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BRIDGING REMOTE SENSING AND LANDSCAPE ECOLOGY

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Abstract: *Landscape ecology is a highly interdisciplinary science of studying the interactions between organisms and their relationships with the environmental conditions and processes. Landscape ecology findings are a core prerequisite for ecosystems conservation and biodiversity preservation. The goal of our paper is to present key considerations on using remote sensing as a means of landscape surveys and to acknowledge the importance of incorporating multisource and multitemporal remotely sensed data into ecological analyses.*

СВЪРЗВАЩИ ЗВЕНА МЕЖДУ ДИСТАНЦИОННИТЕ МЕТОДИ И ЛАНДШАФТНАТА ЕКОЛОГИЯ

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Резюме: *Ландшафтната екология е интердисциплинарна наука, изучаваща взаимодействията между организмите и връзката им с условията на околната среда. Резултатите от изследване на протичащите процеси са условие и научна основа за оценка, стопанисване, опазване и възстановяване на природните ресурси и биоразнообразието. Целта на настоящата работа е да изнъкне тези особености на дистанционно получаваните данни, които тясно свързват дистанционните метоид със съвременните ландшафтно-екологични изследвания. Изложена е систематизирана концепция относно предопоставките за използване на дистанционните методи в ландшафтната екология и новите възможности, които дават при екологичните анализи.*

Introduction

Landscapes can be defined as areas that are spatially heterogeneous, and therefore landscape ecology approaches can be applied at various scales to a wide range of different environments including terrestrial, aquatic and marine systems. Landscape ecology is a highly interdisciplinary science of studying the interactions between organisms and their relationships with the environment conditions and processes. It focuses on understanding the origin, extent, and ecological consequence of spatial heterogeneity across different scales. The findings of this discipline are a core prerequisite for ecosystems conservation and biodiversity preservation. Major research themes for terrain information extraction include landscape structure, spatial arrangement of habitat patches, interactions among the elements of landscape patterns, assessment of ecosystem changes over space and time, evaluation of disturbance effects, and landscape sustainable management.

A landscape encompasses a mosaic of land-cover and land-use types that are dynamic, as are the relationships and precesses that connect them. Landscape-scale measurement approaches should deal with spatially and biologically diverse areas and account for multiple interactions. Data are needed from large areas, often for multiple points in time, and the collection of these data can be expensive and time consuming. Such data, however, are readily provided by remote sensing observations. Remote sensing, the technology of obtaining information via noncontact recording, has swept the fields of ecology, biodiversity and conservation due to the fact that it is a landscape-relevant method that takes into account multiple land cover and land-use categories especyally when dealing with heterogeneous areas. Remote sensing provides consistent long-term Earth observation data at scales from the local to the global domain. The natural features and physical state of a landscape are obtained through object classification of aerial and satellite images. Multitemporal remotely sensed data provide the ability for consistent measurements of landscape condition and allow detection of both abrupt changes and slow trends over time. Deriving environmental change indicators is a main focus of landscape ecology studies.

In fact, the development of landscape ecology as a discipline has been particularly stimulated by the technological developments in remote sensing whose origins lie in aerial photography. Remote sensing data helps to map and study vegetation types, species composition and distribution, the status and seasonal variation of vegetative cover, and human interventions at fine to coarse spatial scales. Thus, remote sensing proves to be a very effective tool to analyze landscape-level elements and characterize biodiversity. It is a key technology for quantifying landscape patterns and processes in the twenty-first century.

The goal of our psper is to summarize key considerations on using remote sensing as a means of landscape ecology surveys and to acknowledge the importance of incorporating multispectral, multisource and multitemporal remotely sensed data into ecological landscape analysis. The basic concepts underlying the ecological remote sensing applications are discussed with emphhsis on the ability of these technologies to map, measure, track and understand ecological changes and interactions. The grounds for integrating remote sensing data into landscape inventories are highlighted.

Conceptual considerations

Remote sensing application in landscape ecology is a complex issue and all its aspects can hardly be considered in a single paper. This section presents some insight into the relationship of landscape ecology with remote sensing. The main crosspoints and bridging elements between both disciplined are identified and discussed. The acknowledgment of these crosspoints is very important since they justify the ecological applications of remotely sensed data and determine the methods used for infirmation retrieval.

Ecological monitoring and management require detailed information over broad spatial scales. Historically, such information was often acquired through interpretation of aerial photographs. Aerial photography to studies of interactions between environment and vegetation was the starting point for Carl Troll to developed the terminology and many early concepts of landscape ecology. Despite the many advantages of aerial photographs [1], there are specific challenges for using them, especially with respect to manual interpretation and traditional aerial photograph analysis. The rapid and excessive spread of satellite imagery over the past few decades has influenced the use and perceived utility of aerial photography. Satellite imagery, with its broad spatial coverage and regular revisit possibilities, has provided researchers and recource managers with a cost-effective alternative to aerial photography. This alternative has contributed to a shift in emphasis of spatial analysts away from aerial photographs and more toward digital platforms. One important development associated with the recent emphasis on satellite imagery, has been the advent of a wide range of digital image analysis techniques [2. 3].

The dissemination of landscape ecology studies intensified starting in the 1980s, a period that coincided with the significant development of geospatial analysis [4]. A key point for the increase in research studies in the field with the use of satellite imagery was the launch of multispectral and hyperspectral sensors onboard LANDSAT, NOAA, SPOT, ASTER, IKONOS, MODIS, QUICKBIRD, EROS, and other satellites. Hyperspectral data provided new possibilities to detect subtle differences between objects and discriminate species-specific land covers such as vegetation categories or soil types [3, 5]. These fine-scale classification possibilities made remarkable contribution to studies regarding biodiversity patterns. Moreover, hyperspectral data have been successfully applied in recording information about critical plant properties (e.g., leaf pigment, water content, bimass, and etc.), discriminating tree species and assessing stand structure, and fairly accurate identification between different species. Image data used for landcover analysis are multisensor (ASTER, Geoeye, Ikonos, MODIS, Hyperion, CHRIS, PROBA and etc.) Also thermal and lidar measurements [6] are applied for quantifying habitat heterogeneity and as predictor variables of habitat quality.

The interpretation of data generated from a varirety of passive (radiometers, spectrometers) and active (radar, lidar) remote sensors has matured as facilitated by the development of a rich set of analytical tools that go well beyond traditional cartographic products. Recent technical advances related to innovative remote sensing methods and products including hyperspectral sensing, multi-angle viewing, and imaging radar add new value to remote sensing applications in landscape ecology. The use of multisensor imagery has become increasingly common in late years, the particular advantages of these data being their digital format, the repeated and large scale coverage and the prospect of monitoring landscape change. Data derived from satellite images are easy to integrate with other data sources for planning purposes. Satellite Earth observation sensors provide unique measurements of geophysical and biospheric variables, and associated processes, regionally or globally and repetitively. These measurements are all the more critical because the Earth as a system changes constantly over a wide range of temporal and spatial scales. The analysis of remote sensing imagery before, during and after a natural or man-made ecological disturbance occurs, allows predicting and measuring the location, extent and the impact of the incident on the physical environment. In contrast to exclusively focussing on the state of the landscape at a single point in time it allows to draw conclusions from multiple temporal stages. Remote sensing is now a fundamental tool for mapping, monitoring and management of ecosystems. Satellite images offer repeatable and quantitative assessments of habitat and environmental characteristics over spatially extensive areas. However, remote sensing and field landscape observations can successfully complement each other. In integration of Earth observation and in-situ data for landscape analysis the challenge is to be able to utilize this complementarity to the full thus strengthening the scientific and practical value of landscape ecology studies.

That the relationship between remote sensing and landscape ecology is significant is due in large part to the strong spatial component within landscape ecology. Landscape classification, quantification and monitoring need multiscale investigations which is illustrated by the fact that studies of habitats often provide different results at different scales for the same species [7-9]. Since the thematic and geometric resolution influence the results of landscape metrics analysis it is crucial that the scale of investigation and the spatial resolution of the data correspond to each other. Multiscale methods may be more informative than those based on only one scale. The availability of remote sensing data at different spatial scales (local, regional and global) meets the needs of landscape structure analysis at multiple scales. The decision about the thematic content and resolution in landscape studies depend on the aim of the investigation and the appropriate remote sensing image data should be chosen. The scale of observation and measurement is undoubtedly one of the most essential considerations to be made in remote sensing data interpretation [10] since landscape ecology addresses complex multiscale questions regarding the influence of spatial patterning on ecological processes. The issue of spatial resolution is extremely important recognizing the scale-dependent nature of environmental phenomena.

The time component (trmporal dynamics) within landscape ecology is another bridging element between remote sensing and landscape ecology. The multitemporal dimension of satellite data ensures large scale information from multiple points in time - which cannot be acquired by other means (e.g. surveying on site). The use of multitemporal measurements is consistent with the landscape ecology approach which departs from traditional approaches by focusing on the structure, function, and spatial patterns of landscape elements, as well as on changes in the landscape mosaic through time. This landscape approach fostered by the use of remote sensing data has implications for conservation planning because the total area, patchiness, connectivity of ecosystems and habitats, and the way biological and physical processes interact over multiple spatial and temporal scales, are all important for biodiversity conservation. Moreover, the spatial data, when integrated with socioeconomic data, have the potential to reveal the complex role of social and economic factors underlying change. It should be noted that airborne remote sensing may be a suitable alternative to high spatial resolution spaceborne imagery, given that the relatively low altitude of airborne platforms enables the generation of very fine spatial resolution data which increases the accuracy of characterisation of small objects.

In short, the relationship between remote sensing and landscape ecology is based on the inherent properties of remotely sensed data as it is shown in Figure 1 and Figure 2.

Fig. 1. Main elements bridging landscape ecology and remote sensing

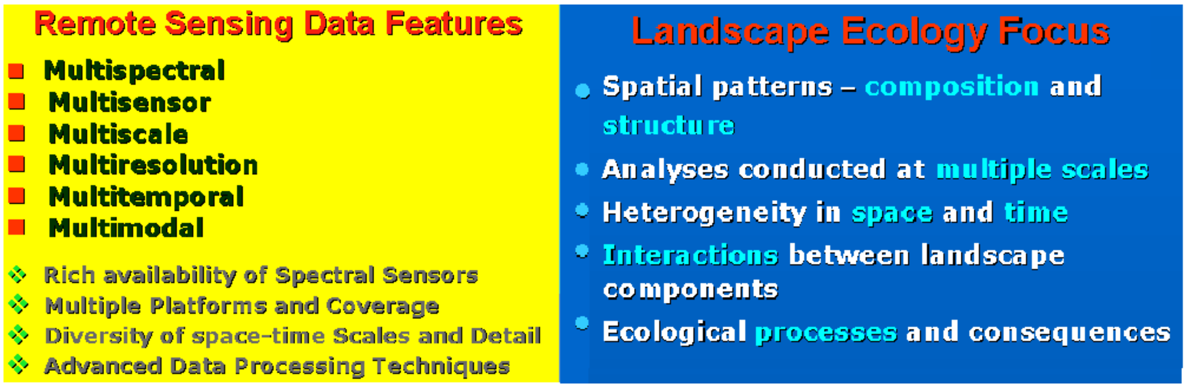


Fig. 2. Relevance of remote sensing data to landscape ecology studies

Ecological remote sensing applications address the main needs and goals of landscape ecology studies, namely the assessment of landscape composition, structure and spatio-temporal dynamics including interactions, processes, and the functional changes in the landscape. The large number and variety of landscape ecological studies and applications that use remote sensing in one way or another confirms their connectivity. This relationship expands and matures as new possibilities are explored based upon technical developments, including those represented by newly launched satellite sensors and novel data interpretation methods. Very high spatial resolution image data provide greater and more varied opportunities for spatially detailed landscape mapping. Advances in technology and decreases in cost are making remote sensing practical and attractive for use in ecological studies and landxcape management. They are also allowing researchers and managers to take a broader view of ecological patterns and processes. The use of remote sensing in landscape ecology provides a rich range of examples of the interface between remote sensing and landscape ecology.

Figure 3 presents in more detail our notion about the crosspoints between remote sensing and landscape ecology. In fact, these crosspoints reflect the dicussesed above fundamental characteristics of remote sensing data and the ecological relevance of these data.

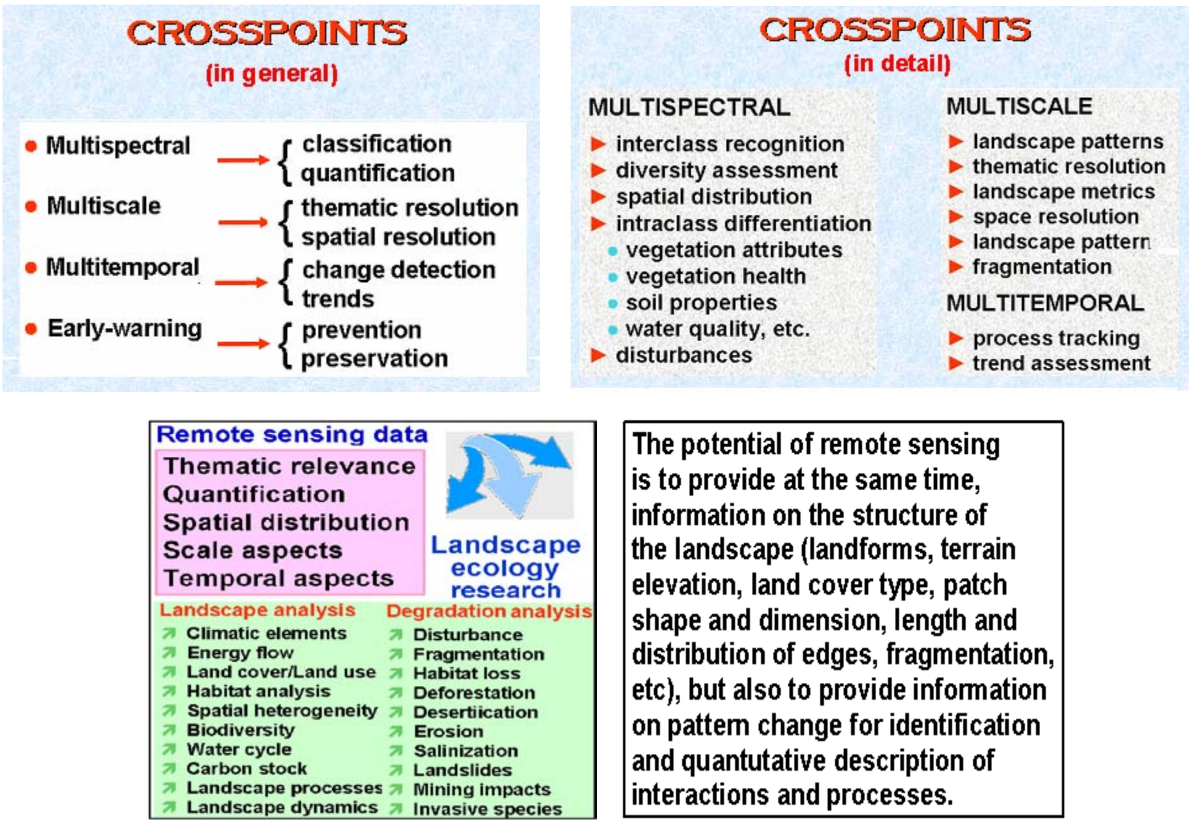


Fig. 3. Relevance of remote sensing data to landscape ecology research

The main advantages of digital satellite images that are relevant to landscape ecology research include broad spatial coverage, high spatial resolution, broad spectral range, rigorous radiometric accuracy, high temporal frequency, systematic collection, continuous change detection, all-weather operation (microwave sensors), numerous data processinsg and analysis methods developed, easily accessible (many images are free), precise and site-specific metadata easily obtained.

In general, there are two approaches of ecological remote sensing. One involves direct observation of land cover categories. Commonly, Habitats are derived from vegetation categories to retrieve the distribution of animal populations. The indirect approache involves the derivation of environmental parameters from remotely sensed images as proxies for ecological phenomena [11]. Landscape-scale quantification [12] of the physical and biological features of an area, covering both measurement and modelling, can include approaches that treat the landscape as a single unit or can include more complex approaches that simulate landscape functioning, i.e flows of nutrients, water or energy between subunits within the landscape. Dealing with the landscape as a system allows analysis to focus on hotspots, both in temporal and geographic terms. In this regard remote sensing is an inarguable landscape relevant method. Data from satellite Earth observations are hihly appropriate in implementing landscape-scale study approaches.

Implementation of remote sensing in landscape ecology studies

The basic concepts underlying the ecological applications of remote sensing are discussed above with emphhsis on the ability of these technologies to map, measure, track and understand ecological changes and interactions. The grounds for integrating remote sensing data into landscape inventories are highlighted. Our first intention was to richly illustrate the implementation **of** remote sensing in landscape ecology by case-study examples. However, the limited size of the paper did not allow doing so. Therefore, in this section we only point out the most widely spread applications of remote sensing in the field of landscape ecology. This is not an exhaustive summary of remote sensing applications in landscape ecology research but is based primarily on publications overview on the subject. Some ststistics (from review papers) on ecological remote sensing use is also presented.

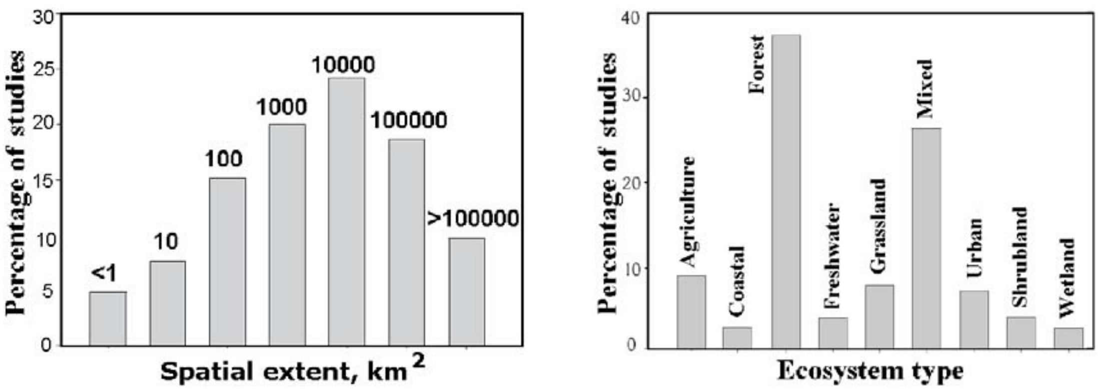
The demand for ecosystem assessment is growing rapidly as information gathering and analysis options are increasing. The focus of remote sensing data incorporation into landscape ecology studies is land cover classification, change detection, quantification of processes, and determination of the degree of landscape disturbance. Numerous publications use interpretation products of remote sensing images in the following key topics related to landscape ecology research:

- land cover/land use classification and mapping (delineation of landscape types, landscape composition and connectivity, size, shape, number, and position of patches, land mosaics heterogenity, habitat arrangement, spatial distribution and abundance of species, species richness, biological diversity, landscape topography, watershed boundaries, and etc.);
- studing relationships and interactions (between spatial patten and ecological processes, vegetation-landform-soil mosaics, landscape components and ecosystems, and etc.);
- assessment of climate variables (temperature, water vapor, rainfall and etc.), energy, nutrient and gas fluxes, heat trandfer, hydrological flows, and etc.
- retrieval of biophysical and biogeochemical variables (vegetation biomass, leaf area index, chlorophyll content, productivity, health condition, stress detection, soil properties - texture, moisture, organic content, mineral composition, forest structure and diversity, and etc.);
- landscape change detection (monitoring landscape-level environmental indicators, such as changes in the size and configuration of habitats and vegetation cover to quantitatively determine changes in ecosystems, landscape mosaics modification, harvesting of natural resources, identification and quantitative evaluation of environmental pressures and threatening processes, etc.);
- monitoring and quantification of disturbances and degradation processess (habitat quality, fragmentation and loss of habitats, deforestation, desertification, soil erosion and salinization, landslides, water quality, wildfire damage, environmental impacts of mining activity, invasive species occurance and spatial distribution, wetlands draining, and etc.);
- landscape rehabilitation monitoring (biodiversity restoration, revegatated areas, vegetation regrowth, wetland regeneration, land reclamation, rehabilitation of waterlogged and saline soils, mine rehabilitation, marine wildlife and habitat recovery after oil spills, and etc.);

Indicative statistics presented in [13] provides some measure of remote sensing use in landscape ecology research. It is based on the review of 438 research papers published in the journal Landscape Ecology (the leading scientific journal in the field) for the years 2004–2008 inclusive. It was found out that only 158 (i.e. 36%) of the studies explicitly mentioned remote sensing. Many of the rest almost two-thirds of the papers made use of geospatial data and mapping derived from remote sensing without having acknowledged this explicitly. The results of the examination in greater depth indicated that aerial photographs (orthophotos) and digital imagery acquired from sensors on board the Landsat series of satellites were the most commonly used types of imagery accounting for 46% and 42% of studies, respectively. Only 0.5% of studies made use of radar data and 2% employed multiple sources of remote sensing data.

The predominant application of remote sensing data across these studies was for thematic mapping purposes focusing on the use of landcover maps as a basis for analysing landscape pattern or spatial structure. This suggested that landscape ecologists were rather conservative in their use of remote sensing data and relatively slow to recognize the potential value of recent developments in remote sensing technologies. In approximately 14% of the examined studies, remotely sensed data were used as input to some kind of environmental models, and very few studies (approximately 3%) were explicitly designed to develop or refine, for example, the development of new approaches to image analysis and classification. A particularly surprising finding was how few studies had employed very high spatial resolution digital image data from spaceborne platforms, such as QuickBird and Ikonos, offering imagery with spatial resolutions of less than 5 m.

Regarding scale aspects, investigations were undertaken at a wide range of scales, ranging from site-based studies of less than 1 km^2 in extent to regional or national-scale investigations. The spatial extent of about 1000–10000 km^2, was the most common. A small number of studies (<5%) were undertaken at a range of scales, with the objective of comparing results obtained at different scales. These findings are illustrated by Figure 4a. With respect to types of landcovers examined, around a quarter (26%) of the studies were undertaken in areas where no single ecosystem type predominated. Figure 4b presents the different landcover types examined in the above mentioned 158 research publications that employed remote sensing imagery. The majority of studies examined one ecosystem type in particular, of which forest was the most common, accounting for 37% of the studies. Many ecosystem types, such as coastal or marine, wetland or freshwater, were poorly represented within the sample of publications, each accounting for ≤4%.



a) b)

Fig. 4. Predominant spatial extent (a) and ecosystem type (b) in landscape ecology studies using remote sensing [13]

We have to point out, however, that the sample of publications considered above is biased, having focused on a single journal over a restricted time period. Both remote sensing and landscape ecology now fall within the scope of a great many journals. Other journals might have provided a very different set of results. For instance, a great number of papers published in journals with a specific focus on remote sensing (such as Remote Sensing of Environment, International Journal of Remote Sensing, IEEE Transactions on Geoscience and Remote Sensing, International Journal of Applied Earth Observation and Geoinformation, and others) tend to be associated with emphasis not on only technical aspects of data processing but particularly on image analysis for deriving environmental and ecological information. Anyway, as suggested in [14], remote sensing specialists might better recognise the importance of ecological issues than landscape ecologists acknowlege to the full the unique capabilities of remote sensing data application to landscape ecology problems. One possible reason is that by its nature and origin remote sensing is an application-oriented discipline and as such responds to urgent research needs as those of ecology-related studies.

Conclusions

Using airborne and satellite data results in improved capabilities for landscape-scale ecosystem studies. Remote sensing technologies contribute to the main objective of landscape ecology to detect spatial and temporal changes, to identify ecological processes, and to quantify the ways in which ecosystems interact. Based on a research papers review, a conclusion is drawn in [14] that as a discipline, landscape ecology needs to engage more actively with the wide variety of remote sensing data and techniques that are already available. This may be particularly useful when the evaluation of habitat quality over a wide landscape is required. It is suggested that the role of remote sensing in landscape ecology can be strengthened by closer collaboration between researchers in borh disciplines, by greater integration of diverse remote sensing data with ecological data, and by increased recognition of the value of remote sensing beyond land-cover mapping and pattern description. Such approaches might improve the analytical and theoretical rigour of landscape ecology, and be applied usefully to issues of outstanding societal interest, such as the impacts of environmental change on biodiversity and ecosystem services.

We identify the following five ways for increasing the contribution of remote sensing to landscape ecology studies:

- expanded interdisciplinary collaboration between landscape ecologists and specialists in remote sensing for better mutual understanding of the inherent properties of remotely sensed data and the possibilities they provide for the needs of the ecological research;
- timely recognition of the new opportunities (higher accuracy, across greater spatial areas, and with greater temporal frequency) provided by advances in remote sensing technologies (platforms, sensors, data types, and analysis methods) for using the increased level of information in addressing more complex scientific questions;
- employing multiple remote sensing data sources, diverse data types and data fusion methods for obtaining more detailed and sophisticated information;
- minimization of the temporal disconnection by overcoming the time lag between the availability of new remote sensing products and their application in ecological research;
- more often integration in landscape ecology studies of field measurements, remotely sensed data, geospatial analytical tools (that go well beyond traditional cartographic products), and simulation modelling.

The intense use of satellite imagery in landscape ecology studies observed in the last decade indicates that in coming years there will be an increase in remotely sensed data incorporation into landscape surveys and analysis. The global view afforded by images obtained from many different remote sensors and at different temporal scales has become an important tool in choosing action strategies regarding the conservation and protection of ecosystems.

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