In: ***Encyclopedia of Life Support Systems(EOLSS)***, Developed under the Auspices of the UNESCO, EOLSS Publishers, Oxford ,UK, **[http://www.eolss.net]**

FIRE IN NEOTROPICAL SAVANNAS

Mario R. Fariñas and **Juan F. Silva**
Instituto de Ciencias Ambientales y Ecológicas, ICAE. Universidad de Los Andes. Mérida. Venezuela.

Keywords: Tropical savanna, fire, grasses, physiognomy, management.

Contents

Summary

This chapter reviews the main characteristics of tropical savannas and their interactions with fire, a main factor involved in the dynamics of these ecosystems. Burning in savannas generally takes place by the end of the dry season, favored by the accumulation of dry biomass in the herbaceous layer. Several factors affect fire characteristics and behavior, such as quantity, quality and composition of the combustive matter, wind direction and velocity, relative humidity of air, and season of burning. Although fire is a mortality factor, common savanna plant species seem to be adapted to burning. Adaptations include underground reserves, protected meristems, re-sprout capacity, clonal multiplication, growth seasonality, thick cork layer, and sclerophyllous leaves. Deleterious effects of fire are greater in the younger or smaller size classes in the population. On the other hand, the passage of fire restores light and nutrients on the topsoil, that together with the return of rains create better conditions for seasonal growth. Under fire exclusion herbs escape from the direct mortality effects of burning but exclusion promotes shading and nutrient depletion which are harmful for the renewal of herbaceous growth. Species differ in their responses to fire regime, therefore the fire regime affects species composition. The fire regime is also important in terms of the physiognomy of the savanna. Frequent burning causes qualitative and quantitative changes in plant community structure and composition promoting open physiognomies with fewer woody elements. Conversely, fire exclusion has been shown to increase tree density in tropical savannas transforming open savannas in woodlands. In modern times, most fires are set by humans. However, natural fires by electric discharges during storms do occur although less frequently than human induced fires. Although fire has been used in savanna management since pre-Columbian times, it remains a complex issue that needs further research.

1. Introduction

The tropical savanna is one of the most extended terrestrial ecosystems, present in old and new tropical regions, and covering about 23 million km^2. In broad terms it refers to vegetation with a continuous herbaceous layer and a discontinuous layer of shrubs and/or trees. Most savanna plant species are perennial.

The woody layer varies widely in relative importance of shrubs vs. trees; it also varies in density of woody elements. Trees are usually low in height and gnarled in shape. The herbaceous layer of Neotropical savannas is mostly made up by grasses and sedges usually referred to as “graminoids” that represent more than 90% of the total biomass. Other less important components are sub-shrubs, and large and small herbs (for details in the structure and function of Neotropical savannas see Sarmiento, 1983). Fire, whose frequency is variable, is considered an intrinsic factor in savanna ecology. Savanna fires, natural or induced, take place in the herbaceous layer. This is due to the accumulation of dry biomass in this layer, which takes place progressively throughout the growth season and increases rapidly as the dry season advances. This dry biomass becomes the fuel for fires that usually take place during the last part of the dry season. Most fires in modern times are of human origin, but some natural fires take place, although at much lower frequency.

2. Fire Behavior in Neotropical Savannas

Fire behavior depends on different factors such as quantity, quality and composition of the combustive matter, wind direction and velocity, relative humidity of air, and the season of burning. The amount of combustive matter available is determined by the rates of biomass production and biomass accumulation. The former depends on water availability during the growing season (and hence on rainfall), whereas the latter depends on grazing intensity and time after last burning. Quality of combustive matter determines the ignition temperature, and in turn depends on the biomass species composition, water contents and plant phenology.

Ignition temperature depends on species composition, wind speed and water content of the vegetation. In some Venezuelan savannas dominated by *Trachypogon spp.*, ignition temperature ranges from 129 ^oC with no wind to 135 ^oC with 3 ms^{-1} wind in the middle of dry season; when other grass species are dominant, ignition temperatures ranges between 130 ºC and 160 ºC without wind. In December, at the start of the dry season, ignition temperature reaches 205 ^{o} C without wind.

Based on its behavior, fires may be “head fires” or “back fires”. The former run fast aided by the wind, whereas the latter run against the wind, moving slowly and causing greater damage to the vegetation. Fire can also be classified as “ground fire”, “surface fire”, and “crown fire”. Ground fires move on the surface, beneath the litter layer; surface fires move within the herbaceous layer; and crown fires propagate through the tree canopy.

Savanna fires are commonly surface fires, with heights between one and five m measured in experimental head fires and between 0.5m and 1.5m measured in back fires. Since adult trees are above 2-4m, they are rarely ignited but could be badly charred. Furthermore, low tree density usually observed in tropical savannas does not favor crown fires, although occasionally the foliage of individual trees may get torched. This occurs more frequently in trees that keep dry leaves on the stem, such as palms (Bond & Keeley, 2005).

Savanna fires are patchy increasing environmental heterogeneity that favors biodiversity and allowing survival of fire-sensitive species.

It is not easy to measure the intensity of fire front, which has been reported in a range of 1200 to 8000 $kJm^{-1}s^{-1}$ (Miranda *et al.*, 1996). Some authors use proxies such as the height of leaf-scorch or char and the percentage area of grassland burnt. These variables are significantly correlated to fire intensity. The burning front moves briskly, and the rise in temperature lasts no longer than five minutes. Since factors affecting temperature during the passage of fire vary widely, reports on air temperature at soil surface show a wide range: from 32 to 600 ^{o}C in African savannas (Gillon, 1983) from 600 to 750 ^{o}C in Brazilian savannas (Miranda *et al*., 1996); in Venezuelan savannas temperatures range from 70 ^{o}C to 472 ^{o}C, depending on the grass layer composition, rate of fire spread and composition of the grass layer.

Top soil is not affected by fire due to the low thermal conductivity of soils and the generally low temperatures of the passage of fire. Temperatures at 2 cm below soil surface seldom exceed 35 ºC. At 5 cm there seems to be no change in temperature. Under high intensity fires heat may penetrate up to 3 cm deep in the soil.

Burning substantially decreases the albedo. In experimental fires in Brazil, albedo decreased from 0.11 to 0.03-0.05, which is lower than soil without vegetation. Decrease of albedo, although results in higher radiation absorption, does not imply higher temperatures but greater temperature oscillations. Normal daily oscillation measured in a Brazilian savanna was 10ºC before and 25-26ºC after burning.

Also important is the fire regime, especially if fire is used as a management tool. In this case, burning is usually programmed to take place annually, every two years, every four years or even more. Concerning season of burning, it could be early, middle or late dry season. For more details on these aspects, see the Section 6 on Fire as a Management Tool.

3. The Effects of Fire on the Herbaceous Layer

Since fire is a common event in the savanna ecosystem, it is convenient to address this issue having in mind that burning or its absence have both positive and negative effects on the herbaceous layer. Plant species in this layer have their buds under or at least at the ground level (geophytes, hemi cryptophytes) and are able to sprout after the passage of fire and the arrival of the first rains. As a consequence, mortality rates due to fire are generally low, especially among adults depending on the intensity of the fire. Also, since fires take place during the dry season when most plant cover is dry, loss of active photosynthetic tissue is nil.

After the passage of fire, most herbaceous biomass is burnt and reduced to ashes leaving large empty spaces between the basal areas of the perennial herbs. With the removal of the aerial biomass, photosynthetic active radiation increases dramatically at the ground level. Similarly, the accumulated ashes bring about an increase in the nutrient availability in the superficial soil. Thus, the herbaceous layer becomes ready for the start of the growth season triggered by the onset of rains with optimal light and improved nutrient status (Solbrig *et al*., 1996).

The growth season has two important components: the regrowth of aerial biomass from the protected buds of the perennial plants, and the growth of new individual plants. The latter can be accomplished by germinating seeds (seedlings) or by clonal multiplication (ramets). Seedlings are likely to be more vulnerable to fire than ramets and mortality depends on the size reached by the end of the first growth season of these individuals.

Knowledge on the different responses of herbaceous species to fire or to the exclusion of fire is scarce. We know that some grasses are relatively unaffected by the passage of fire but are very intolerant to shade. Thus, they exhibit high rates of mortality, especially among young plants, when fire is excluded. This is the case of *Andropogon semiberbis*, a tall, late flowering species from the Venezuelan savannas that exhibits low mortality rates due to fire passage during the dry season.

When fire is excluded, the shade from the aerial biomass of adult plants during the rainy season kills many young plants. Other dominant grasses, such as *Sporobolus cubensis*, are more affected by the passage of fire and seem to be more tolerant to shade.

Since many species in the herbaceous layer present clonal multiplication, some authors have suggested that this is an adaptive trait to recurring burning. Independently of this, ramets produced by vegetative or clonal multiplication seem to be less sensitive to fire. This may explain why the clonal grass *Trachypogon* is the most dominant in large extensions of Neotropical savannas frequently burnt. These savannas are commonly known as "*Trachypogon* savannas". On the other hand, seed-relying species from *Andropogon*, *Axonopus* and other grass genera, are very successful in many savanna areas. Since grass species differ in their reproductive mode, in their tolerance to the passage of fire and tolerance to shade, the fire regime is a main determinant (but not the only one) of the composition and structure of the herbaceous layer in savannas. The interactions between competitive abilities, fire regime, nutrients and water availability are likely to be responsible for the changes taking place in the herbaceous layer. In turn, composition and structure, that is biodiversity, are essential for the stability (resilience) of the savanna community (Silva, 1996).

The protected position of buds is fundamental in the ability to withstand the passage of fire. Such is the case of a number of suffrutescent or sub-shrub species that lose their aerial biomass to fire but that resprout as soon as the rainy season starts. These species have a woody underground stem called xylopodium, with the meristems and reserves that allow the plant to re-sprout. Differently from many savanna trees that also re-sprout after losing their aerial parts to the passage of fire, the sub-shrubs do not overgrow the herbaceous layer even in the absence of fire. Thus, they belong to the herbaceous layer [for instance, *Byrsonima verbascifolia* (Malpighiaceae), *Psidium guianensis* (Myrtaceae), *Clitoria guianensis* (Papilionaceae). As happens with the grasses, some sub-shrub species exhibit clonal multiplication and others do not, relying only in seeds for their persistence as populations.

Annual plants are not as important as the perennial ones in tropical savannas. Since their life cycle is annual, they persist as growing plants only during the favorable season at the end of which produce their seeds and die. Seeds are soon dispersed and when the fire takes place they are already stored in the superficial soil.

Many perennial species rely on seeds for reproduction. Seeds that are produced late in the rainy season wait until the next favorable season in order to germinate. This is accomplished by different dormancy mechanisms. The dormant seeds face several mortality risks during the four or five dry months. One is predation and the other is fire. As far as we know the first represents a major danger whereas fire does not seem as important as a mortality factor of seeds.

In conclusion, the burning of the herbaceous layer takes place during the dry season. It represents a cause of mortality of plants, especially of seedlings. It also restores light and nutrients that together with the return of rains create better conditions for seasonal growth. Under fire exclusion plants escape from the direct mortality effects of burning but on the other hand, this promotes shading and nutrient depletion which are harmful for the renewal of growth. Species differ in their responses to fire and to fire exclusion, therefore the fire regime is an important factor generating changes in the diversity of the herbaceous layer.

4. The Effects of Fire on the Woody Layer

Savanna fire has a deleterious effect on the tree layer, affecting phenology, recruiting and survivorship of trees. Fire and fire-regimes influence composition and structure of savannas because different species differ widely in their responses to fire.

Frequent burning kills younger individuals, reducing tree density, and consequently influencing savanna physiognomy. Savannas under annual burning seem to be more open, whereas under low fire frequency they tend to have a denser tree cover.

Fire effects on the tree layer depend on the factors involved in fire behavior (see above) and also in factors related to tree conditions such as, phenological stage, tree size, depth of cork, and others. Tree survival increases with height and basal area.

After burning kills the aerial biomass, several species re-sprout from the base. Eventually, individuals may escape the deleterious effects of fire when they grow above the grass layer. Frequent fires keep the tree layer homogeneously just above the grass layer forming a coppice.

Studies on the tree layer of Neotropical savannas have shown that tree species differ in their responses to fire depending on their leaf phenology. Evergreen species seem to be more resistant to fire than deciduous species but the extent of the damage depends on the season of burning. The higher resistance of evergreen trees is related to the presence of several traits like sclerophyllous leaves, thick cork layer, the ability to resprout, underground reserves in special organs (xylopodium), clonality, etc. Contrary to the deciduous species, the evergreen are commonly found growing isolated in the grassland. The former are usually found growing in clusters, forming small forest islands which exclude the grasses and consequently savanna fires. However, fire-sensitive species may also be found in regularly burnt savannas.

Although there is little information on savanna tree reproduction and the impact of frequent fires, reproductive mode is considered a functional trait related to fire resistance. Savanna trees reproduce by seeds, but many species also exhibit clonal multiplication, which seems to confer some advantage on the face of disturbances such as fire. Some studies showed that germination and establishment, which are synchronized with onset of rains, are important in the population dynamics of savanna trees. During a few weeks the seedling is characterized by a low photosynthetic rate and low efficiency in water use and has a low probability of survival. During this first growth, they allocate a larger proportion of biomass to underground organs such as a stem named xylopodium, and a deep root that allows access to more humid soil. After this first season of growth seedlings face the combined danger of drought and fire during the dry season. Their survival depends on the amount of underground biomass produced during the first growing season, which would allow them to sprout back after fire.

Results from experimental studies are varied, depending on the type of savanna and the experimental design. Some experiments conducted in Brazil showed that after 18 years of fire exclusion mortality was 7.2% after a first burn and 19.1% after a second year burn. Mortality affected most the smaller size classes and did not depend on season of burning. Other experiments showed no significant differences in mortality as a consequence of season of burning. In Australia, burning early in the dry season did not have any significant effect on tree survival whereas late burning reduced 20 to 40% of basal tree area. These experiments rendered a markedly humped survival curve with small and large trees having a similar low survival.

Fire exclusion has been shown to increase tree density in tropical savannas. In a first stage the increase is due to fire-resistant species, but later fire-sensitive species also invade the grassland. Thus, higher tree survival results in increased density and number of species (Coutinho, 1982; San José & Fariñas, 1983, 1991). In Calabozo, Venezuela, after 25 years of protection from fire and grazing, tree density increased in two orders of magnitude and number of tree species jumped from three to 22. Similar results were reported in Ivory Coast. However, these observations did not exclude other intervening factors such as climate and land use. Other observations showed that during the same time lapse, tree cover increased in non-excluded areas both in Calabozo and Ivory Coast (Silva *et al*. 2001). These findings suggest that fire and savanna vegetation interactions are more complex than expected.

5. Fire and Savanna Physiognomy

Increase in tree cover results in changes in savanna physiognomy from very open savanna-grassland to a close savanna-woodland. Besides fire, other intervening factors have been considered. Some authors consider water and nutrients as the main drivers and fire and grazing as complementary (Frost et al., 1986; Sarmiento, 1984). Since variability in nutrient availability is very low across a given savanna landscape, variations in physiognomy may be due to water availability and changes in the regimes of fire and grazing (Medina & Silva, 1990).

Burning causes qualitative and quantitative changes in plant community structure and composition promoting open physiognomies with fewer woody elements. Fire exclusion in these areas allow the vegetation to return to a estate equal or similar to pre-fire physiognomy or to move to more dense savannas (San José & Fariñas, 1983, 1991). Exclusion effects seem to be more drastic in the extremes of the physiognomic gradient. In São Paulo, Brazil, post fire succession of closed woodland (Cerradão) took 20 years to recover its original physiognomy.

6. Fire and the Management of Neotropical Savannas

It is likely that fire was used as a management tool before the arrival of Europeans. Evidences from Brazil indicate that fire was already used in the Cerrado region at least 12 centuries before the arrival of Europeans (Coutinho, 1982) and perhaps as early as 32000 years BP (Guidon and Delibrias, 1986). New World natives used fire as a tool to decrease woody cover changing woodland savanna to a more open savanna. The frequent burning decreased standing biomass and thus the likelihood of very intense wildfires. Pre-settlement fires varied in frequency, *i.e.*, in intervals from 1 to 10 years or even more (McPherson, 1997).

Savanna burning improved vision near homes facilitating the prompt detection of predators and enemies. The clearing also created better conditions to grow crops such as manihot, corn, etc. Savanna burning has also been used as a tool for hunting since animals could be cornered easing the hunt, especially in savanna areas lacking large herbivores.

In modern times, most fires are set by humans intentionally or unintentionally. However, natural fires do occur although less frequently than human induced fires. The main causes of natural fires in South American savannas are electrical discharges during storms, common at the onset of the rainy season.

After the introduction of cattle by the Europeans, savannas have been mostly used to raise cattle in an extensive way (low animal load). Rainfall seasonality represents an obstacle to raise cattle because the long dry season decreases water and food availability. Fire has been used to remove the dry matter accumulated and promote the early growth of new foliage. This provides food during the harsh late dry season. Additionally, it is claimed that the ascent of ashes toward the atmosphere promotes condensation and early rains.

Management of savannas using fire requires control of frequency, intensity and timing. These three variables are not independent and also interact with other factors such as rainfall, grazing, site characteristics, etc. Despite the fact that the use of fire is such a widespread practice, the scientific knowledge of how fire interacts with other ecological factors and the processes involved in its effects upon vegetation is far from complete.

In the wet savannas of South America, fire frequency is kept near annual and burning takes place toward the end of the dry season. Increasing frequency reduces fuel availability thus decreasing fire intensity. As a consequence, frequent fires are low in intensity and in mortality effects.

When fire is absent for several years, dry biomass accumulates increasing the probability of intense wild fires. Not only they bring about lasting changes in vegetation, but represent a direct threat to human lives and properties as well as to cattle. In recent times, the frequency of fire has decreased in many savanna areas as a consequence of natural changes such as decreasing rainfall and anthropogenic changes such as intensive agriculture, introduced pastures, urbanization, roads, and policy (McPherson, 1997). As a consequence, these savannas are changing to closed-canopy woodlands, and these changes may be permanent.

Managing savannas for cattle ranching seeks a balanced proportion between woody and herbaceous layers that keep savanna production high enough to raise cattle. This goal is achieved combining animal load with fire regime and it has to be site specific since soil, topography and rainfall are factors that intervene in the results. Since fire prescription is not an easy task, it is common that fire gets out of control and spread to other areas. This may turn out to be very harmful to dry forests and also to rain forests where fire spreads through the litter layer. Parallel to this, the widespread use of fire becomes a cultural issue promoting fire as a tool for all sorts of troubles and a source of amusement.

Managed savannas become prone to weed invasion, especially bushes and exotic trees.

Exotic species are commonly free from natural enemies and exhibit high growth rates. The invasion is facilitated by the multiple negative effects of cattle upon the herbaceous plant populations, increasing recruitment of woody plants. These effects are intensified when savannas are overgrazed. Fire is prescribed to exclude weeds, increasing the grass cover and hence food for cattle. Overgrazing may bring the community to a threshold where fire is unlikely to occur and the grass layer cannot recover to its previous condition. When this happens, fire is no longer a useful tool to manage the savanna and restoration becomes a very difficult issue.

As mentioned above, fire is a destructive force that may have negative and positive effects depending on the way it is used. As long as it is under control, its negative effects on plants, animals, atmosphere, and human affairs can be diminished. Although more research is badly needed in order to develop fire managing strategies in savannas, there are already several attempts to generate proper tools to be applied. These efforts have been particularly successful in Australia through the development of ‘expert systems’ that assist managers in the decision-making process. In Brazil, Pivello and Norton (1996) published a prototype of expert system named “FIRETOOL” for savanna management using fire, which unfortunately has remained unverified.

Related Chapters

Glossary

Albedo: Fraction of incident shortwave radiation reflected by Earth.

Biodiversity: The variability found in living organisms at various scales from genes to ecosystems.

Cerradão: A type of savanna found in Brazil characterized by low species richness, a canopy higher and closer than the other savanna types. It also comprises deciduous and semi-deciduous tree species.

Cerrado: the common word used in Brazil to designate savanna vegetation.

Clonality, clonal multiplication: To produce descent asexually

Competitive abilities: The relative capacity of different species to compete for resources.

Cork: A protective layer of nonliving tissue on the surface of stems and roots of many tree species.

Dormant: Organism seasonally inactive with little or no growth.

Expert systems: Computer programs designed for management purposes.

Geophytes: Perennial plants with underground buds.

Hemi cryptophytes: Perennial plants with buds at the ground level or slightly below.

Life cycle: The course through which every living organism passes from fertilized egg to maturity and further death.

Meristem: Undifferentiated plant tissue from which new cells are formed.

Neotropics: The biogeographic region comprising the tropics of the Americas.

Open savanna: Type of savanna with very sparse trees in a dense cover of herbaceous plants.

Phenological stage: The periodical condition of an organism throughout the seasons, such as flowering, fruiting, etc.

Physiognomy: Visible aspect of the vegetation that depends on species composition and structure (types of savanna physiognomies are: open savanna, park savanna, dense savanna and savanna woodland).

Ramet: individual produced by asexual means, member of a clone.

Resilience: Capacity to go back to an equilibrium point after a disturbance (flexibility).

Sclerophyllous: Having leaves that are hard and thick and have a thick layer of cutin (cuticle).

Seedlings: Young individual plant formed by a germinating seed.

Stability: Resistance to change; capacity to remain in an equilibrium condition despite acting disturbances.

Succession: Gradual changes in community structure and species composition.

Suffrutescent: Small plant looking like a shrub, with a woody base and herbaceous above ground biomass.

Woodland savanna: Savanna with a dense tree layer and a scarce herbaceous layer.

Xylopodium: underground organ with growth reserves and meristems found in some plants.

Bibliography

Bond, W. J. & J. E. Keeley (2005) Fire as a global "herbivore": the ecology and evolution of flammable ecosystems. *Trends in Ecology and Evolution*, 20(7):387-394. [This article proposes that fire acts as global herbivore destroying all the aerial biomass].

Coutinho, L.M. (1982) Ecological Effects of Fire in Brazilian Cerrado. In: Huntley, B.J. and Walker, B.H. (eds), *Ecology of Tropical Savannas*, pp. 273-291. Springer-Verlag, Berlin. [This is a very important article reviewing the consequences of fire and fire suppression in Brazilian savannas].

Frost, P., Medina, E., Menaut, J.C., Solbrig, O., Swift., M. & Walker, B.H. (1986) *Responses of savannas to stress and disturbance*. International Union of Biological Sciences. Special Issue. Nº 10. Paris. [This is a classical publication that has oriented ecological research on tropical savannas since the 1980s. It is the result of international cooperation under the program "Decade of the Tropics" of the International Union of Biological Sciences (IUBS)].

Guidon, N. & Delibrias, G. (1986) Carbon-14 dates point to man in the Americas 32,000 years ago. *Nature*, 321: 769-771. [This article presents evidences that suggest American natives already managed savannas using fire 32,000 years ago].

McPherson, G.R. (1997) *Ecology and Management of North American Savannas*. The University of Arizona Press, Tucson. [This essential book gathers most of the previous knowledge on North American savannas].

Medina, E. & Silva, J.F. (1990) Savannas of northern South America: a steady state regulated by water-fire interactions on a background of low nutrient availability. *Journal of Biogeography*, 17:403-413. [Analyzes the relationships between water and nutrient availability with fire effects on savanna vegetation].

Miranda, H. S., Rocha e Silva, E. P. & A. C. Miranda (1996) Comportamento do fogo em queimadas de campo sujo. In In Miranda, H. S., Saito, C. H. y B. F. de Souza D. (editors) *Impacto de Queimadas em Areas de Cerrado e Restinga*. Pp. 1-10. [Compares the temperature and fire effects on several experimental conditions in Brazilian open savanna ("campo sujo")].

Pivello, V.R. & Norton, G.A. (1996) FIRETOOL: an expert system for the use of prescribed fires in Brazilian savannas. *Journal of Applied Ecology*, 33:348-356. [This article represents the first attempt to produce an expert system for the management of South American savannas].

San José, J.J. & Fariñas, M.R. (1983) Changes in tree density and species composition in a protected *Trachypogon* savanna, Venezuela. Ecology, 64:447-453. [This article analyzes the changes on a 3ha plot in a savanna excluded from fire and grazing in the Venezuelan Llanos].

San José, J.J. & Fariñas, M.R (1991) Temporal changes in the structure of *Trachypogon* savanna protected for 25 years. *Acta Œcologica*, 12:237-247. [This article presents additional results in the analysis of the changes in the arboreal and herbaceous layers of a 3ha protected savanna in Venezuelan llanos].

Sarmiento, G. (1983) The savannas of Tropical America. In: Bourliere, F. (ed), *Tropical Savannas*, pp. 245-288. Elsevier, Amsterdam. [This is a classical article reviewing the knowledge on Neotropical Savannas].

Sarmiento, G. (1984) *The ecology of Neotropical savannas*. Harvard University Press, Cambridge, Mass. [In this important book, an authority in tropical savannas reviews the structure and functioning of the savanna ecosystem in the early stage of savanna ecological research].

Silva, J.F. (1996) Biodiversity and stability in tropical savannas. In: Solbrig, O.T., Medina, E. & Silva, J.F. (editors), *Biodiversity and savanna ecosystem processes: a global perspective*. pp. 161-174. Springer-Verlag, Berlin. [Proposes the study of life story traits of savanna plants in order to understand and predict the stability of tropical savanna].

Silva, J. F., A. Zambrano & Fariñas, M. R. (2001) Increase of the woody component of seasonal savanna under different fire regimes in Calabozo, Venezuela. *Journal of Biogeography*, 28:977-983. [Presents results showing how the arboreal cover increased in both a protected savanna plot and in burnt plots under different management regimes].

Solbrig, O.T., Medina, E. & Silva, J.F. (1996) Biodiversity and tropical savanna properties: a global view. In: Mooney H.A., J.H. Cushman, E. Medina, O.E. Sala and E.D. Schulze (editors*), Biodiversity and global change*. pp. 185-205. SCOPE 55, J.Wiley. [This chapter presents a general view of the functioning on the savanna ecosystem, based on the published research done since the 1980s].

Biographical Sketches

Mario R. Fariñas was born in Venezuela. Trained in France, he received his “Troisieme Cycle” Doctorate degree in 1982 and the “Docteur d’Etat en Science” in 1987, both from the Université de Sciences et Techniques du Languedoc. Since 1972 is a faculty member at the Universidad de Los Andes (ULA) in Merida, Venezuela. Since the 1970s he has been doing research on several aspects of the ecology of tropical vegetation. In recent years he participated in an international cooperative effort sponsored by the Inter American Institute for Global Change Research (IAI) with scientists from Argentina, Brazil, Colombia, Cuba and Venezuela. He has been the Venezuelan National Coordinator of the Program on Global Change and Terrestrial Ecosystems (GCTE). He has directed the Tropical Ecology Research Group and the Graduate Program in Tropical Ecology at ULA in several occasions. His current interests include biodiversity and global change, structure and functioning of tropical ecosystems, biometry, multivariate analysis and vegetation complexity
.

Juan F. Silva is a Venezuelan ecologist with more than 30 years doing research on tropical savannas. He received his PhD from Harvard University in 1978 and since then is a faculty member at the Universidad de Los Andes (ULA) in Merida, Venezuela. In recent years he directed an international project sponsored by the Inter American Institute for Global Change Research (IAI) with scientists from Argentina, Brazil, Colombia, Cuba and Venezuela. He has been a member of the Executive Committee of the International Union of Biological Sciences (IUBS) and Vice-president of the Latin American Botanical Network. He was Research Fellow at the Center for International Development at the Kennedy School of Government and Associated Scientist of the Gray Herbarium both at Harvard University. He has been Director of the Graduate Program in Tropical Ecology at ULA and the Tropical Ecology Research Group. His current interests include biodiversity and global change, structure and functioning of tropical savanna ecosystems and sustainable development.