Landscape dynamics of *Paspalum quadrifarium* grasslands analyzed by Morphological Spatial Pattern Analysis (MSPA)

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Background. Despite its wide distribution worldwide, only 4.6% of temperate grasslands are included within systems of protected areas. In Argentina, this situation is even more alarming: only 1.05% is protected. The study area (central area of the southern Salado River basin) has a large extent of grasslands of *Paspalum quadrifarium* (Pq) which has been target since the last century of a variety of agricultural management practices including fire burning for cattle grazing.

Methods. Were used as base data bynary images of presence-ausence data of Pq coming from a 42-year (1974-2016) land cover change study performed over Landsat Imagery (MSS, TM, ETM, and OLI sensors). MSPA (Morphological Spatial Pattern Analysis) and Network Analysis were performed to the data using Guidos Toolbox for the estimation of habitat and connectivity dynamics of the Pq patches (fragments).

Results. Was observed a loss of area and habitat nuclei of this grassland between the beginning and the end of the study period. A drastic reduction in connectivity was also evident in resulting maps. The number of large Pq grassland fragments (> 50 ha) decreased during the study period, and fragmentation measured as number of components (patches) was higher at the end of study period. The Pq pajonal nuclei had their minimum representativeness in 2000, and recovered slightly in 2011, but with a significant percentage increase of the small patches (=islets) and linear elements as bridges and branches. Large corridors (mainly edge of roads) could be observed at the end of study period, while the total connectivity of the landscape pattern drops abruptly.

Discussion. The habitat reduction could have an impact on the ecosystem functioning and the mobility of some species of native fauna. The connecting elements of the landscape were maintained and/or recovered in percentage in 2011 and 2016. This fact, although favoring the dispersion of the present diversity in the habitat nuclei could cause degradation by an edge effect. On the methodological side, the use of a proved tool as Guidos Toolbox for evaluating forest fragmentation could also be useful for monitoring dynamics of a grassland-habitat fragmentation.

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ABSTRACT

Background. Despite its wide distribution worldwide, only 4.6% of temperate grasslands are included within systems of protected areas. In Argentina, this situation is even more alarming: only 1.05% is protected. The study area (central area of the southern Salado River basin) has a large extent of grasslands of *Paspalum quadrifarium* (Pq) which has been target since the last century of a variety of agricultural management practices including fire burning for cattle grazing.
Methods. Binary images of presence-absence data of Pq from a 42-year (1974-2016) land cover change study were used as base data. MSPA (Morphological Spatial Pattern Analysis) and Network Analysis were performed to the data using Guidos Toolbox for the estimation of habitat and connectivity dynamics of the Pq patches (fragments).
Results. A loss of the coverage area and habitat nuclei of this grassland was observed between the beginning and the end of the study period. A drastic reduction in connectivity was also evident in resulting maps. The number of large Pq grassland fragments (> 50 ha) decreased during the study period, and fragmentation measured as number of components (patches) was higher at the end of study period. The Pq pajonal nuclei had their minimum representativeness in 2000, and recovered slightly in 2011, but with a significant percentage increase of the small patches (=islets) and linear elements as bridges and branches. Large corridors (mainly edge of roads) could be observed at the end of study period, while the total connectivity of the landscape pattern drops abruptly.
Discussion. The habitat reduction could have an impact on the ecosystem functioning and the mobility of some species of native fauna. The connecting elements of the landscape were maintained and/or recovered in percentage in 2011 and 2016. This fact, although favoring the dispersion of the present diversity in the habitat nuclei could cause degradation by an edge effect. On the methodological side, the use of a proved tool as Guidos Toolbox for evaluating forest fragmentation could also be useful for monitoring dynamics of a grassland-habitat fragmentation.

Keywords: Land use, Cattle grazing, Morphology, Connectivity, ***Paspalum quadrifarium***

INTRODUCTION

The loss of habitat and the fragmentation of ecosystems are one of the main threats to the conservation of biodiversity worldwide (Fahrig 2003, Hobbs and Yates 2003, Henle et al 2004, Wilson et al. 2016). In Argentina, the conversion of natural ecosystems to agricultural lands has consequences such as the loss of habitat and biodiversity, the alteration of biotic interactions and biogeochemical processes (water cycles, carbon and nutrients), the reduction of the capacity to provide ecosystem services and the transformation of the landscape (Herrera et al., 2012; Volante et al., 2012; Gandini et al. 2014). In this way, given the magnitude of anthropogenic activities on natural systems (Vitousek et al., 1997), understanding if and how biodiversity recovers from disturbances is an important focus of ecology and conservation biology. Woods et al (2016) emphasized the importance of considering spatial scale while the impacts of a disturbance on an ecosystem are quantified. Across the globe, many once- pristine natural ecosystems have been replaced by human-dominated mosaic landscapes, wherein a patchwork of human land-use patterns has been superimposed on pre-existing patterns of heterogeneity in natural environmental conditions. In such landscapes, species have experienced their environment across a range of spatial scales (Tscharntke et al. 2012), so it is important to evaluate these effects across both time and space (Van Horne 2002).

A characteristic type of grassland landscape in the Salado river basin is the "pajonal" of *Paspalum quadrifarium* also known as *Paspaletum* (Vervoorst 1967). It represents one of the twelve plant communities identified for this area and it is a type of grassland characterized by marked abundance of *P. quadrifarium*, a grass that can grow into dense tufts reaching 1 to 1.50 m (Frangi 1986), and various companion species in different proportions. Paspaletum is characterized by its distribution in a wide range of topographies (Lara & Gandini 2013a) forming different vegetation units (Perelman et al. 2003; Lara & Gandini 2013b).

Pajonal grasslands have been under fire and grazing disturbance for a long time. Since the introduction of domestic livestock by European settlers and almost without interruption, this grassland has been managed changing their coverage and land use in different ways (Foley et al. 2005, Vazquez et al. 2012). Mainly fire is currently used in the winter-spring period with the aim of increasing net productivity and thus livestock receptivity (Laterra 2003). In this way, the interaction of fire with cattle grazing lead to deep changes that can be seen across scales of analysis (Herrera et al 2009; Lara & Gandini 2011).

Ecologists distinguish between a particular disturbance event -like an individual storm or fire- and the disturbance regime that characterizes a landscape (e.g., White and Jentsch 2001). Disturbance is a “hot topic” in land and resource management and particularly in grassland management, because many disturbance regimes seem to be changing due to human activities, especially climate change. For example, the risk of large fires is increasing in many areas of the world. The disturbance regime refers to the spatial and temporal dynamics over a longer time period and is described by characteristics such as the spatial distribution of disturbances; disturbance frequency, return interval, and rotation period; and disturbance size, intensity, and severity (Turner & Gardner 2015).

Despite its large distribution worldwide, only 4.6% of temperate grasslands are included within national protected area systems. In Argentina, this situation is even more alarming since only 1.05% is protected (Bilenca and Miñarro 2004). The underestimation of the productive value of these natural grasslands starts from the difficulty of objectively visualizing the goods and ecosystem services that they provide.

Human encroachment on the environment through resource extraction and urban expansion have led to fragmentation (Maguire et al. 2016), with consequences for biodiversity (Chapin et al. 2000), ecosystem processes (Díaz & Cabido 2001, Harrington et al. 2010) and the ecosystem services that they are supporting (Mitchell et al, 2014).

The current increase in agricultural and livestock pressure in the region (Cañibano et al., 2004; Vázquez et al., 2012) pre-supposes a little encouraging scenario due to the replacement of natural pasture coverage. However, Paspaletum (ecological community of Paja Colorada – *Paspalum quadrifarium*) remnant patches persist in the centre of Buenos Aires province (Herrera et al., 2009). These patches were maintained as pasture sites in good state of conservation according to studies of Fundación Vida Silvestre Argentina (Bilenca and Miñarro 2004). So, these sites were classified as Valuable Grassland Areas (PVAs), given their importance as a source of great native animal diversity and the numerous ecosystem services they provide.

Fahrig (2003) considered fragmentation as one of the most damaging threats to biodiversity conservation in recent times because the population viability in fragmented landscapes depends to a large extent on the structural and functional integrity of the landscape. In this context, it is necessary to carry out studies that allow analysing the trends of change in these habitat fragments and their connections to implement management and conservation strategies in areas of high regional ecological importance.

The sustainable management of fragmented landscapes will depend on understanding the spatial ecology of the ecosystem services needed over the long-term (Maguire et al. 2016). In terms of functional integrity of ecosystems, landscape connectivity is considered one of the key properties to maintain biodiversity. Landscape connectivity is defined as the degree to which landscape facilitates the movement of species and other ecological flows (Taylor et al., 1993). It is considered a key aspect to take in account for biodiversity conservation efforts around the world and one of the best responses to counteract the negative effects of habitat fragmentation and to facilitate species adaptation to changes in their natural habitats (Crooks and Sanjayan 2006). Morphological Spatial Pattern Analysis (MSPA) has been promoted in the last decade by the Joint Research Center of the European Commission (JRC) to contribute to the knowledge and exchange of information on issues related to ecosystem patterns of disturbance in human-managed ecosystems, assessing fragmentation and connectivity in Europe and in the world. MSPA is described by Vogt et al. (2007a) as "a customized sequence of mathematical morphological operators to describe the geometry and connectivity of the components of an image."

MSPA approach uses a binary method of image classification based on the geometry and forms of the elements to classify the patterns into seven categories: core, islet, loop, bridge, perforation, edge, and branch (Soille & Vogt, 2008). MSPA approach has been applied in landscape ecology to identify and map the structural patterns of forests at pixel level, allowing identification of fragmentation issues (Vogt et al., 2007a) and the connective elements of a landscape as the corridors (Vogt et al., 2007b). MSPA also has been implemented to analyse the connectivity of forests in Europe through the identification of key structural elements that play the role of connectors and the integration of connectivity indexes based on habitat availability (Saura et al., 2011). Other structural elements such as riparian corridors have been identified through the MSPA approach to study their contribution to structural connectivity and to establish conservation valuation criteria (Clerici and Vogt, 2013). Likewise, the US green infrastructure has been morphologically classified and mapped to know its distribution with a view to forest protection and correct decision-making in landscape planning (Wickham et al., 2010). This approach was used to identify and classify the morphological types of fragmentation, based on the availability of habitat and to recognize the temporal variation between the elements that contribute to the maintenance of landscape connectivity.

Improved landscape connectivity is increasingly considered a viable management strategy to maintain biodiversity, ecosystem functions, and services (Ziter et al. 2013). In a part of the study area -the Salado River basin- the habitat fragmentation pattern has been reported to have increased considerably in the last 40 years (Lara & Gandini 2014), Thus becoming one of the major environmental problems in the basin. In this way, this research presents a novel application of the MSPA approach in the monitoring of change over time in the fragments of grassland, the *Paspalum quadrifarium* habitats.

In this work the MSPA was applied to a remote sensing classification of Landsat images in order to analyze the 40-year temporal change in the habitat fragments of the "pajonal" grasslands (*Paspalum quadrifarium*).

MATERIALS & METHODS

Study Area

The study was carried out in the Flooding Pampa and Inland Pampa areas of the Salado River basin, in the Buenos Aires province (Argentina), covering mainly two different agroecological zones, the "Flooding and Inland Pampas" (Figure 1), which concentrates the greatest representativeness of the ecological community of interest (Gandini et al., 2014).

Data acquisition, pre-processing and land cover classification

A series of five Landsat images (path 225, row 85) for the years 1974 (MSS sensor), 1988 (TM sensor), 2000 (ETM + sensor), 2011 (TM sensor) and 2016 (OLI sensor) was used. The digital numbers (DN) were converted to reflectance (except the thermal band) according to Chander et al. (2009), and the reflectance values were then adjusted for atmospheric scattering using the Improved Dark Object Subtraction method by Chavez (1996).

In accordance with previous reports (Herrera et al., 2009, Lara and Gandini, 2013b), the initial land cover types used were: pajonal, short-grass matrix, pastures, crops and water bodies. To identify the land cover types, supervised classifications were employed using the maximum likelihood algorithm (Lu and Weng 2007). The classifications were performed using all reflective Landsat bands; for 1974: MSS4, MSS5, MSS6 and MSS7; for 1988 and 2011: TM1, TM2, TM3, TM4, TM5 and TM7; for 2000: ETM + 1, ETM + 2, ETM + 3, ETM + 4, ETM + 5 and ETM + 7, and for 2016, Bands 2, 3, 4, 5, 6 of OLI Sensor. The thermal bands of platforms were discarded.

For 1988, the training sites were located by visual interpretation on 44 aerial infra-red photographs (scale 1: 20,000) taken in 1988 summer, following criteria such as texture, shape and colour (Chuvieco,2010). For 2011 and 2016, the control points were selected using a global positioning system (GPS) in the field within relatively homogeneous areas. For 1974 and 2000, the training sites were selected by visual analysis following the medium spectral signature for each land cover type and using areas with similar spectral characteristics –over land cover remained unchanged- (Chuvieco, 2010; Schulz et al., 2010).

Classification results were filtered using a 7 x 7 median filter to remove isolated pixels. Later, the MSS classification (1974) was re-sampled to a 30 x 30 m pixel size to allow multi-temporal comparison with the rest of the series.

The accuracy of the classification maps was assessed with the use of quantity disagreement and allocation disagreement (Pontius and Millones, 2011). These indexes are more useful and simpler than standard Kappa (Congalton, 1991) and allow us to focus on two components of

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disagreement between maps and reference points in terms of the quantity and spatial allocation of the land cover types.

Pajonal fragments were identified based on these classifications, and binary Pajonal presence-absence maps were created. These binary maps of 1974, 1988, 2000, 2011 and 2016 were analyzed using a morphological classification (MSPA) with the software Guidos Toolbox (Soille and Vogt, 2008; Vogt, 2014).

A comparative analysis of landscape connectivity was carried out, evaluating the variations in the size and connectivity of the patches of pajonal. The analysis was performed considering each set of connected patches as a single landscape element. In this way the size of the elements varied as the patches were fragmented and disconnected by the effect of the livestock management (fire and grazing disturbance).

In addition ECA was calculated. ECA is defined as the size of a single habitat patch (maximally connected) that would provide the same value of the probability of connectivity than the actual habitat pattern in the landscape. It is calculated as the square root of the numerator of the PC index (Saura et al. 2011).

RESULTS AND DISCUSSION

A complete set of resulting images of Classification, MSPA and connectivity for a set of 5 analyzed years is stored in supplementary material that could be opened by free software as QGIS (2018) and similar, as well as Guidos Toolbox (Vogt 2014) .txt outputs for seeing running details. For reasons of simplicity of interpretation only maps of extreme years in time (1974-2016) are shown in the main body of text.

Image classification of land cover

Classification error issues are shown in Table 1. Good thematic accuracies for Pq were obtained, and the separation of overall disagreement into two components was used to learn about sources of error and give guidance on how to improve each classification (Pontius and Millones, 2011). Quantity disagreements, and not allocation disagreement, were particularly taken into consideration to assess classification quality since the main aim of this work was focused on regional changes and not pixel-to-pixel changes (Keller and Smith 2014)

Fragmentation and habitat loss

The observation of the MSPA image product (Fig. 2) indicates a loss of area of grassland as a whole, and of the habitat nuclei between the beginning and the end of the study period. A drastic reduction in connectivity is also evident. The number of large pajonal fragments (> 50 ha) decreased during the study period, but the greatest fall was observed in 2000, although in 2011 this trend continued at a lower rate (Table 1).

Fragmentation measured as number of components (patches) resulting from habitat pressure is higher in 2011 and 2016 (Table 1). This observation agrees with MSPA data, in which the pajonal nuclei had their minimum representativeness in 2000, and recovered by 2011, with a significant percentage increase in the small patches (=islets). While edges and curls remained relatively stable, the linear elements (bridges and branches) increased their representativeness (Table 1, MSPA; see also Figure 2). This fact, although favoring the dispersion of the present diversity in the habitat nuclei could cause degradation by an edge effect. The connecting elements of the landscape were maintained and/or recovered in percentage. Larger corridors (mainly edge of roads) could be observed while the total connectivity of the landscape pattern drops abruptly (Table 1, connectivity and Figure 2) in terms of mean and median connectivity after 1988 and %ECA after 2011.

The effect on diversity could be more important when considering that habitat patches form a "network" and that they are not connected to each other (Maguire et al. 2016). This loss of connectivity is clearly evidenced in Figure 3.

Temporal variation of ECA% shows the dynamics of the fragmentation process in the study area: from a value of 28, doubling the patch size in 1988 is necessary to reach similar connectivity (median values). In successive years, the connectivity and ECA decline to a minimum in 2011, showing a slight recovery in 2016.

Within the frame of environmental conservation issues, monitoring these environments and conducting further research on their impact on biodiversity are deemed necessary. In this work, as Wickham et al. (2010) this approach was used to identify and classify the morphological types of fragmentation, focusing on the dynamics of habitat availability, and to recognize the variation in the time of the connective elements of the landscape.

In this research it is noticeable a high and sustained habitat decline in the period 1974-2011 and a slight recovery (in some indicators) in 2016. Monitoring the dynamics of these grasslands is necessary to contribute to their conservation.

This research opens up the need to think about a short-term research on the minimum size of pajonal fragments that preserve ecosystem services, and maintain in an acceptable status their biodiversity components and structure.

CONCLUSIONS

The variations in the size and connectivity of the patches of Pq were significant in the study period (1974-2016). the major effects were the habitat fragmentation and patch size reduction leading to connectivity loss. In terms of fragmentation, there was a true fragmentation, and also habitat loss, determined by a high trend to lower the patch size and connectivity. Slight structural recovery in terms of area could be seen at the end of the study period (2016). This trend is clearer in connectivity issues measured by ECA%.

This work showed that the habitat patches of Pq, have undergone deep transformations since 1974 interchanging the original landscape matrix by other subordinate community, the Short-Grasses Matrix (Lara & Gandini 2014). These changes could be evidenced through the application of a methodology originally used for the study of forest fragmentation, the morphology and connectivity analysis (Vogt et al 2007a).

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Table 1(on next page)

Classification Quality of Pq cover estimation, and numerical results of the morphological and connectivity analysis.

Most significant MSPA results (as percentages over the total) and connectivity analysis: Number of components, maximum, mean and median of connectors / component; and relative ECA

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Analysis	Parm/Form/year	1975	1988	2000	2011	2016
Class. Disagreement % (PJ)	Quantity	1	5	5	4	2
	Allocation	10	18	12	9	12
MSPA	Core (small)	4,35	3,12	3,68	3,17	3,46
	Core (medium)	4,65	2,08	3,12	2,85	2,17
	Core (large)	11,94	4,58	6,06	3,73	3,71
	Islet	1,05	2,53	1,11	1,46	1,75
	Perforation	1,72	0,62	0,56	0,28	0,50
	Edge	13,52	6,87	9,07	7,36	8,65
	Loop	1,08	0,89	0,69	0,32	0,65
	Bridge	3,23	4,85	2,80	1,82	2,46
	Branch	2,43	3,24	2,35	2,13	2,31
Components	# total	2726	2061	2186	2852	3772
Conectivity (links)	Mean of links	1153	379	287	167	49
	median of links	55	49	41	21	43
	max links	80557	28468	16738	15040	43912
	ECA (pixels)	945277	894122	1041192	236552	374184
	relative ECA %	28	57	50	15	25

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Figure 1

Study area and Agroecological zones

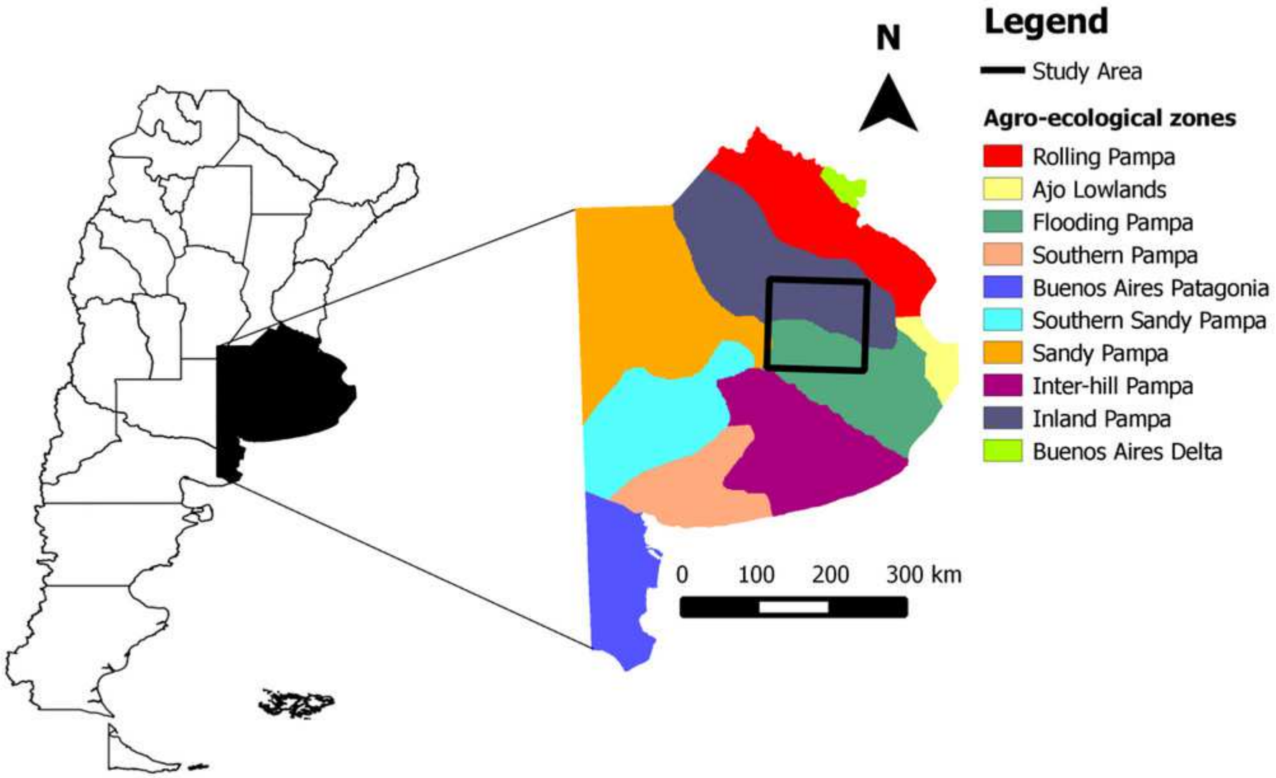

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Figure 2

Map of MSPA segmentation results of *Paspalum quadrifarium* presence-absence data (1974 vs. 2016)

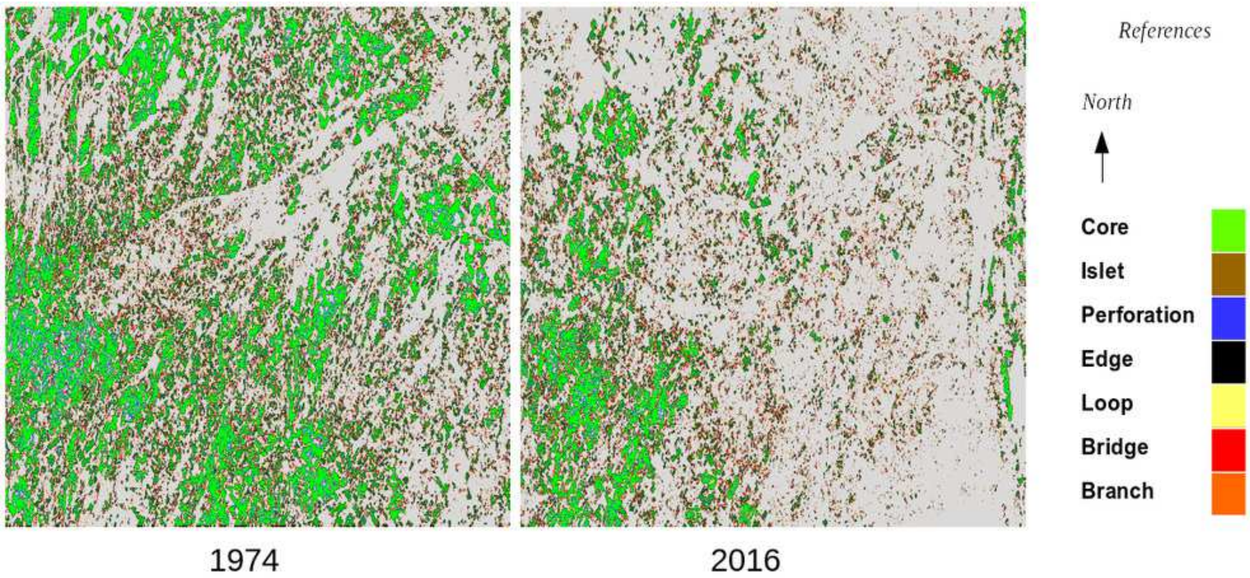
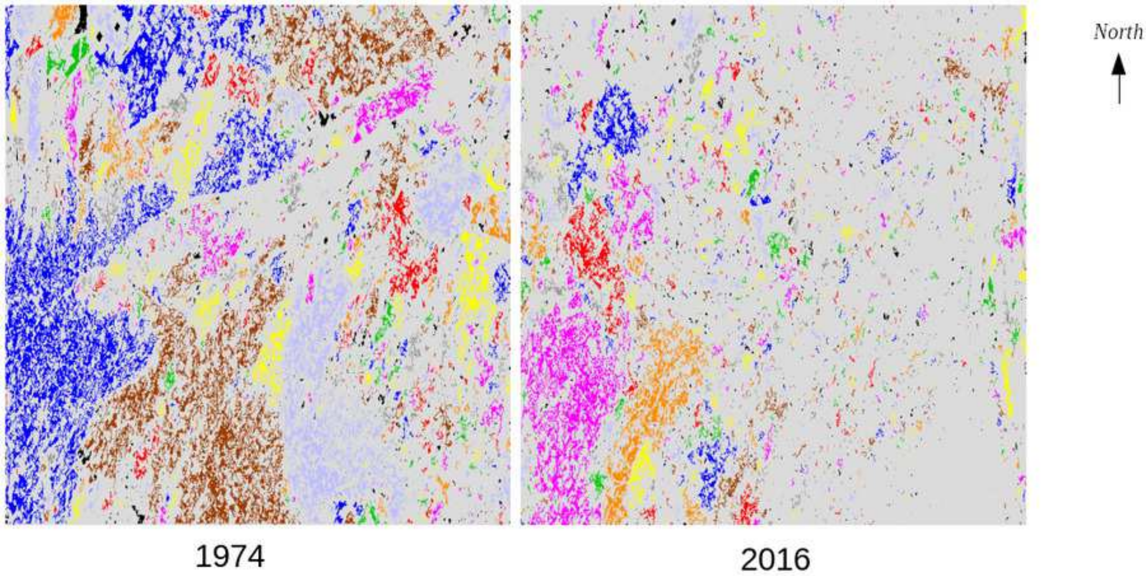


Figure 3

A visual comparison between 1974 and 2016 connectivity results

Different colors indicate patches belonging to different networks



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