Anais da Academia Brasileira de Ciências (2010) 82(4): 1095-1105
(Annals of the Brazilian Academy of Sciences)
ISSN 0001-3765
www.scielo.br/aabc

Rapid assessment methods of resilience for natural and agricultural systems

JUAN C. TORRICO[1] and MARC J.J. JANSSENS[2]

[1]University of Applied Sciences Cologne, Institute for Technology in the Tropics, Betzdorferstr 2, 50679 Köln, Germany
[2]University of Bonn, Unit of Tropical Crops, Sechtemer Straβe 29, D-50389 Wesseling, Germany

Manuscript received on June 9, 2008; accepted for publication on August 16, 2010

ABSTRACT

The resilience, ecological function and quality of both agricultural and natural systems were evaluated in the mountainous region of the Atlantic Rain Forest of Rio de Janeiro through Rapid Assessment Methods. For this goal new indicators were proposed, such as eco-volume, eco-height, bio-volume, volume efficiency, and resilience index. The following agricultural and natural systems have been compared according: (i) vegetables (leaf, fruit and mixed); (ii) citrus; (iii) ecological system; (iv) cattle, (v) silvo-pastoral system, (vi) forest fragment and (vii) forest in regeneration stage (1, 2 and 3 years old). An alternative measure (index) of resilience was proposed by considering the actual bio-volume as a function of the potential eco-volume. The objectives and hypotheses were fulfilled; it is shown that there does exist a high positive correlation between resilience index, biomass, energy efficiency and biodiversity. Cattle and vegetable systems have lowest resilience, whilst ecological and silvo-pastoral systems have greatest resilience. This new approach offers a rapid, though valuable assessment tool for ecological studies, agricultural development and landscape planning, particularly in tropical countries.

Key words: bio-volume, eco-volume, Atlantic Rain Forest, rapid assessment methods, resilience index, farming systems, natural systems.

INTRODUCTION

Rapid Rural Assessment methods have been widely developed in the field of agriculture, economics, sociology, anthropology and epidemiology (Rifkin 2007, Brooke and Knuthk 2002.). It generally consists of drawing a rough picture in a short time span, for agricultural systems in average one day per observation. Rapid assessment methods have been successfully adapted to different agro-ecological regions, and have become an important tool for scientists and decision makers (FAO-PFL 1990). In the evaluation of agricultural and ecological systems, it is difficult to grasp a comprehensive picture of a system in a short period of time. In phyto-sociology, some informative and quick assessment methods were designed particularly in range management or assessment of herbaceous covers. How can then complex ecosystems functions through quick and simplified assessment methods be described with the objective to build simulation models based on simple and available data, like plant height, basal area, biomass, richness, etc.? Only in this sense, it is possible to rapidly identify and quantify rapidly every changing environmental problems and to suggest problem solving remedies within operational deadlines.

We assume two hypotheses: (i) eco-volume is an effective and important parameter to measure the ecological function and the quality of natural systems, and their interactions with agricultural systems; (ii) eco-volume makes possible to measure resilience of agricultural and natural systems, as well as comparisons between both systems: moreover, the evolution in time can be monitored.

Correspondence to: Juan Carlos Torrico
E-mail: juan.torrico@fh-koeln.de

The aim of this paper is to test the eco-volume concept and the resilience index for measuring ecological quality and functionality of agricultural and natural systems.

Rapid Appraisal of both Natural and Agricultural Systems

Measurement of the quality of natural systems and its relation with agricultural systems is a difficult, if not controversial topic for researchers. Basically, agricultural systems are generally evaluated separately from natural systems. It is uneasy to combine both systems appraisals because there are a nearly infinite number of variables, each of them having varying relevance as to the qualitative and quantitative description of an agro-ecological landscape condition. It would be very difficult and prohibitively expensive to measure all those variables, even if they are valid indicators. The environmental problems worldwide and especially in the Atlantic Forest region have created a critical need for methods to quantify potential hazards, and solutions to reverse the deterioration of the ecosystem and to understand its relationship among biological, economical and geological subsystems.

The process of degradation of the Atlantic Forest leads towards continuously changing scenarios, whereby an immediate action is required for regenerating endangered natural systems amidst agricultural mosaics. These many scenarios are a golden opportunity for comparing different assessment methods.

Rapid assessment methods like eco-volume or resilience-index are appropriated to help to solve this problem, and are badly needed to meet the challenges of national and international development goals. Assessing agro-ecological systems at the landscape scale level is important because it can provide information about effects and dynamics of many external influences, and a holistic point of view for decision makers. Eco-volume concept emphasizes the interrelationships among species living within the boundaries of a volume, and encompasses a biocenosis adapted to specific conditions in a given place.

Resilience is also a measure related to the continuity of an ecosystem and its ability to rebuild itself back to an equilibrium level. Both methods get a quick and comprehensive picture of a situation, and can be used to make preliminary decisions about interventions or changes, additional research, diagnosis, and can also be used for monitoring and evaluation.

Eco-Volume

Eco-volume is the aboveground quantifiable space or volume limited by a uniform vegetation stand and its height, within which there are wide interactions between biotic and abiotic components. This concept emphasizes the interrelationships between species living within the boundaries of a volume, and encompasses a biocenosis adapted to specific conditions in a given place.

V_{eco} = land area × eco-height (Janssens et al. 2004)

Eco-height: renders a weighed average over time and across the different vegetation community fractions. In this case, a vegetation reaches community status from canopy closure onwards, and its height will be given by the domineering (upper layer) plants.

The general hypothesis of the eco-volume is: if eco-volume increases, then the possibility to harbour more biomass and biodiversity grows, whereas energy flows and their positive effects on the microclimate will improve by the same token. The quality of V_{eco} can be measured in the easiest way by the total exposed plant bio-surface of which it is composed of, and by the production of annual litter fall, which in turn determines gross photosynthesis at equilibrium when multiplied by 4. Hence, $P_b = 4 \times$ Litter fall [A vegetation reaches eco-climax equilibrium when: (i) $\Delta B = 0$ as total biomass remains constant (Larcher 1994); (ii) $NPP = L_t + \Delta B = L_t$ (yearly litter fall); (iii) $L_t + R_g = R_m$ (R_g, R_m = growth and maintenance respiration); (iv) $L_t \gg R_g$ (biosynthesis costs); (iv) P_b (apparent gross aboveground photosynthesis) $= 2R_m = 2(L_t + R_g) = 4L_t$ (Janssens et al. 2004)].

Ovadia and Schmitz (2002) indicates that there is no clear methodology to measure the ecological function and quality of natural systems, and their interactions with agricultural systems, to determine the interactions among biotic and abiotic components in ecosystems, and to describe the vertical structure in vegetation communities.

Eco-climax and Eco-volume Potential

Eco-climax is defined by Odum (1969) as the culmination state after a succession in a stabilized ecosystem in which maximum biomass (or high information content) and symbiotic function among organisms is kept per unit of available energy flow. This *Eco-climax state* will be considered as the stage at which *eco-volume potential* is highest. This state will be following described.

A climax community is the one that has reached the stable stage. Stability is attained through a process known as succession, whereby relatively simple communities are replaced by more complex ones. Stable climax communities in most areas can coexist with human pressures on the ecosystem, such as deforestation, grazing, and urbanization. Poly-climax theories stress that plant development does not follow predictable outlines, and that the evolution of ecosystems is subject to many variables (Odum 1969).

ECOSYSTEMS FUNCTIONALITY

Ecosystems are very complex and composed of many individuals of multiple species of organisms that interact with each other and with their abiotic environment to produce complex structures, dynamics and energy flows. The eco-volume concept *approaches this problem by* assuming that it is sufficient to abstract all these complex interactions, among individuals in populations, and characterize ecosystem function simply in terms of net changes in numbers or in bio-volume (Bio-volume is the volume of stem, branches, roots, rootlets, twigs and leaves) of individuals at the level of entire populations. Abstracting such individual-scale detail is reasonable if the effects of individual-level interactions attenuate changes in population density on the time scale (Agrawal 2001). Understanding the functioning of ecosystems still remains a challenge up to now. Paine (1966) and Daily (1997) conclude that the functionality depends on the identities of the species contained within ecosystems, and hypothesized that the number of species plays a major role.

METHODOLOGY

In the municipality of Teresópolis, in the mountainous region of the Atlantic Forest, the following agricultural and natural systems have been compared accordingly: (i) vegetables (leaf, fruit and mixed); (ii) citrus; (iii) ecological systems; (iv) cattle, (v) silvopastoral systems, (vi) forest fragment and (vii) forest in regeneration stage (1, 2 and 3 years old). The National Park "Serra dos Órgãos" was taken as a reference natural system. The vegetation types are described in the Table I. A general overview of the farming systems in "Córrego Sujo Basin" is presented in the Table II. And the most important indicators, formulas units and descriptions are presented in the Table III.

The main variables for the measurements of the proposed indexes are simple and explained as below:

Area: If field data are not available, to be determined from satellite images, available freely on Internet. The area should be measured for each vegetable formation, for such as primary forest, secondary forest and agricultural cultivations.

Basal Area and Bio-Volume: The easier way to determine the Bio-volume it is multiplying the basal area of the different vegetal formation times by the average height. A simple way to find the basal area value is through forest inventories and simple field measurements. An average value is enough.

To determine the potential eco-volume is necessary to compare the obtained bio-volume and eco-volume with one of a natural vegetations in a mature state. National Parks or Conservation Areas are highly recommended.

It is very useful to use forest inventories or biodiversity studies. For this calculation, purposes indices like Shannon, Simpson and richness are very useful.

Through algometric correlations or averages content, it is possible to determine the amount of carbon and energy. Average wood density helps a lot.

RESULTS

BIO-VOLUME AND ECO-VOLUME

Bio-volume (V_{bio}) is based on the hypothesis that plants mainly compete for space according to Janssens et al. (2006), Diaz et al. (2004), CIID (1998), Kolnaar (2006) and Hansen et al. (1999). The competition is not only aboveground, but also belowground where occupation of soil space is of primary importance (Casper and Jackson 1997).

The natural systems with a bigger value of V_{bio} are the mature Atlantic Rainforest, 1575 m^3 ha^{-1}, and to a lesser extent its fragments with 912 m^3 ha^{-1}. The agricultural systems with less V_{bio} are the grass, Horticultural and the silvopastoral systems (13, 32 and

TABLE I
Land cover description.

Land cover	Description
Developed forest	Presence of species older than 30 years, high presence of epiphytes and lianas, and the canopy is closed. This kind of vegetable covering corresponds to most of the coverings of the National Park and some fragments. The forest is a semi-deciduous forests.
Forest of intermediate development	The semi-arboreal and bushes species prevail; the arboreal vegetation begins to show predominant; little presence of epiphytes. Mostly composed of the small fragments.
Forest in initial development condition	Lacking epiphytes; the gramineous cover prevails, the bushes and herbaceous plants can reach up to 4 meters high. Many abandoned pastures with more than 5 years in so far not burnt.
Grasses and bushes	Presence of clean areas with gramineous plants for shepherding, in some cases with thin bushes.
Agricultural	Horticulture predominance, besides areas with citrus.
Vegetation of waterlogged areas	*Typha domingensis* dominates; characteristic waterlogged land. Besides these conservation units and the National park, about 212 fragments that have an area average of 12.8 ha are observed in the region.

TABLE II
General overview of the agriculture systems in "Córrego Sujo", Teresópolis.

	Ecofarm	Cattle	Sylvo-pastoral	Fruit vegetables	Leaf vegetables	Mixed vegetables	Citrus
Seeds quality	good	any	any	good	very good	very good	good
Fertilizers	any	any	any	high	high	high	low
Pesticides	any	any	any	high	high	high	any
Herbicides	any	any	any	middle	middle	middle	any
% Crops Area (average)	18	0	0	66	66	66	84
Fallow (months/yr)	2 to 6	0	0	0	0	0	0
Irrigation	low	any	any	high	high	high	Any

74 m^3 ha^{-1} respectively). In Figure 2 results are compared with the ones of other vegetation types calculated from the literature. The systems with less V_{bio} are water plants, *Caatinga* (forest of stunted trees and spiky shrub in the regions of small rainfall in Brazil) and the forest in regeneration (65, 129 and 221 m^3 ha^{-1}, respectively). The ecological cropping of coffee in the Northeast Brazil has a great bio-volume value of 739 m^3 ha^{-1}. Other agricultural systems with a very good value of V_{bio} are the cocoa agroforests in Cameroon (396 m^3 ha^{-1}) (Janssens et al. 2006).

Eco-volume encompasses a vertical structure within which there are wide interactions between biotic and abiotic components. For example, in forests one can recognize different strata like an herbaceous stratum, a bush stratum and a tree stratum. The eco-volume is subjected to either periodic or abrupt changes based on climatic cycles or due to man-made disruptions, like deforestation or extraction of plant material. These changes can also be natural through phyto-sociological succession.

The forest systems have highest values of eco-volume ranging from 44500 m^3 ha^{-1} for semiarid forest in northeast Brazil, up to 250000 m^3 ha^{-1} for primary mountain rain forest in the Atlantic region. The aquatic plants dominated by *Typha domingensis* present 9500 m^3 ha^{-1} of eco-volume. The highest values of eco-volume in agricultural systems (average: 90000 m^3 ha^{-1}) correspond to agroforestry (coffee and cocoa), and ecological

TABLE III
Measured variables and parameters.

Indicator/formula [unit]	Description/observation
Eco-volume / $V_{eco} = H_{eco} \times$ area [m^3]	The surface of a given phytocenose or agricultural system multiplied by the eco-height. Eco-Volume is normally expressed on ha basis ($m^3 ha^{-1}$). Eco-volume is the product of the area occupied by a uniform type of vegetation and its eco-height.
Eco-height / (H_{eco}) [m^3]	Eco-height renders a weighed average over time and across the different vegetation community fractions. In this case, a vegetation reaches community status as from canopy closure onwards, and its height will be given by the domineering (upper layer) plants.
Bio-Volume / V_{bio} = Basal stem area × Heco [m^3]	Bio-volume, is the total volume of the plants (trees, bushes, herbaceous, etc.) that occupy a certain space. Hence, the bio-volume of a plant is its fresh biomass divided by its corresponding specific fresh weight. When only dry biomass is known, the total fresh mass can be estimated by dividing total (dry) biomass through dry matter content. This concept is based on the hypothesis that plants mainly compete for space. It is expressed in $m^3 ha^{-1}$. Based on the tube theory by West et al. (1999), a very quick approach is proposed by Janssens et al. (2006). If a plant is an assembly of tubes all of its parts being squeezed within a cylinder equivalent to the total bio-volume.
Eco-Volume efficiency / V_e = Yield /V_{loss} V_e = Yield/(V_{pot}-V_{eco}) (Fig. 1)	Relates the yield expressed either in money or energy units to the lost V_{eco} w.r.t. which is the maximal eco-volume at eco-climax in the same locality. It measures the efficiency in relation to the potential V_{eco} (V_{pot}). It is expressed in MJ m^{-3} or Money m^{-3}.
Resilience Index / R_i	Measures the resilience of the systems by comparing bio-volume (V_{bio}) with the potential eco-volume (V_{pot}). Bio-volume represents the current state of the systems, and V_{pot} represents the state in equilibrium of the ecosystems. Resilience Index measures the ability of the ecosystems to endure changes, disturbances and stresses, as well as its capacity to rebuild itself until an equilibrium level, at which it is capable of achieving its ecosystems functions, and providing goods and services.

systems. The horticultural systems and grassland have reduced values averaging 24000 m^3 ha^{-1} (Fig. 2).

Eco-volume emphasises the interrelationships among species living within the boundaries of a space or volume (area × eco-height). These interactions are as important as the physical factors to which each species is adapted and responding. Each eco-volume encloses a biological community (or biocoenosis, defined by Möbius 1877) adapted to specific conditions in a given place (Tansley 1935).

The functionality of the eco-volume tends to be overlooked. Janssens et al. (2004) indicate that eco-volume has an effect on precipitations [additional precipitations, also coined as eco-precipitations (Eco-pre-

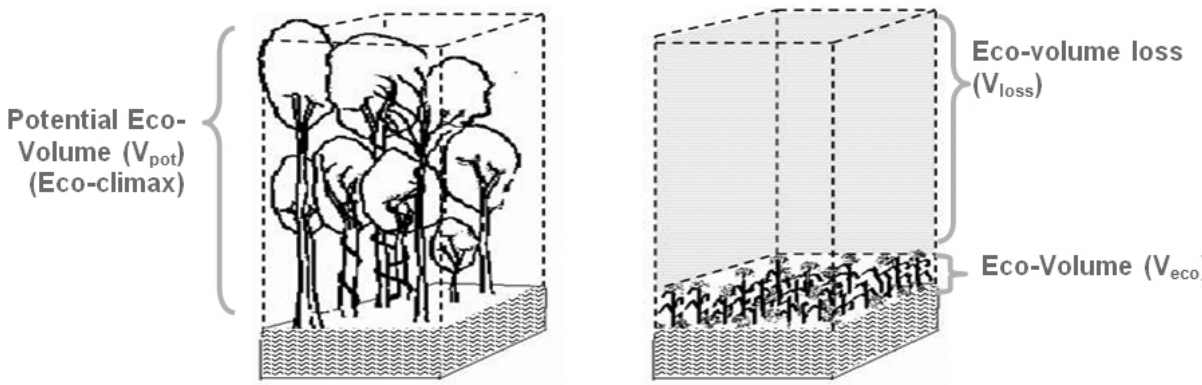

Fig. 1 – Illustration of the potential eco-volume (V_{pot}), eco-volume (V_{eco}), bio-volume (V_{bio}) and eco-volume loss (V_{loss}).

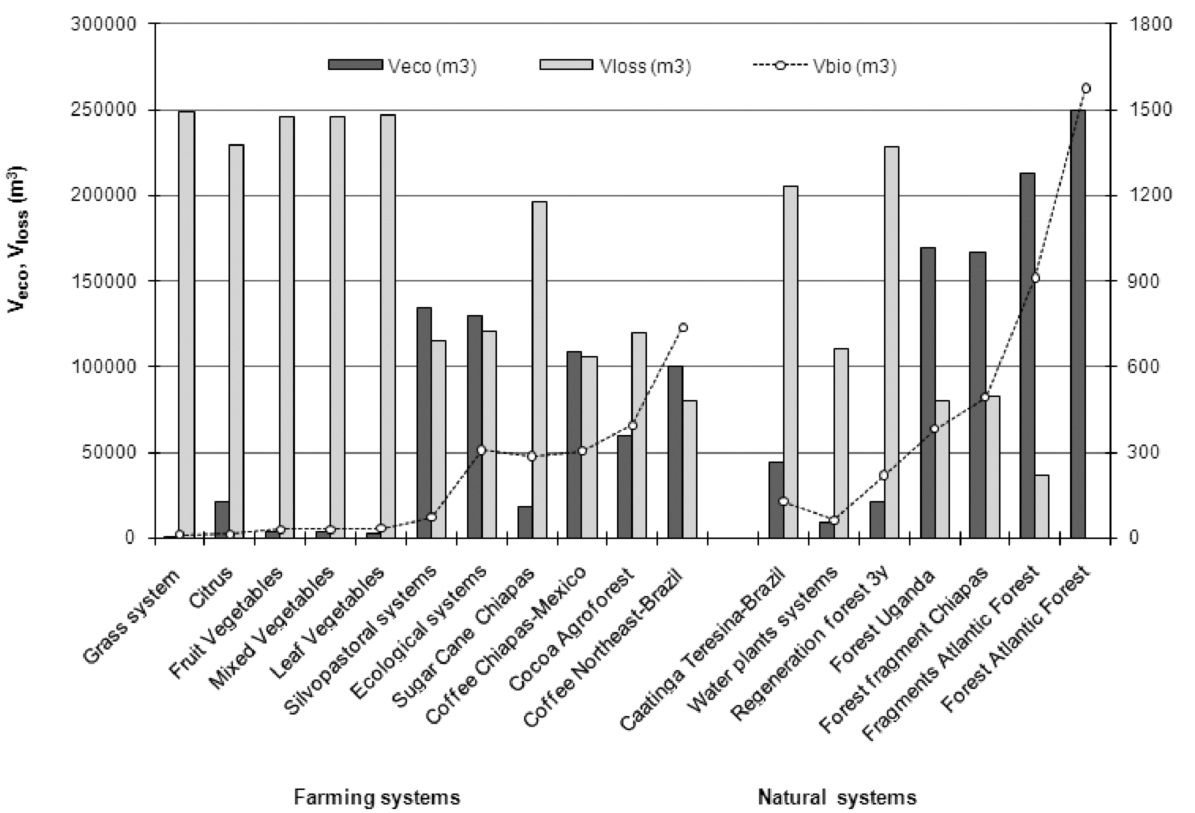

Fig. 2 – Eco-volume (V_{eco}), bio-volume (V_{bio}) and volume-loss (V_{loss}) of agricultural and natural systems.

cipitations are complementary rains generated by ecological sound management of a watershed basin), are generated], as well as on regulation of other ecological functions, like microclimate and water cycle. Eco-volume leads directly into such areas where water cycling, Gross Primary Productivity (GPP), Net Primary Productivity (NPP), and energy flow. Eco-volume is also related with the landscape ecology concept proposed by Troll (1939), whereby interactions between environment and vegetation are investigated.

The potential eco-volume (V_{pot}) is the state of full maturity of a forest, sometimes called “climax”. This stage shows a structured functional unit in energy equilibrium and matter flows among its constituent elements, attaining maximal interactions between organisms (plant, animal and other living organisms – also referred to as a biotic community or biocoenosis) living together with their environment (biotope) and working as a limit concept. Therefore, we calculate $V_{pot} = V_{loss} + V_{eco}$.

The V_{pot} for the region of Teresópolis is given by the mature forest of the National Park "Serra dos Órgãos" (250000 m^3 ha^{-1}). For the waterlogged areas where only aquatic plants measured (V_{eco} amounts to 120000 m^3 ha^{-1}), for the coffee region in the northeast of Brazil, we measured an average V_{eco} of 180000 m^3 ha^{-1}.

The Volume-loss (V_{loss}), equals V_{pot}-V_{eco}, and represents the regression of an ecosystem in terms of V_{eco}. The bigger the V_{loss}, the bigger will be the ecosystem losses in quality, function, and services (Fig. 3).

The eco-volume efficiency (V_e), yield expressed in dry matter (ton DM), or energy (MJ) or money per lost eco-volume appears to be a powerful discriminating tool. For example, to produce a ton of dry matter in the grass and citrus systems it was necessary to sacrifice 166067 m^3 and 145397 m^3 of V_{eco}, respectively. This represents the volume of an medium-size football stadium. This high attrition is due to the very low productivity of these systems. The same V_e applied to monetary units highlights the most efficient system in Teresópolis as being the fruit-vegetables system with an average value of 3451 $m^3 * \text{ton DM}^{-1} * \text{ha}^{-1}$. If we divide the V_{loss} by yield expressed in Euros it follows that to generate hundred Euros, it is necessary to sacrifice an eco-volume as large as a football stadium. From this point of view the cattle, silvo-pastoral and citrus systems are the less efficient systems and the more destructive of the ecosystems.

RESILIENCE

Resilience is considered to be the capacity of a system to endure stress and bounce back. It has found application in many different fields. Pimm (1991) defines it as a measure of how fast (time) a system returns to an equilibrium state after a disturbance. Holling (1973) defines it as a measure of how far the system could be disturbed without shifting to a different organization (persistence). Schulze and Mooney (1994), Ehrlich (1986) and Walker (1992) define resilience as the ability of ecosystems to resist stresses and shocks, to absorb disturbance, and to recover from disruptive change. Resilience is a buffer against environmental changes or disturbances (Vergano and Nunes 2006).

For us, resilience is related to the continuity of an ecosystem and its ability to endure changes, disturbances and stresses, as well as to its capacity to rebuild itself up to an equilibrium level, at which it is capable of achieving its ecosystems functions, and providing goods and services. The more resilient the ecosystem, the faster is the returning process to the original long-lasting equilibrium state, the bigger is the ability to tolerate changes, disturbances and stresses, and the higher is the probability of keeping the efficiency of the ecosystems.

The resilience index or R_i, measures the resilience of the systems by comparing the actual bio-volume (V_{bio}) with the potential eco-volume (V_{pot}). Bio-volume represents the current state of the systems, and V_{pot} represents the state in equilibrium of the ecosystems.

The systems with indices between 0.3 and 0.5 possess high resilience capacity. Above 0.5, the systems are approaching the climax stage. Indices between 0.1 and 0.2 represent systems with average resilience capability; those smaller than 0.1 are indicative of low resilience. It is interesting to note that Ri is in fact a measure of crowding intensity $C_i = V_{bio}/V_{eco}$ (Janssens et al. 2004), where eco-volume is considered at its maximum climax level. It also points to the fact that high levels of bio-volume cannot be attained without a corresponding eco-volume.

When agricultural systems, like cattle and vegetable systems, are predominant in the landscape, the natural system can not guarantee the provision of the same goods and benefits as in the previous equilibrium state and thus, has a very low resilience. The lower the natural capacity to adapt to changes, the higher is the risk to decline (Fig. 3).

Figure 3 shows situations related to the stability and resilience of ecosystems. The left part of the graphic (high resilience) prevails when a system generally approaches stability (or climax). The latter stage can suffer the effects of low disturbances or stresses, the impact of which can be quickly and easily reverted to the stable equilibrium state, e.g. small deforested areas in the rain forest. The right part of the graphic (low resilience) occurs when stress and disturbances are bigger. Conse-

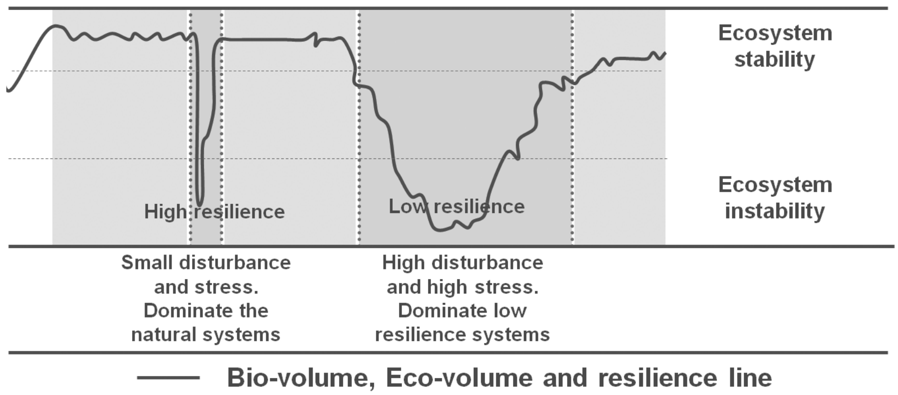

Fig. 3 – Bio-volume, eco-volume and resilience line; ecosystem stability in small perturbed and low stressed natural systems, and in high disturbed and high stressed low resilience systems. Ecosystem stability as a function of recovery time.

quently, the ecosystem presents difficulties in returning to the stability stage or needs long time and large resources to do so, e.g. current agricultural and cattle systems that dominate the landscapes in the Atlantic Rain Forest region.

The agricultural systems with bigger resilience index (Ri) were Coffee Northeast in Brazil (0.41), Cocoa in Cameroon (0.22), Coffee in Chiapas Mexico (0.14) and ecological horticulture in the Atlantic rain Forest (0.12), all four of them being agroforestry systems. The lowest indices correspond to the grass (0.005), citrus (0.006), vegetables (0.013 on average) and silvo-pastoral (0.029) (Fig. 4).

The forest systems present middle to high resilience. The Atlantic Rain Forest is near the climax level. The aquatic plant systems and the forest in regeneration (3 years old) present a low resilience index (0.054 and 0.088, respectively). The lowest index corresponds to a young Caatinga (Caatinga is a xeric shrubland and thorn forest, which consists primarily of small, thorny trees that shed their leaves seasonally) with only 0.052 (Fig. 4).

Biodiversity and Resilience

The environmental services of biodiversity are certainly significant, probably much more so than the direct benefits of biodiversity in the form of material goods (Myers 1996). Biological diversity appears to enhance resilience of desirable ecosystem states, which is required to secure production of essential ecosystem services (Elmqvist et al. 2003). Species that directly or indirectly influence the ability of the ecosystem to function will enhance resilience, contrarily to sets of species that do not have a significant role in altering the state of the ecosystem (Walker 1992). We found a statistically significant correlation of 0.93 ($\pm$ 0.06) between Resilience index and Richness at 99% of confidence level. The model based on the resilience index explained 87.3% of the variability. The Atlantic Rain Forest has the biggest number of species (263 species with DBH bigger than 5 cm on 0.8 ha while surprisingly the cocoa agroforestry in Cameroon and the coffee agro-forestry system in Northeast Brazil have a larger number of species (120 and 122, respectively) than all of other farming systems including the ecological one as well (Fig. 4).

Jones and Lawton (1995) affirms that some connections exist between resilience and biodiversity. Biodiversity can make an important and positive contribution to ecosystem resilience. For Ricklefs and Schluter (1993) and Perrings et al. (1995), biodiversity could supply the most important services in natural systems. However, many authors are uncertain about the exact contribution of species composition and richness to the ecosystem dynamics (Perrings and Opschoor 1994, Solbrig 1991 and Schulze and Mooney 1994). Johnson et al. (1996) says that no pattern or deterministic relationship needs to exist among species diversity and the stability of ecosystems. Ecosystem processes often appear to be quite resilient to biodiversity decline as they can keep on supplying environmental services after loosing a good number of

Agricultural systems	Resilience (%)	Richness
Grass system	0.005	8
Citrus	0.006	8
Fruit Vegetables	0.012	19
Mixed Vegetables	0.013	21
Leaf Vegetables	0.014	19
Silvopastoral systems	0.029	34
Ecological systems	0.124	96
Coffee Chiapas-Mexico	0.142	99
Cocoa Agroforest	0.22	120
Coffee Northeast-Brazil	0.411	122
Caatinga Teresina-Brazil	0.052	16
Water plants	0.054	6
Regeneration forest (3 y)	0.088	30
Forest Uganda	0.154	43
Forest fragment Chiapas	0.198	64
Fragments Atlantic Forest	0.365	110
Forest Atlantic Forest	0.63	263

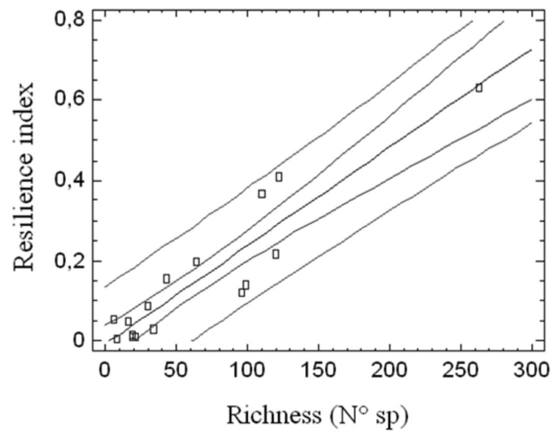

Fig. 4 – Simple Regression-Resilience index *vs.* Richness. The output shows the results of fitting a linear model to describe the relationship between Resilience index and Richness. The equation of the fitted model is Resilience index = –0,0075 + 0,0024 $*$ Richness. Correlation Coefficient = 0,934. R-squared = 87.3 percent.

species and large numbers of populations (Lawton 1994 cited Myers 1996).

It is incorrect to say that we can lose lots of species with impunity. A cut-off stage would (eventually) arrive when there would be simply too few species to keep basic ecosystem functions (Myers 1996). The same author finds that biodiversity contributes as an environmental service tool of semi-absolute value in the sense of reducing severe risk, but plays only a relatively minor role in supplying many other services. Paine (1969) and Holling et al. (1995) affirm that resilience may be linked to the prevalence of a rather limited number and groups of organisms (*keystone species*).

CONCLUSIONS

1. Given the difficulty to determine interactions between biotic and abiotic components in ecosystems, and considering the ecological importance of the vertical structure in vegetation communities, eco-volume is an important methodology and rapid assessment tool to evaluate the ecological function and quality of natural systems, as well as their interactions with agricultural systems.

2. An alternative measure (index) of resilience was proposed by considering the actual V_{bio} as a function of the potential eco-volume. By means of this method, it is possible to easily measure resilience and its evolution in time. This method allows the comparison between natural and agricultural systems with the same units. It also enables the integration of other variables like biodiversity, energy flow, accumulation of carbon, etc. to obtain a better scenario likelihood of the ecosystems capacity to return to their original climax equilibrium state. It is shown that there does exist a high positive correlation among resilience index, biomass, energy efficiency and biodiversity.

3. Grass and vegetable systems have lowest resilience and eco-volume, whilst ecological and silvo-pastoral systems have greatest resilience and eco-volume.

4. Increasing eco-volume is important to the long-term health of ecosystems. Fragmentation and disturbance of forest ecosystems (reduction of eco-volume) represent interruptions and/or destructions of both the horizontal and vertical connectivity as they impact negatively on the ecosystem functionality. Hence, provision of goods and services for the human well-being, as well as for wildlife and plants, cannot be supplied any longer.

5. In agricultural systems, bio-volume (V_{bio}) is controlled by the farmers with different purposes, such as weed control, pruning for yield achievement, adaptation to machinery, etc. Depending on the

system, V_{bio} and biomass production usually remain constant, as illustrated by most systems (grasses, horticultural, cane of sugar, citrus). The ecological and agro-forestry systems tend to increase their V_{bio} at a slow rate until they remain almost constant. This stage for these agro-forestry systems is to be considered as an "equilibrium point" between agricultural and natural systems, where resilience index, eco-volume, bio-volume, biodiversity and energy flow are all higher and more efficient.

RESUMO

Foram avaliadas, em região montanhosa da Mata Atlântica do Rio de Janeiro a resiliência, função ecológica e qualidade tanto do sistema agrícola como natural, através dos métodos de avaliação rápida ("rapid assessment methods"). Para este fim, foram propostos novos indicadores como eco-volume, eco-altura, bio-volume, eficiência volumétrica e índice de resiliência. Os seguintes sistemas agrícolas e naturais foram comparados: (i) hortaliças (folhas, frutos e mistos); (ii) citros; (iii) sistema ecológico; (iv) gado; (v) sistema silvo-pastoral; (vi) fragmento florestal; (vii) floresta em estágio de recuperação (1, 2 e 3 anos de idade). Uma forma alternativa de resiliência foi proposta considerando o bio-volume real como uma função do eco-volume potencial. Os objetivos e hipóteses foram alcançados; demonstrou-se que existe uma correlação altamente positiva entre índice de resiliência, energia da biomassa, eficiência energética e biodiversidade. Pecuária e sistemas de hortaliças apresentaram as mais baixas resiliências enquanto sistemas ecológico e silvo-pastoral tiveram maiores resiliências. Esta nova estratégia oferece uma rápida e valiosa ferramenta de avaliação para estudos ecológicos, desenvolvimento agrícola e planejamento paisagístico, especialmente em países tropicais.

Palavras-chave: bio-volume, eco-volume, Mata Atlântica, métodos rápidos de avaliação, índice de resiliência, sistemas agrícolas, sistemas naturais.

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