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Restoration and Conservation of Rainforest and Cerrado Biomes within Environmental Corridors: Spatial and Temporal Analyses Applying the Hyperspectral and Multispectral Remote Sensing Technologies

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Abstract

Habitat fragmentation is one of the most acute challenge of present time, leading to the loss of biodiversity and degradation of natural ecosystems. At the end of the 20th century arose the comprehension of necessity to organize the natural protected areas as a network creating a continuity of natural cover, as a countermeasure for the consequence of fragmentation. This concept was called the Ecological Network strategy. However, the current lack of knowledge on the changes in the health of ecosystems in protected areas does not provide a clear confirmation that ecological networks are a more effectively solution for conservation purposes than isolated protected areas, interfering in the transition of the ecological network principle of protected areas organization and causing a number of other sequels that reduce the effectiveness of conservation work. The reason for this lack of knowledge is the complexity and the high cost of studying the state of ecosystems over large areas using only field methods. However, the modern remote sensing technologies can be used to solving this problem. In our project we intend to develop a pilot methodology of a complex assessment of ecosystem health based on the hyperspectral and multispectral remote sensing imagery. By means of elaborated methodology we will assess the current health of ecosystems and their changes over 20-30 year period for rainforest and cerrado biomes inside some environmental corridors. The outcome of the project will be the pilot version of the methodology estimating the ecosystem health and the results of the evaluation of habitat condition within the selected environmental corridors.

1. Introduction

1.1 The background of the investigation

1.1.1 The Ecological Network strategy as a countermeasure of habitat fragmentation

The reduction of biological diversity, degradation and loss of natural ecosystems together with deterioration of environmental conditions (quality in soils, water and air) are the gravest challenges of our times. In many regions of the world there is a disastrous environmental situation affecting the health and quality of life of hundreds of thousands of people. The fragmentation of natural habitats is one of the main causes of this situation. There is an increasing political awareness of the urgency of measures to avoid, mitigate, and compensate the destructive impact of habitat fragmentation on the environment (Tillmann, 2005). In Brazil, like in most of the tropical countries, the devastating effect of fragmentation is especially strong. It is causing a huge loss of biodiversity, decrease of population numbers of valuable species and general degradation of tropical biomes (Ayres *et al.*, 2006).

The conservation of biodiversity and intact natural habitats, the restoration of degraded and destroyed ecosystems are considered now as one of the most important priorities. Those objectives are entrusted largely on protected natural areas - lands where any human activity are prohibited or restricted. However, isolated conservation areas cannot solve this task in the proper extent, since fragmentation breaks off migration of many species, while human impact increases in direct proportion to the length of fragment borders.

At the end of the 20th century the comprehension of necessity to organize the protected natural areas as a network or as a system of connected natural lands arose. In Europe and North America this concept is often called as a "Ecological network" or "Econets" strategy, while in the Southern Hemisphere (including Brazil) it is more often called as a "Environmental corridors" strategy. This strategy directly corresponds to the global concern for biodiversity conservation, degraded ecosystem restoration, fighting the deforestation and desertification (Tillmann, 2005; Pan-

European Biological and Landscape Diversity Strategy 1996; Veen and Sanders, 2010; Jongman and Troumbis, 1995; Jongman, 2002).

The essence of Ecological Network strategy lies in the establishment of protected areas in a system of network, creating a continuity of natural cover. The natural lands included in ecological networks usually have the severity of protection regimes increasing from its periphery to the center. The **central nodal elements** of an ecological network consist from the conservation units with the strictest protection regime. Often those areas are the nature reserves protecting the most valuable and vulnerable natural lands, where any human activity expecting scientific researches is prohibited. A connection between central nodes of ecological network can be provided by **ecological corridors**. The **buffer zones** adjacent to the nodal conservation units and ecological corridors are usually characterized by the more relaxed regime of nature protection. The sustainable nature exploitation including agriculture and livestock grazing is often allowed on the periphery of those areas. Also buffer zones are appropriate for ecological tourism and environmental education. The **ecological corridors** can be established on migration routes of birds and large mammals. The logging, ploughing, industry, construction of the linear structures and hunting are usually prohibited within the ecological corridors. In some countries there is a special legislation about the Ecological Networks and Ecological Corridors (Tillmann, 2005; Jongman and Troumbis, 1995).

The acceptance of the Ecological Network strategy as a key strategy for the creation and management of protected areas has two main reasons. At first, the large natural territories should be protected in sustainable condition for favorable migration of populations of many species. This is especially crucial when species migrate over long distance. Often it is impossible to provide and maintain a strict regime of protection for all relevant areas. The ecological networks are created in order to ensure the ecological connectivity between natural habitats, to protect the most important migration routes and, at the same time, do not harm the social and economic exploitation of territories. At second, the natural continuity created in ecological networks reduces or completely terminates the processes of degradation in the included habitats. It increases the health of the whole ecosystem and promotes ecosystem restoration.

1.1.2 Environmental Corridors strategy in Brazil

In Brazil the conservation strategy identical to the Ecological Network strategy was entitled as the "**Concept of ecological corridors or biodiversity corridors**" ("O conceito de corredores ecológicos ou corredores de biodiversidade"). It has been elaborated within the Ministry of Environment since 1997 with the World Bank (Banco Mundial) support by dint of the Rain Forest Trust Fund (Fundo Fiduciário da Floresta Tropical) under the Pilot Program for the Protection of Tropical Forests in Brazil (PPG-7). This program deals with the dynamics of tropical forest fragmentation and promotes the formation and conservation of major corridors in the Amazon and Atlantic Forest (Ayres *et al.*, 2006).

In Brazil, to designate the conception of linking natural areas, the terms of "ecological corridor" and "environmental corridor" are more frequently used instead of terms like "Econet" or "Ecological network". The term "**environmental corridor"** (*corredor ambiental*) – means a large area with a width from several dozen kilometres to several hundred kilometres, which can contain several highly protected areas. The "**ecological corridor"** (C*orredor ecológico*) – means a strip of natural land connecting two natural fragments with a width from several hundred metres to several kilometres. Both terms are closely consistent with the essence of the Ecological Network conception.

Since 1997 a number of protected environmental corridors in biomes of rainforest including Amazon and Atlantic forests, in coastal biomes, cerrado and some others were created in Brazil. (Ayres *et al.*, 2006).

1.2 About a problem

However, there is a serious obstacle in the transition to the ecological network principles applied to the organization of protected areas: the lack of reliable investigations about the positive and negative changes in the health of natural ecosystems within protected areas. As a consequence, the advantages of ecological networks for nature conservation comparing with isolated protected areas are not clearly recognized yet. This leads to the following negative consequences:

1. Habitat fragmentation is not considered as a significant problem by both the scientific and the public communities. This causes the lack of investment of financial and human resources to practical solution of fragmentation problem by means of creation of ecological networks.
2. There is a lack of information on the Ecological Networks strategy as a much more effective principle of protected areas construction in contrast to isolated protected areas for implementation purposes of biodiversity and intact habitat conservation, degraded natural lands restoration.
3. The regular and comprehensive monitoring of changes in ecosystem condition has not been conducted in most of protected areas. The positive and negative effects of applied methods of natural ecosystem conservation and restoration were not analyzed and were not taken into account in the elaboration of management plans for those territories.

The main reason for listing these problems lies in the complexity of identification and analyses of the changes in ecosystems due to the large size of protected natural areas, high financial and labour cost of field researches and the difficult access to remote lands.

However, this difficulty can be solved in our days with the help of remote sensing technologies, which application for environmental issues is growing intensively in recent years. To date, a lot of investigations devoted to the identification or estimation of various ecosystem characteristics were conducted. A number of those researches were implemented for the tropical biomes. A valuable methodological experience was accumulated in scientific publications. However, despite of numerous elaborated techniques based on the remote sensing data and detecting the separate ecosystem characteristics, there is still no integral methodology allowing a comprehensive assessment of the ecosystem health.

2. Objectives

2.1 General objectives

Our investigation will be devoted to looking for a solution of the problems mentioned above. We intend to develop a pilot methodological approach combining the available remote sensing and field techniques. This will allow implementing a complex analysis of the tropical ecosystem health on large areas. Here by *"ecosystem health"* we understand the affinity of ecosystem characteristics to conditions of intact or slightly disturb ecosystem of the same type. The last one we call the “standard” ecosystem or the ecosystem with the maximum quality of health.

We also intend to use the elaborated methodology to study the ecosystem health in rainforest and cerrado biomes within the environmental corridors established in Brazil in the late 1990s. Our research will be focused at the implementation of two general objectives:

1. To elaborate methodological approaches of complex estimation of natural ecosystem health, based on combination of remote sensing data, GIS and field measurements.

2. To implement the complex assessment of current natural ecosystems health and their long-term process of changes in the Environmental corridors of rainforest and cerrado biomes, established in Brazil in the late 1990s.

Both general objectives are related with each other, but have different specific goals and independent justifications. Below we consider them separately.

The practical verification of elaborated methodology in two tropical biomes differing by their ecological characteristics will allow enhancing the methodology application. Probably it will permit to create a general methodological approach, applicable in different natural zones. It will also allow comparing the results of the restoration and conservation processes within ecological corridors of two main tropical biomes of Brazil.

The pilot methodology working in two biomes will address this important question for the scientific and conservation communities. By dint of publication of the results, participation in thematic conferences and collaboration in the project implementation, our work can provoke the inflow of specialists to this area, which can subsequently lead to the development of a range of high quality methodological approaches for all natural zones.

2.2 Specific goals and justifications

2.2.1 Specific goals for the first general objective

For the first general objective will be implemented the following specific goals:

1. To conduct a review of ecosystems characteristic, which can serve as indicators of ecosystem health and, at the same time, which can be detected from remote sensing data.
2. To elaborate a set of techniques obtaining the indicative characteristics of ecosystem condition from the remote sensing data and a principle of their treatment for estimation of ecosystem health.

2.2.2 Specific justification for the first general objective

The proposed methodology allowing implementing the comprehensive analysis of ecosystem health will have a great scientific and practical importance for study, conservation and restoration of tropical ecosystems. This methodology can be used for several goals listed below.

2.2.2.1 Preparing of evidence-based and cartographically illustrated reports for the funding organizations sponsoring environmental projects in tropical regions (national and international).

The environmental projects can be yielded only with the sufficient financial support from the international or national foundations. In order to submit requests for financial assistance and getting it stable for many years, it is necessary to demonstrate results proving the effectiveness of the received funding for tropical biomes restoration and conservation. The proposed methodology will allow implementing assessment of changes in ecosystem health and demonstrating them in clear, cartographically illustrated and evidence-based form.

2.2.2.2 Elaboration of the effective management plans for protected areas belonging to Environmental corridors.

The spatial and long-term estimation of the environmental corridors condition conducted on the basis of the proposed methodology will help to develop the effective management plans for protected areas, included into corridors. In particular it will allow to identify the problem areas, which need a special attention; to analyse the efficacy of applied methods of tropical ecosystems restoration and conservation and to select the best ones for future work.

2.2.2.3 Estimation of the results of methods using for tropical ecosystems restoration and conservation. Selection of the most effective methods for future work.

The complex assessment of tropical ecosystems health will allow analyzing the positive and negative effect of applied methods of ecosystem restoration and conservation. This analysis can be conducted for up to 40 years, since the beginning of the 1980s, when the intensive regular satellite imagery of the earth's surface was launched. It will allow achieving the better results in tropical biomes restoration and conservation.

2.2.2.4 Evaluation of the results of different types of nature management for the aims of sustainable agriculture, livestock and forestry.

The proposed methodology will allow indicating the positive and negative results of different types of natural management, which can be used to increase the efficiency, environmental stability and profitability of agriculture, livestock and forestry.

It is important to note, that mainly due to the aims of “precise agriculture", the special technologies of the remote sensing, basing on imagery of extremely high resolution, the hyperspectral imagery, the shooting by UAV devices, received a strong impetus of development. It has been implemented a lot of investigations devoted to detecting the quality of agricultural planting, The huge experience outlined in accessible publications can be used for elaborating the methodologies estimating the conditions of natural protected areas.

2.2.2.5 Study a long-term process of changes in ecosystem condition under the influence of various factors (both natural and anthropogenic).

The proposed methodology will allow to analyze changes in ecosystem health for a long-term period (since early 1980s), that can be interesting from the scientific and conservation point of view. For example it can allow detecting the long-term negative impact of the specific industry on the surrounding ecosystems, and applying the obtained results for elaboration and introduction the necessary changes in the production technology.

2.2.3 Specific goals for the second general objective

For the second objective will be implemented the following specific goals:

2.2.3.1 To elaborate an algorithm of a complex spatial and long-term assessment of ecosystem health of protected areas in which we will try to include the possible range of appropriate modern technical capabilities.

2.2.3.2 To implement the assessment of ecosystem health within the Environmental corridors according to the elaborated methodology and algorithm. Due to assessment implement the following:

a) Compare the current ecosystem health with its health before or in the beginning of the corridor establishment. To study all the process of ecosystem changes that occurred during the years since the Environmental corridor was founded.

b) Compare the ecosystem health and its change over the years for two old protected areas located within ecological corridor (i.e. surrounded by natural areas) and isolated (surrounded by anthropogenic or strongly disturbed lands);

c) Compare the ecosystem health and its change over several years for two areas of young restored forests located within ecological corridor (i.e. surrounded by natural areas) and isolated (surrounded by anthropogenic or strongly disturbed lands);

d) To characterize the present conditions of ecosystems:

- To identify the problem areas, where the level of degradation has increased (the ecosystem health become worse);
- To identify the successful areas, where the level of degradation has decreased (the ecosystem health become better);
- To identify the stable areas, where the ecosystem health did not change.

2.2.3.3 Try to identify the most reliable reasons of increase and decrease of health of ecosystems. Dividing those reasons on the external influence (which can be human or natural impact by permanent or occasional character); and consequence of implementation of the special restoration or conservation technology. Implement this item for those areas, for which the appropriate information will be available.

2.2.3.4 To present the obtained results as a report with the detailed analyses, GIS maps and recommendations for managements plans of studied protected areas. Create a Web-GIS platform of open access to store all important cartographical and imagery data.

2.3.4 Specific justifications for the second general objective

Implementation of the spatial and the long-term assessment of the ecological corridors can be used for elaboration the effective management plans of protected natural areas belonging to them. Particularly it can be used for detection the problem areas which need a special attention; for estimation the effectiveness of the technologies, which were using for restoration and conservation of natural areas over many years and consider the positive and negative experience in the management plan elaboration. The experience of our study can be applied for the same purposes on other environmental corridors of these biomes.

2.4 Collaboration for the project implementation

For project implementation we intend to collaborate with the following researchers:

1. Prof. Milton Cezar Ribeiro (Laboratório de Ecologia Espacial e Conservação (LEEC), Deptomento de Ecologia, UNESP, Rio Claro);
2. Prof. Ricardo Ribeiro Rodrigues (Laboratório de Ecologia e Restauração Florestal (LERF), ESALQ, USP, São Paulo)
3. Prof. Giselda Durigan (Instituto Florestal (IF), São Paulo)

Also we will seek possibilities of collaboration with any Brazilian and foreign specialists, elaborating the remote sensing technologies for environmental studies in tropical regions.

2.5 Two stages or levels of the objectives implementation

Project implementation will be divided in two stages, which at the same time can be considered as two levels of the objectives realization. We call these levels the *minimum program* and the *maximum program*. We divide project in those levels because of uncertainty the issue of financial capacity of the project. The difference between them is a scale of study, which causes the difference in set and quantity of studied parameters indicated the ecosystem condition; the difference in details and accuracy of the results.

1. Minimum program (small scale of study): study of the entire territory of the ecological corridor.
2. Maximum program (large scale of study): study the selected small areas within the ecological corridors ("case studies")

However, the proposed separation is above all a temporal stage of the project implementation. Firstly will be realized the first stage (the minimum program), as having a low demand of funding and working hours of data acquisition and processing. And then (if will be the appropriate financial capacity) will be implemented the second stage (the maximum program). However, we will strive to realize the second stage in any possible volume, since even a small research in a large scale can give an important contribution for the project's objectives.

It is important to note that the minimum program is not worse than the maximum program, both stages realize of independent goals:

The minimum program – is a middle and low scale study basing on Landsat, ASTER and MODIS satellite images, which available gratis through the Internet sources (see Table 1). The ecosystem health of the entire area of environmental corridors can be studied in the frame of a Doctoral project only by imagery of middle or low scale. It is not reliable task to study such grand areas by the high scale imagery, because it will need too much money and working hours of data processing.

The maximum program is a large-scale study, based on paid high-resolution imagery and field works. Implementation of this program will provide opportunity to make the elaborated methodology more complex and accurate, including more indicative parameters of ecosystem health, exploring the territory in details. However, working on a large scale, is realistically to assess only a small selected areas (the "case studies").

3. Material and methods

3.1 Study areas

The study will be implemented for selected parts of the following Environmental corridors:

- Corredor Central da Mata Atlântica or Corredor da Serra do Mar
- Corredor do Cerrado or Corredor Cerrado-Pantanal;
- One of the following: Corredor Norte da Amazônia; Corredor Central da Amazônia; Corredor Leste da Amazônia; Corredor Oeste da Amazônia;

The choice of environmental corridors or theirs specific parts for investigation will be done before the start of the project. The choice will be driven with the possibility of high-resolution imagery acquisition. Priority will be given to the regions where that imagery can be obtained gratis. At the same time, the choice will be related with the research interests of the scientific groups, in cooperation with which the project will be implemented. Priority will be given to the regions, where the appropriate researches are already underway and regions having data of the past studies, which we can use in our investigation.

3.2 Types of data

We intend to explore the ecosystem health based on three types of data:

Remote sensing imagery, which includes the orbit satellite imagery, the aircraft imagery and the UAV[1] imagery. It can be multispectral and hyperspectral; with low, medium and high spatial resolution; with open access (acquired gratis) and paid.

Remote sensing derivative products – are the georeferenced data (or geodata)[2], representing the ecosystem parameters as a map, produced by handling of multispectral satellite images[3]. They have low or medium spatial resolution and open access.

Field data – characteristics of ecosystem, measured in the field and their subsequent analysis in the laboratory.

The short review of those types is considered below.

3.2.1 Remote sensing imagery

The remote sensing data can be divided by a platform of shooting; by a spatial resolution of imagery; by a spectral resolution of imagery and by access to the produced data.

The platform of shooting can be orbit satellite, aircraft and unmanned aerial vehicle (UAV). Some of satellite imagery has open access (they are acquired gratis from web-archives). Others satellite imagery, all aircraft and UAV imagery require payment. Price can be rather large, it depends from the spatial resolution of data: the higher is the spatial resolution, the higher is the price for the remote sensing data. By the spatial resolution and access to data the remote sensing imagery can be divided on two groups:

- **Imagery of medium spatial resolution (15 - 100 meters per one pixel) and low spatial resolution (250-1000 meters per one pixel).** Those images have open access - they are downloaded gratis from the storage web-archives. The desired scenes (applicable by quality and date) are selected from those archives by users, some types of imagery and derivative products preliminary should be ordered. These data are used for study the large territories (from several dozen to several hundred sq. km.). We intend to use this type of data for explore the entire area of the Environmental corridors (for conduct study of a small scale).
- **Data of high spatial resolution (2.5 -10 meters per one pixel) and very high spatial resolution (0.25-1.0 meters per one pixel).** This type of data includes satellite imagery, aircraft imagery and UAV imagery. The aircraft survey must be ordered at special agency; the UAV imagery can be ordered at the operator or can be produced by the final user itself. The satellite imagery must be ordered from the archives. These data are usually requiring payment, although some of them are allowed free of charge in limited volume for scientific and educational purposes. There are a lot of remote sensing imagery of this type, several examples of those perspective for the proposed investigation are listed in the Table1.
  This type of data we intend to use for study the small sample areas within the Environmental corridors. After selection the most acceptable imagery for the project purposes will be acquired (by payment or, in finding opportunities, by application for free obtaining for the scientific purposes).

[1] UAV - is an unmanned aerial vehicle. Others names - "dron", RPA (remotely piloted aircraft). It is an aircraft without a human pilot aboard. Its flight is controlled either autonomously by onboard computers or by the remote control of a pilot on the ground or in another vehicle.

[2] Geodata or georeferenced data – are the data, having a geographical referenced (determined geographical coordinates - latitude and longitude), which can be cartographically visualized in a GIS software as a map.

[3] All known derivative products are made from the multispectral imagery. However, since the derivative products are just ready geodata which were prepared by operators, the emergence of products presenting the data of hyperspectral imagery is possible.

Also the remote sensing imagery can be divided by spectral range, number of spectral bands and interval between bands adjacent on two groups:

- **Multispectral imagery.** This class of imagery has several spectral bands (usually from 3 to 11, even though MODIS has 36 spectral bands), including the visible spectral range (0.4-0.7 μm) and spectral range outside the visible spectral range. The spectral bands may have large unequal gaps between each other and be rather broad. The major part of the Remote sensing imagery – is the multispectral imagery.

- **Hyperspectral imagery**. This class of imagery has many narrow spectral bands (from 150 to 900) which cover a part of spectral range by regular survey. The intervals between adjacent spectral bands are the same and equal to10-20 nm. Presently only a single hyperspectral satellite operates. It is the HYPERION with 30 m spatial resolution, its data are given gratis, but needed to be ordered. Also it's possible to use data of HICO hyperspectral satellite, which produced hyperspectral imagery from 2009 to 2014. However, soon are expected the launch of two satellites which will produce the hyperspectral imagery of open access – the HyspIR with 60 m spatial resolution, its launch is expected in 2015-2016; and EnMAP with 30 m spatial resolution, its launch is expected in 2018. Also is possible to use the AVIRIS aircraft hyperspectral imagery of high resolution (from 4 to 20 m). It can give a lot of possibilities for study, however each flying line is need to be ordered and algorithm of obtaining the AVIRIS images for necessary territories can be rather complicated and expensive. The satellite and aircraft imagery, which perspective to use in the proposed investigation, are presented on the Table 1.

The most of the researched based on remote sensing data were implemented on multispectral imagery (predominantly by medium and low spatial resolution because of the open access of those data).

The hyperspectral imagery have spectral range smaller, than multispectral imagery: only 0.4 - 2.5 μm (Visible, NIR and SWIR spectral zones). However, inside this spectral range, they have a multitude (from 200 to 900) spectral bands producing images of surface with equal small interval between each other. This allows to obtain the detailed spectral curves of each object on surface within the 0.4 - 2.5 μm spectral range.

The exact schedules of spectral curves make it possible to conduct a spectroscopic analysis of the surface and through it to determine the number of ecosystem characteristics that cannot be detected by multispectral images or by any other methods (except of labour intensive and expensive field research, which can give more accurate results but only for small areas). The detection of the precise spectral curves of superficial objects is the main advantage of hyperspectral imagery, which is widely used for explore the environmental conditions.

The use of hyperspectral data, due to their high potential in identifying the accurate information of the Earth's surface (which cannot be identified for large areas in any other way), is intensively developing in the world. They attract professionals of different spheres. These technologies are especially important for environmental researches and practice activity, in particularly for ecosystem restoration and conservation; for sustainable agriculture, animal husbandry and forestry. We intend to use the large experience of the hyperspectral data application in our investigation.

3.2.2 Remote sensing derivative products

The main difference between remote sensing imagery and derivative products is that derivative products present ready georeferenced data prepared by specialists, while imagery present raw or quasi raw[4] data of surface survey. They are given to final users as a package of all images taken in different spectral bands and a text file with data description. To detect the surface characteristic from the raw remote sensing imagery, it is necessary to process it by special complicated methodologies and algorithms in specialized software. For this reason, the use of derivative products is much easier, than raw imagery. However, their diverse is small, and spatial resolution is always middle or low. To obtain comprehensive surface characteristics and working with in high spatial resolution, it is necessary to process the remote sensing raw data independently.

The remote sensing derivative products can be divided on two types.

The first type of derivative products is the result of standard processing of a raw satellite image, presenting the revealed parameter of environment as map. This standard processing of the raw data includes several corrections of the raw images and subsequent operation with scenes obtained by different spectral bands. This operation can be implemented by each user independently, because all raw data of satellite image (i.e. a package of scenes obtained by various spectral bands and metadata with description) are located in open access and can be obtained by everybody. Because of complexity of processing and necessity of special knowledge, many people prefer to use ready derivative product, prepared by specialists, instead of prepare them by themselves. However, a diversity of those products is not large, and many of environmental characteristics is necessary to obtained by processing of the raw satellite imagery. The derivative products perspective for the proposed investigation are presented in the Table1, these are the MODIS and ASTER products.

The second type of derivative products is the result of much more complicated processing of the raw data, frequently basing on several types of satellite images and field studies. A technique of creation of these products is the result of scientific work of specific research teams. For this reason, an ordinary user cannot replicate it on their own, but can only use the data themselves.

The derivative products of this type representing data for tropical region and perspective for our investigation are presented in the Table 1. These are the GEOCARBON; Pan-tropical Forest Carbon Mapped with Satellite and Field Observations; Carbon Storage in Tropical Forests.

3.2.3 Field data

Remote sensing imagery allow studying large areas, therefore they give information about the surface, which cannot be obtained by field research. However, field methods can give more accurate and diverse results for small areas. Combination of remote sensing and field approaches is widely used for scientific and practical purposes of environmental studies. We intend to use this combination in proposed investigation in the second stage of project implementation. The preliminary list of field observations that we intend to conduct is the following:

1. Manual measurement of spectral curves of selected plant species for subsequent identification of the same species on a high resolution hyperspectral imagery of the studied area. Measurements will be carried out by spectrograph device directly in the field or in a laboratory on fresh samples collected in the field.
2. Making high resolution multispectral and hyperspectral images of the studied areas by dint of UAV device.
3. Counting the approximate number of species of specific groups of organisms within parcels of transects to assess the level of biodiversity of the studied area (trees, herbaceous plants,

[4] The most of recent satellite images passed several corrections and only after that are given to final users. But the first (ancient) satellite imagery are stored in the archives as almost raw data without any correction and other processing.

maybe some mammal families). The calculation will be based on detection and calculation the different morphological types of organisms of selected groups.

4. Measurement of the following parameters of trees indicating the forest health:
   a. Perimeter of all trees measured at a height of 130 cm above the ground (PAP);
   b. Basal area (in percents from the area of a parcel);
   c. Percentage of trees with diameter measured at a height of 130 cm above the ground bigger than 20 cm. Or the distribution of the various diameters of trees within the transects.

5. Detection of vegetation and soil characteristics of the studied areas for verification of the remote sensing data revealing the same characteristics (and, at the same time, the biological indicators of ecosystem health):

   a. Identification of the chemical elements indicating of ecosystem health in the samples of soil and vegetation of the studied area.
   b. Soil moisture measurement.
   c. Surface temperature measurement
   d. Biomass measurement (weighing plant mass) in the spatial unit of the studied area. (?)

To realize the technologically complicated field work we will seek collaboration with the other research groups doing the similar work - for learning methodologies and, probably for use of their equipment. Also we will seek the published data about conducted investigations, which we can use in our research objectives.

3.3 Possibilities of remote sensing technologies in revealing of the environment characteristics, which can be used as indicators of ecosystem health

The preliminary review of indicators of ecosystem health, the character of their work as indicators and those data of remote sensing, which can identify them, is considered below and in the Table 2. The review presents the technical frame of the proposed investigation. The basis of the review is the scientific publications and materials of specialized Internet resources (websites of data producers and geotechnical communities). The review includes only perspective for the proposed research and the tropical region information.

The ecosystem parameters detected or estimated by the remote sensing data can be divided by the following groups (Table 2):

Surface temperature

The surface temperature in rainforest biome is directly correlates with the health of rainforest ecosystem. In general the smaller is the surface temperature, the better is the ecosystem health; the higher is the surface temperature - the worse is the ecosystem health. It caused by several interrelated factors, changing the temperature inside the forest (exactly this temperature is detected by the satellite image[5]). Those factors are: *shading* (the better is the health of rainforest ecosystem, the stronger is the effect of shading inside it and the greater the shaded area, and, consequently, the smaller should be the temperature inside the rainforest); and *soil moisture* (the better is the health of rainforest ecosystem, the moister should be the soil, the smaller should be the temperature inside the rainforest). For this reason, a *hot spot* (areas of increased surface temperature in compare with lands adjacent) - can indicate a local damage of ecosystem, which can be caused by logging, disease, fire and buildings. In contrary, a cold spot on a territory can means, that on its area

[5] For areas covered with dense vegetations, the thermal bands of satellite images register the temperature of vegetation cover. For areas devoid of plants, thermal bands show the soil temperature.

was formed especially advantageous conditions for forest recovery or conservation. If this founding will be confirmed by other studies, we can conclude, that the technology of forest restoration or conservation used on this area was effective and its experience should be used in future work.

In young forest planting a decrease of surface temperature can indicate means a favorable growth of young forest (since the shading and water retention are growing). The increase of surface temperature, the hot spots most likely indicate problems, deterioration of health, probably caused by death or illness of the young forest.

Therefore a thermal analysis (in conjunction with other studies) can be very important in assessing the growth of young forest and testing of new methodologies for forest restoration.

Soil moisture

Soil moisture is an important direct indicator of ecosystem health in both rainforest and cerrado biomes and young forest planting: the moister is the soil, the better is the health of ecosystem; the drier is the soil, the more degraded is the ecosystem. The reason of it is that vegetation retains moisture in the soil that comes with precipitation, it includes it in his circuit, reduces evaporation and leakage into groundwater. (Sánchez et al. 2014; Pietroniro and Toyra, 2005)

Vegetation indices

Vegetation indices of image are the result of specific mathematical operations between values (Digital numbers) registered for each pixel by different spectral bands between Red and Near Infra Red spectral range. The use of vegetation indices allows to reveal some information about vegetation cover. The equation of vegetation indices and their interpretation are based on a reflective properties of plants and reflective properties of open soil, they were obtained and confirmed empirically. The vegetation characteristics revealed by vegetation indices have a great potential for the proposed methodology, as powerful indicators of ecosystem health. (Srinivas at al, 1998; Huete and Justice, 1999)

Chemical composition of leaf and canopy

The remote sensing data of high spectral resolution and imaging spectroscopy can be used for estimation of leaf and canopy chemical properties. Numerous leaf-level spectral reflectance studies have demonstrated connections to a variety of foliar characteristics, including N, chlorophyll, carotenoids, water, and even specific leaf area SLA (Asner and Martin, 2008). The content of nutrients such as nitrogen (N) and phosphorus (P) in chemical composition of leaf are central to revealing plant and whole ecosystem function and health. Others leaf properties are important for this purpose are water content, pigments such as chlorophylls, carotenoids and anthocyanins, and SLA.

This direction has a great potential for the proposed methodology, as powerful indicators of ecosystem function and health, revealing by the remote sensing data. We intend to study it in details and apply to estimation of ecosystem health. (Darvishzadeh, 2008, Zhang et. Al.2015)

Morphometric parameters of trees (height, crown diameter)

The morphometric parameters of trees (height diameter of crown) – is the important indicator of rainforest biomes. Presence of trees higher than 30-40 metres with broad crown means a good health of the rainforest ecosystem - its undisturbed condition or successful result reforestation). Absence of high trees identifies a significant degradation of rainforest ecosystem (Novichikhin, 2011)

Habitat fragmentation, place of logging, forest fires and burnt areas

Assessment of habitat fragmentation and the area devoid of natural vegetation - one of the key indicators of health of natural ecosystems. This parameter can be measured by high-resolution images.

Detection places of illegal logging (fresh and old), points of forest fires and burnt areas are also important diagnostic parameters for estimation the ecosystem health.

Biodiversity of plant species, phenological variation

Were developed several methods, allowing to estimate the number of plant species and phenological variation in studied area from the remote sensing data. Some of them were carried out in tropical forests. The number of natural plant species is a key indicator of health in all tropical ecosystems. The higher is diversity of natural plant species, the higher is the ecosystem health. Analysis of phenological variation can help to estimate the extent of difference in plant species composition between standard ecosystem and studied area (Carlson et al. 2007; Nagendra et al. 2010; Saini et al. 2014).

Parameters of plant biomass and carbon cycle

All parameters of plant biomass and carbon cycle are very important for estimation the ecosystem health. In general, the higher is the value of LAI, FPAR, Above-ground biomass, Carbon flux, photosynthetic productivity (Table 2), the higher is the health of tropical ecosystem. For clarity the value of these parameters can be compared with their value in standard ecosystems (Langnera et al. 2012).

Detection of technogenic pollution

Detection of technogenic pollution on land and water objects also can be important factor of ecosystem health. More frequently it can indicate the local problem, thus this possibility is very important for the regular monitoring of ecological corridor area.

3.4 Data processing and analysis

For each stage of the project implementation will be analyzed its own list of ecosystem parameters (indicators of ecosystem health), which will be revealed from its own list of remote sensing data. The general algorithm of the both stages implementation is considered below.

Steps of the minimum program implementation (the first stage of the project)

3.4.1 The ecosystem characteristics, which can work as biological indicators of ecosystem health and, at the same time, which can be revealed or estimated by dint of remote sensing data will be selected. Each perspective direction from the preliminary review of those indicators (Table 2) will be studied in details and applied in practice in the steps considered below.

3.4.2 The intact or weakly disturbed natural area with ideal or quasi ideal ecosystem health (which can serve the “standard” ecosystem) will be found for each type of ecosystem, included in the studied environmental corridors.

3.4.3 The remote sensing data, required for the first stage implementation, will be selected and download from Internet sources (Table 1).

3.4.4 The spatial analysis of ecosystem health of the entire area of selected parts of environmental corridors will be implemented. For this purpose the ecosystem characteristics (i.e.

the biological indicators of ecosystem health determined in the first step) will be revealed for the studied areas and for the “standard” ecosystem. Then, the obtained results of identical set of measures will be compared between each other. In general we will assume, that the greater will be the difference between values of parameters in studied areas and in the “standard" ecosystem, the worse the health of the studied area will be (i.e. the stronger will be its level of degradation).

3.4.5 The temporal analyses of changes in ecosystem health since the year of environmental corridor establishment will be implemented. For this purpose the set of indicators of ecosystem health will be reveled from the series of satellite images, made in the period from the year of environmental corridor foundation to present times. Basing on the obtained data, the compare of ecosystems condition in different years will be implemented, the maps and plot of the temporal changes of ecosystem health will be constructed and analyzed.

Steps of the maximum program implementation (the second stage of the project)

3.4.6 Will be specified the ecosystem characteristics, which can work as the biological indicators of ecosystem health and, at the same time, which can be revealed or estimated by dint of remote sensing data in combination with field measurements. Each perspective direction from the preliminary review will be studied in details and applied in practice in the steps considered below.

3.4.7 The intact or weakly disturbed natural area with ideal or quasi ideal ecosystem health (which can serve the “standard” area) will be found for each case study.

3.4.8 The remote sensing data, required for the second stage implementation, will be purchased.

3.4.9 The case studies implementation. The list of goals considered above in the item 2.3.3 "Specific goals for the second general objective" will be realized.

3.4.10 A report with analyses will be prepared, including GIS maps and recommendations for managements plans of studied protected areas. A Web-GIS platform of open access will be created where all important cartographical and imagery data will be placed.

4. Expected results

We expect that the result of our work will be elaboration of methodology allowing a comprehensive estimation of ecosystems health in rainforest and cerrado biomes; and the results of assessment of ecosystem health in selected environmental corridors by means of elaborated methodology.

We intend to publish the achieved results in appropriate international peer reviewed journals. We expect that our results can be published on topics (i) methods of tropical ecosystems restoration, (ii) methods and techniques of remote sensing for the environmental study; (iii) description of the specific situation of conservation and restoration of cerrado and rainforest biomes in selected ecological corridors.

Another important expected result of our work is a Web-GIS platform of open access. There we will place the cartographical and imagery material prepared during the project implementation as georeferenced data with attribute tables containing data description. In future this Web-GIS platform can be applied in different scientific, educational and management objectives by various people. Also this platform can gain a subsequent development, as a collective Online Web GIS platform devoted to collective collection of different information about the nature of ecological corridors and their protected areas. For example by this manner will be possible to collect and cartographically visualize in Online form the data of different animal and plant species location, data of animal census, location of problem spots which need a special measures, etc).

5. Schedule

The work should be completed in four years, which accords with the Graduate Program in Ecology at the State University of Campinas.

Years	2016		2017		2018		2019	
Semesters	1º	2º	1º	2º	1º	2º	1º	2º
Minimum program implementation (first stage)								
3.4.1	X	X						
3.4.2 (with Field works)	X	X						
3.4.3	X	X						
3.4.4		X	X	X				
3.4.5		X	X	X				
Maximum program implementation (second stage)								
3.4.6			X	X	X			
3.4.7 (with Field works)			X	X	X			
3.4.8			X	X	X			
3.4.9			X	X	X	X		
Statistical Analyses, Illustrative maps construction				X	X	X		
Web-GIS platform of open access creation					X	X		
Writing the thesis					X	X	X	
Writing the papers					X	X	X	X
Defense of the thesis								X

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APPENDIX

Table 1. The remote sensing data which can be used for detection the natural ecosystem characteristics

Remote sensing imagery / Derivative product	Type	Access	Satellite / Method of data preparing	Spatial resolution (metres in 1 pixel)	Spectral range (µm)	Time interval (days)	Number of bands	Years of work	Scene size (sq km)
Landsat1, Landsat5, Landsat7, Landsat8	multispectral satellite imagery	free	Landsat1… Landsat8	15-100	0.43 - 12.51	16	from 4(L-1) to 11(L-8)	1972 - present	185 x 185
ASTER	multispectral satellite imagery	free	Terra	15-90	0.52 - 11.65	16 and less	15	2000 - present	60 x 60
ASTERGDEM v.2 Digital elevation model (DEM)	derivative product from ASTER imagery for several years	free	Terra	30	**	**	**	produced from the collection of ASTER images since 2000 to 2011	divided by tiles of 1x1 degree

AST08	derivative product from ASTER image	free	Terra	90	**	16 and less	**	2000 - present	60 x 60
MODIS	multispectral satellite imagery	free	Terra, Aqua	250m, 500m, and 1000m	0.405 - 14.385	0.5-1	36	1999, 2002 - present	1130 x 1130
MYD15A2 (Aqua), MOD15A2 (Terra)	derivative product from MODIS image	free	Terra, Aqua	1000					
MCD43A4	derivative product from MODIS image	free	Terra and Aqua (combined)	500					
MCD43B1	derivative product from MODIS image	free	Terra and Aqua (combined)	1000					
MCD43B3	derivative product from MODIS image	free	Terra and Aqua (combined)	1000					
MCD45A1	derivative product from MODIS image	free	Terra and Aqua (combined)	500					
MOD11A1,MOD11A2	derivative product from MODIS image	free	Terra	1000					
MOD13Q1, MOD13A1	derivative product from MODIS image	free	Terra	250m, 500m					
MYD13Q1	derivative product from MODIS image	free	Aqua	250					
MOD44A	derivative product from MODIS image	free	Terra	250					
MOD44B	derivative product from MODIS image	free	Terra	250					

MYD17A2	derivative product from MODIS image	free	Aqua	1000					
GEOCARBON	derivative product consists from set of data	free		1000				2011 - 2014	
Pan-tropical Forest Carbon Mapped with Satellite and Field Observations Project of Woods Hole Research Centre	derivative product from set of different data	free	Method: Field + LiDAR(GLAS) + MODIS	500				2010	
Carbon Storage in Tropical Forests Project of NASA	derivative product from set of different data	free	Method: Lidar (GLAS) + spatial imagery (MODIS, SRTM, QSCAT) + Inventory plots	1000				2000	
HYPERION	hyperspectral satellite imagery	free	The National Aeronautics and Space Administration EO-1 satellite	30	0.4 - 2.5 (220 spectral bands)		220	2001 - present	7.5 x 100

HICO	hyperspectral satellite imagery	free	International Space Station (ISS)	90	0.35-1.079 more accurate: 0.4-0.896)	3	128	2009 (Sep) - 2014 (Sep)	42 x 192
AVIRIS	hyperspectral aircraft imagery	Flight line is ordered. Graduate student may receive one AVIRIS flight line per year for graduate research at no cost		from 4 to 20	0.4 - 2.5		224		
EnMAP	hyperspectral satellite imagery	free		30	0.42 - 0.1 (VNIR) 0.9 - 2.45 (SWIR)	4		will be launched in 2018	
HyspIR NOT LAUNCHED YET	hyperspectral satellite mission	free		60	0.38 - 2.5 (VSWIR) in 10 nm contiguous bands; 3.0 - 12.0 (TIR)	19 days (SWIR) 5 days (TIR)		will be launched in 2015-2016	

ECOSTRESS NOT LAUNCHED YET	hyperspectral satellite mission (part of HyspIR)	free		100 or less (69 x 38)	8-12.5			will be launched in 2015-2016	
DigitalGlobe True-color imagery in Online form through the "Add Basemap" option of ArcGIS	The true-color band composition of very high resolution accessible by ArcGIS	Free required licence of ArcGIS		about 1 m	A single true-colour image created from red, green and blue bands of visible spectrum (0.3-0.7 µm)				
SPOT1..SPOT7		paid		Panchromatic : 1.5 - 10 m Multispectral : 6 - 20 m	Panchromatic : 0.45 – 0.745 µm Infrared: 0.760 – 0.89 µm			1986 - present	
GeoEye, IKONOS, QuickBird EROS, WorldView and others		paid		0.3- 4	Visible, Infrared 0.45-0.9				
LIDAR		paid							

Table 2. The environmental characteristics, detected by the remote sensing data, which can be used as indicators of ecosystem health

Parameter of surface, detected by the remote sensing data, which can be used as indicator of ecosystem health	Definition of indicator	How the indicator works Rainforest, Cerrado, Young forest planting	Type of remote sensing imagery
Derivative characteristics of heating solar			
Surface temperature; Soil temperature on open areas	On the open areas (without plants) it represents the surface temperature; On the areas covered with plants it shoes the surface temperature inside the vegetation cover (in forest - inside forest canopy)	In Rainforest: the smaller is the surface temperature, the better is the ecosystem health; the higher is the surface temperature - the worse is the ecosystem health. In Young forest planting: the same. In Cerrado: probably the same or use the compare with the conditions in "standard" ecosystem.	Multispectral imagery (thermal bands)
Contrast of surface temperature between area adjacent	The difference between surface temperature of adjacent pixels of image	This parameter can be used in combination with other parameters	Multispectral imagery (thermal bands)
Albedo coefficient (*)	**Albedo** – is a reflection coefficient or reflectivity of the surface, measured from "0" (no reflection) that is typical for the perfectly black surface to "1" – is a complete reflection of perfectly white surface. The smaller is the value of albedo of the surface, the less this surface reflects the solar radiation incoming to it, and therefore the more it heats up itself and air above it due to the absorption of the solar radiation.	This parameter can be used in combination with other parameters	Multispectral imagery (thermal bands)
Hot spots, cold spots of surface temperature	Spot of increased and decreased surface temperature in compare with the area adjacent	The hotspots indicate the local decrease of ecosystem health, they may require a special set of regenerative measures. It can be illegal logging, construction, ploughland, forest disease, fresh fire or burnt place. In Young forest planting it could mean	Multispectral imagery (thermal bands)

		the death of the young plants or their disease	
Soil characteristics			
Soil moisture	Estimation of soil moisture	In Rainforest the wetter the soil, the higher is the health of ecosystem. In Cerrado: probably the same, bit it is require to compare with soil moisture in standard ecosystem.	1.Multispectral imagery (thermal bands). 2.Hyperspectral imagery.
The optical, thermal and dielectric properties of soil		The possibility as indicator is need to be studied	1. Multispectral imagery (thermal bands) 2.Hyperspectral imagery.
Extent of soil degradation and landscape instability (soil erosion, soil crusting and compaction, soil salinization, soil alkalinization, desertification)		Remote sensing data allow to estimate these critical parameters of ecosystem health.	1.Multispectral imagery 2.Hyperspectral imagery
Vegetation characteristics			
Vegetation indices (NDVI and others)	Vegetation indices - are the derived empirically. Result of mathematical operations with different spectral bands of origin image, revealing some information of vegetation cover.	Each vegetation index has its own scale of values and interpretations of these values, describing the properties of vegetation	Multispectral (Visual, NIR bands)
Phenological variation of tree species in different season		1) Phonological variation of tree species in different season can be used for identification of predominant tree species; 2)The compare of phonological variation in different season with standard ecosystem can help to estimate the level of deviation from standard ecosystem	Hyperspectral imagery

Chemical composition of leaf and canopy	Leaf nutrients such as nitrogen (N) and phosphorus (P) are central to revealing plant and whole ecosystem function and health. Others leaf properties are important for this purpose are water content, pigments such as chlorophylls, carotenoids and anthocyanins, and specific leaf area (SLA). Leaf water is an important factor regulating canopy temperature and moisture stress, both of which are particularly acute in tropical forest canopies. Pigments are fundamental determinants of light capture and utilization, and they provide protection against the harmful effects of high radiation, which is also common in the tropics. SLA is a leaf structural property linked to the entire constellation of foliar chemicals and photosynthetic processes.	Each key chemical element need to be compared with its content in standard ecosystem.	Hyperspectral imagery
Leaf and branch spectral reflectance	Leaf-scale reflectance spectra are controlled by **1) leaf biochemical properties** (e.g., water, photosynthetic pigments, structural carbohydrates), which create wave length specific absorption features; **2) leaf morphology** (e.g., cell-wall thickness, air spaces, cuticle wax), which affects photon scattering	By Leaf spectral reflectance will be possible to estimate the leaf biochemical and morphology properties. The precise possible methods of those analyses are need to be studied.	Hyperspectral imagery
Biological diversity of plant species		In general, the higher is the biological diversity of native plant species, the higher is the health of ecosystem. However, we should to consider, that existence of invasive plant species indicate of serious decrease of ecosystem health. Most likely this parameter can be determined only in field study.	Hyperspectral imagery

Types of wetlands identification wetland mapping			1.Multispectral imagery 2.Hyperspectral imagery
Vegetation type			1.Multispectral imagery 2.Hyperspectral imagery
Quantifying agricultural crops			
For forests			
Extent of forest fragmentation			Multispectral imagery (of high or middle spatial resolution
Extent of deforestation			Multispectral imagery
Diameter of crowns, altitude of trees (for both parameters - for trees within forest and lonely standing)		In Rainforest the presence of high trees (50-70 m) with crown of large diameter - indicates the high health of ecosystem. The absence of those trees - indicates of significant degradation and low health of ecosystem. In Cerrado it is require to compare with standard ecosystem.	Multispectral imagery of high resolution
Predominant species composition (will not for tropical healthy areas, but probably can work on degraded forest areas)			1.Multispectral imagery 2.Hyperspectral imagery
Extent of vegetation health for known type of vegetation			1.Multispectral imagery 2.Hyperspectral imagery
Detection places of illegal logging (fresh and old), points of forest fires and burnt areas.			Multispectral imagery (of high and middle spatial resolution)
Parameters of plant biomass and carbon cycle			
Leaf Area Index (LAI)	LAI is defined as the one-sided green leaf area per unit ground area in broadleaf canopies and as half the total needle surface area per unit ground area in coniferous canopies.	LAI can be used to measure the activities (photosynthesis, transpiration, and evapotranspiration) and the production of plant ecosystems Leaf area index (LAI) has been one of the most useful and important parameters to characterize the vegetation activities from local to global scales.	1.Multispectral imagery 2.Hyperspectral imagery

Fractional Photosynthetically Active Radiation (FPAR)	FRAR is the fraction of photosynthetically active radiation (400-700 nm) absorbed by green vegetation.		1.Multispectral imagery 2.Hyperspectral imagery
Above-ground biomass (C/ha)	kg of carbon per hectare	The higher Above-ground biomass the higher health of ecosystem or planting	1.Hyperspectral imagery 2. Derivative products of remote sensing imagery
Carbon flux	**Carbon flux**- is the photosynthetic and respiratory activity of terrestrial ecosystems		1.Hyperspectral imagery 2. Derivative products of remote sensing imagery
Photosynthetic rate or photosynthetic productivity (связь с carbon flux)		The higher photosynthetic productivity the higher health of ecosystem or planting	
Human activitiies			
Detection of technogenic pollution on land and sea.			