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Remote Sensing aided Monitoring of Non-Timber Forest Resources - A literature survey

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Preface

The current report is an activity within the project Scale Dependent Monitoring of Non-Timber Forest Resources Based on Indicators in various Data Sources (MNTFR), founded by the European Commission, framework IV, FAIR programme. In addition, the Swedish Research programme Remote Sensing of the Environment (RESE) has contributed as well. The aim is to provide a literature study that could serve as background and orientation for further development work that will be done in the two projects. This is the final version of the report, a slightly different version have already been delivered to EU as a first-year delivery in MNTFR.

Umeå in year 2000

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Contents

1. Introduction

Forests have traditionally been multiple use areas. However, during the last century the scientific literature on forests has been dominated by timber related issues. The non-wood forest-based resources such as recreation, biodiversity, water, wildlife habitat, range and fisheries did not gain recognition until multiple-use of forests became a renewed concept (Hytönen et al. 1995). That recognition came when the Multiple Use Sustained Yield Act (USA) was passed in 1960 which promoted sustained management of all renewable forest resources, including the non-wood ones. Another catalyst for interest in forests as non-wood resources was the 1992 Convention on Biological Diversity. These non-wood resources have been treated under different names e.g. non-wood goods and services (NWGS), non-wood benefits (Wibe 1994) that can all be regarded synonymous to non-timber forest resources (NTFR) which is the term used in the present project.

The landscape can be thought of as a hierarchically organised system (Forman and Godron 1986). In order to understand the landscape, and to be able to predict changes using this, three linkages must be known. Each landscape element is linked to the: 1) encompassing element at the next higher level; 2) nearby elements at the same scale; and 3) component elements at the next lower level. Each level in the hierarchy represents a single scale, from fine grained to coarse grained (Forman 1995).

The occurrence of resources and their distributional pattern in the landscape are to a large extent scale-dependent (Turner 1989). The same can be said about processes, although processes are usually aspects of biodiversity that are less easy to observe. With processes, the time dimension should also be included since many processes occur very slowly. In order to determine the existence of processes or NTFRs, indicators are sometimes used. Indicators work as observable substitutes for the object or process of interest, the existence for which they provide evidence.

Due to the described hierarchical nature of the landscape, the scale-dependency of monitoring and mapping resources, and the necessity to use indicators, there is a need to combine different data sources, i.e. field data, mapped information and when feasible remote sensing data. Usually when remote sensing data is used, it must be combined with a field sample with known geographical position.

The objective of the present literature review is to provide an overview of remote sensing related methods for monitoring NTFR. Our aim is not to produce a complete review of the topic, but rather to present a sample of studies that can be regarded as good representatives of what has been achieved and reported in the scientific literature. The focus is on published studies, research and operational monitoring where remote sensing has been used for monitoring of non-timber forest resources. The whole NTFR concept is considered, in the event that we find meaningful studies, but the focus falls primarily on biodiversity monitoring. The scales used in most studies are from stand (1 ha) up to landscape (100 km by 100 km) level, and using remote sensing data sources with image elements ranging from 1 to 200 m.

2. Methods

The study was done by surveying scientific literature related to remote sensing and landscape ecology. Publications thought to be valuable to MNTFR were searched for in three steps 1) by entering key words into two search engines on the web, WebSPIRS, and the Science Citation Index 2) by systematically going through a number of selected scientific journals 3) by using reference lists from publications selected in the first two steps for back-tracking cited literature. Key words included in the literature search on the web were: berries, biodiversity, biological diversity, canopy structure, edges, gap analysis, habitat, hunting, indicators, non-timber forest resources, non-timber resources, non-wood benefits, non-wood goods and services, recreation, remote sensing, satellite imagery, scale, and vegetation mapping. In step two, issues including 1997 until present were searched from the following journals: Canadian Journal of Remote Sensing; International Journal of Remote Sensing; Landscape Ecology; Remote Sensing of Environment; Scandinavian Journal of Forest Research.

When the literature had been collected they were divided into seven categories. The first category included literature that did not necessarily included remote sensing techniques. It was included to provide the topics and questions related to MNTFR. The following six categories include literature dealing with remote sensing aided mapping and monitoring of: biological diversity, GAP-analysis, habitat-species relationships, landscape planning, recreation, and vegetation.

The U.S. Gap Analysis Program is described in a separate section, and contains several issues relevant to the topics covered in this review. Because GAP is a large institutional programme which applies remote sensing for ecological purposes, has generated a large amount of recent literature, and has gained experience that is relevant for similar efforts currently under discussion in various parts of Europe, it has been more thoroughly covered in this report. A description is first presented in running text before methods and results are presented for a few selected states and applications.

Several articles could fit equally well in several categories due to the varied topics covered. However, despite the cross over of articles they are reviewed under the category decided to be most relevant.

3. Review of literature

3.1 Topics of concern in landscape ecology

This first section aims at exemplifying the areas of interest with regard to the NTFRs. It includes papers on landscape planning, forest biodiversity and the selection of indicators for biodiversity. Some of the issues and questions covered in the papers concern: size distribution and numbers of patches in the landscape; how to measure shape of patches; spatial processes in land transformations; natural disturbance regimes; the relationship between area and number of species present; the definition of biodiversity; how to measure biodiversity; what are the criteria for, and how do you select indicators for biodiversity; at what scale(s) should biodiversity be managed; how is data from different sources harmonised; how do you produce a management plan that conserve forest biodiversity?

Dudley, N. and J.P. Jeanrenaud, 1998. Needs and prospects for international co-operation in assessing forest biodiversity: An overview from WWF.
The paper gives a review of a few attempts to develop indicators of forest biodiversity. Many attempts have been made to assess biodiversity at national or even international level and indicators working at these scales are 'inevitably very general and can act only as fairly coarse filters'. Five different levels of biodiversity surveys are presented, from national, via landscape, structural, indicators to genetic level. Criteria for good indicators are presented. Birds are perhaps the most commonly used indicators. More recently, lower plant forms such as fungi, lichens and bryophytes have been used.

Key words: Biodiversity, indicators.

Fries, C, G. Lindén, and E. Nillius, 1998. The Stream Model for Ecological Landscape Planning in Non-Industrial Private Forestry.
A model for ecological landscape planning over several small private properties in northern Sweden is presented. In this northern boreal landscape, streams are regarded as very important landscape features for the conservation of biodiversity. Areas with high conservation values are normally those in which natural processes still go on, i.e. in natural and near-natural forests. The suggested model includes, among other things, the establishment of zones, with special management for biodiversity, along streams; protection of a portion of stands with natural forest features; protection of a portion of stands in which self-thinning has started; and favouring of deciduous trees.

Key words: biodiversity, boreal forest, landscape planning, streams.

Gustafson, EJ. 1998. Quantifying Landscape Spatial Pattern: What Is the State of the Art?
The article covers different aspects of landscape heterogeneity and measures thereof. It discusses the relationship between pattern and process as main issues in landscape ecology. The landscape pattern is ever changing since the landscape is a dynamic system, thus adding a temporal aspect to heterogeneity. Heterogeneity is also a function of scale, with the two factors grain and extent affecting the measures. Most landscape mapping has been conducted using thematic maps. However, there is an alternative approach using point-data to produce continuous surfaces representing the variation observed in the landscape. The author argues that with homogeneous patches there is a loss of information on the within-patch variability that is always there. Some ecological aspects are better represented by gradients than by discrete patches e.g. DEMs, climate variables and habitat suitability maps. The author acknowledges the difficulties in analyzing landscape pattern and stresses the importance of scale. At what scale does the process of interest operate, and/or at what scale does the organism(s) studied perceive the heterogeneity of the landscape?

Key words: spatial pattern, index, indices, spatial heterogeneity, patchiness, landscape ecology, scale, geostatistics, spatial models.

Kapos, V. and S.F. Iremonger, 1998. Achieving global and regional perspectives on forest biodiversity and conservation.
The article mainly deals with the urgent need for international cooperation on biodiversity monitoring. It states that the greatest difficulty is the problem of how to harmonize or make

compatible data that derive from different sources and are based on different definitions and classification systems. The conservation of biodiversity has been a priority of the international community since the Convention on Biological Diversity (CBD) was drafted in Rio in 1992.

Key words: Biodiversity, hotspots, harmonizing data.

McLaren, M.A, I.D. Thompson and J.A. Baker, 1998. Selection of vertebrate wildlife indicators for monitoring sustainable forest management in Ontario.
The criteria for selecting vertebrate indicators were applied in a hierarchical manner. In development of sustainable forests, indicator species have been used as fine filters to assess changes within ecosystems and landscapes. The criteria are of three different kinds, based on biological, methodological or status grounds. The selected species must be sensitive to changes in their habitats; the cause and effect for species declines must be well understood; selected species must represent a range of body sizes/home range sizes; a range of life history strategies should be represented (all trophic levels, year-round residents have high priority, both specialists and generalist should be included); biologically rare species should be selected; species should indicate a range of habitat types; all key stone species should be included.

Key words: indicators, scale, fine filters, criteria of indicators.

Naesset, E. 1997. Geographical information systems in long-term forest management and planning with special reference to preservation of biological diversity: a review.
The increased interest in biodiversity issues when planning the management of forest ecosystems has greatly increased the needs for information and new analysis. GIS provide some solutions. Biodiversity is measured by surrogates, such as species richness, species composition, etc. The main focus of the paper is the use of GIS in long-term forest management. Databases are established, mainly from remote sensing, and then GIS works as a bridge between the databases and management of the natural resources. Particularly raster-based GIS is very useful in combination with remotely sensed data.

Key words: Biodiversity, forest management, GIS, indicators, ASIO.

Naesset, E., T. Gobakken, and H.F. Hoen, 1997. Economic Analysis of Timber Management Practices Promoting Preservation of Biological Diversity.
A forest management model aiming at preserving biodiversity is presented. The model is based on the ASIO-concept (Angelstam and Rosenberg 1993). A forest stand map and a vegetation map were put in a GIS spatial decision support system (SDSS). No remote sensing methods were used but the authors stress the importance of landscape pattern indices that can be captured using remote sensing-techniques.

Key words: biodiversity, GIS, planning, ASIO-model, landscape indices, spatial decision support system (SDSS.)

Noss, RF. 1990. Indicators for Monitoring Biodiversity: A Hierarchical Approach.
The author stresses that biodiversity suffers from it’s vagueness and needs to be recognized as an end in itself. There is a need for measurable indicators and a validation of the relationship of those indicators and the components of biodiversity they represent. The hierarchy concept of

biodiversity suggests monitoring at multiple levels of organization, and at various spatial and temporal scales. That makes for use of remotely sensed data. In certain ecosystems, "a disturbance measure as simple as fire frequency and seasonality may be one of the best indicators of biodiversity". Noss puts emphasis on three important attributes of biodiversity- composition, structure and function.

Key words: Biodiversity, composition, structure, function, nested hierarchy, environmental monitoring, indicators.

Noss, R.F. 1999. Assessing and monitoring forest biodiversity: A suggested framework and indicators.
The article provides an overview of indicators and their use for monitoring and assessment of forest biodiversity. Remote sensing data on forest cover, worldwide, were used to identify forest blocks that meet the criteria for Frontier Forests. The author also describes the use of Landsat TM images in the US GAP-analysis program. It is stated that the main threats to forest biodiversity is simplification and fragmentation.

Key words: Forest planning, monitoring, biodiversity, indicators, GAP-analysis, Landsat TM, adaptive management.

Prendergast, J.R. 1997. Species richness covariance in higher taxa: empirical tests of the biodiversity indicator concept.
Prendergast looks into the use of higher taxa indicator species, and finds that it is highly variable, very spatially complex, and calls into question the use of biodiversity indicator taxa as a conservation tool. Using butterfly, bird and dragonfly presence data, smoothed over 10 km x 10km squares across Britain, they found that spatial variability between these taxa was very high, and inconsistent. Species richness data also appeared to not be correlated. He felt that knowledge about the correlation's of higher taxa species was not sufficient, and therefore certainly not for use as indicators, if understanding was not complete. He notes that further work to be undertaken would be to test species richness covariance of taxon subsets which are more specific to particular habitat types.

Key words: conservation, butterflies, diversity.

Schlaepfer et al. Workshop on Environmental Criteria/Indicators for the Sustainable Development of Boreal and Temperate Forests.
There is a need to develop an ecosystem perspective in forest monitoring. Research is needed to determine the value of indicators in relation to new objectives and principles that arose from the Rio Summit. A list of indicators for various aspects of biodiversity in boreal and temperate forests is suggested and important concerns when selecting indicators is presented. It is stated that *processes* are usually more sensitive indicators than *patterns*, but are also more difficult to measure.

Key words: Criteria, indicators, biodiversity, monitoring, Sustainable use.

3.2 Vegetation mapping

The following papers on remote sensing methodology focuses specifically on boreal or temperate forest mapping and estimation, generally for purposes not pertaining to timber attributes, which have used data primarily of no greater spatial resolution than 30m (although some have used AVHRR or MODIS data) and also range down to the new high resolution data. Different kinds of methods are also reviewed. Papers that have used remotely sensed data for ecological purposes, such as information on structure, age, LAI, and to capture landscape patterns are reviewed. It also reviews some relevant issues to vegetation mapping, such as accuracy assessment, and the effect of scale and aggregation.

3.2.1 Very high resolution data

Aplin, P., P.M. Atkinson, and P.J. Curran, 1997. Fine spatial resolution satellite sensors for the next decade.

Aplin, Atkinson and Curran review the fine spatial resolution satellite sensors,)including the new commersial satellites with about 1 m pixels), either in operation or planned. Twenty-five satellites, with launch dates ranging from 1974 until 2002 are reviewed, with information about mission, spectral and geometric properties, and orbital characteristics.

Key words: land-cover.

Blackburn, G.A. and E.J. Milton, 1997. An Ecological Survey of Deciduous Woodlands Using Airborne Remote Sensing and Geographical Information Systems

Blackburn and Milton have used Compact Airborne Spectrographic Imager (CASI) data to analyze information related to gaps in the canopy of a deciduous woodland area in England. The study area, which was approximately 4 km^2, consisted of oak woodland which varied in age from 300 years to recently planted stands, and also heath, grasses, and coniferous tree species. Using two dates of CASI data (July and November), and 8 spectral bands throughout the visible and near-infrared range, they compared use of a Principal Component Analysis (PCA) on single date and multi-date combinations of the data, for giving information about gaps in the canopy. They found that in a single date image, a CASI band ratio of the third PC, which represented canopy openness in deciduous woodland. In multi-date analysis, the third PC gave good vegetation type information, as well as discriminating between gaps and non-gaps. In doing an unsupervised classification of these two different types of PCA data, they found that the classification of the single date July PCA gave the highest accuracy (78%) in discriminating both the vegetation types and the gap/non-gap classes. The November date gave poor results due to shadowing in a few of the stands. Information such as gap size, gap abundance, shape of gaps, gap spacing were taken from the July classification and used to derive measures such as fragmentation index, percentage of interior canopy and amount of edge habitat. Using this information, inferences could be made regarding gap creation mechanisms, regeneration dynamics, and species diversity and distribution. It was felt that the high spatial resolution of CASI especially helped give information about gaps created by the loss of a single tree.

Keywords: forest, canopy, reflectance, vegetation, Landsat, ecosystem, index.

Wulder, M.A., E.F. LeDrew, S.E. Franklin, and M.B. Lavigne, 1998. Aerial Image Texture Information in the Estimation of Northern Deciduous and mixed wood forest leaf area index (LAI).
Wulder et al. attempted to improve estimates of Leaf Area Index (LAI) which is an important variable for models that describe the flow of energy, gas, water and other elements in the ecosystem. If methods are improved, remote sensing can be used to provide data for global modeling of canopy photosynthesis and evapo-transpiration. The study area was the Fundy Model Forest in New Brunswick, Canada, which was characterized by a complex mix of deciduous and coniferous species. They used low altitude airborne sensor data (CASI) with a 1m spatial resolution. With this data, they used empirical spectral indices in assessing the utility of vegetation indices and texture in the estimation of LAI. They explain the limitations of using the NDVI to derive LAI, which is that NDVI, as calculated from a remote, nadir-viewing platform, measures only the horizontal aspects of the forest. Yet, as vertical structure becomes more complex, LAI increases, something not readily detected from using NDVI. Texture was derived from the data, and when incorporated as a variable into statistical relationships, was found to improve the correlation between NDVI and LAI. In hardwood forest, it improved ability to estimate LAI by 20%. In heterogeneous stands, texture was a more important determinant than the spectral data in heterogeneous stands. They also found an improvement by stratifying the stands based on species type, primarily for the coniferous species, which tended to be plantations. They propose that information derived from CASI data can aid in relating subpixel characteristics to lower resolution data, such as Landsat TM.

Key words: ecosystem processes, regional applications, vegetation indexes, foliage biomass, oregon transect, stand structure, lodgepole pine, general-model, reflectance, canopy.

3.2.2. SPOT HRV

Cohen, W.B. and T.A. Spies, 1992. Estimating structural attributes of Douglas-Fir Western Hemlock forest stands from Landsat and SPOT imagery.
Cohen and Spies (1992) compared the utility of SPOT-HRV panchromatic (acquisition date June 24, 1989) to Tassled Cap indices created from multispectral Landsat TM data (acquisition date July 30, 1988) for analysis of forest structural attributes in several different ways. Regression models were used to estimate values for stand attributes, with results that both the SPOT HRV and Landsat TM data were found to be equally good at estimating forest age class and stand structure. They also investigated the effect of topography on the ability to accurately estimate stand attributes and found it to be an important influence which affected the results. They found shadow to especially influence the mid-infrared TM bands 5 and 7. Their solution to this was to use the Tassled Cap indice of ”wetness” which was insensitive to the large topographic differences found in their study area. They found that tree size, density of trees, a structural complexity index and stand age were the variables most reliably estimated. As they looked to the future, they anticipated that the introduction of a panchromatic band to Landsat would perhaps make it a preferred data source for use in estimating forest stand attributes in the Pacific Northwest.

Key words: thematic mapper data, remote-sensing data, tm, tasseled cap, canopy closure, reflectance, texture, transformation, classification, information, vegetation.

DeWulf, R.R., R.E. Goossens, B.P. De Roover, and F.C. Borry, 1990. Extraction of forest stand parameters from panchromatic and multispectral SPOT-1 data.
De Wulf et al. demonstrated an improvement in estimating basal area when incorporating the SPOT panchromatic band with multispectral data.. They used a February 1, 1987 SPOT panchromatic and a June 27, 1986 SPOT multispectral scene for a plantation forest in Belgium (*Pinus sylvestris* being 35% of the cover), and found that XS1 (green) and XS2 (red) bands of SPOT showed no relationship, perhaps due to the small dynamic range, to parameters such as stand density, stand age, average tree diameter, stand basal area, average canopy height and stand volume. Stand density and age were best related to the panchromatic band as well as the XS3 (near-IR) band.

Key words: SPOT, forest stand parameters.

3.2.3 Landsat TM

Carpenter, G.A., S. Gopal, S. Macomber, S. Martens, C.E. Woodcock, and J. Franklin, 1999. A Neural Network Method for Mixture Estimation for Vegetation Mapping.
Many applications would benefit from preserving the within stand heterogeneity instead of generalizing stands to homogeneous polygons. The article covers different algorithms to estimate vegetation mixtures in Landsat TM bands (TM1-5 and TM7) images. The study includes maximum likelihood classifiers and a new methodology based on the ARTMAP neural network. In a high (H)-resolution case landscape features are significantly larger than pixels making for an accurate representation of the landscape. In the low (L)-resolution case, feature units are smaller than pixels, so that each pixel represents a mixture of landscape components. The study area is in the Sierra Nevada Mountains in California, dominated by temperate conifer forests with a mixture of hardwoods, brush and evergreens. In this study, topographic correction failed to improve mapping accuracy. Of the algorithms tested, ARTMAP produced the best results. Accurate estimates of proportions of hardwood and conifer cover within stands were produced.

Key words: Landsat TM, neural network, maximum likelihood classifier, resolution.

Coppin, P., and M.E. Bauer, 1994. Processing of multitemporal Landsat TM imagery to optimize extraction of forest cover change features.
Coppin and Bauer used three Landsat TM images (1984, 1986 and 1990) to investigate methods needed to pre-process multi-date data for change detection work in a boreal forest study area. They note that most change studies could identify particular changes over time, but were not sufficiently able to accurately preserve the nature and spatial variations of changes. The main problem was the signal-to-noise ratio, and how to maximize the information by reducing the noise. Causes of noise can be atmospheric scattering, solar zenith or azimuth angles, and sensor calibration inconsistencies from image to image. Four processing steps were involved: data calibration to exo-atmospheric reflectance, scene rectification and registration, atmospheric normalization and transformation to ground reflectance, and generation of vegetation indexes. The pre-processing of the data was quite important in deriving meaningful vegetation index information. They found the green ratio, and the Kauth-Thomas brightness and greeness indexes to be the most informative for forest cover change. For most forestry management purposes, a six-year time span was adequate for detecting changes in the forest, with aspen regeneration being more problematic.

Key words: digital data, reflectance.

Fazakas, Z., Nilsson, M., Olsson, H. 1999. Regional forest biomass and wood volume estimation using satellite data and ancillary data.
Tree biomass and wood volume were estimated for a boreal forest area in Sweden, using a single date of Landsat TM bands 1-5 and 7. The satellite data were combined with forest inventory plot data and used as input to a k-Nearest Neighbour algorithm for the estimation. The accuracy on grid-cell level was poor, but increased with the aggregation of cells into larger areas. It was found that using this method provided satisfactory estimates (10% RMSE) when cells were aggregated to 100 ha or more. There was a bias towards the mean value of the data, generally with underestimation of higher values, and overestimation of lower values. Volume estimates were slightly better than the biomass estimates.

Key words: Forest biomass, forest wood volume, digital satellite images.

Franklin S.E., M.B. Lavigne, M.J. Deuling, M.A. Wulder, E.R. Hunt, Jr. 1997. Landsat TM Derived Forest Covertypes for Modelling Net Primary Production.
Franklin et al. compared the accuracy of properly assigning the correct land cover class from two different classifications of Landsat TM data, for a study area in the Fundy Model Forest, in southeastern New Brunswick, Canada. The forest is characterized primarily by heterogeneous hardwood forest (maple, aspen, beech and birch), coniferous forest (pine and spruce), and mixed deciduous/coniferous. A single TM scene was used with all six bands, and atmospherically adjusted. They chose to use a simple classification method, and excluded the use of ancillary data sources. Classification 1 used the stand data to find the mean TM value, and run a supervised classification based on these training sets. Classification 2 allowed the image analyst to select training pixels to submit to a supervised classification. They then compare the model results of predicting Net Primary Production (NPP) using three different data sets (the stand data, and the two classifications). Their finding was that, due to the heterogeneity of the actual forest, the best classification was from Classification method 2 (91% accurate). Both the stand data (74% accurate), and using the stand data to derive a mean value (65% accurate) generalized the heterogeneity too much. Because different equations are used in calculation of LAI and NPP for each of the forest types (hardwoods, softwoods or mixed woods), they demonstrate the important implications of using the best possible land cover map. This pertains also to other ecosystem modelling as well as in the calculation of landscape metrics.

Key words: reflectance, vegetation, imagery.

Ghitter, G.S., R.J. Hall, S.E. Franklin, 1995. Variability of Landsat Thematic Mapper data in boreal deciduous and mixed-wood stands with conifer understory.
Ghitter et al. examine two Landsat TM scenes (leaf-off and leaf-on) and several different image processing methods in order to determine whether coniferous understory can be detected with accuracy. They also tested classification schemes for understory, and tested different band combinations to find which were most accurate. Their study area is comprised of mixed-wood boreal forest (primarily aspen, poplar, spruce and pine) in south-central Alberta, Canada. 14 different classes of overstory and understory combinations were used for training of the TM data. Different sources of training data were compared: a polygon map generated from color IR

photography, and field plots. The field plot data gave better results than the polygons. The 14 classes were discriminated with 74% accuracy. However, the best results (81% accuracy) came from merging of the 14 classes into fewer classes, especially when having 10 classes by merging 80%, 90% and100% deciduous overstory (with presence or absence of understory) together, and also having a 70% deciduous overstory (30% coniferous overstory) class and a 60% deciduous overstory (40% coniferous overstory) class. Use of all TM bands and an NDVI from each date provided the best classification accuracy. They felt improvements to the classification could be made by incorporating texture information, and/or spectral mixture analysis.

Key words: multispectral data, classification, discrimination, reflectance, imagery.

Hall, F.G., D.B. Botkin, D.E. Strebel, K.D. Woods, S.J. Goetz, 1991. Large-scale patterns of forest succession as determined by remote sensing
Two Landsat MSS scenes (1973 and 1983) were acquired to study the spatial pattern of and the transition rates between forest ecological states, for a 3,600m2 area of boreal forest in northern Minnesota state (U.S.). One area was centered on a managed vs. non-managed (protected wilderness area) forest. The MSS data were adjusted for sensor, atmospheric and seasonal differences before a supervised classification was used to assign pixels to ”ecological states”. They determined changes of succession, regeneration and disturbance from classes of clearings, regeneration, broadleaf, conifer, and mixed forests, for the wilderness and managed areas separately. Ecological state patterns, transition rate and recurrence time, and landcover patterns are examined and compared between the two areas, and differences are found. They found that in both areas, during the 10 year period over one-half of the landscape elements changed. However, a Markov analysis did not show that the landscape, at a regional level, was undergoing significant change.

Key words: biosphere, ecosystem dynamics, global change, landscape ecology, long-term ecological research, stability, succession, boreal forest, area, Minnesota, reflectance, dynamics, climate, pollen, carbon, lake.

McDonald, A.J., F.M. Gemmel, and P.E. Lewis, 1998. Investigation of the Utility of Spectral Vegetation Indices for Determining Information on Coniferous Forests.
This work investigates the forest information content of vegetation indices including the SR, NDVI, PVI, SAVI, TSAVI, and GEMI. Only red and near-infrared bands were included. Two reflectance models were used, a geometric-optical and a Monte Carlo ray-tracing model, to determine the sensitivity of the indices to variations in stand characteristics. The article also covers an examination of effects of the atmosphere on the indices, and an analysis of Landsat TM data. Sites used for ground-truth measurements included a mountainous conifer site in southeast British Columbia, Canada and a boreal forest site in Finland. Results showed that indices were not linear with respect to forest cover and, in many situations an index was not stable for a given cover. Indices were significantly affected by solar zenith angle, background reflectance, stand structure and leaf-area index. Selection of indices should be according to stand characteristics since no index performed well for all covers. At low covers, GEMI was best and for high covers SAVI and TSAVI performed best.

Key words: spectral vegetation indices, Landsat TM, reflectance models.

Metzger J.P. and E. Muller, 1996. Characterizing the complexity of landscape boundaries by remote sensing
Using a single date Landsat TM image, Metzger and Muller attempted to characterize boundaries in a landscape in south-eastern Brazil. Although their study focuses mainly on agriculture and grassland types there are some forested classes; they also urge that further research using similar methods in other landscape types is needed. Eight land cover types were classified using a maximum likelihood classifier on bands 3, 4, 5 and an NDVI band. Boundaries were determined from this classified data. Indices were created pertaining to boundary complexity and proportion. They found that their indices were sensitive to the spatial patterns, and provided new information compared to other spatial indices, because they account for neighboring class types. Two different levels of analysis were carried out: one on the landcover level, and also the landscape level. The Landcover Boundary Diversity Index (Hbi) and Landcover Proportion of Coverts (Ci; points where three or more types converge) were the two indices that provided the best information about landcover richness, physiognomy, and boundary complexity. They found that landcovers with compacted shapes were had low Ci which did not increase when the shape's area was increased, whereas elongated landcovers had high Ci, and increased in area led to a significant increase of Ci. They found that patches controlled by natural factors had higher fractal dimensions than smaller, usually anthropogenically-influenced patches. On the landscape level, they found that indices of Landscape Boundary Diversity (HB), Landscape Proportion of Coverts (C) and Landscape Shape Index (F) provided information on the landscape diversity and fragmentation. Again, they remind that their findings could depend upon the landcover processes and types occurring in this particular landscape. Further research should also incorporate multi-scale analysis, and consider that boundary widths should be adjusted to the application, rather than to the remotely sensed data spatial resolution.

Keywords: boundary, covert, landscape indices, landscape physiognomy, fragmentation, diversity, remote sensing.

3.2.4 Low resolution data

Asner, G.P., B.H. Braswell, D.S. Schimel, and C.A. Wessman, 1998. Ecological Research Needs from Multiangle Remote Sensing Data
The authors write on the potential benefits of multi-view angle remote sensing, and how it can contribute to ecological and biogeochemical research on ecosystem and global-scales. They particularly focus on the MODIS and MISR instruments. On the ecosystem scale (<1km resolution), they propose that a combination of these satellites' data can help in research about nutrient cycling, ecosystem management, habitat studies, and other biogeochemistry applications. Information such as canopy structure and functions (e.g., LAI), as well as determining characteristics of the landscape structure can be gained through methods such as combining multi-view angle data with other satellite data for improved classification, improved spectral mixture analysis, and other types of modeling, such as geometric-optical model inversions.

Key words: leaf-area index, reflectance model, atmospheric CO2, land-surface, terrestrial ecosystems, radiative-transfer, vegetation index, spectral indexes, sugar-beet, climate.

Stoms, D.M. and W.W. Hargrove, 2000. Potential NDVI as a baseline for monitoring ecosystem functioning.
Stoms and Hargrove take a large study area covering three states in the U.S. (Washington, Oregon and California), where the vegetation ranges from temperate rainforest to desert. Their aim was to investigate the relationship between potential and actual NDVI which would indicate levels of environmental stress such as urbanization, or changes in vegetation. Because satellite data are not available from a long enough time period to produce base-line information about NDVI, they used a model to predict the potential NDVI. A regression tree analysis (RTA) was used with biophysical variables (e.g., precipitation, temperature, soils and elevation information) for building the model. The potential NDVI was then compared to actual NDVI measures taken from a time series of 14-days of AVHRR data. The difference image should then provide information on change. They found their model to be useful, and believed it to be a promising step for other applications in monitoring magnitude and direction of change in ecosystem functioning. However, they did add the caveats that there were limitations, and that more research into application of their method was needed. One addition they felt might help future analysis would be the introduction of ecoregion data.

Key words: none.

3.2.5 Scale issues

Hyppänen H. Spatial autocorrelation and optimal spatial resolution of optical remote sensing data in boreal forest environment 1996.
Because of the focus on higher resolution data, Hyppänen aims to measure what the optimal spatial resolution of optical remote sensing data should be in order to discriminate forest characteristics such as cover type. Having this information may lead to improved classification through multi-scale remote sensing. He examines this in a study area near Helsinki, Finland, in a boreal forest environment. Four different age classes of Norway spruce and Scots pine are mapped using a 1:30,000 color infrared aerial photo and resampled to a 1m pixel size. Data were then generalized in 1m steps, up to 10m resolution. Semiovariograms were used to measure the variation between the spatial objects in the photo and local variance was used to help determine optimal spatial resolution. He found that the range (distance where measurements stop correlating with each other) for Scots pine was 5m and for Norway spruce was 7m. Range was also age dependent. The reason for this may have been due to the more complex structure of the spruce trees. Local variance was the same for both species with a maximum at a resolution of 3m for infrared and green bands, and 2m for the red band. Older forest had a higher variance than younger stands, perhaps also due to the more complex structure of the older forest. Hypännen remarks that the optimal spatial resolution determined by this study was much higher than those of commonly used satellite data.

Key words: images, variograms, models, scale.

Marceau, D.J., and G.J. Hay, 1999. Remote Sensing Contributions to the Scale Issue
Marceau and Hay review a number of papers that have examined the subject of scale in remote sensing, which is a particular case of the modifiable areal unit problem (MAUP), and how future work could be applied to look at issues of scale. One of the first important papers he mentions

was by Woodcock and Strahler (1987), who concluded that choice of appropriate scale depended on three things: output information desired, methods used in image processing, and spatial structure of the scene. Marceau found in a previous review that over two decades of land cover mapping, there were considerable inconsistencies from class to class. Classification accuracy was most improved by using different window sizes for each of nine classes, suggesting differences in scale. They find that many applications use remotely sensed data without regards to scale, and that effects of the MAUP in remote sensing need to be fully understood to avoid errors in the analysis.

Key words: Scale, Scaling, Remote Sensing, Modifiable Areal Unit Problem (MAUP).

Moody, A. and C.E. Woodcock, 1995. The influence of scale and the spatial characteristics of landscapes on land-cover mapping using remote sensing.
Using a single date of Landsat TM data which was classified by an unsupervised classification into 6 landcover classes, Moody and Woodcock aimed to focus on the spatial pattern of individual landcovers and the effect of scale on pattern. Their study area was in the Plumas National Forest in northern California, and included oak and pine forest. They began with the 30 m resolution data, and aggregated these data up to 90, 150, 240, 510 and 1020 m resolution. Using statistical analysis they aimed to find which spatial properties that best explained the relationship between error and spatial scale. Their findings were that there can be significant relationships between the spatial characteristics, particular to certain cover types, and scale-dependent errors. However, they found that these errors could be understood, using measures of landscape spatial characteristics.

Key words: scale, spatial pattern, proportion error, regression tree, indicator variable, remote sensing, landcover.

3.3 Landscape planning

The following articles used remote sensing as a tool to assist in monitoring, planning and management for different purposes. Primarily these applications use the data for forest or habitat areas.

Folving, S et al. The FIRS project-progress report and first results from the foundation actions and themes.
The main objective of the FIRS (Forest Information from Remote Sensing) project was to assist in the development of a unified European forest information system. It was based on experiences gained from the MARS (Monitoring Agriculture with Remote Sensing) project and aimed at providing both production-related, and ecology-related forest information, in the form of both statistical and mapped data. One part of FIRS involved European forest mapping and a second part, European forest monitoring. In the latter part there is an automatic change detection system, based on NOAA-AVHRR data.

Key words: Remote sensing, mapping, monitoring, NOAA-AVHRR.

Frohn, R.C. 1997 Remote Sensing for Landscape Ecology.
This text summarizes guidelines provided in: United States Environmental Protection Agency (U.S. EPA) 1994. Landscape Monitoring and Assessment Research Plan. There is a wide variety

of landscape metrics and EPA ranked the status of a number of these into one of three categories: for use as watershed integrity indicators; landscape stability and resilience indicators; and biotic integrity and diversity indicators. Three metrics *Contagion, Fractal Dimension and Dominance* were regarded ready for field tests and implementation.

Hocevar, M. and M. Kovac. Ecological monitoring of preserved forested landscapes in Slovenia by means of remote sensing and GIS.
An ecological monitoring system was developed with the aim to aid in the management of multifunctional forests. The monitoring system is hierarchically organised in four levels from national level to tree level. It contained analyses of land cover and land use; characteristics of forest stands; forest functions inventory (wildlife habitat, protection function, biodiversity, natural and cultural heritage) and inventory of the environmental quality. Different remote sensing techniques were used e.g. analogue photo interpretation of CIR photos, automatic classification of multispectral Landsat TM imagery and various procedures of digital photogrammetry.

Key words: Ecological monitoring, GIS, hierarchical design, remote sensing, orthophoto, forest management.

Holmgren, P, and T. Thuresson, 1998. Satellite Remote Sensing for Forestry Planning – A review.
The article review´s the use of remote sensing in forest management planning. The authors are pessimistic and mean that satellite data seldom contain enough information to support the operational decision process needed in forest management. The classification of land areas into discrete classes consistently end up with accuracy in the range 65-85%, which is too crude for meaningful forest management planning. They state that estimates on a continuous scale e.g. timber volume, are more suitable than discrete classifications.

Key words: Forest management, land classification, remote sensing.

Iverson, L.R., R.L. Graham, and E.A. Cook, 1989. Applications of satellite remote sensing to forested ecosystems.
Remote sensing methods for mapping forest ecosystems are reviewed. It covers delineation of structural and functional characteristics of forests; the use of satellite imagery for classification and mapping of forest types. The two standard procedures, unsupervised and supervised, classification of forest types are described.

Key words: AVHRR, land-use change, Landsat TM, Landsat MSS, landscape pattern, satellite remote sensing, SPOT.

Prendergast, J.R., R.M. Quinn and J.H. Lawton, 1999. The Gaps between theory and practice in selecting nature reserves.
In this paper, Prendergast et al. review some common approaches and site selection algorithms used to identify areas of biodiversity, and potential reserves, and examines why they were or were not effective. They conclude that as the science of conservation biology has progressed, it is becoming clear that there may be no single procedure of identifying areas of conservation interest which is universally appropriate. They point out that the data often used for indicator

taxa are at spatial scales not relevant to practical conservation, and that the covariance between taxa is often highly variable both geographically and taxonomically. Due to many of these factors Prendergast et al. say that attempts to develop diversity indices that incorporate both measures of species number and individual abundance have subsided. They cite work that tests 30 different site selection algorithms, which comes to the conclusion that the individual circumstances will dictate which algorithm worked best. Prendergast et al. note that of all the reserve selection projects he reviews, gap analysis seems to provide the most practical approach, with the advantage of adding to already existing reserves. They proceed to show the complexity of reserve siting, by showing conflicting results from various projects in the literature. They mention a model that predicted land-use by taking into account the socio-economic and climatic factors, and finds it could have potential for conservation planning. They say that taking into account pressures on land availability especially in Europe, would be very important. They take the landscape of Britain for an example, which is a highly fractured landscape, which is subject to very different laws and uses, which influence the reserve. Prendergast et al. point out that species data for large areas are often of a large-scale, too large to relate to small habitat patches, as are often found in the highly fragmented European landscape. Prendergast et al. say that new thinking in Europe is moving away from the reserve mentality, and that the needs of humans and wildlife will be more integrated. This will cause a shift in how landscape analysis and reserve siting will be done. But until then, most of the reserve siting theories have remained just that, theoretical. Very few, outside of Australia and parts of the U.S., have put the theory to practice. Prendergast et al. attribute this to the complexity of the problem, insufficient data, equipment and expertise, and the lack of communication between reserve managers and the scientific community researching the use of technology.

Keywords: *cape floristic region, species richness, biological diversity, conservation biology, national-park, united-states, biodiversity, algorithms, hotspots.*

Quattrochi, D.A and J.C. Luvall, 1999. Thermal infrared remote sensing for analysis of landscape ecological processes: methods and applications

Thermal infrared (TIR) remote sensing can provide important information about surface energy fluxes and temperatures which could increase the understanding for landscape processes and responses. Data can be acquired from a space borne sensor as the Heat Capacity Mapping Mission (HCMM) satellite, or Landsat TM. It can also be acquired from an airborne sensor as the Thermal Infrared Multispectral Scanner (TIMS). The authors are optimistic about future use of TIR data in landscape studies. A list of remote sensing related acronyms is presented.

Key words: Thermal infrared remote sensing (TIR), landscape ecology, landscape elements, Landsat TM, AVHRR.

Riitters et al. 1995. A factor analysis of landscape pattern and structure metrics.

Fifty-five metrics of landscape pattern and structure were calculated for 85 maps of land use and land cover. A multivariate factor analysis was used to identify the common axes (or dimensions) of pattern and structure which were measured by a reduced set of 26 metrics. The first six factors explained about 87% of the variation in the 26 landscape metrics. These factors were interpreted as composite measures of average patch compaction, overall image texture, average patch shape, patch perimeter-area scaling, number of attribute classes, and large-patch density-area scaling. We suggest that these factors can be represented in a simpler way by six univariate metrics –

average perimeter-area ratio, contagion, standardized patch shape, patch perimeter-area area scaling, number of attribute classes, and large-patch density-area scaling.

Schumaker, N.H. 1996. Using landscape indices to predict habitat connectivity.
This study investigates the correlations between nine common indices of habitat pattern and the results of simulated dispersal success using GIS data on old-growth forest in the Pacific Northwest, USA. The GIS habitat data was produced using Landsat MSS data, aerial photography, and field data. The nine indices showed weak correlations with the results from the dispersal modeling. The best predictors combine information about both patch areas and perimeters, and patch area is by itself one of the best predictors of dispersal success. A new pattern index, patch cohesion, was identified which had a better fit to the modeling results. The author claim that all pattern indices should be subject to detailed experimentation before being accepted and used.

Key words: Advanced Very High Resolution Radiometer (AVHRR), dispersal, fragmentation, GIS, habitat connectivity, landscape ecology, Landsat MSS, patch cohesion, pattern index.

Tomppo, E., C. Goulding, and M. Katila, 1999. Adapting Finnish Multi-Source Forest Inventory Techniques to the New Zealand Preharvest Inventory.
The Finnish satellite-image aided National Forest Inventory (NFI) method developed for multi-source forestry was adapted for preharvest forest inventory of radiata pine (Pinus radiata) stands in New Zealand. The method combines Landsat TM images with known stand boundaries from digital maps and ground measurements. The so called kNN method applied in the study will produce an estimate of all variables for each pixel. The correlation coefficients between intensity values and volume parameters were low. The pixel-level estimations are not strong enough for operational use but estimates obtained for areas of about 40 ha where acceptable.

Key words: Forest inventory, kNN-method, Landsat TM, resource monitoring, satellite imagery.

Turner, M.G. 1990. Spatial and temporal analysis of landscape patterns.
The analysis of ecological problems require considerations of both spatial and temporal scales. Turner stresses the importance of developing methods that will preserve information across scales, or quantify the loss of information when changing scales. A grid cell based spatial analysis program (SPAN) is used in conjunction with GIS to quantify landscape patterns. Neutral models are used to study the relationship between observed landscape patterns and an ecological process. The author points out that different indices may provide different information at different spatial scales. The grain and extent of a study are important factors since they might affect if a pattern or process is observed.

Key words: GIS, scale, landscape ecology, spatial pattern analysis, neutral model, spatial analysis program (SPAN).

3.4 Biological diversity

The literature covered in this section mainly deals with the linkage of biodiversity to different landscape features. It deals with the impact of scale and resolution when mapping biodiversity, and also investigates the effect of broad cover types when estimating diversity.

Biological diversity, or biodiversity, is a widely used term and we think it is in place to present some of the most used definitions, of which one is 'the variety and variability among living organisms, and the ecological complexes in which they live, encompassing genetic, species, ecosystem, and landscape levels' (U.S Congress Office of Technology Assessment 1987). However, DeLong (1996) argues that a definition including ecosystems is not consistent with the 'bio-' part of biodiversity since ecosystems include the abiotic, non-living environment. He presents two new, quite long and wordy, definitions but also accepts a definition that has been in use for some time: 'the variety of life and its processes', assuming that life's processes are biotic ones.

Conroy, M.J. and B.R. Noon, 1996. Mapping of Species richness for conservation of biological diversity: Conceptual and methodological issues.
Conroy and Noon consider the approach taken by GAP (top-down, coarse filter approach), and take the opposite approach, going from the finer resolution and scaling-up to see if the two methods produce similar results. They maintain that errors in the vegetation and species mapping greatly effect the outcome of analyses done for biodiversity. They also demonstrate how higher scale maps are not always suitable for prediction of multiple numbers of vertebrate species habitat. In fact, they say, no single scale is suitable for a number of different vertebrates, unless those species happen to have identical habitat needs. However, they say that it is impossible to know *a priori* about what scale to map, without knowing something about both the animal species habitat preferences and the landcover itself. The danger of coarse-filter mapping is that information vital to biodiversity may be lost through aggregation. They suggest that rather than the coarse-filter mapping approach, that mapping for biodiversity applications should be done starting with the population level using multistage, adaptive sampling (according to species' needs), definite quantifications of uncertainty in the data which are explicitly conveyed to end-users, and use of "decision theory" in management decisions.

Key words: biological diversity, conservation, decision theory, gap analysis, GIS, landscape modelling, mapping, population modelling, reserve design, sampling, scaling.

Flather, C.H., K.R. Wilson, D.J. Dean, W.C. McComb, 1997. Identifying Gaps in Conservation Networks: Of indicators and uncertainty in geographic based analysis.
Flather et al. consider the implications of using vegetation and species data of various scales when doing biodiversity analysis or reserve design. Their objective was to answer the questions of "whether some of the currently proposed biological indicators (e.g., vegetation maps and/or species surveys) reflect actual biodiversity" and "what are the implications of designing nature reserves using such data (which contain uncertainties)?" They chose to work from a population level and from data existing in the literature. They came to the conclusion that biological indicators often did not give general information, but was very dependent on that particular species. Also of equal importance was that managers who are making decisions about conservation of areas, should realize the errors that can occur in vegetation maps, or any other spatial data, or the joining and analysis of that spatial data in a GIS.

Key words: biodiversity mapping and disclosure of uncertainty, cartography and error propagation, conservation network, gaps in, conservation reserves, designing of, gap analysis, indicator taxa, reliability of, landscape conservation, reserve design, role of ecological processes in, species diversity and richness, species-habitat relationships, maximize biological *diversity, nature-reserve selection, species richness, monitoring biodiversity, habitat relationships, strategies, models, scale, woodlands, patterns.*

Innes, J.L. and B. Koch, 1998. Forest biodiversity and its assessment by remote sensing.
Remote sensing is claimed to be the most efficient tool available for determining landscape-scale elements important for forest biodiversity e.g. canopy layering, corridors and the nature of edges. The use of remote sensing in biodiversity studies is based on the premise that relationships exist between the structure of the landscape and its units and the diversity in the landscape. Assessment of biodiversity needs to be undertaken at several different scales. The combination with ground measurements is important for biodiversity monitoring. Different remote sensing technologies e.g. radar, laser, thermal remote sensing and optical technologies, available for studies of forest biodiversity are discussed. Photography and digital optical images are claimed to be the most important ones. Data from airborne sensors are both in film and digital format while spaceborne is mainly digital due to transport problems. They list the existing and planned high resolution optical satellite systems.

Key words: Biodiversity, remote sensing, landscape assessment, satellite imagery, primary- and secondary information, FRAGSTATS, GAP.

Miller, R.I. 1994. Editor of: Mapping the Diversity of Nature.
The book mainly deals with methods used to map nature and it is based on the notion that biodiversity is linked to landscape features that can be observed and quantified using remote sensing techniques. It covers the topic of different spatial (from 10 m for SPOT HRV to 1km^2 for NOAA-AVHRR) and temporal (snapshots of prevailing conditions to centuries) scales of environmental variables and remotely sensed data. The importance of stating both grain and extent of the data used at each hierarchical level is stressed. The hierarchical organization of variables affecting biodiversity and its implications on monitoring is covered. The monitoring of species-habitat relationships is discussed. The resolution of different spaceborne sensors is specified. There is quite a detailed description of the GAP-analysis project in Idaho.

Key words: Biodiversity, conservation, scales, species mapping, hotspots, vegetation mapping, satellite imagery, GAP-analysis.

Stohlgren, T.J., M.B. Coughenour, G.W. Chong, D. Binkley, M.A. Kalkhan, L.D. Schnell, D.J. Buckley and J.K. Berry, 1977. Landscape analysis of plant diversity.
Stohlgren et al. used vegetation maps and GIS to look at plant diversity in Rocky Mountain National Park in Colorado, USA. They wanted to know whether different resolutions of typical vegetation maps used for biodiversity studies would influence the answers to the questions ”Do areas of high or unique diversity remain undetected because of low MMU resolution?” and ”Does use of broad cover types lead to a significant underestimate of diversity?” In the paper they provided a methodology to improve mapping of plant diversity at local levels and also describe their work in using the data to within wildlife models, biodiversity-ecosystem models and regional resource mapping programs. The vegetation maps were created from multiple spatial scale mapping using Landsat TM data and color aerial photos. One of the vegetation types of interest, because it was fractured, rare, and important, was Aspen forest. They created a vegetation map with a 0.02 ha MMU and compared it to vegetation maps with resolutions of 2 ha, 50 ha and 100 ha. Their results showed that the 50 and 100 ha resolution maps didn’t

adequately represent the plant diversity, and underestimated the quantity of habitat patches. While the 2 ha resolution data gave accurate estimates of the diversity, the number of habitats was still less than from the 0.02 ha map, and the Aspen class as well as other rare or key habitats disappeared from the classification. Going from the 0.02 ha map to the 100 ha map showed a non-linear decrease in the total number of vegetation polygons, a linear decrease in the number of vegetation types, and a linear decrease in the total number of species estimated. Hierarchical collapsing of classes into a regional map resulted in a 22% loss of area for the Aspen class.

Key words: map accuracy assessment, geographic information systems, keystone ecosystems, plant species richness patterns, wildlife models, ecosystem models.

Stoms, D.M. and J.E. Estes, 1993. A remote sensing research agenda for mapping and monitoring biodiversity.
The authors emphasizes the potential of remote sensing as a tool in resource management. They focus on the improvement of spatial and temporal data on species richness. Vegetation cover is not suitable as the sole index of habitat suitability. The realized niche is narrower than the fundamental niche. Several landscape level indices derived from satellite images are described. The key variables derived from satellite images are patch size, inter-patch distance, and habitat connectivity.

Key words: biological diversity, indicators, remote sensing, scales.

Vencatasawmy, C.P., H.M. Reese, H. Olsson, M. Nilsson, 2000. Repeatability of landscape indices extracted from satellite images of different dates.
Vencatasawmy et al. set out to determine the repeatability of getting information about landscape pattern and landscape indices from satellite data, using four SPOT scenes taken within a one-week time period. Using two different methods, one being semi-variograms and the other a post-classification analysis using Fragstats, they find that the results are not consistent. From the semi-variograms the ranges, which are indications of scale, are different. Using Fragstats to create indices such as core area or edge density from the classified data revealed that the indices varied from image and differences in atmospherical optical thickness. The potential reasons for this are attributed to the difference in each image's view angle and noise. Image processing algorithms, used to derive landscape pattern information, should be made robust to these influences.

Key words: landscape indices, spatial analysis, satellite images, SPOT, Fragstats, variogram, kNN algorithm, forestry, Sweden

3.5 Species-habitat relationships

The following articles look at the correlation between species and habitat. They investigate what variables to use when producing habitat cover types, and assess the accuracy with which habitat types can be separated. Habitat can be defined as ”the resources and conditions present in an area that produce occupancy- including survival and reproduction- by a given organism. Thus it is a species-specific term which relates the presence of a species, population or individual to an area's physical and biological characteristics. Simply put, habitat is wherever an organism is provided with resources that allow it to survive (Hall et al. 1997).

Cardillo, M., E.W. Macdonald, and S.P. Rushton, 1999. Predicting mammal species richness and distributions: testing the effectivness of satellite-derived land cover data.
The aim of the study was to evaluate the power of satellite-derived land cover data in predicting species richness and occurrence of terrestrial mammals in Great Britain. The land cover map was based on Landsat TM imagery. All mammal and land cover data were measured from one hundred 10 x10 km cells of the British national grid. Principal Component Analysis (PCA) was used to explain the predictive powers of different variables. They found the predictive power of land cover data to be poor, and it was strongly scale-dependent. The predictive power increased when regions were analysed separately. Regional stratification is therefore recommended. Principal Component Analysis (PCA) was done to describe the variation in land cover.

Key words: Biodiversity mapping, land cover, mammals, species richness, Landsat TM, Great Britain Land Cover Map.

Debinski, D.M., K. Kindscher, and M.E. Jakubauskas, 1999. A remote sensing and GIS-based model of habitats and biodiversity in the Greater Yellowstone Ecosystem.
Remotely sensed data and GIS were used in stratification of habitats to guide sampling of biodiversity in Yellowstone, USA. The goal was to analyse species-habitat relationships, much the same way as in GAP-analysis but at a finer scale (1 ha minimum map unit). Landsat TM data with 30 m resolution was used for the vegetation mapping. An Iterative Self-Organizing Data Analysis (ISODATA) was used to identify, and cluster, spectrally similar pixels. A great number of spectral classes were clumped to generate the vegetation types. Different methods were used to depict the distribution patterns of plants (quadratic plots with species specific coverage along a transect), butterflies and birds (auditory and visual surveys and netting to collect presence/absence data). Twenty to thirty percent of the animal species, and 65-100 percent of plant species showed at least one statistically significant habitat preference.

Key words: remote sensing, GIS, habitat, biodiversity, GAP.

Holopainen, M., and G. Wang, 1998. Accuracy of Digitized Aerial Photographs for Assessing Forest Habitats at Plot Level.
The study aims at determining the accuracy of predicting forest habitats in digitised colour-infrared aerial photographs, based on dominant tree species, stand age and ground vegetation. The study area is located in a conifer dominated part of southern Finland. The variation in reflectance values for the same habitat class is the main problem. Factors affecting the results e.g. solar direction and viewing angle are discussed. DEMs were used for photo calibration. Regression calibration proved better than ratio calibration to improve the stratification accuracy. Twelve habitat types were separated with 85.3% accuracy and 48 habitat types with 57.7% accuracy.

Key words: Biodiversity, forest classification, remote sensing, aerial photographs, multiuse forestry planning, scale, pre-stratification.

Naugle, D.E., K.F. Higgins, S.M. Nusser, and W.C. Johnson, 1999. Scale dependent habitat use in three species of prairie wetland birds.
The study investigates the influence of scale in the use of nesting and foraging habitat in several bird species in South Dakota, USA. Measures of habitat use were obtained through traditional field work while measures of habitat abundance was obtained through classification in Landsat TM images. An unsupervised classification was used to produce 100 spectral classes which were later visually interpreted. Black and white aerial photographs were used to enhance the visual land cover interpretation. The results show that some bird species are affected, not only by the conditions in the nesting habitat, but also respond to attributes at the landscape level. Wetland area was the variable explaining most of the variation in habitat suitability.

Key words: Habitat use, scale dependency, remote sensing,

3.6 The US Gap analysis programme

3.6.1. History and basic concepts

Gap analysis is not a new concept, with its foundations being proposed in a few earlier papers (Specht 1975; Bolton and Specht 1983; Burley 1988). The current U.S. Gap Analysis Program ("GAP") has borrowed from these concepts, and adapted them for use with more current technology (e.g., GIS) to create data and do analyses. The ideas were first proposed in 1987 by Scott et al., in order to give ”a quick overview of the distribution and conservation status of several components of biodiversity. It seeks to identify gaps (i.e., vegetation types and species that are not represented in the network of biodiversity management areas) that may be filled through establishment of new reserves or changes in land management practices (Scott et al. 1993).” GAP should provide a ”rapid and efficient method” which would be ”cheaper and more likely to succeed” in conservation evaluation of large areas. GAP was introduced ”with the observation that saving endangered species, however laudable, fails to address the primary factors driving species toward extinction: continuing loss, fragmentation, and degradation of natural landscapes.” GAP was ”envisioned as a national and global land-use planning process that will identify and maintain much of biodiversity in a set of core biodiversity management areas (Noss 1987b; Scott et al. 1993).” The January 1993 issue of Wildlife Monographs, which outlined these ideas behind Gap analysis, has become one of the most often cited articles regarding GAP.

There have been many other papers published explaining the basics and evolution of GAP (Scott et al. 1987; Davis et al. 1990; Noss 1990; Scott et al. 1993; Scott and Jennings 1994; Jennings 1995; Jennings 2000). The program’s methods towards achieving their objectives can be summed as, that through landscape scale analysis of spatially explicit data, which includes large-area vegetation maps, vertebrate species distributions, and land stewardship maps within a GIS, a coarse-filter can be created as a preliminary step to pro-actively identify unprotected areas, that if unpreserved can pose future threats to biodiversity. The coarse filter approach adopted by GAP is based upon ideas put forth by Jenkins (1985) and Noss (1987a).

Jennings (2000) explains that today’s GAP has expanded, with the introduction of aquatic environments analysis. Jennings also points out that GAP has changed some of their basic ideas as a result of research done since 1993. One idea was that the use of biodiversity "hotspots" may not be what was anticipated, due to work done by Prendergast et al. (1993), who showed low correlation between indicator species habitats, and Reid (1998), who found that use of "hotspots" was quite scale dependent. Another evoloution through the years has been the change and variety of methods and data used to create GAP vegetation maps.

For GAP, the dominant natural cover type (”actual vegetation” as opposed to ”potential vegetation”) is mapped because it is an ”easily described measure of habitat” and can be an indicator of overall biodiversity patterns (Noss 1990; Franklin 1993; Scott et al. 1993). The vegetation map ”provides the foundation for [the] assessment of the distribution of biodiversity (Scott et al. 1993).” The primary data source for the vegetation maps is remotely sensed data, preferably Landsat TM (to cover large areas), although in a few cases other data sources were occassionally used. The minimum mapping unit of the vegetation maps has generally been 100 ha, with a smaller MMU (40 ha or smaller) allowed for certain vegetation types or areas. As stated earlier, the vegetation maps are intended to be used as a coarse filter only, from which an estimated 85-90% of species can be protected (Scott et al. 1993); further finer-scale investigations should then be conducted for the other 10% and within other areas of potential interest.

In addition to the GAP remote sensing method papers that will be reviewed later, there are also other relevant issues to vegetation mapping upon which GAP has produced literature, such as accuracy assessment (Edwards et al. 1998; Congalton 1996; Ma and Redmond 1995; Stoms 1996; Stoms et al. 1994; Sader et al. 1995; Dzur et al. 1996a; Moisen et al. 1994), effect of scale and generalization on mapping (Stoms 1992; Bassett et al., *in press*), and, the common classification scheme used for GAP vegetation maps which is called the National Vegetation Classification Scheme (NVCS; Grossmann et al. 1998). This classification scheme has a lineage which follows from the UNESCO scheme (1973), Anderson et al. (1976), and Driscoll et al. (1984). This classification scheme has a hierarchical structure, allowing classification with differing levels of information and for different needs. The upper levels of the system are based on the structure of the vegetation and on characteristics of the leaves. The lower levels are based on species composition.

Several papers exist on the creation of vertebrate maps (Butterfield et al. 1994; Cassidy et al. 1994; Csuti 1994; Edwards et al. 1996; Krohn 1996; Master 1996), and one was found specific to creation of the land ownership maps (Beardsley and Stoms 1993), although information on these aspects also exist in project final reports. A number of papers have also been published on the analysis of GAP data and their applications to conservation biology (Stoms et al. 1992; Homer et al. 1993; Butterfield et al., 1994; Machlis et al. 1995; Merrill et al. 1995; Noss et al. 1995; Caicco et al. 1995; Csuti and Kiester 1996; Kiester et al. 1996; Jennings 2000). A few of those applications are reviewed later in this paper.

Scott first started considering the idea for GAP’s spatial analysis while he was mapping bird habitat in Hawaii (Scott et al.1986). He then transferred these ideas toward working on a pilot project in the state of Idaho (Scott et al. 1987). After success with this project, the idea was introduced to U.S. congress and became a federally funded program, now housed in the U.S.Geological Service-National Biological Service. However, GAP is most often not the sole funder of GAP data development. The money is given at a state by state level, often as a contribuition to a cooperative development of the data. Data development is often done at universities or state agencies, and include partnerships with federal agencies, other state agencies, and private organizations. Therefore, because GAP is both cross-disciplinary, as well as inter-organizational, a lot of literature pertaining to GAP can be found in many different publications with emphasis on different fields of research.

GAP mapping projects are currently being or have been conducted in each of the 50 states in the U.S (38 states will be complete in 2000). Because mapping is conducted at the state level, each state may develop satellite data interpretation techniques particular to their needs in interpreting their vegetation. This has led to a wide variety of techniques within GAP (Eve and Merchant 1998). However, from the beginning of GAP, Scott and Jennings felt that a standardized, cook-book approach to satellite data classification would probably not work well in a large and diverse effort such as the GAP program (Scott et al. 1993; Scott and Jennings 1998).

However, GAP does provide some guidelines, many of which can be found in the Gap Handbook. The most basic of these requests are that the vegetation classes should conform to the NVCS; use of TM imagery at 30 m pixel resolution, no more than 3 years old at the initiation of the project; use methodology and standards described in the handbook; achieve higher order classification accuracy of at least 80%; land cover mapping should go 10 km into adjacent states to facilitate edge-matching; map resolution of at least 2 ha, although vectorized version at a coarser scale (up to 100 ha) can be made; and, an accuracy assessment following handbook guidelines should be carried out (Crist and Jennings 1999).

GAP requests documentation of each individual project by requiring final reports and having metadata standards (Cogan and Edwards 1994). They also try to facilitate continuity between neighboring states by designating cooperative regions of states, distributing an annual bulletin (GAP Bulletin) and holding annual meetings for exchange of information. The GAP home page (http://www.gap.uidaho.edu/gap) has links to all of these pieces of information, the Handbook, and also contains state status reports, links to state GAP home pages, a link for International GAP projects, an updated GAP literature list, and other information.

3.6.2 Summary of GAP remote sensing methodology in the literature

The following discussion focuses on the literature describing image processing methods used to create vegetation maps for GAP. By using web-based searches, search of the Expanded Science Citation Index (key words: GAP, satellite, remote sensing, vegetation mapping), and subsequent searches into further links and reference lists of the various sites and literature found, a total of 74 articles were found which pertain particularly to remote sensing methods developed for GAP. The distribution of these articles was wide, with 18 articles from conference proceedings; 14 web available publications; 11 from scientific journals; 11 from book chapters (from a total of three books); 7 from lesser known journals (unsubscribed to by the SLU library system which has 4,300 journals); 5 U.S. Government publications; 5 university publications; 1 private company's publication; and 1 unpublished report. If one looks into the reference lists of these publications, one also finds repeated references to remote sensing methods that were drawn upon for development of GAP methodology, but were not necessarily GAP publications; some of these occur repeatedly, specifically, Franklin et al. 1986, Bauer et al. 1994, Fiorella and Ripple 1993, Schriever and Congalton 1993; Stewart and Lillesand 1995; Congalton 1991.

There are two basic types of vegetation mapping which are being used for GAP: one uses computer interpretation of digital remotely sensed data, and another uses visual interpretation.

The first GAP pilot project was a land cover map of the state of Idaho which was created using existing vegetation maps and refined based on Landsat MSS analog data. (Scott et al. 1993). The next project began in 1989 for the state of Oregon, which also used visual interpretation of analog satellite data (Kagan and Caicco 1992). Subsequent projects, began in 1990 for the states of California (Davis et al. 1995), Utah (Homer et al. 1997) and Arizona, using a combination of digital satellite data classification, visual-interpretation of satellite imagery, and reference to ancillary data. These earlier projects compiled from either aerial photos or Landsat MSS will be re-mapped using TM data.

One catalyst to GAP has been a cooperative buy of satellite data which facilitated the availability and distribution of Landsat TM data among the states (Loveland and Shaw 1996). This led to the more widespread use of TM data by the states, as it was previously unaffordable for each individual state to buy full coverage on its own funds. GAP mapping then began in many more states. Some of the states have used single date TM, dual-season/multi-year TM, dual-season/same year TM, and one state (North Dakota- newly underway in 1999) is using triple-season (spring/summer/fall) TM data. Different data transformations have included use of Tassled Cap, and Principal Components Analysis and nearly all states have used some sources of ancillary data to aid in stratification and masking, such as ecoregions, soils, wetlands, and census data.

Methods of classification have included unsupervised, supervised, hybrid classifiers, unsupervised ”hyper-clustering” using SPECTRUM (Benjamin et al. 1996), and/or visual interpretation. The sources of ground truth have been aerial videography (Grahm 1993; Airola 1996; Slaymaker et al. 1996), forest inventory data, or other collected field data. Data generalization and aggregation to a common MMU was a debated subject in many GAP final reports. Many states did this in different ways, but said that they thought more research was needed to find a method that would be accurate and of less trouble.

3.6.3 Individual state GAP projects

A closer look at some individual states’ projects may be helpful. The following states were chosen due to their vegetation type (boreal forest) and/or to represent the variety of methods used. Details are given regarding the type of vegetation, methods used, ground truth source, data generalization, results, and the primary documents produced by the GAP project. All of the following information was downloaded from the web; the final reports available on the web contain very detailed and useful information to those considering the development of large scale projects similar to GAP.

Krohn W.B., R.B. Boone, S.A. Sader, J.A. Hepinstall, S. M. Schaefer, S.L. Painton, 1998. The Maine Gap Analysis Project: Final Report

(see also Krohn et al. 1999; Hepinstall et al. 1999; Sader et al.1997; Sader 1990)

The state of Maine is the most extensively forested state in the U.S., with most of the forest being ”non-mature shade-intolerant tree species”. Boreal forest type is dominant in Maine. A good deal of effort was also spent on classifying blueberry cover. Ground truth came from 1994 aerial videography. The data source was dual-season/multi year (pairs from 1991 and 1993) Landsat TM. The data were combined into a 10-band file (TM band 3, 4, 5, ratios 4/5, and 4/3 for 1991 data, and principal components 1, 2, 3 and ratios 4/5 and 4/3 for 1993 data).

The first classification of data was a supervised classification, with subsequent confused classes masked out and run through an unsupervised classification. Ancillary wetland data were used, as well as other ancillary data, to aid in interpretation of confused classes such as recent clear cuts, urban areas, blueberry fields, and regenerating forest. Majority filters were used to generalise the final classification. The final classification had 37 classes; forest classification was not done to a species level, but rather to deciduous vs. coniferous and regeneration stage. The overall accuracy for forestland class was 94%, with within forest class accuracy being 65%.

Lillesand, T.M., J. Chipman, D. Nagel, H. Reese, M. Bobo and R. Goldmann, 1998. Upper Midwest Gap analysis image processing protocol.
(see also Lillesand 1996; Stewart and Lillesand 1995; Reese et al. 2000)
The state of Wisconsin's vegetation consists of boreal forests in the north, and grassland and agriculture in the south. Ground truth came from field data which were collected in a large in-field sampling effort. Wisconsin is one of six states which followed a common image processing protocol, with slight variations from state to state, as outlined for the Upper Midwest GAP region. Image processing methods included dual-seasonal/same year Landsat TM digital data to take advantage of phenological changes in the vegetation, principal component analysis, a hybrid supervised/unsupervised classifier, stratification of each scene into classification units using ecoregion data, and incorporation of ancillary vector information to mask uplands, wetlands, and urban cover types.. Final spatial resolution of map was 0.4 ha (2 ha nominal MMU) , after smoothing with an in-house "clump-sieve-fill" algorithm. Mapped 31 classes. Deciduous versus coniferous forest were 94% accurate, and mapping done to species level had an accuracy of 77%. It was felt that well timed multi-seasonal TM data were critical.

Redmond, R. L. and M.L. Prather, 1996. Mapping Existing Vegetation and Land Cover Across Western Montana and Northern Idaho: Final Report.
(see also Lachowski et al. 1995; Tady et al. 1995a,b)
The vegetation of northern Idaho and western Montana is primarily forested (57%), with grass and shrubland also being prominent vegetation. This is also an area of high topographic variation. Ground truth came from field samples and existing forest inventory plot data. A two step classification was used, first using unsupervised classification of single date TM data (bands 3, 4 and 5). Then a supervised approach using the field data and a nearest neighbor class assignment. Size class and canopy cover was also assigned. There was some visual interpretation of urban and agricultural types. A DEM was used to help classify riparian vegetation separately. 58 cover types were mapped. One of the class assignments involved a second- and third- ”most likely class”. Cover type accuracies varied from scene to scene, from 87% to 53%. Canopy closure and size classes varied from 78 to 23%.

Slaymaker, D.M., K.M.L. Jones, C.R. Griffin and J.T. Finn. 1996. Mapping deciduous forests in Southern New England using aerial videography and hyperclustered multi-temporal Landsat TM imagery.
The southern New England states (Massachusetts, Connecticut and Rhode Island) have a wide variety of forest types, but mainly mixed deciduous forest, with much of that in small patches. The ground truth came from large-scale airborne video data systems which assign GPS coordinates in each frame. Original analysis using unsupervised classification of single date TM data did not work well. The final method is based on an unsupervised ”hyper-clustering” via SPECTRUM software of 12 bands of dual-season/multi-year Landsat TM data (spring 1992 and

summer 1991). The clusters are then assigned classes using a set of hierarchical and sequential decision rules based on terrain, neighbourhood associations and field data. Mapping was done to species level, with 71 cover types. Pilot project accuracy on one scene was 90% (Slaymaker et al. 1996). The final land cover map was completed in 1997, although accuracy has not been completely assessed, due to necessary revision of errors found in one region. They felt the large number of sample points provided by videography, as well as using multi-seasonal TM data contributed to higher accuracies.

Smith, K. G., R. S. Dzur, D. G. Catanzaro, M. E. Garner, and W. F. Limp, 1998. Arkansas GAP final report. State-Wide Biodiversity Mapping For Arkansas
(see also Dzur et al. 1996a, 1996b)
The state of Arkansas has vegetation is mainly agricultural, and forest that is primarily deciduous. Ground truth came from state forest inventory plots and field visits. Supervised classification on single date Landsat TM data was used. A Tassled Cap transformation was first used for the TM data, as well as stratification using ancillary soils data. 37 classes were mapped with a final 100 ha MMU. They used a similar generalization technique as Montana. Basic level accuracy was 92%, species level accuracy was determined to be about 49% overall. Of interest, they also made a comparison of the 100 ha map to the original 30m resolution, and found that agriculture increased by 4% in area, one class disappeared altogether, and 18 out of 22 types which covered less than 1% of the state's land area, lost over one-half their area when aggregated to the 100 ha MMU. Some of these were fractured and patchy classes of vegetation.

3.6.4 Summary of problems and caveats

Eve and Merchant (1998) compiled a summary report about GAP land cover mapping methods used in every state. They found that the classification techniques varied widely among the states. They confirmed that the accuracy assessment of the resulting land cover maps has also been variable. Some of the indicated trouble spots were access to adequate and appropriate dates of imagery, dealing with shadowing and clouds, collecting adequate field data, edge matching with adjoining states, and consistency of the classification scheme. Recommendations for future projects are given by both Eve and Merchant, as well as from GAP project leaders.

Caveats regarding the use of GAP vegetation maps were given in Scott et al. 1993, and include that notice should be taken of the MMU and scale considered when making analyses; that age (and therefore old-growth forest) is not mapped; and that boundaries between vegetation types as represented on the maps are likely sharper than as usual in reality where ecotones and subtle gradients can exist. Scott also repeatedly iterates that GAP is not considered a panacea to solving the problems of biodiversity conservation, and is never intended as a replacement for thorough biological inventories. Jennings (2000) says that it "seems unlikely that any single method or algorithm will be adequate for establishing biodiversity conservation areas."

There have been caveats coming from outside of GAP as well, with wildlife ecologists who are sceptical about GAP's approach to conserving biodiversity (Dean et al.1997; Conroy and Noon 1996; Bolger, Scott and Rotenberry 1997; Schmidt 1996).

3.6.5 GAP Applications

Homer, C.G., T.C. Edwards, Jr., R.D. Ramsey, K.P. Price, 1993. Use of Remote Sensing Methods in Modelling Sage Grouse Winter Habitat.
Homer et al. (1993) wanted to determine whether large-scale remote sensing information (from Landsat TM) could be linked to fine-scale plant and animal patterns (shrub habitat used by sage grouse). The mapping concentrated on shrub types of differing densities. Through GIS analysis they found the grouse showed preference for 3 of the 7 shrub types mapped. They determined that this application could be used to expand wildlife habitat research and management decisions.

Key words: conterminous united-states, selection experiments, ecoregions, movements.

Kiester, A.R., J.M Scott, B. Csuti, R.F. Noss, B. Butterfield, K. Sahr, and D. White, 1996. Conservation Prioritization Using GAP Data.
Kiester et al. (1996) used GAP data in the state of Idaho to prioritze locations for conservation and further detailed research. Vegetation maps were created from Landsat MSS, with 118 classes, and a MMU of 259 ha (see Caicco et al. 1995). Species data were represented in a hexagonal grid. They found that within the state, there were seven areas which had 100% coverage of unprotected vertebrate species, and 96% coverage for all vertebrates. They mention that, due to Idaho's vegetation, the large-ranges of the species, and the nature of the low-spatial resolution of the grid, outcomes would be quite different for areas different from Idaho. In fact, there were several combinations of possible "final" outcomes of the gap analysis within this project. However they followed selection rules based on work by Pressey et al. (1993). Their study suggested further research on four specific areas which they found to be the most important areas for pro-active protection.

Key words: sampling design, diversity, selection.

Merrill, E., T. Kohley, M. Herdendorf, W. Reiners, K. Driese, R. Marrs, and S. Anderson. 1996. Wyoming Gap Analysis: A Geographic Analysis of Biodiversity, Final Report. USGS Biological Resources Division: Laramie, Wyoming.
Merrill et al. (1996), have analyzed the Wyoming landscape using GAP data and found that out of the 41 vegetation classes that were mapped, seven were well protected, 16 had a small percentage protected, identified 5 unprotected covertypes for priority protection, 8 unprotected covertypes as secondary priorities, and 3 for third priority. They identified 80 animal species as being insufficiently represented in protected areas, especially in certain areas of the state where conservation areas were uncommon. They do mention that the exact amount of land needed to help protect species is unknown until further detailed studies are done. They could also see, from the land ownership patterns, that future conservation of these unprotected animal species would require work with certain land management agencies, and also private landowners.

Stoms, D.M. 2000 GAP management status and regional indicators of threats to biodiversity.
In this paper, Stoms describes an application of the GAP data in which they compare management status and several other ecological indicators which represent impacts on biodiversity, including land use zoning, projected human population growth, and the spatial extent of road effects. Stoms mentions that the prominent Landscape Ecologist, Forman, has

called for an effort to study the effect of roads on biodiversity and other ecological resources. Stoms finds that road density is an indirect indicator of existing impact on ecological integrity, although could be improved further.

Keywords: biodiversity, California, ecological indicators, gap analysis, land use, projected human population growth, road density index, zoning.

Strittholt J.R. and R.E.J. Boerner, 1995. Applying Biodiveristy Gap Analysis in a Regional Nature Reserve Design for the Edge of Appalachia, Ohio, (U.S.A.).
Strittholt and Boerner (1995) used GAP to identify areas to include in a nature reserve. Their study area was 378 km^2 in southcentral Ohio state, where plant biodiversity was known to be high. The area was known for its outstanding deciduous forest, as well as small remnant prairies, and currently had a number of areas under protection. Their aim was to see what areas of the different vegetation assemblages they would need to additionally preserve, if they were to preserve an arbitrary amount of 25% of each vegetation community. The data used were a vegetation map from GAP, other ancillary data (e.g., geology, elevation, and hydrography), incorporation of more detailed vegetation information in selected areas using low altitude aerial photo interpreted maps, some vegetation information from 1:24,000 map sheets, a land-ownership map, and a pre-settlement vegetation map. The MMU was 1 ha, and mapped 6 forest communities which were red cedar/mixed conifer, wet hardwoods, mesic hardwoods, dry hardwoods, oak, and oak/tulip/maple. In a non-random sampling of accuracy, they found the land cover data to be 90% accurate.

Their first findings were that 1,549 ha should be added to attain their goal, especially within the class of oak. However, that scenario changed significantly when incorporating the pre-settlement ("native") vegetation map. The area requiring protection now tripled, with more areas required for wet and mesic hardwoods. The point was that the gap analysis should perhaps not be based on representation of the present vegetation, which was there as a result of human alteration, but instead should be compared to a map of native vegetation communities which were uninfluenced by disturbance. They felt that future analysis would be further enhanced by incorporating the pre-settlement vegetation map and by examining regions using ecological boundaries (ecoregions or watersheds). The database they created is currently being used by nature conservation organizations to plan additional reserve areas.

Key words: biological diversity, old-growth, dynamics, forest, map.

3.6.6 The future of GAP

It is hoped that further analysis of the methods used to process the vegetation data will be carried out, and also the effect of errors in the data on analysis. Then, further recommendations and changes from GAP might be expected. It is recognized that the vegetation maps are a snapshot in time and updates are planned on a 5-10 year cycle. Some states are already in the process of updating. There will certainly be more reporting on results of analysis, as that is the stage that many states are currently entering.

3.7 Recreation

No articles were found that were suitable to review for this category!

4. Discussion

Non-timber forest resources in general and biodiversity in particular are vague entities (Noss 1990) that can not be measured and monitored with any single and straightforward method. As presented in this survey, not all NTFRs are readily observable and the study or monitoring of some of them require the use of indicators. According to hierarchy theory as applied in landscape ecology, the patterns of these resources and indicators are discernible only at certain scales.

4.1 Landscape Ecology issues

It is within the frame of landscape ecology that ”an understanding and predictive ability can be reached for wood products, species, game, clean water, housing, recreation, or other often-conflicting objectives” (Forman 1995). Landscape ecology in combination with conservation ecology should be used for setting goals to reach sustainable use of the renewable resources, of which the NTFRs are part. Remote sensing provides useful tools to help measure quantitatively the goals so that progress towards them can be monitored.

4.1.1. Pattern-process relationships

There is a great demand for measurement and monitoring of landscape-level patterns and processes. This is due to the premise that ecological processes are linked to and can be predicted by some (often unknown) ecological pattern exhibited at coarse spatial scales (Gustafson 1998). Dispersal of species is one such process where the successful dispersal of individuals is affected by the pattern of habitat patches in the landscape. Our limited understanding of the links between pattern and process is repeated for the sensitivity of indices of landscape pattern to changing patterns (Haines-Young and Chopping 1996).

4.1.2 Indices and indicators

The interest in landscape indices has increased as a result of the integration of landscape ecology and conservation biology with the aim to produce better measures of habitat fragmentation (Schumaker 1996). In the literature there are several attempts to link indices of landscape pattern to ecological functions. However, these indices are often suggested by remote sensing and GIS oriented researchers. Noss (1999) points out that many landscape metrics suggested in the literature have no validated relationship to the biological phenomena of interest. Thus, there is a tremendous need to validate indicators and indices of landscape patterns for a wide range of species of conservation concern. The fact is that there are few pattern indices producing values that are useful by themselves because relationships between ecological processes and absolute values of indices is rarely known (Gustafson 1998). Gustafson (1998) states that indices of landscape heterogeneity represent a link between pattern and process, but they need to be validated. A first order measure as the amount of certain resource, e.g. the area of suitable habitat, can be a very useful measure (Schumaker 1996). There are several second order measures related to the landscape patterns and Schumaker (1996) found the predictive power of several of the most used indices to be very low. Experts have not yet reached an agreement on what measures of landscape patterns that should be used (Davidson 1998). Often a single measure is mistakenly used as an overall measure of fragmentation (Davidson 1998). ‘Through adaptive management, which requires the rigorous use of indicators for monitoring, we will hopefully learn as we proceed and not cause too much damage’ (Noss 1999).

While landscape indices are used to describe the structure of a landscape, indicators are used as indirect measures of the presence of certain species, functions or processes in that landscape. Biological indicators are most effective if they are measured against a baseline (CBD 1997) that is used as a reference mark. Other important benchmarks are *thresholds* and *targets* which indicators should be compared to.

The selection of indicators is very difficult. The suit of indicators should cover the compositional, structural and functional aspects of biodiversity as well as the multiple scales ranging from regional to genetic levels (Noss 1990). The Convention on Biological Diversity (CBD 1997) recommends the selection of a 'core set of indicators' aiming at answering some key questions regarding biodiversity e.g. how much is the status of biodiversity changing as a result of human activities, and why is it changing. The recommendation given by Noss (1999) when selecting indicators that should be good targets for monitoring is that they should consist of: area-limited species, dispersal-limited species, resource-limited species, process-limited species, keystone species, narrow endemic species, and special cases. All indicators of importance cannot be included, therefore one should strive for the 'driving' ones, and leave the 'passenger' ones outside. In the first four groups the species that is most sensitive would presumably be an umbrella species for the others in its category (Noss 1999).

Noss (1990) concludes that the assessment of total biodiversity needs many indicators and several of them may profitably be non-living ones, e.g. structures or processes. Therefore a mix of biotic and abiotic indicators, and indices may be the best solution. These need to be monitored at multiple levels (region, landscape, local, population, genetic) of organization. However, sometimes attributes of species populations better work as validation measures for the indicators, i.e. determining if they indicate what we think they do, rather than using them as indicators themselves (Noss 1999). He suggests that forest cover and its pattern might be the easiest indicator to monitor using remote sensing and demographic responses of species can provide the validation of our indicators, and be used as thresholds for management planning (Noss 1999).

4.1.3 Scale

The hierarchy concept suggests that biodiversity be monitored at multiple levels of organisation, and at multiple spatial and temporal scales (Noss 1990; Innes and Koch 1998). Haines-Young and Chopping (1996) found that parameters and processes of importance at one scale are often found not important or not predictive at another scale. Indices of spatial pattern and heterogeneity are dependent upon the scale at which the measurements are made (Turner 1989). Habitat mapping is also scale dependent and species specific (Conroy and Noon 1996), so much thought must be given to the scale at which the ecological process being studied operates, and/or the scale at which the organism(s) being studied perceives (or responds to) the heterogeneity of the landscape (Wiens 1989). Therefore it is important that, in studies linking pattern and process, these should be measured at the same spatial scale (both grain and extent) (Gustafson 1998).

”The effects of scale on the calculation of landscape indices is among the most profound of all those reviewed, so much so that it has led Aspinall (1996) to observe that, in the case of diversity measures, one can obtain almost any answer by changing the taxonomic and geographical resolution of the input data” (Haines-Young and Chopping 1996). They recommend the use of the highest resolution available. According to Marceau and Hay (1999) scale is of such vital importance that a science of scale should be established.

4.2 Remote sensing issues

Remote sensing can produce data needed for monitoring non-timber forest resources, including vegetation data; other forest data such as age, structure, and biomass; indices such as LAI; and data on magnitude or direction of change. These data are used as input to analyses about for example landscape indices, reserve siting, or other landscape characteristics. In order to produce usable results, the input data need to be as appropriate, accurate, and reliable as possible. There have been many studies, some of those which were reviewed in this report, that attempt to improve accuracy by using different combinations of remote sensing or ancillary data, or use various methods to obtain better or different information.

Choosing the most appropriate data source involves consideration of the sensor's spatial resolution in relation to the spatial resolution of the objects to be resolved, as well as the vegetation types and landscape patterns of the study area (Conroy and Noon 1996; Gustafson 1998). In practice, there is a choise between a low resolution "many tres per pixel" model, with pixel sizes in the order of 10 m – 30 m, and a high resolution "many pixels per tree" model, with pixel sizes in the order of 1 m or smaller. The low resolution "Landsat type" pixels are easier to interpreat with automatic methods, but the information content in the data is limited.

Spectral resolution of the sensor is also important. It is generally agreed that the near-infrared band of both SPOT and Landsat is quite important for forest remote sensing (Ripple et al. 1991). It has also been found that forest age, regeneration, basal area and species are better classified using generally all the TM bands Landsat TM data than using all or some of the SPOT bands (Brockhaus and Khorram 1992; Horler and Ahern 1986). Such results was probably obtined since the important short wave infrared wavelengths, which are sensitive to cast shadows, and therefore also to biomass, not were present in the early SPOT data.

4.2.1. Classification of data

Vegetation class information has been derived using a number of different methods, including unsupervised (usually ISODATA), supervised, hybrid unsupervised-supervised, or visual interpretation. Information about age, biomass and species composition was produced from a k-nearest neighbour (Tomppo et al. 1999; Fazakas et al. 1999) supervised algorithm. Forest variables, such as age or biomass may be more appropriate as continuous data, rather than discrete classes (Holmgren and Thuresson 1998). "Texture" algorithms (Ghitter et al. 1995; Wulder et al. 1998) can be used to provide information about forest structural complexity. Edges can be detected using statistical techniques, or qualification of edges can be derived from vegetation classification.

Various data sources, (e.g., data from the same or different sensors, ancillary data) have been combined to create better classification of vegetation species, forest structure, or vegetation change. This can include multi-seasonal, multi-sensor, or multi-year data, for example.

The use of multi-seasonal data has proven useful in separating classes with seasonal differences. Where forests have a deciduous component, phenological information provides more information than a single date scene (Schriever and Congalton 1993; Lillesand et al. 1998; Slaymaker 1996). Multi-seasonal data may make it possible to attain vegetation species level classifications, which may be important to habitat assessments, or as input to LAI (Franklin et al. 1997). Multi-seasonal data may also provide information about understory (Ghitter et al. 1995).

A single spatial scale of data may no longer be considered optimal when mapping detailed land cover classes which have different properties. A number of studies have suggested the use of multiple-scale (or multiple-stage) data, meaning using more than one spatial-scale data source. The data should be appropriate for each land-cover type (which vary in need due to both species type and the pattern in the landscape) within the area to be classified. (see Moody and Woodcock 1995; Metzger and Muller 1996; Hyppänen 1996; Hocevar and Kovac; Conroy and Noon 1996; Innes and Koch 1998; Miller 1994; Stohlgren et al. 1997; Marceau and Hay 1999)

Multiple-year data are used, often to detect magnitude and direction of changes in vegetation both at local and regional scale. Temporal scale between data acquisition dates should be appropriate to the application, atmospheric conditions corrected for, and the algorithm used should be sensitive to the change parameters desired for the application. Examples of their use are shown in Hall et al. (1991), and Coppin and Bauer (1994). Multiple-angle data may provide some information about vertical complexity of forests (Asner et al. 1998).

Field data are needed in order to aid in interpretation of the data into meaningful classes. This field data can come from forest inventory data, aerial photographs, or field surveys, for example. One of the important aspects is that the scale and classification of the field data should be appropriate for use with the remote sensing data. One of the projects reviewed here recommended the use of aerial videography which provided a large number of sample points (Slaymaker 1996), and allowed easy ”revisit” of the sites. It is important that field data be as precisely located as possible, and GPS aids in that cause. In some studies, field plot data gave more accurate results than polygon data (Franklin et al. 1997; Ghitter et al. 1995; Reese et al. 2000), although this is likely dependent upon the cover type, and the scale at which the field data were collected in comparison to the satellite data.

Ancillary data are used to aid in classification by separating confused classes or giving additional information. Data stratification, by ecoregion for example, has been shown to improve vegetation classification (Lillesand et al. 1998), while DEMs have been used to help classify riparian vegetation, or other topographically dependent vegetation classes. Other new techniques, which show promise in getting more information or higher accuracies from remotely sensed data are Spectral Mixture Analysis and Artificial Neural Networks (Carpenter et al. 1999; Lees).

Classifications of remotely sensed data often contain ”salt-and-pepper” pixels, which are smoothed by data generalization. Data generalization can change the classification considerably, and should be done cautiously. Applications in this paper found data generalization to be problematic, sometimes causing classes which appear at one scale to disappear at the generalized scale (Turner 1990). Often these classes are the most rare, or fractured classes of interest (Stohlgren et al. 1997; Smith et al. 1998). Some methods of generalization can eliminate certain patterns (e.g., linear) of classes. Generalization of data should be done in a way so as to preserve the legitimate features, and if classified with multiple data sources, then generalized at multiple-stages.

Ecologists and other end-users of remote sensing classified data are requesting explicit measures of accuracy pertaining to the classes (Flather et al. 1997). Confusion matrices, or other measures of accuracy should be given about the data. The errors can influence biodiversity measures (Conroy and Noon 1996) and indices (Franklin et al. 1997). A classification option which seems an innovative way to provide accuracy information is to include a ”2nd most probable” class as an attribute (see Redmond and Prather 1996).

4.2.2. Repeatability and comparability of remote sensing data

If meaningful analyses are to be made, the information from remote sensing data should be reliable, repeatable, and comparable, especially within a single application. Data comparability across applications becomes even more complicated. Comparability and repeatability of classified data is not a simple matter. Much of the information that comes from remote sensing data relies on ”snapshots in time” that are regarded as the ”truth”, if they are interpreted well. However, it has been shown that there may be other factors to consider when trying to understand the information remote sensing data provide. Parameters that are estimated and indexes calculated are seemingly affected by characteristics such as sun angle, view angle and atmospherical optical thickness at the time of acqusition (Vencatasawmy et al. 2000; McDonald et al. 1998). This results in indices which are not stable due to data qualities, rather than actual changes in the landscape. If unaware of these problems, false results could be interpreted. Some ways to avoid problems of comparisons among different scenes would be use of topographic correction, atmospheric correction, and algorithm robust to the factors which influence the classification.

Another factor which is important in creating data that are comparable across time and location is a common classification scheme (Scott et al. 1993; Kapos and Iremonger 1998). This is an arena where ecologists and remote sensing technicians must reach common ground, to develop classification schemes that can be achieved by remote sensing techniques, yet provide meaningful data to the ecologists. Classes should not be too broad so as to make too general a classification, thereby affecting the biodiversity analysis (Stohlgren et al. 1997). However, they must be achievable by remote sensing techniques with acceptable accuracy.

5. Conclusions

There are waste amount of studies about classification of remote sensing data and estimation of raster data bases with forest parameters, using satellite data in combination with field data. Such methods have been shown to be useful for overviews of the forest landscape and correctly applied also for improved statistics of forest resources. The information content in Landsat TM and SPOT HRV type of data is however considered to limited for operational forest management planning. There are many suggestions about how the remote sensing generated raster data could be used for analysis related to landscape ecology and biodiversity. However, many such suggestions have a weak evidence in ecological science. This is especially true for general indices that are supposed to be related to biodiversity. A quite safe way seams to be to work on a species level and compute species specific habitat maps, which could be improved when more knowledge about the species is gained. There are still only few operational programmes where remote sensing has been used for biodiversity related assessments. The probably best and largest operational programme to obtain inspiration and experiences from, is the GAP analysis programme in the USA.

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