and Gambia has been considered as affected by a deterioration of savannahs (Ndiaye, 1990), of agricultural landscapes (Lericollais, 1989) and the spread of mudflats over mangroves. Casamance and Guinea-Bissau are affected by a diminution of agroforests which are converted into cashew orchards in Guinea-Bissau (Fazendeiro-Catarino, 2004) and by a deterioration of the mangrove rice systems in Casamance (Bosc, 2005; Ecoultin et al., 1999).

The West-African coastline has been extensively studied since long, as shown in works by Cormier-Salem (1994, 1999)) or former studies (Péllissier, 1966; Trochain, 1940) and these often report land cover changes. Most of the studies using remote sensing to map landscape changes are focused either on a single landscape or a limited area. For example, Diop, Soumare, Diallo, and Guisse (1997); Moreau (2004); Ackermann, Alexandre, Andrieu, Mering, and Olivier (2007) and Dieye, Diaw, Sané, and Ndour (2013) focused mainly on the evolution of the Saloum Delta’s mangrove massifs. Vasconcelos, Mussa Biai, Araujo, and Diniz (2002) studied all the landscapes in the case of two sites in Guinea-Bissau. Tappan, Sall, Wood, and Cushing (2004) defined the different eco-regions for the whole of Senegal and mapped a number of forms of land cover changes locally. Cuq, Madec, and Gourmelon (1996) produced a land cover map of Guinea-Bissau with a very detailed typology, but no map of changes. Andrieu (2008) and Andrieu & Mering (2009) made it possible to carry out a first...
study of land cover changes in these regions, but there is a 16-year gap with the recent image used for this work. The update which is the purpose of this paper will enable us, on the one hand, to bring up to date what is known about a region going through numerous and quick changes, and on the other hand to attain a time length and a repetitiveness of maps allowing new analyses of the repetitiveness of changes.

The objective of this mapping exercise, carried out by analysing satellite images at various dates, is to answer the following questions: how significant is deforestation on the West-African coastline at present? Are woodland progression phenomena being observed? What are the spatial structures of changes on a regional scale? Can different evolutions be observed during different periods over those 36 years? How significant are temporary changes and cyclic changes?

Site of study, nomenclature and prior knowledge of changes

The studied area covers the Saloum Delta, the Western Division of Gambia, Lower Casamance and the northern Guinea-Bissau coastline with its two river systems: Rio Cacheu and Rio Mansoa. The coastline considered here is a 50–100 kilometres wide strip. Going by the estuarine systems, these four regions will enable us to obtain a quick regionalisation of land cover changes.

We will seek to highlight changes in the vegetation cover via the simplest possible nomenclature enabling to describe the physical environment which breaks down into three kinds of environment, the last two of which having or not a wooded cover:

- The infra-tidal environment comprising the Ocean water and tidal channels.
- Salt marshes, including mangroves, mangrove rice areas and mudflats (here only used for mudflats not covered by mangroves).
- Dry land, where land covers are much less contrasted, with various types of wooded formations (savannahs, forests, palm groves, fallow land) and very little or non-wooded areas (built land, bare soil, low and very open vegetation).

We’ll thus retain five themes for the classification nomenclature:

- The water
- The mangroves
- The Mudflats and mangrove rice systems
- The wooded dry land
- The little or non-wooded areas on dry land.

According to Andrieu & Mering (2009), in the years 1980, the mangrove experienced at the same time sectors of disappearance and sectors of appearance or re-appearance, ending with a slight overall recession. Wooded areas on dry land went through a similar pattern. In the years 1990, between disappearance and appearance or re-appearance sectors, the result was slightly positive for the mangrove. The result was clearly positive for wooded dry land with disappearance sectors smaller than re-appearance sectors.

The purpose of the present update is to find out whether wooded dry land and mangrove continued to progress during the years 2000 and 2010, and also to identify the regions which continued on the past patterns, whether tending to regression, progression or stability.

Thanks to the landcover maps of 1979, 1989 and 1999, some repetitive changes are already known, the most important is the regeneration between 1989 and 1999 of mangrove that died between 1979 and 1989 (Andrieu and Mering, 2009). Some southern forest regions are well known to be managed as Shifting slash-and-burn cultivation with clearings and long fallows which generate repetitive changes (Andrieu and Mering, 2009). The fourth mapping in 2015 is the occasion of a quantitative analysis of such repetitive changes.

Material and method

Material

The selection of images (Table 1) is based on the cover, on spatial resolution, and the years and seasons when they were taken. Given the scale of the area studied, we have decided to analyse LANDSAT images in order to reduce the number of scenes to be processed and guarantee the homogeneity of cartographic results. We managed to cover the area studied with a mosaic of three LANDSAT scenes. Considering the very flat topography and the Sahelian very dry atmosphere, no correction has been applied.

Concerning the dates when the images were taken, four sets of images were selected: one of the oldest possible cover, in 1979, a second one taken at the end of the years 1980, a third at the beginning of the years 2000 and one of the most recent possible covers, at the end of 2015.

Finally, we systematically selected images taken at the beginning of the dry season when the cloud cover rate is usually low but the vegetation still green. The images selected according to these criteria are presented on Table 3.

| Table 1. List of images. |
|--------------------------|
| **MSS** | **TM** | **ETM+** | **OLI** |
| Saloum  | 23/11/1979 | 15/10/1989 | 04/11/1999 | 08/11/2015 |
| Gambia-Casamance | 05/11/1979 | 15/10/1989 | 06/11/2000 | 08/11/2015 |
| Guinea-Bissau | 26/11/1979 | 30/11/1989 | 04/12/2001 | 03/12/2015 |
Table 2. Error matrix analysis (columns) ground truth parcels against (rows) 2015 land cover map (Unit Pixels).

|            | Water | Mangrove | Mudflats | Woodland (Dry) | Farmland | Total | Commission errors (proportion) |
|------------|-------|----------|----------|----------------|----------|-------|-------------------------------|
| Water      | 7005  | 0        | 1        | 0              | 0        | 7006  | 0.000143                     |
| Mangrove   | 0     | 255      | 4        | 0              | 0        | 259   | 0.015444                     |
| Mudflats   | 0     | 0        | 631      | 0              | 0        | 631   | 0                             |
| Woodland   | 0     | 1        | 0        | 2362           | 640      | 3003  | 0.213453                     |
| Farmland   | 0     | 0        | 0        | 13             | 4597     | 4610  | 0.002820                     |
| Total      | 7005  | 256      | 636      | 2375           | 5237     | 15,509| 0.042491                     |
| Error Omission proportion | 0 | 0.003906 | 0.007862 | 0.005474 | 0.122207 | 0.042491 |

Table 3. Transition matrix between 1979 and 1989 (in per cent).

| 1979 | Water | Mangrove | Mudflats | Woodland (Dry) | Farmland | Area in 1989 (km²) |
|------|-------|----------|----------|----------------|----------|-------------------|
| Area in 1979 (km²)→ | 5958.1 | 3052.8 | 2890.3 | 6252 | 7000.8 |
| Water | 21.7 | 0.6 | 0.1 | 0.0 | 0.2 | 6045.3 |
| Mangrove | 0.4 | 9.7 | 1.5 | 0.3 | 0.3 | 3011.6 |
| Mudflats | 0.4 | 1.6 | 10 | 0.0 | 0.2 | 3180.1 |
| Woodland (Dry) | 0.0 | 0.0 | 0.6 | 19.7 | 5 | 6280.5 |
| Farmland | 0.0 | 0.4 | 0.4 | 5.3 | 21.6 | 6633.8 |

Stacked classification processing procedure

The procedure has been published (Andrieu & Mering, 2009) with illustrations of each step. It has been reused in other contexts (Braud et al., 2014). Therefore, we will give only a brief presentation of this procedure here with the flowchart (Figure 1).

In all images with the same georeferencing, the pixels of rectangles common to all four images were extracted, and the MSS scene was resampled so as to align it on the resolution of more recent images, although this resolution increase is superficial and of little interest, bearing in mind that 3 dates are at 28.5 against only one at 57, this choice is justified.

The general method is based on the visual interpretation of radiometric curves which exclude automatics methods. Though, the classification technic is unsupervised as long as it does not use training sites. The supervised classification method implies using control zones based on the exact location of a large number of parcels of “ground truth” (Masoud & Koike, 2006; Nagendra, Pareeth, & Ghate, 2006). As we were not in possession of such data, we could not use this method.

Unsupervised classifications (Murray et al., 2003) divide the pixels into a number of classes decided upon by the user. So, we carry out a classification of the pixels in fifteen classes, via the K-means algorithm (Diday, 1971) on the MicroImages TNTmips® 2012 software. Here, the number of classes chosen, fifteen, is sufficient to draw up the map by regrouping these classes (Andrieu & Mering, 2009; Andrieu, 2008; Ackermann et al., 2007; Thampanya,). Indeed, a number of the environments studied and which we intend to map have low spectral separability between themselves: for example, it is the case between dense mangrove woodlands and some wooded areas on dry land, and also between light-colour bare soil on dry land and some dry mudflats. The large number of classes makes it possible to systematically obtain at least one class for each type of land cover.

We obtain a fifteen-class image and also statistics for each of these classes, which are synthesised in the form of radiometric curves. By analysing the radiometric curves, these fifteen classes can be regrouped into five classes that fit the nomenclature at best. The result of this first step is a first map of the land cover.

We consider that this first step is not accurate enough and that a classification, even with 15 classes, and even with the best possible interpretation of the curves, contains errors (Kappa index 0.90 for the landcover map of 2015). For this reason, as a second step, we carry out stacked classifications in order to gradually refine the definition of the classes (Figure 2). We create five binary images corresponding to these five classes that we'll call “masks” subsequently. For each mask, in order to increase numeric contrasts between pixels of the same class, we carry out a principal component analysis (PCA) on all six channels within the mask. From the rasters resulting from the PCA, we subsequently carry out a non-directed classification (still using K-means) in six classes on the PCA principal components. After increasing radiometric contrasts via the PCA and because there is a smaller number of pixels, it becomes possible to detect the pixels that were wrongly classified in the first step. It is then possible to reallocate them to the class of the nomenclature to which they belong according to their radiometric behaviour. Samples of this step are given in Andrieu and Mering (2009).

Moreover, it was deemed preferable to analyse the scenes separately and form the final mosaic after carrying out classifications on each scene. Thus, the images have been processed using the same procedure, taking into account, during the interpretation stages, their specificities, related to the dates when they were taken which corresponded to slightly different periods of the year.
Maps of changes

The maps result of the intersection of consecutive land cover maps two by two. On the one hand, it can be expected that certain code combinations are absent in the result, on the other hand, changes from dryland to marine or estarine mudflats (or the contrary) are not studied here. For example, at such a short pace of time, spaces of dry land cannot be transformed into mudflats, and the opposite is neither likely. Therefore, we’ll consider that codes describing these types of change correspond to “errors” in the initial interpretation of the classes. These codes correspond to 2.3%; 3.3% and 2.8% of the studied area for the 79–89; 89–99 and 99–15. Not all are strictly errors because are included real changes in the sandy parts of the coastline. Taking these choices into account, the 25 classes are considered as follows:

- Five classes corresponding to a stable land cover.
- Four classes corresponding to the major changes studied here (mudflat converted into mangrove and conversely; wooded dry land converted into non-wooded area and conversely).
- Eight classes corresponding to coastline fluctuations of the mangrove.
- Eight classes corresponding to sandy coastline fluctuations and “errors”: combinations, including water at a given date and dry land at another date.

In addition to mapping and quantifying changes, the second part of this paper is the analysis of repeated changes which was made possible by obtaining four dates. Thus, we next combined the 25-class 1999–2015 map of changes (Figure 4) with a map where the number of land covers for each pixel at the three previous dates (1979, 1989, 1999) has been quantified (Figure 3). The map (Figure 4) shows the complete map of number of land cover types (1979, 1989, 1999 and 2015) with values from 0 (stability) to 3 (3 changes). Only the three first dates where here used.

Crossing the map of number of changes between 1979 and 1999 with the change map between 1999 and 2015 produces a matrix on which, in a line, each of the 24 classes of stability or change between 1999 and 2015 is divided into 3 columns: stability, one change and two changes.
Comparison with the situation on the ground

Two different field observations enabled the validation of these maps (Table 2). First in February 2017, ground truth parcels have been realized for the 5 landcover types, in the Saloum region for the 2015 map. The error matrix (Table 4) has been produced by cross-tabulation between truth parcels and landcover map.

The map of changes in vegetation cover between the end of the years 1970 and the beginning of the years 2000 had already been compared with the situation on the ground during a field mission in 2005 for each type of change on ten sites spread randomly on the whole area described in (Andrieu and Mering, 2009).

60 sites covered: 10 sites of mangrove progression, 10 of mangrove stability and 10 of mangrove regression, 10 sites of dryland forest or savannah progression, 10 of stability and 10 of regression, each change type is divided in 5 estuaries or deltas, each point is randomly chosen in a patch of the change type wider than 1 pixel.

The first step consisted in verifying the “current” land cover according to the previous nomenclature knowing that the map was a few years ago. Concerning the places mapped either as stable woodlands or as progressing, the task was to check that the land was wooded. Concerning surrounding areas or non-wooded area at the three dates, it consisted in making sure that these were indeed non-wooded areas.

Subsequently, we tried, by analysing the landscape and the vegetation, to deduce the situation of the land cover at the end of the years 1970 as follows:

In the case of stable woodland, the aim was to be able to confirm that present-day individuals were or not capable to cover 20% of the land at the end of the years 1970. To do so, it is necessary to estimate in the field the age of plant individuals by measuring trunk diameter and carry out age-range counts. In order to precise the dynamic, we evaluate regeneration by counting young shoots and new shoots on stumps.
Finally, we look for factors of potential damage by counting stumps, identifying traces of fire, of pruning, overgrazing or senescence.

In the case of the appearance or re-appearance of woodland, the aim is to confirm that it was absent when the previous view(s) was (were) taken. To do so, we need to confirm that the forest is young by estimating the age of trees and carrying out individual counts by age strata. Next, we have to search for regeneration factors (reforestation, deferred grazing, natural regeneration) and for traces of previous land use (old furrows, levees, hedges for fallow land, stumps for a commercial forest being regenerated...)

In the case of the disappearance of woodland, the aim is to confirm the presence of woodland at the end of the years 1970, which is a delicate task. A solution consists in looking for standing dead trees or signs of former woodland. Also, we look for indications of the possible causes of deforestation (stumps, fires, cultivation...). Finally, we test the possible presence of recent or future regeneration (counting young shoots, new shoots on stumps...).

The mapping results were amply validated by ground verification, bearing in mind that only one of 60 sites appeared as a mapping error (1.6% of sites), only for one date. Therefore, it enabled us to identify the main phenomena of change (Andrieu & Mering, 2009):

- The progression of mudflats over the mangroves through declining in hyperhaline sectors.
- Diking mangroves for growing rice and abandoned rice fields turned wasteland after the dike has broken.
- Clearing for farming and fallow land turned wasteland.
- Planting cashew orchards.
- Dry land logging combined with late burning.

The verification also showed a number of forms of cyclic dynamics:
- The immediate regeneration of felled mangrove, and even the stability of mangroves when thinned
- Shifting slash-and-burn cultivation.

Results

Mapping of changes and their areal extent

In the years 1980 (Figure 3; Table 3), the years 1990 (Figure 4; Table 4), and between 1999 and 2015 (Figure 5; Table 5), both stable and changing areas are, on the whole, in the same proportions as in the years 1980 and 1990. The only break in the 1979–1999 period trends is that in the last 15 years, mangroves went through a remarkable progression dynamic given that 3.6% of the area of study is covered by a mangrove that appeared between 2000 and 2015. Compared to these 3.6%, only 0.6% of the image corresponds to a regression of the mangrove.

Table 4. Transition matrix between 1989 and 1999 (in per cent).

|          | 1989 Area in 1989 (km²) | Water | Mangrove | Mudflats | Woodland (Dry) | Farmland | 1999 Area in 1999 (km²) |
|----------|------------------------|-------|----------|----------|----------------|----------|------------------------|
| Water    | 6045.3                 | 3011.6| 3180.1   | 6280.5   | 6633.8         | 5908.4   |
| Mangrove | 21.2                   | 0.4   | 1        | 0.0      | 0.0            | 0.0      |
| Mudflats | 0.5                    | 8.4   | 2.2      | 0.0      | 0.2            | 2728.5   |
| Woodland (Dry) | 1.3                  | 2     | 10.1     | 0.3      | 0.2            | 3436.3   |
| Farmland | 0.0                    | 0.6   | 0.5      | 19.9     | 6.1            | 6840.6   |

Figure 4. Land cover changes between 1989 and 1999 (Andrieu and Mering, 2009, modified).
The progression of the mangrove occurs mainly in the north and centre of the Saloum Delta and in the centre of the Casamance delta, i.e. the two deltas with very high salinity where mangrove regression has been studied for several decades and where Ackermann et al. (2007), Andrieu (2008) and Andrieu & Mering (2009) were the first publications to underline the importance of this new phenomenon of progression. The northern and western zones of the Saloum delta were also mentioned by (Dieye et al. in 2013). The mangrove has also spread significantly in a number of zones in the upper part of the Gambia channels and of estuaries in the north of Guinea-Bissau, here the decreasing salinity is associated with abandoned rice fields.

On dry land, the result is slightly positive (5.5% of progression against 4.9% of regression), i.e. an

![Figure 5. Land cover changes between 1999 and 2015.](image)

![Table 5. Transition matrix between 1999 and 2015 (in per cent).](table)
apparent prolongation of the 1979–1999 period dynamics. The main regions where a regression of wooded dry land (savannahs here) can be observed are the Sine and the Kaolack region. The two banks of Rio Cacheu in Guinea-Bissau are the second region of disappearance of wooded dry land (forest here). Significant losses of vegetation cover also occur in the Banjul region. The sectors where forestation progresses are in the continental Lower Saloum and Gambia’s Niumi where gallery forests accompanied by cashew orchards seem to have reformed in the depressions. Finally, there are rather significant areas of wood progression between Rio Cacheu and Rio Mansoa. Two sectors showing both progression and regression can be observed, first on the south bank of the Gambia and in the north of Casamance, in the form of small patches (of parcel size) corresponding to the beginning and end of fallows and other similar agricultural dynamics. Second, on the north bank of Rio Cacheu, near the border with Senegal, large patches where the forest has disappeared can be observed, surrounded by an ensemble of small progression patches. The spatial distribution of the progression and regression zones on dry land in the south of the Gambia is globally the same since 1979. But in the north, a clean break can be observed, because in the Sine, which was previously characterized by a significant progression of woodlands, the new woodlands and some stable old woodlands have disappeared. In continental Lower Saloum, a dynamic of the “pioneer front” type has been going on for several decades and agricultural zones have at the end of the 90s covered nearly every area that was not protected by a protected forest status “forêt classée”. During the last 15 years, the return of dense agroforests and the appearance of cashew orchards are what appears, on the map, as progressions of the wooded cover.

**Factors of land cover changes**

Field study in 2005 and 2017 enabled to identify the factors of change.

Regarding mangrove’s rare regression and important progression, the explanation can be found in rainfall fluctuations and its consequences in estuarine hydrology and pedology. As a matter of fact, the drought (1968–1994) has led to an increase in salinity and soil evaporations. Both soil salinity and acidification (explained by the oxidation of sulphur when evaporation increases) lead to mangrove to naturally die in the higher part of the mudflats. With the recovery of rainfall in the mid 90’s, soil salt and sulphur leaching enabled the mangrove regrowth with both new seedlings (mainly of *Rhizophora mangle*) and sucker of almost dead trees and bushes (mainly of *Avivennia Africana*). The mangroves are, in Senegal, strongly protected (UNESCO biosphere reserve, National park, etc.) and NGO are active on plantations projects. Field study seems to show that natural regeneration is more important than plantations (5 sites on 6 in the Saloum Delta). The third change process is linked to sedimentation process. As a matter of fact, new mudflat getting to the level of foreshore with tide fluctuation can be quickly occupied by mangrove. On the contrary, mudflat inundated by the tide can get too high and too dry for mangrove thanks to same sedimentation processes. On 10 to 15 years, these process can be mapped (but only small patches) and contribute to the land cover change. The new mudflat with new mangrove seems to be around 0.8% of the studied area mapped as conversion from water to mangrove. The sedimentation-provoking mangrove dying will be part of the 0.6% of the image mapped as conversion from mangrove to mudflats.

On dryland, the main changes are in resource management: agriculture and forestry. First, the increasing wooded areas are divided in three processes, forest regrowth after fires, or thanks to a stronger protection by state and NGOs. Second, cashew nut tree groves have been increasing very strongly these last 15 years. Third, some field have been abandoned and vegetation spontaneously comes back. On the other side, the conversion from wooded to non-wooded are explained by two factors, the first is the opening of savannah (or abandoned fields) to take or take back new surfaces for rice or peanut production. The second is forest degradation, as for example the Djilor “forêt classée” known to have been drastically over-exploited for wood and by cattle.

**Analysing repeated changes**

Intersecting the map of recent changes (1999–2015) with the map of the number of past changes enables us first to observe that the recent stability is located, for three quarters of the zone of study’s areal extent, on the zones that were stable between 1979 and 1989 and between 1989 and 1999 (Figure 6). Over 80% of dry land non-wooded areas that were stable between 1999 and 2015 have been as such since 1979. The figure is hardly lower as regards mudflats and stable mangroves between 1999 and 2015. It falls to nearly 72% for wooded dry land. The high values as regards these four classes show that important centres of stability exist on the coastline. The lower value as regards wooded dry land means that the recent period is slightly different from the previous ones and that even some forests or savannahs that were stable between 1979 and 1999 were finally lost between 1999 and 2015.

Contrary to these high values concerning stable zones, those areas having gone through a change of land cover between 1999 and 2015 are mostly zones that had already gone through such change.
Over 78% of the recent regression of mangroves is located in areas having already gone through land cover changes: a third went through three changes and nearly half through two changes already. The progression of mangroves between 1999 and 2015 occurred for a third on pixels having gone through three land cover changes, for a quarter through two changes, and finally, 43% of these progressions occurred on mudflats that were stable at the three previous dates. This means that the extent of progression of mangroves between 1999 and 2015 is such that it has included pixels that had lost their vegetation cover before 1979.

Over 60% of the recent regression of wooded dry land occurred on pixels that had already gone through land cover changes, mostly on pixels having gone through changes during the previous decade. The progression of wooded dry land has a similar profile, with close to 65% of repeated changes and an even larger portion due to recent changes. At this point, we can therefore conclude that sectors which were stable until the years 1990 have become unstable and go through regular land cover changes ever since.

In the light of three maps of land cover changes covering close to 40 years, and of these calculations of areal extent of repeated changes, it is possible to observe stable sectors in the strict sense (for example the Kalounayes forest or the Saloum Basin farmlands), sectors that are stable in their cycles (the south bank of the Gambia and certain parts of Casamance and Guinea-Bissau) where, at each pace of time, the same type of parcel structures can be observed, the rotations of which are shown by the mapping. Finally, major changes resulting from transformations of ecosystems and of territorial systems can be observed. The latter are generally micro-regional paths contrasted from a small region to another. For example, the Sine, which was a highly agricultural region in the years 1970 and as much in the years 1980 on dry land, went through significant reforestation between 1989 and 1999, which was eliminated between 1999 and 2015.

Continental Lower Saloum’s protected forests were well preserved from 1979 to 1999, given that they appear either as stable woodland or in progression. On the other hand, between 1999 and 2015, the northern most forests (Djilor) and those close to urban poles have suffered significant damage.

**Discussion**

The first point that needs discussing concerns the characterization of changes. Although these are undeniable significant in this area at this pace of time (20–25% of the zone of study), that must be qualified by highlighting the dichotomy (relative, of course) between stable and unstable sectors. Moreover, it would be necessary to bring complements in order to characterize the changes beyond mere appearance (re-appearance) or disappearance of the wooded cover. On the ground, the whole variety of processes can be observed, linked to the great variety of causes (climate, commercial forests, changes in agricultural land, etc.). Furthermore, describing these changes at the same pace of time, same scale and with the same nomenclature within a north-south gradient which is so contrasted in terms of climate, biogeography and agricultural organizations may have its limits. For example, in the Sine’s most open savannas, overlapping rates are hardly above the 20% threshold.
which, here, constitutes the limit between wooded and non-wooded land. Thus, small fluctuations in the density of the vegetation cover in the Sine shift, on these maps, large areas from wooded to non-wooded whereas the same fluctuations in a dense forest environment will not show on the map. The same can be said about bush-like formations open on the limit between mangroves and mudflats. Here also, slight density fluctuations, if they occur on both sides of the 20% threshold, will show either as appearances or disappearances. Conversely, the alternation of cultivations and fallsows in the north will always remain below the 20% threshold whereas in the agroforestry systems in the south of the Gambia, these will show as progressions and regressions of the wooded cover according to this mapping method. So, it is difficult to draw general conclusions concerning the study as a whole, which explains why most of the interpretations deal separately with the north and the south.

The second point of discussion concerns the relevance of mapping and quantifying the repeated changes for characterizing the lands and their landscape structures via concepts such as: vulnerability, resilience, resistance, meta-stability and stability, etc.

The terms stable and resistant can be used for the types of land cover that have been mapped in the same way at the four dates during the 36 years that have been studied.

It seems possible to define as meta-stables two types of change: on the one hand the sectors of shifting cultivation or other fallow systems where, even though proportions remain the same at each decade, the mapped land cover changes correspond in fact to a stability of the agroforestry land management. On the other hand, a significant portion of pixels having gone through 3 land cover changes appears in all the changes in the mangrove cover. These pixels, in mangrove in 1979, mudflats in 1989, mangrove in 1999 and mudflats again in 2015, or the opposite, seem to clearly indicate environments that are naturally fluctuating. Indeed, on the ground, at the limit between mangrove and mudflats, without taking the decennial fluctuations of climate and water salinity into account, numerous propagules are deposited but with high infant mortality. It is even easier to understand taking into account the strong variation of rainfall in the whole period.

It seems possible, with relative confidence, to describe as vulnerable the whole of wooded formations, agricultural structures or non-forest areas which form (or re-form) in the course of a decade and disappear in the following decade.

Consequently, the term resilient seems to be suitable in such context, instead of vulnerability, because the mangrove or the forest that re-builds itself quickly after regressing will be resilient. The level of resilience or vulnerability will be proportional to the time gap between the change and the return to the previous land cover.

The conceptual model called “roller-coaster”, which is inspired from thermodynamics, seems to be suited here insofar as stable spaces appear as resistant to disruptions and disturbed environments appear as reacting to disruptions (Godron, 1984).

Conclusion

First, the stacked undirected classifications method with PCA proved to be well adapted to carrying out a mapping of the land cover using a predefined nomenclature, bearing in mind that 59 of 60 verification sites were validated.

Second, the main results reveal a relative equilibrium between regressions and progressions of the vegetation cover at a 36-year pace of time. The trend moves from slightly negative results in the years 1980 to a positive result in the years 2000, which goes against the thesis of a significant deterioration of vegetation landscapes. The recent progression of the mangrove appears as the main changes, in proportion to the various land covers. However, the simplicity of the nomenclature used probably masks numerous changes in local ecosystems and does not make it possible to either map or quantify the vegetation’s intrinsic evolutions, like for example the decline in biodiversity or biomass reduction. Deforestation on the West-African coastline concerns 1232 km² (4.9% of the study area) for continental woodlands and 419 km² (0.6% of the study area) for mangrove. Though, woodland progression phenomena have been observed for larger surfaces: 1383 km² (5.5% of the study area) for continental woodlands and 905 km² (3.6% of the study area) for mangroves. Microregional patterns appear in continental woodlands (regression in the north Saloum, progression in the south of Saloum, association of important progression and regression (Guinea bissau), association of medium progression and regression (Gambia), association of little important progression and regression (Casamance).

Third, these analyses enabled us to demonstrate that changes in land cover are complex both in space and time on the West-African coastline; no significant phenomena are observed here, such as phenomena of the "pioneering front" type where an extensive forest matrix would be reduced more or less regularly. This process has only been observed in continental Lower Saloum in the years 1980 and 1990. In each region, at each pace of time, sites were progressing and others regressing simultaneously, both as regards the mangrove and dry land. Nevertheless, the great majority of stable sectors are so at all four dates whereas the great majority of sectors of changes for the 1999–2015 period are sectors of repeated changes. Microregional patterns appear in mangrove progression:
important in Saloum, stronger in Casamance. Different evolutions can be observed during different periods over those 36 years as woodlands and mangroves have known regression during the 1980s and progression since. Temporary and cyclic changes are very important with zone of long-term stability and zones of repetitive changes.

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