Chapter 14
The Socio-Ecology of the Caatinga: Understanding How Natural Resource Use Shapes an Ecosystem

Felipe P.L. Melo

Abstract The use of natural resources can be a main source of disturbance to natural ecosystems if human populations depend heavily on biomass to attend to their basic needs. However, our understanding of how natural resource use affects natural ecosystems is insufficient. The Caatinga is the most populated dry forest worldwide, and inhabitants depend largely on the exploitation of the natural ecosystem for several purposes such as fuelwood and raising livestock. These constitute 'chronic anthropogenic disturbances' (CAD), the impacts of which, in the long run, may compete with habitat loss and impacts on ecosystem health. In this chapter I present a theoretical framework for the assessment of the impacts of three main sources of CAD on the Caatinga. I discuss how (1) firewood harvesting, (2) raising of free ranging goats, and (3) biological invasion are all linked to changes observed in the Caatinga biota. These sources of CAD are all linked to the socio-economic condition of human populations inhabiting the Caatinga and can be understood and, to some extent, quantified through socio-economic assessments. Finally, I propose a theoretical framework on how the original features of the Caatinga ecosystem may change as a function of the intensity of CAD, leading to two alternative states of both conserved and altered similarity to the original ecosystem. Understanding natural resource use by human populations is crucial to being able to assess the threats to biodiversity and ecosystem functions properly as well as to design conservation strategies to avoid both ecosystem degradation and depletion of human livelihoods.

Keywords Chronic anthropogenic disturbance • Non-timber forest products • Goats • Fuelwood • Biological invasion • Ethnobiology • Biological invasion

F.P.L. Melo (✉)
Laboratório de Ecologia Aplicada, Departamento do Botânica, Centro de Biociências, Universidade Federal de Pernambuco, Recife, PE, Brazil
e-mail: felipe.plmelo@ufpe.br

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14.1 Introduction

Understanding human-caused disturbance in tropical ecosystems has been a 'race against the clock' for ecologists and conservationists. Some research fields such as landscape ecology and restoration ecology have achieved milestones in understanding how habitat structure affects native biotas in human-dominated ecosystems. We can design conservation strategies aiming to protect biodiversity considering landscape features such as amount of habitat, the size of habitat patches, and connectivity among them. However, these approaches usually neglect human presence in the landscapes and how human populations explore natural resources (Torres et al. 2016). Therefore, significant knowledge gaps remain regarding how the human component may shape the future of these landscapes in a world where increasingly more tropical forests are embedded into human-dominated landscapes (Melo et al. 2013). These are the landscapes we will have to manage when aiming to increase both human livelihoods and the likelihood of persistent biodiversity, as very few large areas remain relatively free from human-caused disturbance and hence can be conserved as protected areas with restriction to direct use and exploitation (Ibisch et al. 2016).

The Caatinga in northeastern Brazil is the most populated dry forest of the world, with 28.6 million people living within its limits (Gariglio et al. 2010). These are amongst the poorest people in Brazil and the average Human Development Index is barely above that considered to be medium development (>0.5). Additionally, the Caatinga inhabitants strongly rely on natural resources for subsistence (Cavalcanti et al. 2015). Small-scale slash-and-burn agriculture, as well as free grazing by goats, can be considered the main land use type in the Caatinga, although some specific regions are subject to more intensive use such as irrigated agriculture, mining, and charcoal production (Schulz et al. 2017). This scenario generates a fuzzy mosaic of land uses across this ecosystem that is too complex to be assessed solely by traditional approaches derived from the landscape ecology.

Combining the best analytical tools from both natural and social sciences can be an alternative for evaluating the threats and trends in the Caatinga and other regions that are not suffering from the pressure of an expanding agricultural frontier. These ecosystems are not the main target for agricultural expansion like other more fertile and humid biomes such as tropical wet forests. Therefore, the main source of disturbance in these regions is the direct use of natural resources by inhabitants, which can vary a lot as a function of their socio-economic condition, access to industrialized goods, and market prices of both timber and non-timber forest products. These small-scale disturbances derived from the use of natural resources have been practiced for centuries in the Caatinga but have rarely been assessed properly as an important source of disturbance with the potential to reshape its biotic composition (but see Ribeiro et al. 2015, 2016). Only recently have studies explicitly detected how environmental features related to natural resource use affect plant and ant communities, leading to biological impoverishment regarding both taxonomic and phylogenetic diversity (Ribeiro-Neto et al. 2016; Ribeiro et al. 2015, 2016).

Socio-ecological studies of the impacts of the use of natural resources by smallholders on biodiversity are somewhat biased towards assessing game hunting (Torres et al. 2016), timber production (Shanley et al. 2002), and domestic use of fuelwood (Specht et al. 2015). Drawing a bigger picture of how these sources of disturbance can affect an ecosystem demands interdisciplinary approaches that are rarely found in the literature as they can easily lead to flawed data and weak conclusions.

In this chapter I present a theoretical framework on how to assess the role of human-caused disturbances in the Caatinga ecosystems which could eventually be generalizable to other ecosystems where both the landscape configuration and use of natural resources by human populations are likely to interplay as drivers of the response of the biota to disturbances. I use the results of a long-term ecological project taking place in the Catimbau National Park (https://www.peldcatimbau.org/), a typical sandy Caatinga with all kinds of disturbances from deforestation to overgrazing, including slash-and-burn agriculture and biological invasion. In this chapter, I try to put together pieces of evidence from several studies on the use of natural resources in the Caatinga and some theoretical approaches to better understand and predict the responses by this threatened ecosystem to the most common sources of disturbances taking place in this region.

14.2 The Role of Different Types of Disturbances in the Caatinga

14.2.1 Acute Disturbances

Habitat loss is the main cause of biodiversity loss and the greatest threat to ecosystem services worldwide (Thompson et al. 2017). This fact is not surprising as high deforestation rates are still a horrifying reality for many tropical regions, although reductions or even reversible trends (afforestation + regeneration) can be detected in some specific regions (e.g., China, Vietnam, Costa Rica) (Meyfroidt et al. 2010). Habitat loss is, therefore, an 'acute' disturbance as it usually happens very quickly and transforms the landscape in a manner such that one can easily distinguish the original habitat from the other land uses (Fahrig 2003). The scientific literature includes plenty of studies addressing both the effects of habitat loss and fragmentation on biodiversity as well as its socio-economic drivers. Because of this, conservationists have dedicated much of their research and political influence to creating protected areas with the aim of safeguarding as much as possible of the remaining natural habitats (Pimm et al. 2001).

According to non-official estimations, the Caatinga forest has lost up to 63% of its original area as a result of deforestation (Chap. 13). However, we do not know the pace of this habitat loss as this ecosystem is not continuously monitored like other ecosystems in Brazil such as the Amazon Forest and Atlantic Forest. The best official data available recorded deforestation over a period of 7 years (between 2002 and 2009) and registered average annual rates of around 0.2%, accumulating to approximately 2% deforestation during this period. The most recent study actually suggests a net gain in forest cover for the Caatinga in the last decade (Schulz et al. 2017). Probably because the soil in the Caatinga regions is not appropriate for agribusiness unless irrigated, the deforestation rate is below that across the humid tropics. The main cause of deforestation in the Caatinga is the use of tree biomass as firewood for the plaster and mining industries (MMA 2010).

14.2.2 Chronic Anthropogenic Disturbances

Chronic anthropogenic disturbances (CAD) can be defined as the "continuous harvesting of small portions of biomass" (Singh 1998) and the Caatinga forest has been chronically used for a long time and by many different cultures (MMA 2010). There is almost no single plant that is not used by local people for diverse purposes such as medicinal, fuelwood, fences, and housebuilding (Dos Santos et al. 2009). Also, small pockets of slash-and-burn agriculture and free-grazing goats are part of the Caatinga ecosystem as much as its remaining natural habitats, native fauna, and flora (MMA 2010). These scenarios constitute typical examples of how CAD has been affecting the Caatinga ecosystem for centuries. However, there is little to no scientific literature properly assessing the role of this source of disturbance as a driver of changes in biodiversity worldwide, and we are just beginning to understand its effect on the Caatinga biota, specifically plants and ants. For example, Ribeiro et al. (2015, 2016) found that the distance to the nearest city and number of livestock are inversely and directly related, respectively, to the taxonomic and phylogenetic diversity of woody plants. However, all of the available studies use proxies of CAD that are mostly related to accessibility to natural resources (e.g., distance to roads and cities), which may offer insightful clues on the shifts caused by natural resource use dynamics on this ecosystem. However, the drivers of natural resource use, as well as its intensity, need to be better and directly assessed if we are to understand the role of this source of disturbance on the Caatinga ecosystem. In Sect. 14.3, I present data on the potential impacts of three different types of CAD, directly measured in the Caatinga, namely fuelwood harvesting, free-ranging goats, and invasive species. The main goal is to understand the specific role of each of these types of disturbance in the reorganization of the native biota of the Caatinga and to try to draw a bigger picture of their impact on the Caatinga ecosystem.

14.3 Main Sources of Chronic Anthropogenic Disturbances

14.3.1 Fuelwood Harvesting

In the Caatinga ecosystem, fuelwood is the largest source of energy for both the industrial and domestic sectors (Ramos et al. 2008). The gypsum mining industries located in the Caatinga consume 1.5 million m^3/year of tree biomass and other small industries such as brickworks scattered throughout the region must have an important impact, but this is officially unknown along with its methods of harvesting native vegetation (Sá et al. 2009). In total, the domestic consumption of fuelwood by rural population in Caatinga is estimated to be the highest in Brazil (Sá et al. 2009). Therefore, the vegetation in this region is primarily degraded by unsustainable harvesting of tree biomass for both industrial and domestic purposes.

A case study in Catimbau National Park, in Pernambuco state, Brazil, confirmed this trend by assessing the relationship between socio-economic variables and use of fuelwood for 89 households located within this protected area. Briefly, up to 85% ($N = 80$) of the households interviewed in the Catimbau National Park depend on fuelwood for daily cooking, and 99% of this fuelwood is harvested from surrounding vegetation (Cavalcante 2015). The per capita consumption of fuelwood registered in this area reaches 606 ± 457 kg/year of woody biomass (Cavalcante 2015). If we extrapolate the per capita consumption to the entire population of the national park, estimated to be around 1200 people, we came to the astonishing number of 720 tons/year that is harvested only for fuelwood purposes. This is equivalent to the deforestation of up to 10 ha of the Caatinga every year (Cavalcante 2015). This pressure is not randomly distributed across species but focused on those useful as fuelwood, and therefore it is expected to cause severe impacts on specific populations of these species on a regional scale. The outcomes of this pressure are changes in the abundance and taxonomic composition of the remaining caatinga vegetation, as already observed in areas under high chronic disturbance pressure (Ribeiro et al. 2015, 2016).

The issue of fuelwood harvesting is more complex than it appears and has synergisms with both environmental and socio-economic changes experienced by human populations living within the Caatinga. First, some of this fuelwood demand is being met by an increasingly available resource, namely the invasive species *Prosopis juliflora*, which dominates abandoned agricultural areas along the riversides (Wakie et al. 2014). This species meets several demands and purposes beyond fuelwood for cooking, including feeding goats and cattle and fence building. Our data suggest that 20% of the households in the Catimbau use *P. juliflora* as an alternative to native tree species for those purposes, thus reducing pressure on native vegetation (Fig. 14.1).

Socio-economic drivers are also a determinant of whether a household tends to consume fuelwood as well as the amount of biomass harvested. Poorer people are more prone to relying on fuelwood to meet their daily needs for cooking; however, per capita income has been shown not to be a good predictor of biomass consumption

Fig. 14.1 Common scene of women head-carrying loads of fuelwood for cooking. Note the fences built with both native and exotic woody species in the Catimbau National Park, Brazil

(Specht et al. 2015). Many other factors may affect the amount of biomass consumed by rural people, some linked to economic issues (how much income is spent on butane gas) and the availability of human power to harvest fuelwood (Specht et al. 2015). Preferences for certain wood species with high calorific value must represent a greater pressure over high-valued species (Ramos et al. 2008) and these preferences have possibly changed the tree species composition of the Caatinga over the last three centuries to the point that what we see today should be the result of centuries of harvesting of tree species to meet the variable demands of the rural population.

14.3.2 Free-Ranging Domestic Goats

Official data from the Brazilian Government estimated a population of 7.6 million goats in the Caatinga in 2006 (IBGE 2006). However, this estimate is based on registered farms and therefore significantly underestimates the total number of goats being raised in the region. As a comparison, our data estimates 4–6 goats/km^2 for the study area as a whole and 11 goats/km^2 for those habitats preferentially selected by goats (Jameli 2015). This may represent 3–9 million unregistered animals for the region as a whole. Goats and sheep have been reported to cause important impacts on native vegetation elsewhere in the world, mainly on islands (Johnson et al. 1986). Overgrazing by these animals can change the vegetation structure and cause local species extinction (Johnson et al. 1986). Their effect on the Caatinga vegetation has been neglected by both Brazilian authorities and academia to date, despite the fact that government rural development programs have been promoting goat raising for decades.

Considering the Caatinga context, free-ranging goats must be one of the most important disturbance sources for natural vegetation as family-based, small-scale agriculture has been declining in the last decade (Schulz et al. 2017). Minimum-income programs (e.g., 'Bolsa Familia' and rural retirement) implemented by the Brazilian Government have probably pushed subsistence agriculture down as the workforce, once provided by family members including children, is now engaged in formal education as a requirement for assessing these programs. To date, the most cost-effective rural activity for poor households is raising free-ranging domestic goats. Our data for Catimbau National Park show that 80% of the approximately 200 families inhabiting this protected area raise goats as a source of income and protein. None of them employ any costly techniques other than providing a supplementary diet during dry seasons. There is a popular expression used by ranchers that 'goats are raised by nature (or God), not by people.' This summarizes very clearly how they recognize that these goats grow to feed on the natural vegetation with little to no human investment other than watching them to avoid losses.

One common assumption is that free-ranging domestic animals may represent a serious risk to natural environments (Carmel and Kadmon 1999; Schulz et al. 2016). This is supported by a vast set of evidence published elsewhere in the scientific literature. However, virtually no direct evidence exists on the impacts of goats in the Caatinga vegetation. An exception is that Schultz et al. (2016) demonstrated a reduction of soil carbon at shallow depths in the presence of goats. Ribeiro et al. (2016) also suggest that the total number of livestock (number of goats and cattle summed up) has a proportional negative effect on plant communities and affects their taxonomic composition in the Caatinga. Although insightful, these studies measured the effect of goats indirectly and combined with cattle, and conclusions are very limited on the real role of these animals in changes in vegetation. In this section I provide some evidence suggesting that we must be cautious before considering goats to be an important source of disturbance to Caatinga vegetation that is likely to have evolved in coexistence with large herbivores since ancient times (Pennington et al. 2000; França et al. 2015). The thorny caatinga vegetation presents several types of chemical and physical defenses against large herbivores such as spines, sclerophylly, and tannin. Therefore, the Caatinga ecosystem is likely to deal with herbivores in a better way than other seasonally dry tropical forests (SDTFs) where such functional attributes of plants are present but probably not as dominant as in the Caatinga. A first step to better understanding the role of grazing by free-ranging goats is to assess how goats move through caatingas and their range when using native vegetation for feeding.

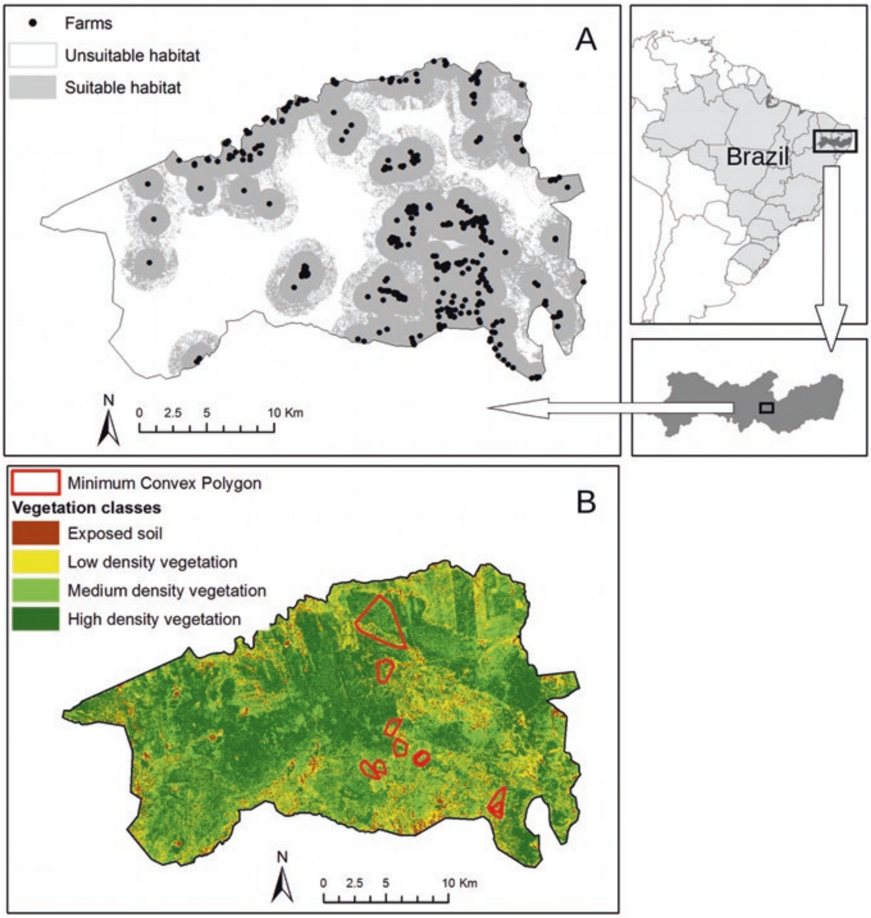

Fig. 14.2 Spatially explicit model of habitat use by free-roaming goats at the Catimbau National Park, Brazil. Distance to human settlements (**a**) and type of vegetation (**b**) are the predictor variables and suggest goats usually forage close to humans in regenerating areas dominated by pioneer species (Adapted from Jameli 2015)

Using small global positioning systems (GPS), we tracked ten free-ranging domestic goats for up to 14 days with the aim of ascertaining their home range as well as the type of vegetation they use more during the daytime (5:00 am to 5:00 pm) when feeding. Our results suggest that goats have a range of about 100 ha on average (Fig. 14.2) and can roam as far as 2.6 km from their owner's house (Jamelli 2015). However, the more interesting finding was that these domestic goats prefer successional areas over natural vegetation. They use open areas and less dense vegetation in a proportion higher than available in the landscape. The opposite is true for areas with denser vegetation (more mature forest), which goats tend to avoid and use in a proportion smaller than is available in the landscape (Jamelli 2015).

Therefore, the results available to date do not support the idea that goats are a significant degrading force of the Caatinga as has been suggested for islands or other regions. In the Caatinga, it is likely that they mostly act as a barrier to forest regeneration as they have been shown to be closely associated with human settlements. Our models demonstrate that the two most important variables predicting goat presence/absence in Catimbau National Park are (1) distance to the owner house; and (2) the successional state of the vegetation. In brief, goats tend to be found in open, successional areas close to their owner's houses, mostly feeding on abandoned agricultural fields where pioneer species proliferate. Goats in the Caatinga do not go feral as in other regions around the world but are extensively managed and avoid areas of denser vegetation.

14.3.3 Invasive Species

Biological invasion is amongst the most important cause of species extinction around the world (Malhi et al. 2014). However, recent literature has shown that such a phenomenon is more severe on islands and lakes than in continental biotas (Head et al. 2015). The 'few winners versus many losers' paradigm has been updated to include the role of native winners among those proliferating species that may cause biotic homogenization (Tabarelli et al. 2012). In continental biotas, exotic species, although potentially playing an important role, do not seem to be as important as the proliferation of natural disturbance-adapted species (Lobo et al. 2011). The Caatinga vegetation must respond in the same way, and disturbance-adapted native species must therefore be proliferating in human-altered ecosystems (e.g., Euphorbiaceae species; Rito et al. 2017).

The emerging concept of 'novel ecosystems' (sensu Hobbs et al. 2013) has shed light on the potential role of exotic species on the functionality of human-dominated ecosystems (Hobbs et al. 2014). Therefore, exotic invasive species, if managed, can be as useful as their native counterparts and contribute significantly to the functioning of emerging novel/hybrid ecosystems (Head et al. 2015). The Caatinga has been used and inhabited for millenniums, more intensively during the last three centuries when several exotic tree species have been introduced (Almeida et al. 2015).

One of the most important tree species with huge invasive potential is the 'mesquite' (as it is known in Mexico) or 'algaroba' (the common name used in the Brazilian Caatinga), the *Prosopis juliflora* (Fabaceae). This species is estimated to now occupy 1,000,000 ha of the Caatinga, with reports of negative effects on native tree and shrub species (Andrade 2015). The available models for *P. juliflora* show, for example, that they are closely linked to human settlements and riversides in Ethiopia (Wakie et al. 2014). In the Caatinga, we have found that former agricultural lands very close to riversides that are now abandoned are prone to invasion by *P. juliflora* (Fig. 14.3). Therefore, it is reasonable to link the abandonment of agricultural lands to the invasion of *P. juliflora* and, thus, land use changes (this time freeing land for forest recovery) led to a novel ecosystem.

Fig. 14.3 Border of a natural lake in the Catimbau National Park in Caatinga, heavily invaded by *Prosopis juliflora* (green belt) after abandonment of an area once used as agricultural field. Note in the picture that this invasive species is close to the water and is not found on drier soils

The interesting thing about the *P. juliflora* invasion is that it can be good for the Caatinga's socio-ecosystem as a whole because the benefits of this invasive species can be much greater than the damage it may cause, or at least this is a reasonable hypothesis. First, *P. juliflora* seems to be a poor competitor in less disturbed areas of the Caatinga as it appears to occur mostly in currently abandoned areas previously used for agriculture. This species is often found in mono-dominant stands mainly along riversides and dry river beds heavily degraded by former agriculture. The competitive ability of *P. juliflora* can be more easily demonstrated when it suppresses the growth of some native Caatinga species (Nascimento et al. 2014). In Catimbau National Park, the populations of *P. juliflora* are almost exclusively found along drainage networks and very close to human settlements (Freitas 2015; Fig. 14.3). Distance to rivers and to human settlements accounted for 46% of the likelihood of presence/absence of *P. juliflora* in this protected area (Freitas 2015). We can, therefore, consider that this species has been used and managed by humans for decades and therefore serves many purposes that would otherwise be met by exploring native vegetation.

14.4 How Is the Caatinga Managed by Humans?

Given the scenario presented here, we can draw a picture to understand how human presence in the Caatinga ecosystem has led to a set of modifications to its original characteristics, not necessarily with massive deforestation, but driven by what we have defined earlier as 'chronic anthropogenic disturbance' (CAD). One main lesson is that one must consider that at least three primary sources of changes that are acting in synergism lead to such transformations: (1) use of timber and wood for several purposes, mainly firewood; (2) millions of free-ranging domestic goats; and (3) invasive species colonizing abandoned agricultural lands. With these three sources of CAD in mind, we can propose a model to understand what we find in the Caatinga ecosystem today (Fig. 14.4).

First, it is useful to answer the following question: are the human-modified caatingas becoming a novel or hybrid ecosystem? Depending on the scale analyzed, we

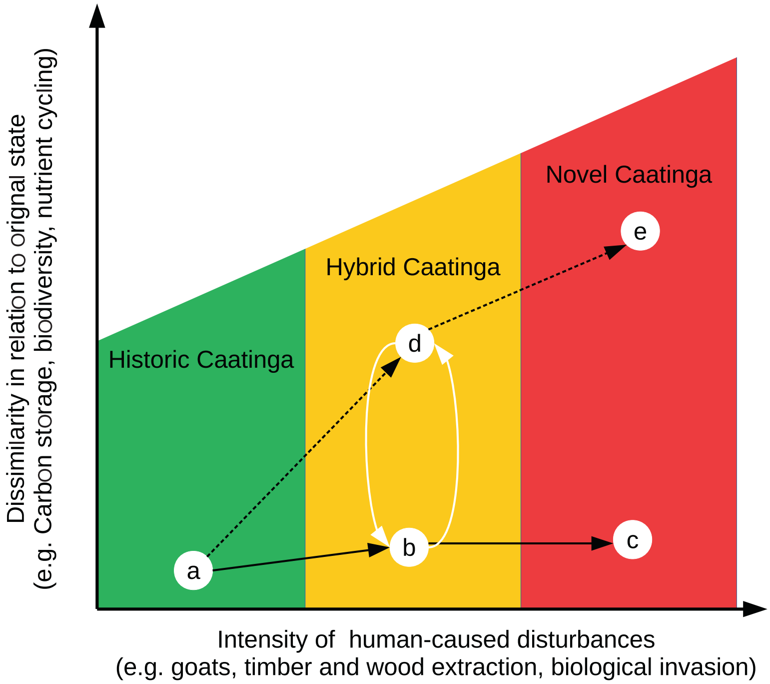

Fig. 14.4 Conceptual model of how chronic anthropogenic disturbance (x-axis) can be related to changes in both biotic and abiotic conditions (y-axis) of the Caatinga. Original ecosystem (green zone and circle '*a*') can be modified following two paths depending on how local biota and abiotic conditions respond to disturbance. Well-managed Caatinga might follow the continuous arrows (states '*b*' and '*c*') preserving most of its original function and biotic/abiotic conditions. Shifts between states '*b*' and '*d*' probably take place when land rotation and restoration occurs. Otherwise, a degradation path can be followed if responses of the ecosystem lead to increasing dissimilarity due to overexploitation of the natural resources (Figure modified after Hallett et al. 2013)

may find both novel and hybrid scenarios. If we look at the millions of hectares of river banks once converted into agricultural fields and now abandoned and heavily invaded by *P. juliflora*, they can be considered to be a novel ecosystem (Hobbs et al. 2013). These areas have changed with regards to their biotic association (species assemblages) and diverge in function from that of pristine areas of caatingas (Hallett et al. 2013); they can, therefore, be considered as novel ecosystems. However, most of the region—which is not suitable for agricultural purposes—is somewhat conserved and resembles what was once (and still is) the most species-rich dry forest in the world, even with cumbersome and ancient timber extraction and grazing by millions of free-ranging goats, sheep, and cattle. These are the areas where CAD have been in action for centuries, probably changing the relative abundances of both plant and animal species and disrupting some ecological interactions but keeping the original physiognomy and largely its ecological function. These can be considered the hybrid ecosystems of the Caatinga region, conserving both biotic and functional resemblance in the original ecosystem.

Therefore, a more realistic picture can now be drawn of what the Caatinga we are talking about is. This SDTF is a very resilient ecosystem that has been able to deal with centuries of CAD but is currently threatened by large-scale deforestation and expansion of irrigated agriculture. Although acute disturbances are important in understanding the fate of an ecosystem, assessing the role of chronic disturbances is crucial for those biomes traditionally managed by humans long before the arrival of any agricultural frontiers. We cannot understand the biological organization of the Caatinga by searching only for landscape metrics measured by satellite images but must also look at the main socio-economic drivers of land-use change. These drivers will shape how people use natural resources and therefore the fate of the Caatinga.

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