International Cartographic Association
Association Cartographique Internationale

Analysis of the spatial extension of pineapple monocultures in northern Costa Rica using heterogeneous geographic data

Jean-François Girres[a*], Delphine Prunier[b], Tania Rodriguez[c], Auréa Pottier[d], Eric Léonard[d], Victor Audic[e], Maëlane Hellard[e], Jean-Albert Magnaudet[e]

[a] *Université Paul-Valéry Montpellier 3 – AMIS/ESPACE-DEV, Montpellier, France – jean-francois.girres@univ-montp3.fr*

[b] *Universidad Nacional Autónoma de México, Mexico - prunier.delphine@sociales.unam.mx*

[c] *Universidad de Costa Rica, San José, Costa Rica – tania.rodriguez.echa@gmail.com*

[d] *SENS, IRD, CIRAD, Univ Paul Valery Montpellier 3, Univ Montpellier, Montpellier, France – aurea.pottier@ird.fr, eric.leonard@ird.fr*

[e] *Master Géomatique de Montpellier, Montpellier, France – victor.audic@laposte.net, maelanehellard@yahoo.com, jamagnaudet2@gmail.com*

* Corresponding author

Abstract: In recent years, Costa Rica has become the world's leading producer and exporter of pineapple, with more than 65.000 hectares of its territory dedicated to this crop. The development of these intensive pineapple crops is mainly concentrated in the north of the country, especially in the border area with Nicaragua. This rapid expansion in these regions has many economic, social and environmental consequences. In order to understand the local impact of this phenomenon, a first analysis of land use changes for the benefit of pineapple monocultures must be performed. For this purpose, pineapple crop delineation layers in 2000 and 2019 were provided by MOCUPP, a United Nations agency responsible for monitoring agricultural areas in Costa Rica. Landsat 5 satellite images from 1998 and 2001 were also used to generate land cover classifications. The pineapple crop delineation layers produced by MOCUPP are characterized by heterogeneous granularities and positional accuracies, complicating the analysis of land cover changes through the generation of artefacts. To address this problem, an artefact removal procedure was conducted, based on the use of minimum shape and size indicators. The assignment of land use changes to pineapple crops allowed the assessment of deforested areas between 2000 and 2019. Thus, over this period, more than 6300 hectares of forest were lost to pineapple crops, mainly in the cantons of Los Chiles and San Carlos, in the northern part of the country. Finally, this article illustrates the problems associated with the use of heterogeneous data to analyse land cover changes. To avoid these problems, the use of prior data integration procedures, such as data matching algorithms, is recommended.

Keywords: pineapple monocultures, land-cover changes, Costa Rica, spatial data quality

1. Introduction

Costa Rica is a country internationally recognized as a sanctuary of biodiversity (Evans, 1999; Pringle, 2017). However, this image hides a lesser known reality, related to the development of monocultures of the globalized agribusiness on its territory. Several crops are concerned, but one of them is particularly emblematic: the development of pineapple monocultures. Today, Costa Rica is the world's leading pineapple producer and exporter country (Dawson, 2019). Intensive pineapple cultivation began to develop in Costa Rica in the 1980s. At that time, the main crops grown in the country were coffee, cereals (beans, rice, corn), sugarcane, and bananas. Pineapple was only produced in small quantities in the country. In the 1990s, the first pineapple exports began, coupled with the use of genetically modified pineapples (allowing the fruit to be sweeter and to give fruit all year round). Pineapple monocultures then began to develop strongly in Costa Rica, so that the country became the world's leading exporter of pineapple with approximately 65.000 hectares allocated to this activity on its territory in 2019.

The development of pineapple crops in Costa Rica during the last decades mainly concerns the northern part of the country, at the border with Nicaragua, as exposed on the map on Figure 1.

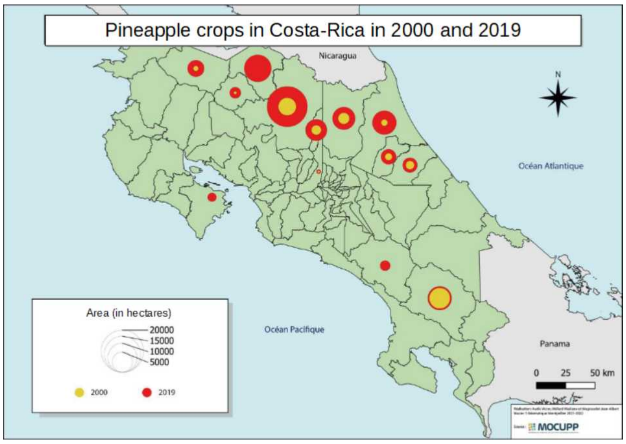

Figure 1. Evolution of pineapple crop areas in Costa Rica between 2000 and 2019.

This development of pineapple monocultures has disrupted the existing structure of agricultural production and the organization of work. Thus, small and medium-sized producers are gradually selling or renting their land to large multinational companies, which have become the main owners of land dedicated to pineapple cultures. Pineapple monoculture, like most intensive agricultural export activities, relies heavily on the exploitation of a precarious and mobile labor force, in this case Nicaraguan migrant laborers. (Rodriguez Echevarria and Prunier, 2020).

At the environmental level, the development of pineapple monocultures has a strong impact on existing natural resources. This is manifested through the systematic use of phytosanitary products (Echeverría-Saénz et al, 2012), but also through the pressure that the development of these monocultures exerts on other surrounding land uses, particularly forest resources and basic grains.

In this context, the objective of this research is to quantify the expansion of pineapple monocultures in northern Costa Rica, between the years 2000 and 2020, in order to assess its impact on other land uses. In particular, we sought to evaluate the extent to which pineapple expansion affected areas of other monocultures (citrus, banana), forested areas, grazing areas or subsistence crop areas. While the sustainability of development can be measured in terms of impact in deforestation, it is also important to examine the phenomena of land cover change and the displacement of peasant production.

The study area is limited to the following cantons located in northern Cost-Rica: Upala, Guatuso, Los Chiles, San Carlos, Río Cuarto, Gracia, Alajuela, Sarapiquí, Pococí, Guácímo, Siquires (figure 2).

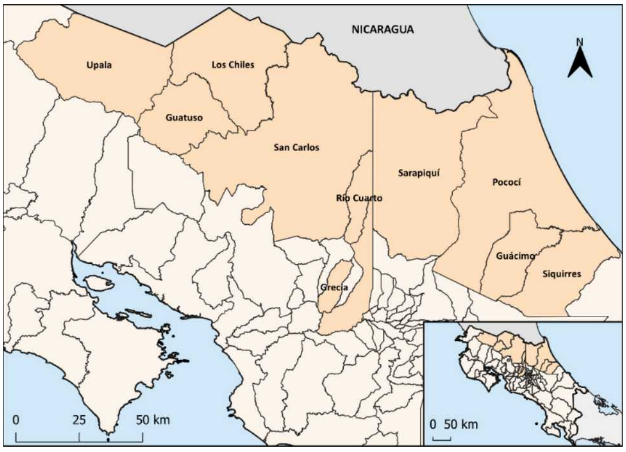

Figure 2. Delimitation of the study area (in beige color).

2. Geographic data used

To analyse the land uses impacted by the development of pineapple monocultures in northern Costa Rica, several geographic data are mobilized.

2.1 Pineapple cultures

Two vector layers, representing pineapple crops delineation in 2000 and 2019, have been provided by MOCUPP (Monitoreo del Cambio de Uso y Cobertura de la Tierra en Paisajes Productivos), a UNDP agency responsible for monitoring agricultural areas in Costa Rica (MOCUPP, 2017). Figure 3 illustrates the delineation of two pineapple crops in 2000 and 2019.

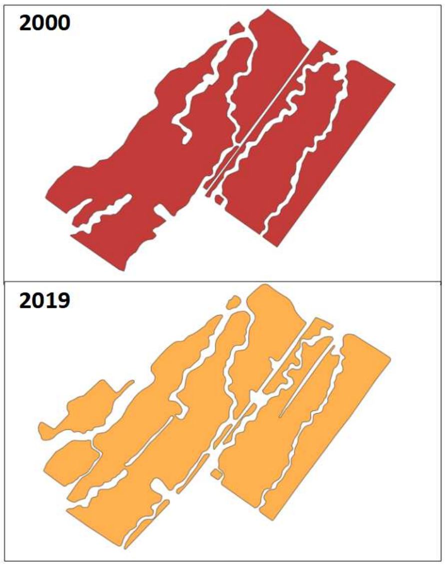

Figure 3. Delineation of pineapple crops in 2000 and 2019.

The two layers provided by the MOCUPP constitute an essential input for this research. However, these datasets are characterised by variables levels of details.

To evaluate the heterogeneity of the two datasets, a set of basic indicators is computed for each layer: the area, the perimeter, and the number of vertices. Finally, an indicator based on the ratio between the perimeter and the number of vertices is proposed to measure the granularity of the two datasets. Granularity indicators, based on inter-vertices distances, have already proven to be useful to determine the level of details of vector data (Girres, 2015). These indicators are presented in table 1.

	Pineapple layers	
	2000	2019
Area (sq. m.)	133059330	654507293
Perimeter (m.)	1389462	8462634
Vertices	36529	372975
Perimeter/Vertices (m.)	38.04	22.69

Table 1. Indicators for characterizing layers of pineapple crops

First of all, these indicators concretely illustrate the phenomenon of expansion of pineapple cultures in Costa Rica, because the total area has increased from 13305 ha in 2000 to 65450 in 2019.

On a geometrical point of view, we can observe that the granularity between the two datasets is very different. For the year 2000, the ratio perimeter/vertices is about 38 m. It means that a vertex has been captured on average every 38 m. For the year 2019, the ratio perimeter/vertices indicates that on average, a vertex is captured every 22 m. We can therefore deduce that the level of details has increased between the two layers, because the inter-vertices distance has been almost divided per two.

This situation can be explained by several factors in the production processes of the two datasets. The main factor is the spatial resolution of the source imagery used to delineate pineapple cultures. Indeed, between 2000 and 2019, the spatial, spectral and temporal resolutions of satellite images have constantly improved, making it possible to observe phenomena with ever-increasing levels of detail (Sozzi et al., 2018). To delineate pineapple crops, MOCUPP mainly uses freely available satellite imagery. Thus, Landsat images (30 m. spatial resolution) were used for 2000 and Sentinel 2 images (10 m. spatial resolution) were used for 2019.

On the other hand, since 2015, MOCUPP updates yearly pineapple cultures on the entire territory of Costa Rica. The experience acquired by MOCUPP has made it possible to improve the data production processes, thus contributing to a better level of detail of the pineapple delineation.

The overlap of pineapple cultures in 2000 and 2019 (figure 4) illustrates the geometric heterogeneity between the two datasets, which is characterised by varying granularity and positional accuracy. This heterogeneity can be sources of difficulties to compare the two layers.

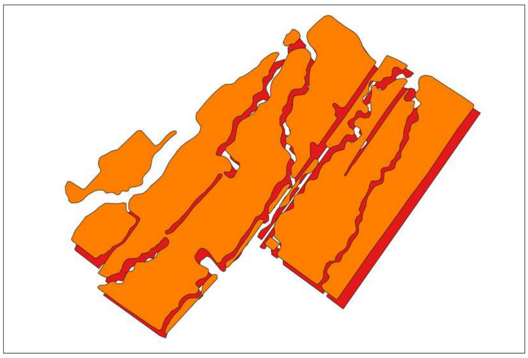

Figure 4. Overlaps of pineapple crops between 2000 (red) and 2019 (orange).

2.2 Satellite images

In order to identify on which type of pre-existing land use pineapple crops were installed during the two last decades, satellite images have been acquired.

Several difficulties were encountered in identifying available and usable satellite optic images in the early 2000s. First, in the early 2000s, the supply of satellite sensors was much more limited than today. Among the optical sensors available at that time were Landsat 5 and Landsat 7, or SPOT 2 and SPOT 4. In addition, the northern part of Costa Rica is a very cloudy area, which makes it difficult to acquire usable satellite images.

Finally, three usable images, acquired by the Landsat 5 satellite were identified: one image of 14/01/2001 for the eastern part of the study area (cantons of San Carlos, Río Cuarto, Gracia, Alajuela, Sarapiquí, Pococí, Guácímo, Siquires) and two images of 10/09/1998 for the western part of the study area (cantons of Upala, Guatuso, Los Chiles). These three images were downloaded from the Earth Explorer website (https://earthexplorer.usgs.gov/).

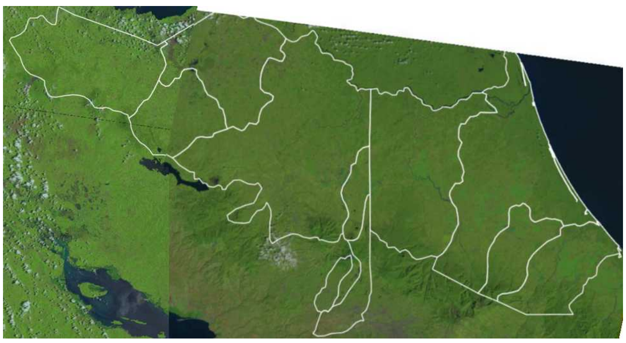

Figure 5. Landsat 5 satellite images acquired in 1998 (west) and 2001 (east).

Advances in Cartography and GIScience of the International Cartographic Association, 4, 9, 2023.
31st International Cartographic Conference (ICC 2023), 13–18 August 2023, Cape Town, South Africa. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-4-9-2023

These images are delivered at a pre-processing level 1, which signify radiometric and geometric corrections. Landsat 5 images has a spatial resolution of 30 meters, which is quite close to the average inter-vertices distance observed for the pineapple layer in 2000.

The exploitation of these heterogeneous data to evaluate the evolution of pineapple monocultures in Cost Rica is described in the following section.

3. Methodology

In order to analyse the land-use changes in favour of pineapple monocultures between 2000 and 2019, a three-step methodology is proposed (figure 6).

First, it is necessary to identify the areas of expansion of pineapple crops. For this, a comparison of the vector layers of pineapple crop delineation between 2000 and 2019 provided by the MOCUPP allowed to: (1) identify unchanged pineapple crops between 2000 and 2019, (2) identify new pineapple areas in 2019.

Secondly, a land use classification of the Landsat 5 images (in 1998 and 2001) is performed.

Finally, the new pineapple areas in 2019 are compared to the Landsat image classifications obtained for the years 1998 and 2001. These comparisons made it possible to: (1) identify the areas of forest in 2000 transformed into pineapple crops in 2019, (2) identify the other agricultural areas (other crops, pasture...) transformed into pineapple crops in 2019.

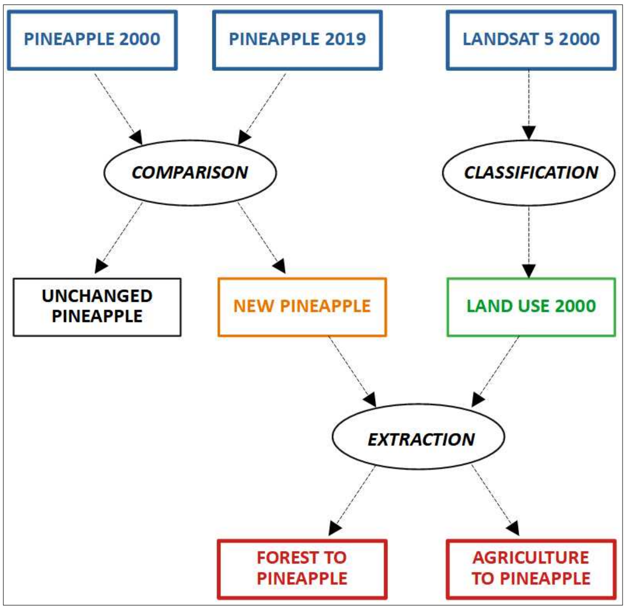

Figure 6. Overall methodology

The proposed methodology had to deal with the problems inherent to the heterogeneity of the source data, and in particular to their variable levels of detail. Solutions to resolve these problems are detailed below.

3.1 Pineapple layers comparison

The pineapple crop delineation vector layers for the years 2000 and 2019 provided by MOCUPP were built with different production processes, and in particular with source images of variable resolutions (Landsat 5 images in 2000 and Sentinel 2 images in 2019). The geometries of these two layers are therefore impacted, and comparisons performed between homologous areas can generate artefacts, which can have consequences on the results of the analysis.

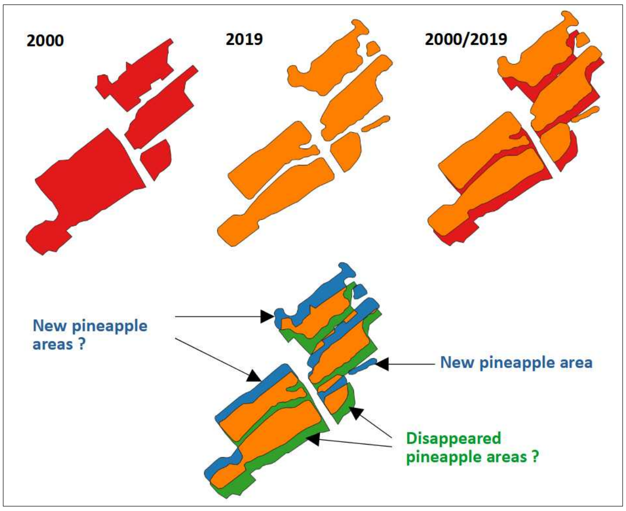

Figure 7. Result of a basic comparison between pineapple crop layers in 2000 and 2019

For instance, figure 7 presents the results of a raw comparison between the two layers of pineapple crops, where:

- orange polygons are unchanged pineapple areas (areas present in 2000 and 2019),
- blue polygons are new pineapple areas (areas present in 2019 but not in 2000),
- green polygons are disappeared pineapple areas (areas present in 2000 but not in 2019).

A visual validation shows that some of the blue polygons are not in reality new pineapple areas, or that some green polygons are not disappeared pineapple areas. These polygons are artefacts, and need to be processed appropriately for the analysis. Indeed, the use of the raw output data generated from the comparison could lead to inconstant results for the following analysis.

Thus, a task of elimination of the artefacts was carried out in order to keep only the polygons necessary for the analysis of the land cover changes. The layer of pineapple crops in 2019 was used as a reference, as its level of detail is considered higher. The elimination of the artefacts, corresponding to inconsistent polygons has been performed manually, based on the shape and the minimal size of the artefacts. Several rules have been proposed to perform this task. For instance, polygon artefacts of small surface (under 0.5 ha) and with a small compactness were deleted (figure 8).

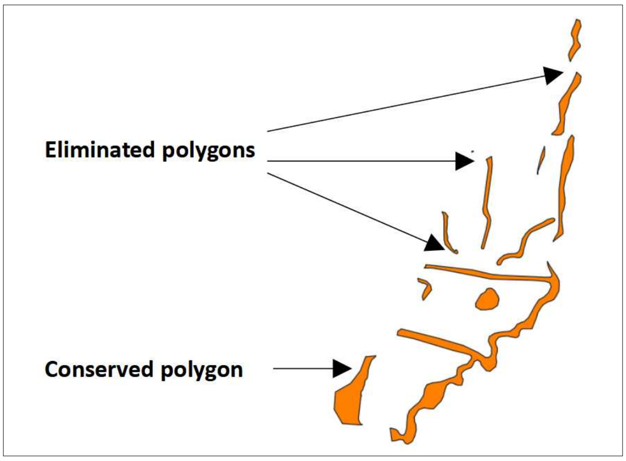

Figure 8. Eliminated and conserved polygons based on surface and shape and minimal size

The visual validation task allowed to control each decision for eliminating or keeping a polygon. Finally, a layer representing new pineapple cultures was produced (figure 9).

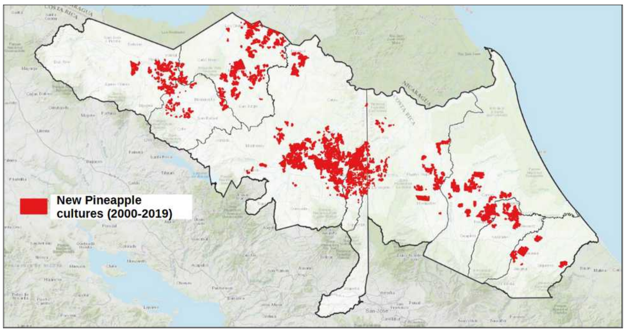

Figure 9. Layer of new pineapple cultures in northern Costa Rica between 2000 and 2019

This layer of new pineapple cultures will be compared with pre-existing land-use classes in 2000, generated from Landsat 5 images classifications.

3.2 Image classification

In order to determine the geographic distribution of the different land use types pre-existing the pineapple crops, a supervised classification was performed from Landsat 5 images. The main objective of the image classification process was to identify forest areas, as well as other agricultural activities (crops, pasture). Also, bare soil, water surfaces, as well as clouds and their shadows were classified. Once the image was classified, a 7*7 majority filter was applied to remove isolated pixels.

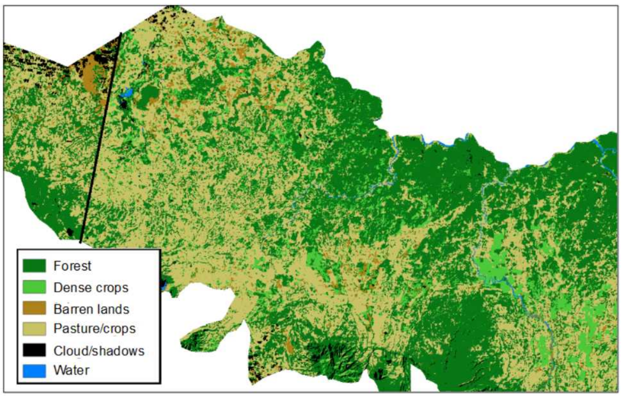

Figure 10. Land-use classification based on Landsat 5 images.

The result of the land-use classification is shown in Figure 10. The classification was found to be satisfactory with an overall accuracy of 80% when compared to a sample of test data.

The quality of the classification can be further analysed using the producer and user accuracy indicators for the different classes. Producer's accuracy (omission error) is about 97% for the forest class. It means that 97% of the sample of forest test data was well classified, and that 3% of the sample was affected to other classes (especially crops and pastures). Also, producer's accuracy was about 91% for crops and pastures.

User's accuracy (commission error) is about 66% for the forest class. It means 66% of the sample of test data classified as forest is a forest area, but that 34% of the sample classified as forest should be affected to an other class. These confusions were mainly associated with dense cultures, which can be classified as forest during the classification process.

Because of the uncertainty associated with the classification of certain crops types (e.g. dense cultures), particular attention will be given to analyse the extension of pineapple monocultures on pre-existing land-use types.

3.3 Pineapple layers comparison

The analysis of land cover changes, carried out using Landsat 5 image classifications, is also impacted by the spatial, spectral and radiometric resolutions of these images, which make the discrimination of certain land-use types sometimes delicate. The process for assigning each type of pre-existing land-use to new pineapple crops also had to be adapted. Indeed, when several land-use types are assigned to a single polygon, the majority land-use type was assigned. Finally, a visual validation was also performed to control if the pre-existing land-use type assigned to new pineapple culture was correct.

Thus, the layer of new pineapple cultures in 2019 was categorised according to pre-existing land-use types (in 2000), as presented in figure 11.

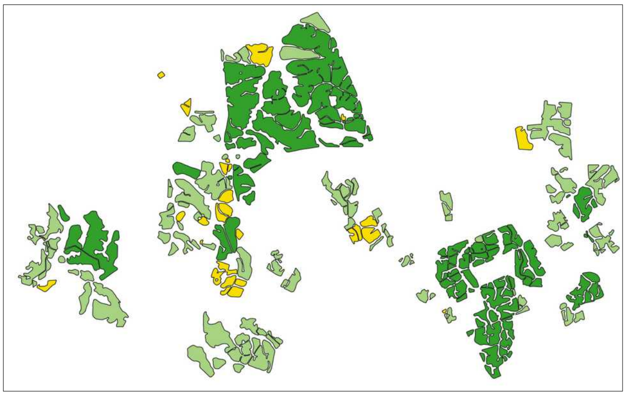

Figure 11. New pineapple cultures categorized according to their preexisting land-use type (forest in dark green, other agricultural activities in soft green, bare soils in yellow)

Land-use changes are finally assigned to each canton of the study area, in order to provide statistical results on the impact of the expansion of pineapple mono-cultures in northern Costa Rica.

4. Results and discussions

Despite the constraints inherent to the heterogeneity of the source data, this analysis has produced several encouraging results. Because of the uncertainty associated to the image classification, only the forest class will be used to analyse the expansion of pineapple monocultures on pre-existing land-use types (i.e. deforestation).

Globally, between 2000 and 2019, there was an increase of nearly 56786 hectares of pineapple cultivation in Costa Rica, of which approximately 49031 hectares were located in the northern part of the country. In this same region and during the same period, the deforested area is about 6366 hectares, mainly in the cantons of Los Chiles and San Carlos (figure 12).

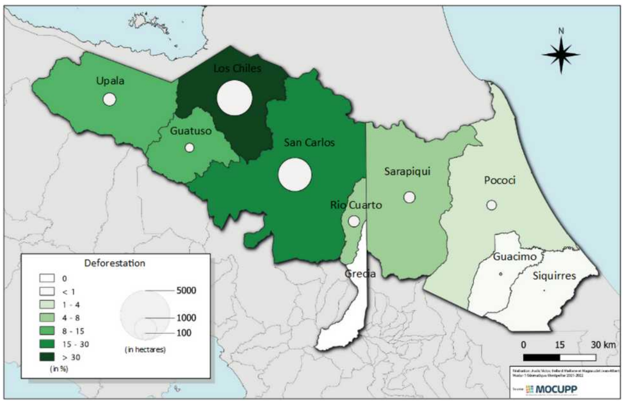

Figure 12. Distribution of deforestation for pineapple crops in Costa Rica by cantons

In the canton of Los Chiles, more than 30% of the new pineapple cultures in 2019 are deforested areas. These results show that despite the implementation of measures to prohibit deforestation in Costa Rica, areas of forest continue to be cleared for the benefit of export monocultures. During the same period, other agricultural practices (pasture, small crops) have also been transformed into pineapple monocultures in the study area. Further investigations are needed to provide a more detailed analysis of the changes in agricultural practices in northern Costa Rica.

While the major trends in pineapple monoculture expansion and deforestation in northern Costa Rica cannot be disputed, the precise estimation of land cover change can be discussed.

Indeed, as seen previously, the input data for pineapple crop delineation in Costa Rica are characterized by a high degree of heterogeneity, which is reflected in variable granularity and positioning accuracy. Nevertheless, these data are a valuable source of information that should be used appropriately. Also, the results of the Landsat 5 image classifications are subject to uncertainty, due to the spectral confusions that can be generated between certain nearby classes. In order to overcome these various constraints inherent to the quality of the input geographic data, as well as to the processing performed, long manual validation phases were carried out.

In order to avoid repeating these costly manual validation tasks in the future, several data qualification and pre-processing steps could be automatically performed to facilitate the comparison of crop areas at different dates.

First, a matching of homologous areas could be performed, in order to identify polygons corresponding to the same crop areas at two different dates, although with different geometries. Polygon dataset matching algorithms, such as proposed by Olteanu Raimond, et al. (2015) would facilitate the identification of homologous crop areas between two dates. To implement these data matching procedures, measures to characterize the data with different indicators adapted to polygonal geometries could be proposed, such as the Turning function (Arkin et Al, 1991) for instance, or shape indicators (Bel Hadj Ali, 2001; Vauglin, 1997). Based on the automatic data matching process, the identification of homologous crop areas would allow to avoid tedious validation tasks, and to focus the analysis on the changes between two dates.

Furthermore, to facilitate the elimination of artefacts between two coverages, the use of size and compactness indicators, such as Millers's compacity indicator for example, allows to easily eliminate artefacts induced by heterogeneous geometries overlaps.

These contributions in the pre-processing and data processing phases would allow for greater efficiency in comparing the evolution of crop areas at different dates.

5. Conclusion and further works

The mobilization of heterogeneous data, such as the delineation of pineapple crops at different dates, or classifications of satellite imagery, allowed the evaluation of land cover changes in Costa Rica between 2000 and 2019, and in particular the loss of forest in the north of the country. This analysis is based on the development of procedures to control and validate the different treatments obtained from the initial data.

In order to avoid repeating these time-consuming procedures, data qualification and pre-processing methods, such as automatic data matching, can be implemented. Such methods would facilitate comparisons between heterogeneous but valuable databases. Also, during the comparison phase between different dates, the use of adapted indicators can facilitate the elimination of artefacts, which can potentially disturb the analysis of land cover changes and impact the final results.

Generally speaking, these recommendations intend to enhance the value of the data produced by the MOCUPP and to facilitate their use in land cover change analyses.

The perspectives of this work concern a more detailed analysis of changes in agricultural practices in favour of pineapple monocultures. Also, the transposition of these analyses on other types of crops that are developing in Costa Rica, such as palm, is also envisaged.

6. Acknowledgements

The authors thank the members of the MOCUPP for providing the data necessary for this research and the PAPIIT program (Universidad Nacional Autónoma de México) for the financing of project IA300821 "Agricultural extractivism, production chains and labor markets in Central America. Approach from the Costa Rica-Nicaragua border".

7. References

Arkin, E. M., Chew, L. P., Huttenlocher, D. P., K., K., Mitchel, J. S. B., 1991. An efficient computable metric for comparing polygonal shapes. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 8, pp. 121-147.

Bel Hadj Ali, A., 2001. *Qualité géométrique des entités géographiques surfaciques.Application à l'appariement et défnition d'une typologie des écarts géométriques*. PhD Thesis, Université Marne-La-Vallée.

Dawson, C., 2019. L'ananas au Costa Rica. Fiche pays producteur. *Fruitrop* (Ed. Française), Vol. 262, pp. 50-55.

Echeverría-Saénz, S., Mena, F., Pinnock, M., Ruepert, C., Solano, K., de la Cruz, E., Campos, B., Sánchez-Avila, J., Lacorte, S., y Barata, C., 2012. Environmental hazards of pesticides from pineapple crop production in the Río Jimenez watershed (Caribbean coast, Costa Rica). *Science of the Total Environment*, Vol. 440, pp. 106–114.

Evans, S., 1999. *The Green Republic: A conservation history of Costa Rica*. University of Texas Press.

Fagan, M. E., de Fries, R. S., Sesnie, S. E., Arroyo, J. P., Walker, W., Soto, C.,Chazdon, R. L., Sanchun, A., 2013. Land cover dynamics following a deforestation ban in northern Costa Rica. *Environmental Research Letters*, Vol. 8(3) pp. 1-9.

Girres, J.-F., 2015. Estimation of geographical databases capture scale based on inter-vertices distances exploration, *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume II-3/W5, 2015, pp. 305-310, doi:10.5194/isprsannals-II-3-W5-305-2015

MOCUPP, 2017. *Surveillance du changement de l'utilisation des terres productives*. 61 pp.

Olteanu Raimond, A.-M., Mustière, S., Ruas, A., 2015. Knowledge formalization for vector data matching using Belief Theory, *Journal of Spatial Information Science*, Vol. 10, pp 21-46. doi:10.5311/JOSIS.2015.10.194

Pringle, R. M., 2017. Upgrading protected areas to conserve wild biodiversity. *Nature*, Vol. 546 (7656), pp. 91-99.

Rodriguez Echevarria T., Prunier C. 2020. Agricultural Extractivism, Border and Migrant Workforce: The Expansion of Pineapple Monoculture in Costa Rica. *Frontera Norte*, Vol. 32, 23 pp.

Sozzi, M., Marinello, F., Pezzuolo, A., Sartori, L., 2018. Benchmark of Satellites Image Services for Precision Agricultural use. *Proceedings of the European Conference on Agricultural Engineering (EurAgEng'18)*, 8-11 July 2018, Wageningen, The Netherlands, pp. 1-6.

Vauglin, F. 1997. *Modèles statistiques des imprécisions géométriques des objets géographiques linéaires*. Thèse de doctorat, Université Marne-La-Vallée.

