Article

Spatial Analysis of the Drivers, Characteristics, and Effects of Forest Fragmentation

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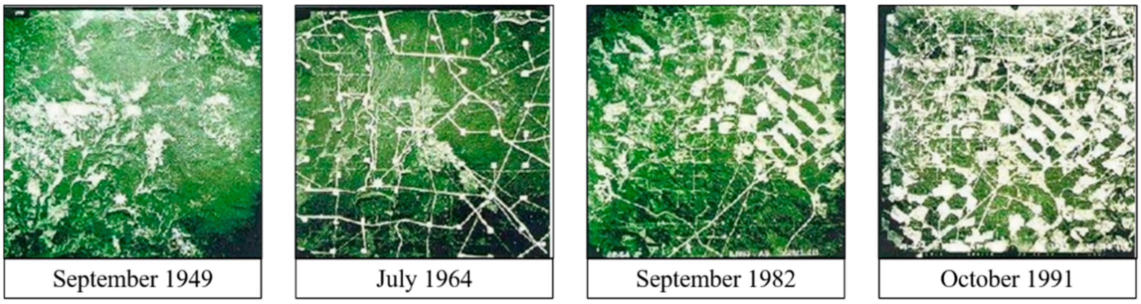


Figure S1. A time-lapse of forest fragmentation in northern Alberta, showing forest being slowly overtaken by agricultural and urban land in 1949, 1964, 1982 and 1991. Source: [1]

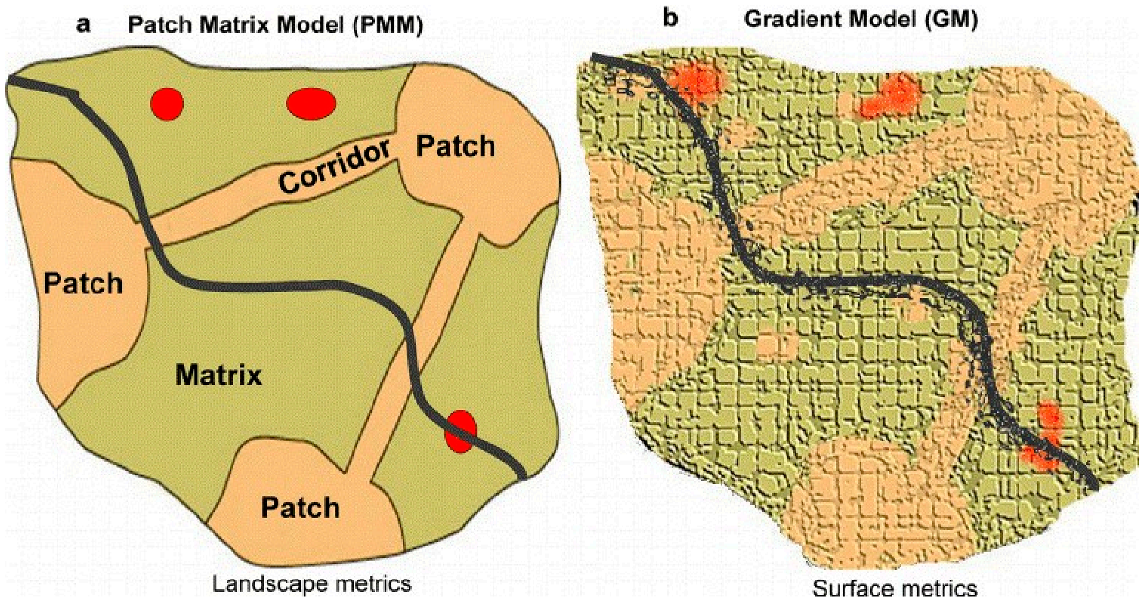


Figure S2. A pictorial representation of the difference between the patch-matrix and gradient surface models. Source [2]

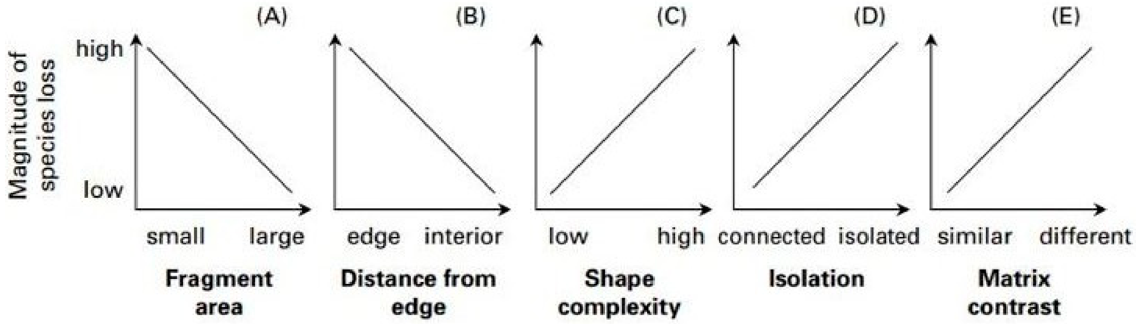


Figure S3. Graphs depicting common generalisations about species responses to fragmentation of their habitats. Source [3]

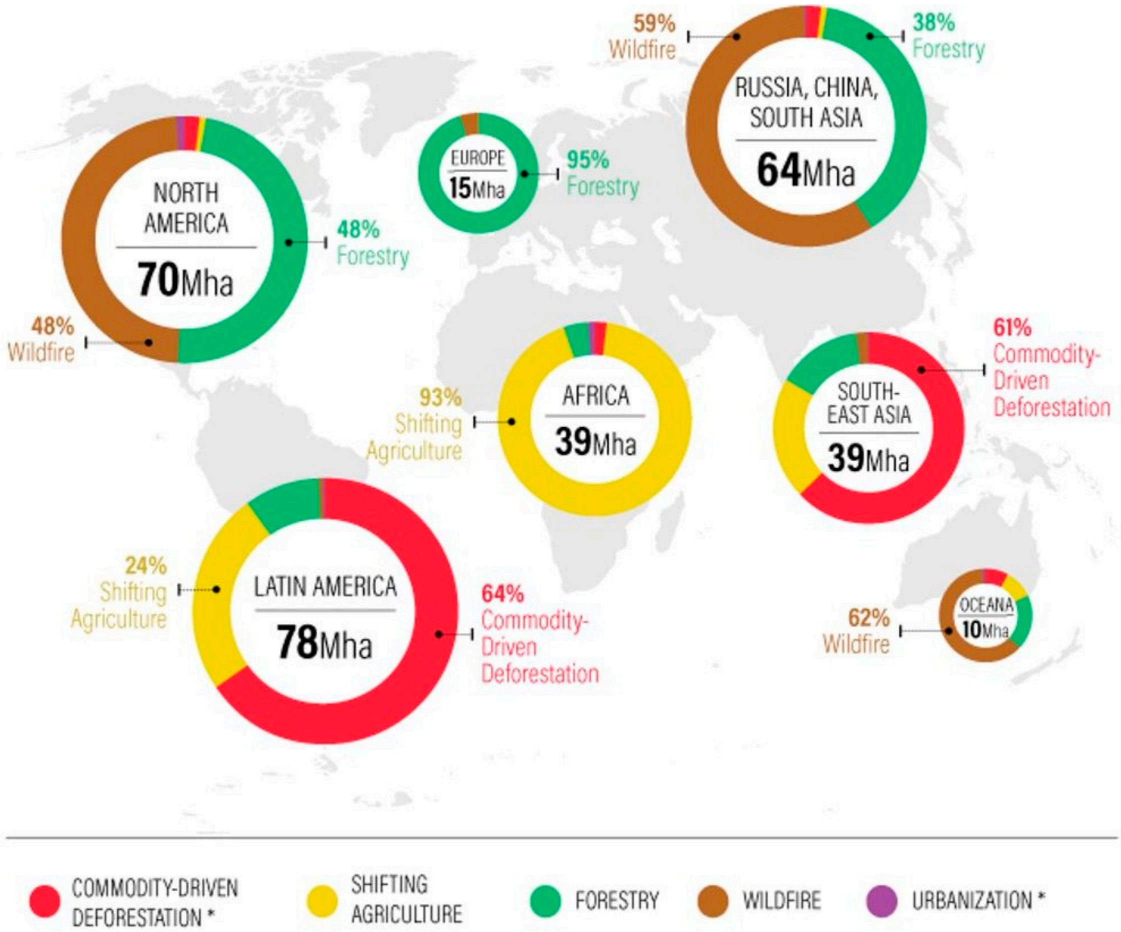


Figure S4. A map of regional tree cover loss by driver between 2001 and 2015. Source [4]

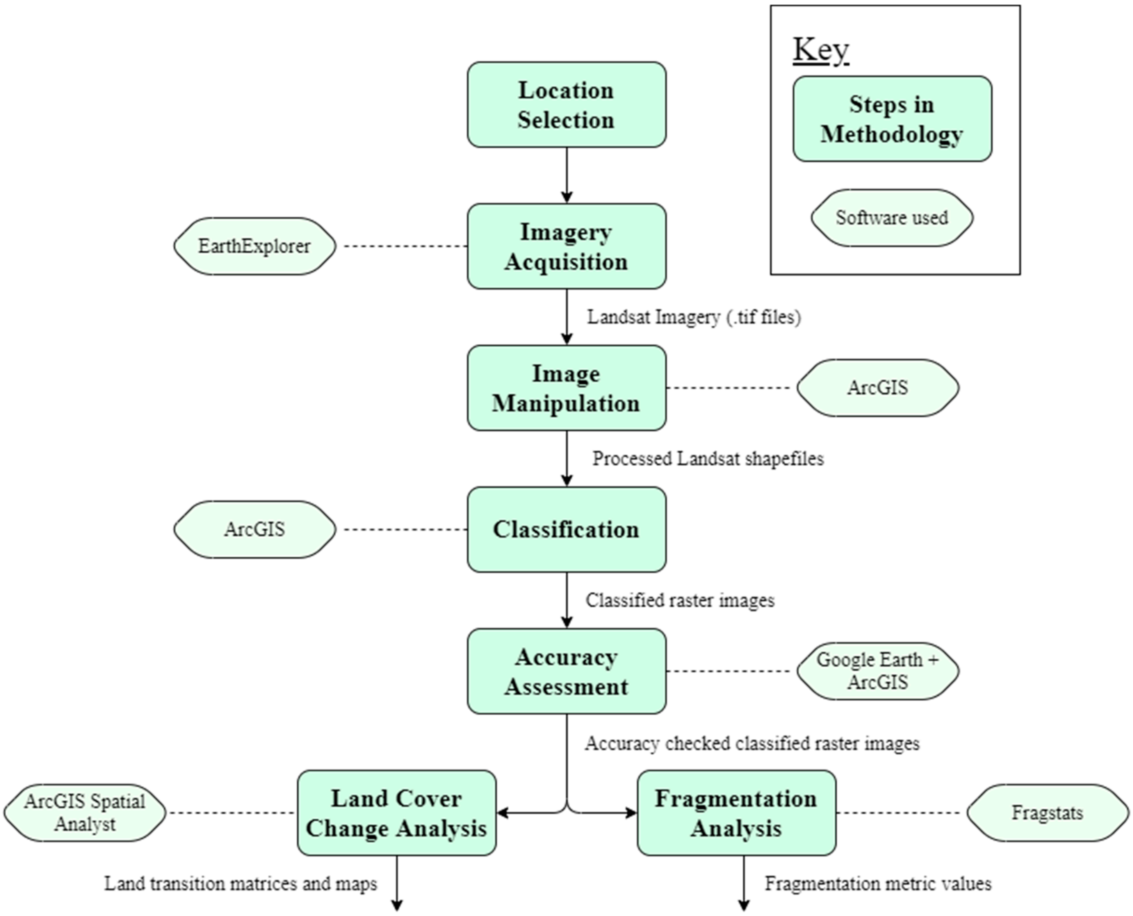
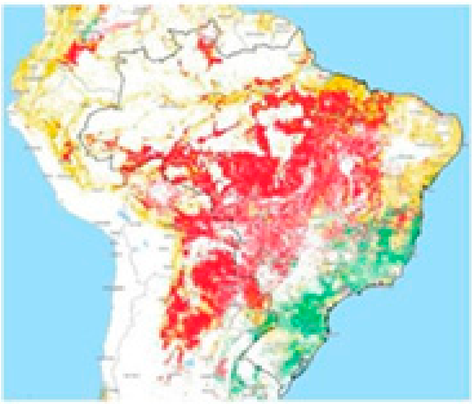


Figure S5. A flow diagram of the steps taken in this study to derive fragmentation information, with relevant software.



Commodity-driven deforestation
Shifting agriculture
Forestry
Wildfire
Urbanisation

Figure S6. Tree cover loss by dominant driver in Brazil. Source [5]

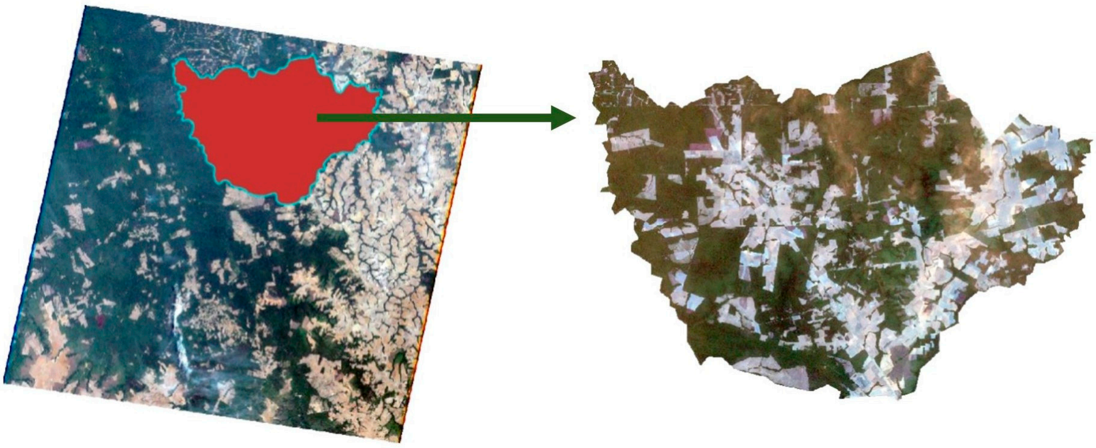


Figure S7. An example clip of the municipality of Tapurah from a Landsat scene Figure 2000.

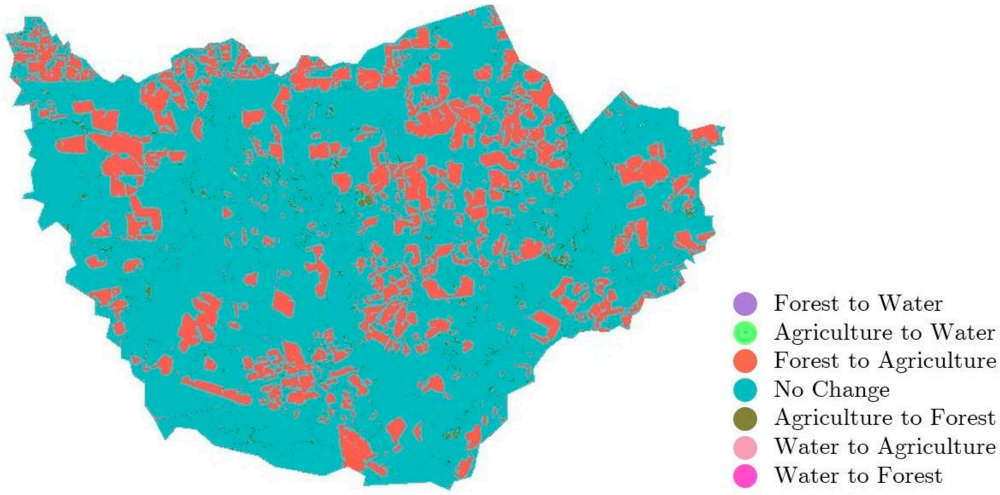


Figure S8. A difference map showing the land cover changes in Tapurah from years 2000 to 2019.

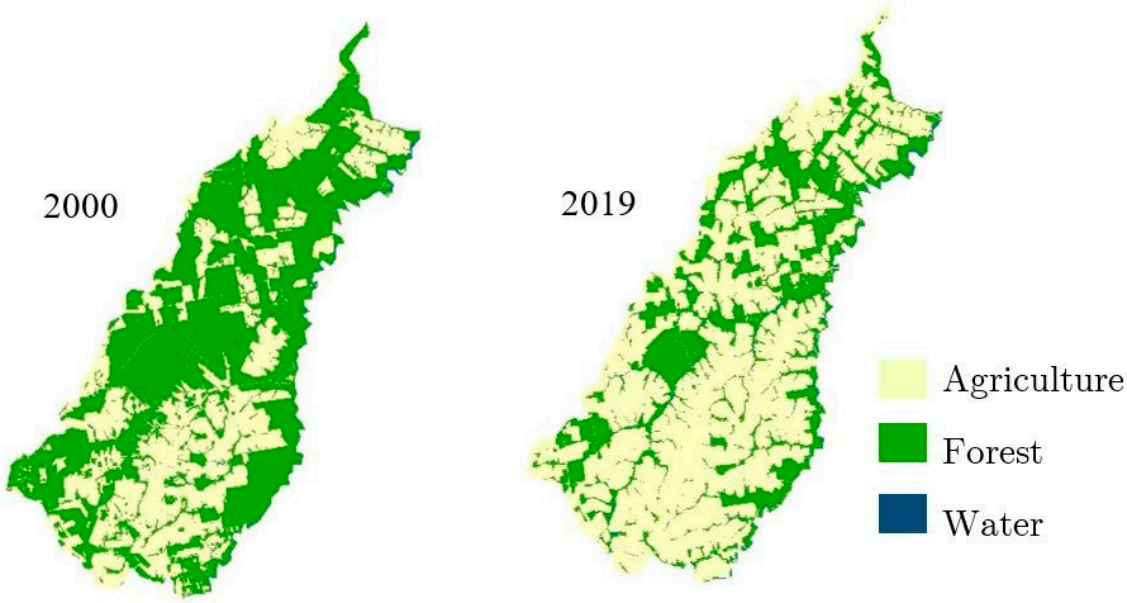


Figure S9. A land cover map of the municipality of Ipiranga do Norte, which experienced the greatest loss of total forest area over the 19 years of study.

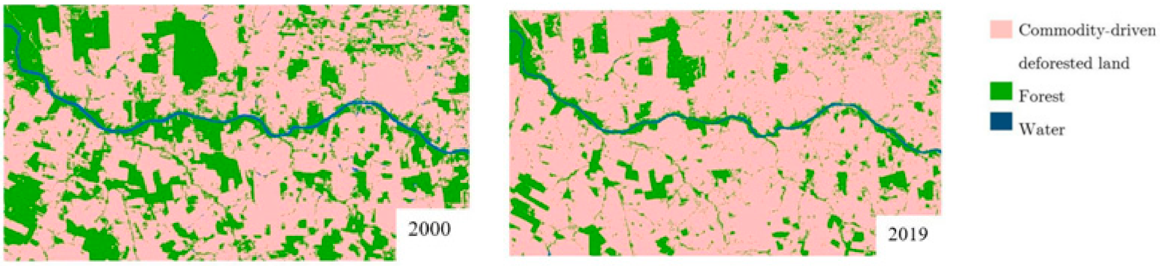


Figure S10. A close-up land cover map of the municipality of Cacoal, which experienced the greatest reduction in mean forest patch area.

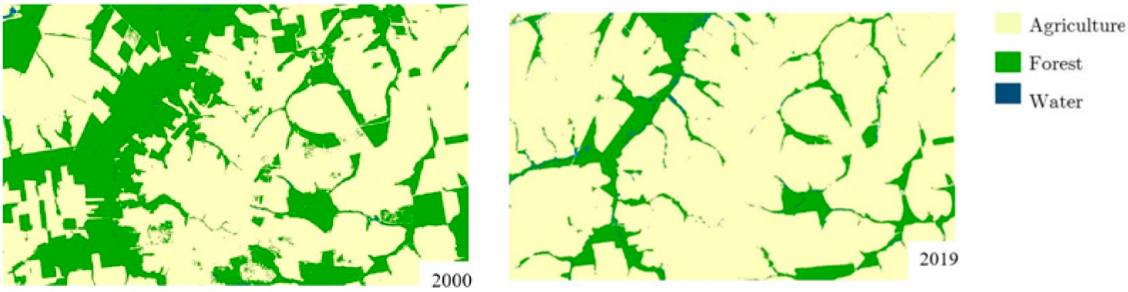


Figure S11. A close-up land cover map of the municipality of Ipiranga do Norte, which experienced the greatest increase in area-weighted edge length.

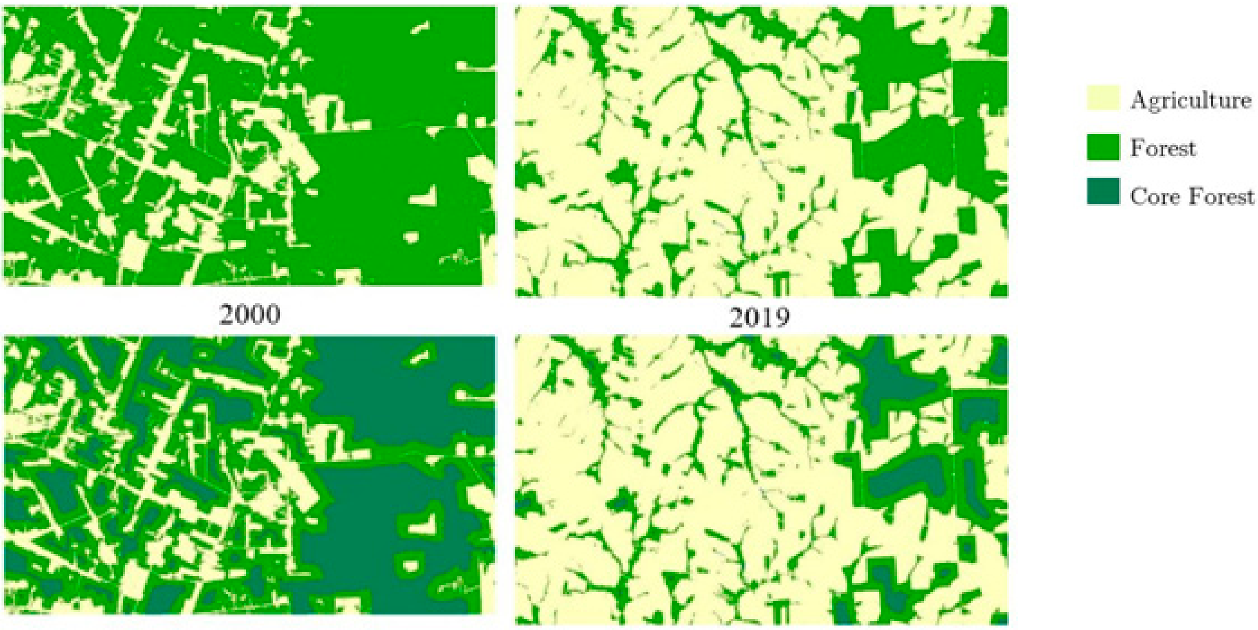


Figure S12: A close-up land cover map of the municipality of Itanhangá. The top two images Scheme 2000. to 2019, whilst the bottom two show the same but with core forest area highlighted in dark green.

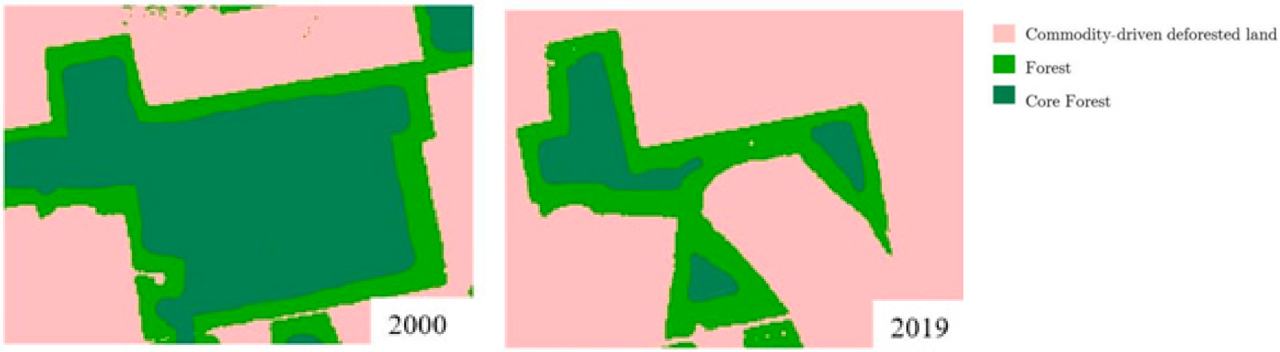


Figure S13. A close-up land cover map of the municipality of Cacoal, demonstrating an increasing number of disjunct core areas.

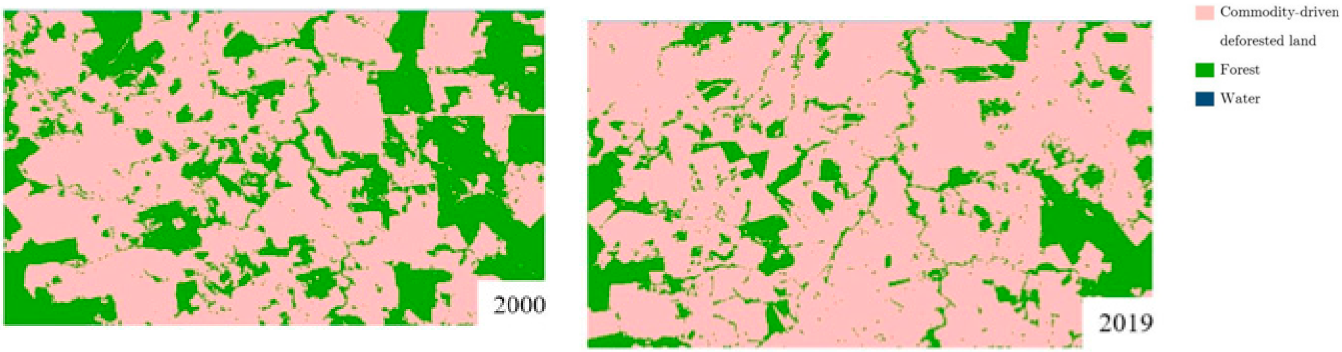


Figure S14. A close-up land cover map of the municipality of Pimenta Bueno, demonstrating

Table S1. An error matrix demonstrating the likelihood of incorrect classification for the Tapurah 2000 image.

		Classification		
		Forest	Agriculture	Water
Aerial	Forest	44	4	4
	Agriculture	0	52	1
	Water	0	0	5

Table S2. A Land Cover Transition Matrix for the state of Tapurah between the years 2000 and 2019 showing the total land cover change between land types in km^2. Each cell a_{ij} represents the total area which was class type i in 2000, and had transitioned to class type j by 2019. Total areas of each class type for the years 2000 and 2019 are provided in the far right column and bottom row respectively.

		2019			
		Forest	Agriculture	Water	Total (2000)
2000	Forest	2129.8	958.9	6.4	3095.2
	Agriculture	57.2	1810.3	0.9	1868.6
	Water	0.9	0.1	9.2	10.1
	Total (2019)	2188.0	2769.4	16.5	4973.9

Supplementary Information SI1

Landscape Models

There are currently two main models used by landscape ecologists to understand landscape patterns - the *'Patch-Matrix Model'* (PMM) and the *'Gradient Surface Model'* (GSM) (Figure S2). Other models are generally extensions of these [6]. Each model provides different landscape information as a basis from which to measure fragmentation.

The Patch-Matrix Model (PMM) (or 'patch-corridor-matrix' model) proposes that landscapes be classified as a mosaic of different *'patches'* with distinct boundaries between landscape types [7]. Patches form the simplest elements in a landscape such as areas of water, forest stands or any other relatively homogenous ecological feature. The PMM is often praised for its simplicity, as in this model any variation within a habitat patch is ignored to provide a landscape structure which is conceptually simple to understand [8}. However, there can be a drastic reduction in information that comes from ignoring heterogeneity within patches and the approach has the disadvantage that it can hide ecologically important findings [6]. However, PMM is by far the most common method, with a wide range of forest fragmentation studies performed using metrics derived from categorical patch-matrix landscape maps [9–13] (To overcome the issue of simplicity [14] have used graph theory analysis, to evaluate the ease of movement of particular species between habitat patches by representing paths between patches as weighted connectors, thus demonstrating the impact that fragmentation has on the potential for movement.

Unlike the patch-matrix model, the GSM does not assume homogeneity of ecological values within patches. It does not attempt to classify land-use into patches at all, but instead considers only continuous surface characteristics [6]. Practical examples of these could be the vegetation cover, canopy density or height at every point on a landscape surface. By not confining pixels in an image to a single land use category, but instead assigning ratio values to each pixel, the true heterogeneity of the landscape can be captured [6]. However, the difficulty associated with determining GSM values such as tree density from remote imaging is a limiting factor.

Supplementary Information SI2

Fragmentation Metrics

There are several levels at which metrics can be measured to investigate landscape fragmentation. These are grid cell, patch, class and landscape [15}. Grid cells refer to the smallest image unit that can be distinguished, which depends on image quality. A commonly used resolution value is $30m^2$, as in Landsat imagery [9] use grid cell- level fragmentation measures to produce a binary forest/non-forest map of an area through categorising each $30m^2$ grid cell and computing the number of adjacent pixel pairs which were both categorised as forest. Whilst this approach provides a holistic view of a landscape, there are relatively few metrics that can be computed from grid cells [15,16] . A class refers to all patches of a given type, such as all forest patches. Class-level metrics aggregate information over all patches of the given class, such as 'total forest area' and 'mean patch size' [10}. (PMM studies tend to use a combination of both patch- and class-level metrics but an issue is the strong interdependency between many of these measures.

Landscape metrics refer to the collection of metrics of all class types, such as all forest, grassland, water and urban classes [15]. *Landscape-level metrics* therefore aggregate information over all classes, such as average patch area of all classes, so are less useful if attempting to quantify fragmentation of a particular land use type or for a species which is suited to specific habitat types.

Supplementary Information SI3

Structure versus Function

Structural fragmentation metrics are those that do not explicitly relate to an ecological process, but instead describe the physical configuration of a landscape. Fragmentation studies using structural metrics are by far the most numerous with many examples in relevant literature [17–21]. Structural measurements often relate to area, distance between neighbouring patches, edge density, patch shape, core area, and aggregation, among others. Such measurements can use increasingly more abstract and complex mathematical principles such as morphological spatial pattern analysis and fractal geometry, but these are all still computed from the same base categorical landscape maps. All structural connectivity measurements suffer from the same drawback in that they are difficult to relate to real-life ecological processes [15]

In contrast, *functional fragmentation metrics* relate the landscape pattern explicitly to ecological processes such as its ability to support species' populations [15]. Measurement of functional connectivity is a less popular method because it is far more difficult to quantify from spatial configuration alone [22]. Studies which use functional metrics consider how landscape fragmentation affects aspects such as metapopulation capacity, meaning the ability of a landscape to support species metapopulations, time spent searching for a new habitat patch, or ease of movement of indicator species [23,24]. It is difficult to determine to what extent models of species' behaviour in fragmented landscapes reflects genuine behaviour, meaning studies involving functional metrics are rare [24]. It is therefore far more common for studies to first define structural composition of a landscape using structural fragmentation metrics, and then attempt to compute their functional relevance from ground studies or species' behaviour models at a later date.

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