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An Environmental Decision Support System for an Efficient Monitoring and Planning of Woody Biomass for Energy Production, with Remote Sensing Aid

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Abstract: The proposed paper describes the architecture of a GIS-based Environmental Decision Support System (EDSS) that integrates software tools and sensors, such as: remote sensing for environmental monitoring and support to mathematical models, optimization models (for planning plant size, kind, and biomass harvesting), dynamic forest growth models, and models for carbon dioxide balance calculation. The proposed EDSS is innovative as regards the current literature because it will be a tool for operational monitoring, cost minimization and efficient planning intervention, in accordance with natural and anthropogenic events that occur on the sites. The features of the EDSS and of the user-friendly interface are showed in connection with a case study.

***Keywords**:* Environmental Decision Support System; Environmental Modelling; Remote Sensing Data; Geographic Information system.

1. INTRODUCTION

The sustainable biomass exploitation for energy production requires the effective monitoring, design, planning and management of the related biomass supply-chain, including the integration and processing of different typologies of digital data (topographic maps, forest inventories, remote sensing, GIS data), the optimization of the logistics operations and of the energy conversion process, the assessment of the environmental impacts, the ability to combine economically appealing and environmentally sustainable strategies, as well as the participation in the decision of the different actors and stakeholders. Nowadays, there are several technological solutions that are available to produce energy from biomass. In addition, there are also several methodologies, available from the scientific community, to manage digital information based on Geographic Information Systems (GIS) and Decision Support Systems (DSS) to support decisions and planning (Freppaz et al., 2004; Voivontas et al., 2001).
On the other hand, the statistical and information sources about forest resources are heterogeneous and often fragmented, and difficult to be interpreted. Moreover, the in situ campaigns for forest inventories and resource quantification have very high costs. In this framework, tools that are able to interpret data, quantify environmental impacts, minimize costs for planning and management strategies are necessary. Among them, Remote Sensing (RS) can be a valuable aid to make available accurate information about the static and dynamic characteristics of the vegetal biomass. In the current literature, there are several works that show the importance of RS techniques for forest biomass assessment and

exploitation. Among them, Saatchi et al. (2007) show how radar sensors from airborne or spaceborne platforms have the potential of providing quantitative information about the forest structure and biomass components, Zheng et al. (2004) estimate the aboveground biomass using Landsat 7 ETM+ data, and Baltzer et al. (2003) examine the retrieval of tree growth from multi-temporal spaceborne L-band synthetic aperture radar (SAR).
In particular, the RS can represent a tool of pre-analysis, monitoring and evaluation of biomass resources for energy production. This tool can provide a basic set of thematic data to be supplied to the proposed EDSS, with the aim to replace part of the "traditional" cartographic and inventory information that often are available but too old and fragmented to be considered reliable.
Another important characteristics of the proposed EDSS is the user-friendly interface that easily allows scenario customization. Moreover, the EDSS is able to take into account different issues (environmental, energetic, economic and social) for the sustainable planning of the forest biomass use.
The potential users of the EDSS are Public Authorities that want to locate, size, and choose the technology for a plant, and want to define the harvesting plan, taking into account economic costs and environmental sustainability. The EDSS can also be used by a private company that needs to make a feasibility study for a plant in a territory, and that needs to evaluate the sustainable options and to minimize costs.
In the following sections, the EDSS architecture and the features are described in detail. Then, the different modules that can be used for different planning strategies are presented. Finally, a specific section is dedicated to the RS module and its integration into the EDSS.

2. THE EDSS ARCHITECTURE

The developed EDSS allows the planning of the biomass use in a given region, in order to minimize costs and guarantee the environmental sustainability.
In particular, the architecture is based on the following modules:

1. the GIS-based interface – a data aggregation system of territorial information that allows mapping data, working with different layers, and creating different scenarios (plant location, industrial biomass sources, forest parcels selection);
2. the database - for a suitable management of the information, the data planned in the GIS module and the results deriving from the optimization module are stored in a relational database;
3. the Remote Sensing (RS) module - strictly integrated with the GIS-based interface and the database system – it includes the necessary algorithms to elaborate the satellite data and to integrate them with the forest models and the optimization tools. In particular, this module is devoted to the evaluation of the current state of biomass resources, the vegetation species, the ground slope, the road network, etc. The multitemporal remote sensing analysis can also detect the natural or anthropogenic modifications that occur in the study areas;
4. the optimization module, subdivided in strategic planning and tactical planning to face the different aspects of the planning process.

The users can view the territory via a GIS oriented interface. The territory is divided in parcels, characterized by a homogeneous biomass type. As a first step, the users can customize the problem and create scenarios.
By default, the system appoints as eligible all the parcels. However, it is possible to eliminate those parcels that cannot be considered for harvesting because, for example, they are hardly reachable, environmentally protected, or the owner does not allow their use. Moreover, it is possible to add other biomass collection sites, such as, for example, biomass deriving from agriculture/industrial production, by inserting location, biomass quantity, and purchase cost. As regards plant typologies, it is possible to pick the plant directly on the map through the interface. Moreover, one can choose the plant typology and change parameters. After that, a procedure calculates the distance of the centroid of the selected parcels from the first available road and from the plant location. All data and calculations are stored in a database. Then, the optimization procedure is called. When the optimization procedure ends, the optimal results are shown on the map. For a suitable management of the information, the data planned in the GIS module and the results deriving from the

optimization module are stored in a relational database. Communication with the database is managed by a proper ODBC (Open Database Connectivity) interface, while the optimization module is called within the MS Visual Basic 6.0 program by a specific Lingo 8.0 component.

Figure 1 shows the interface that allows integrating all the modules. In particular, on the top of the interface there are utilities that can help to save files, modify parameters directly linked to the database, zoom, spam, parcels characteristics interrogation, insertion of plant location and industrial biomass sources data and location (using images that can be placed directly on the map), parcels selection for the specific Scenario. On the left there is a column where it is possible to select the following layers: provinces, communes, biomass parcels, territorial images. Once a layer is selected, it appears on the right, directly on the territorial area. It is also possible to decide which layer wants to be brought to front or behind other layers (by simply putting the layer on the top of the legend).

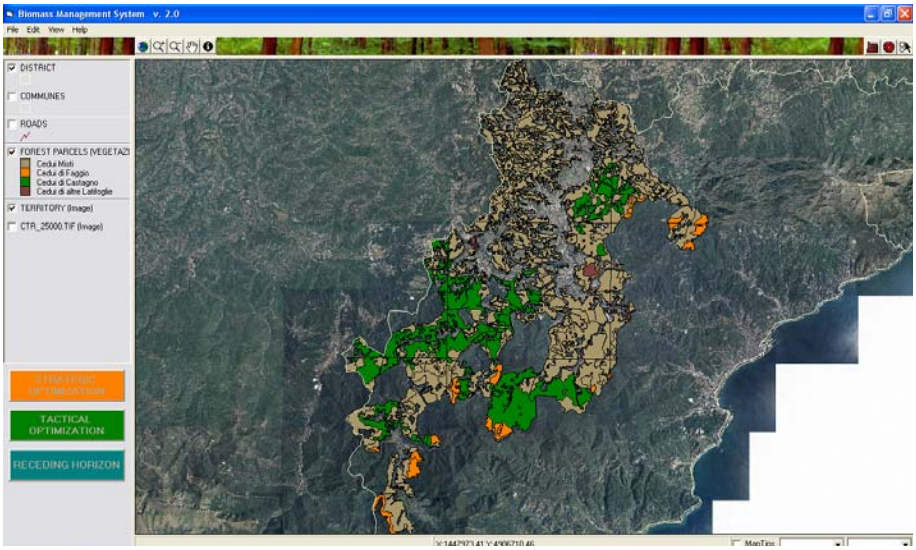

Figure 1. The software interface: the Val Bormida (Savona Province, Liguria Region, Italy) study area.

3. THE STRATEGIC PLANNING DECISION TOOL

3.1 The Decision Problem Description

Strategic planning level decisions refer to plant sizing and location, to the choice of the technology to be adopted, to the degree of exploitation of forest resources. Such a model corresponds to a linear programming problem. It is supposed that there is a unique plant location, which has been already selected, and that the matter of the decision problem is relevant to the plant size and the harvesting to be yearly performed, taking into account constraints deriving from Italian regulations over forest exploitation. The different plant technologies can be taken into account in the decision problem as they determine the values of specific parameters. Running the model for the various technological options, the user can obtain the optimal results for combustion, gasification, and pyrolisis processes and compare results on the basis of economic and environmental considerations. The decision variables are those quantities that represent the decisions to be taken, and are necessary to formalize the objective function and the constraints. In particular, for the strategic planning decision model, they are the annual biomass quantity harvested in the *j-th* slope class of the *i-th* parcel, and the plant capacity, expressed in terms of the maximum developed thermal power for the *k-th* technology. The objective function takes into account the costs and the benefits of the decision problem. In particular, in order to evaluate the overall cost function to be minimized, it is necessary to consider felling and processing, primary transportation (i.e. the transportation from the parcel to the first available road), transportation (i.e., from the first available road to the plant location), purchasing and plant costs, as well as the benefits deriving from the sales of the products.

3.2 Inputs and parameters in the EDSS

The EDSS dynamically changes the parameters related to plant characteristics when a specific technology is selected. Specifically, the plant technologies considered in the EDSS are: Grate Firing Combustor and Steam Cycle – GFC; Fluid Bed Combustor and Steam Cycle – FBC; Fluid Bed Gasification and Gas Engine – FBG; Fast Pyrolysis and Diesel Engine – FP. The Scenario is set taking the image showing the plant and putting it in the desired location. When the picture of the plant is placed by the user in the desired map, another window appears (on the top-left). Here it is possible to insert the name of the plant and to select the plant typology among the four different technologies. The technology brief description appears when the kind is selected. On the bottom of the window the plant location coordinates appear. Clicking the “Ok” button, the system calculates the necessary distances between the parcels and the plants, and selects the parameters relevant to the specific plant.

The same procedure can be followed for agro-industrial point sources of biomass. The wheel image on the top-right of the interface is selected and located on the map on the desired point locations. A window appears in which data about biomass type, quantity, heating value, moisture content and price are asked.

All Scenario data are transferred to the database and the software is ready for the use of the optimization modules.

3.3 EDSS results presentation: application to a case study

The system has been applied to the consortium of municipalities in the mountain community of Val Bormida, inside the Savona Province, to evaluate the sustainability of a power plant. The study area has a high tree density index, with respect to the Italian tree index; in fact, it is covered for a big part of its area by natural forest vegetation (mostly homogeneous hardwood forest). The total study area is about 28000 hectares, excluded the parts of forest territory that can not be exploited for the presence of legislative constrains (natural parks and protected area) and/or because they have been characterized by forest fires and hydro geological disasters or they are areas of great bio-naturalistic importance.

Figure 2 reports the results for the strategic optimization problem for GFC directly on the interface from where it is also possible to perform queries on the obtained results, directly working with the map. All results are stored in the database module. The selected parcels for the Scenario are shown in different colours in a thematic map, on the basis of the degree of use they are subject to. In fact, the thematic map represents, for each parcel, the quantity of harvested biomass per the available biomass that can be harvested (considering law limits and silvicultural knowledge for each biomass type). Three different main numerical outputs can be found on the interface: the Scenario Characteristics, the Scenario Detail, and the Parcels Detail. They can be viewed by clicking on the correspondent label on the interface. In Figure 2, the Scenario Detail is showed.

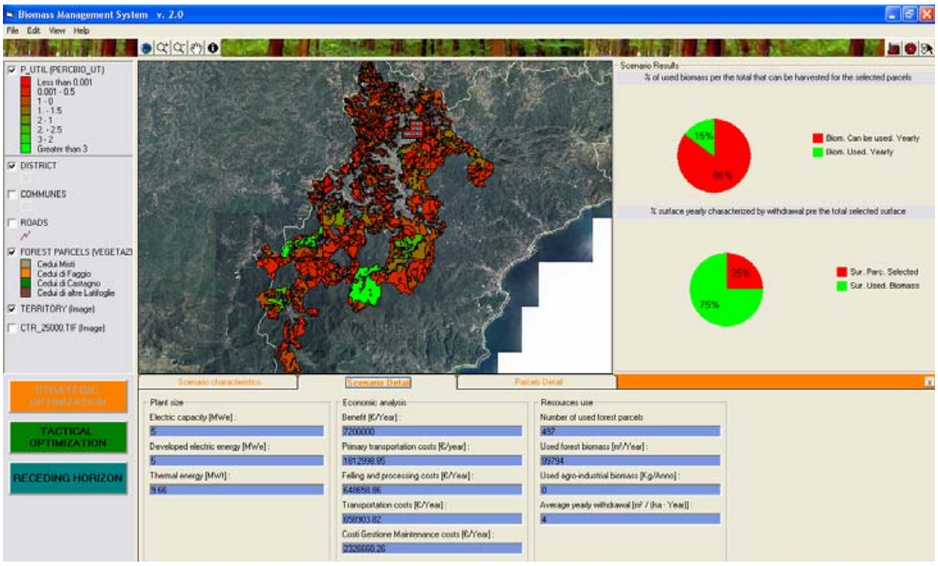

Figure 2. The optimal results for the strategic planning (GFC technology): “Scenario Characteristics” and “Scenario Detail”.

4. THE TACTICAL PLANNING DECISION TOOL

4.1 The Decision Problem Description

Tactical planning level decisions refer to a medium-short term horizon, and are generally considered within a discrete-time setting, assuming that the decisions of the strategic planning level have been established (i.e., plant capacity and location are fixed). In this case, a dynamical formalization of vegetation growth models and carbon sequestration models is needed. In this work, the control variables are represented by the yearly amount of biomass harvested from the *i-th* parcel. The state variables, necessary to represent the system state, are the amount of biomass present in each parcel at a specific time, and the average age of a forest parcel. Three different types of cost, related to biomass harvesting, have been considered. Two state equations are then formalized as a function of the control variables. The objective function is then composed by: cost of forest biomasses felling and processing, cost of forest biomasses primary transportation, transportation cost from the landing points to the plant. Finally, a calculation of the carbon dioxide balance is implemented as a function of the state and control variables.

4.2 Inputs and parameters in the EDSS

At the tactical planning level, the creation of the Scenario is the same as the one described at the Strategic level. One can also choose to use the results for the optimal capacity selected by the strategic optimization. However, a possibility is given in order to select a desired plant capacity for the Scenario. When the tactical optimization problem is clicked, a window appears that allows the user to choose a plant capacity. From the same window, it is also possible to set the optimization time horizon. Data are then stored in the database. All parameters related to forest growth models and carbon sequestration models are instead in the database and it is not possible to modify them through the interface. Only an expert user can modify them through the database, according to the forest characteristics of a specific case study.

For the tactical planning model two possible optimization procedures are called: the tactical planning optimization, and the receding horizon control scheme. In the first case, the optimization horizon is selected and the optimization tool is called once, while, in the second case, a receding horizon procedure is called and also the simulation horizon can be chosen.

4.3 EDSS results presentation: application to a case study

The optimization has been run for the Val Bormida case study. Figure 3 reports the results for the tactical optimization problem. Also in this case, results for Scenario characteristics, Scenario detail, and Parcels detail can be calculated. Moreover, results for calculated emissions are reported.

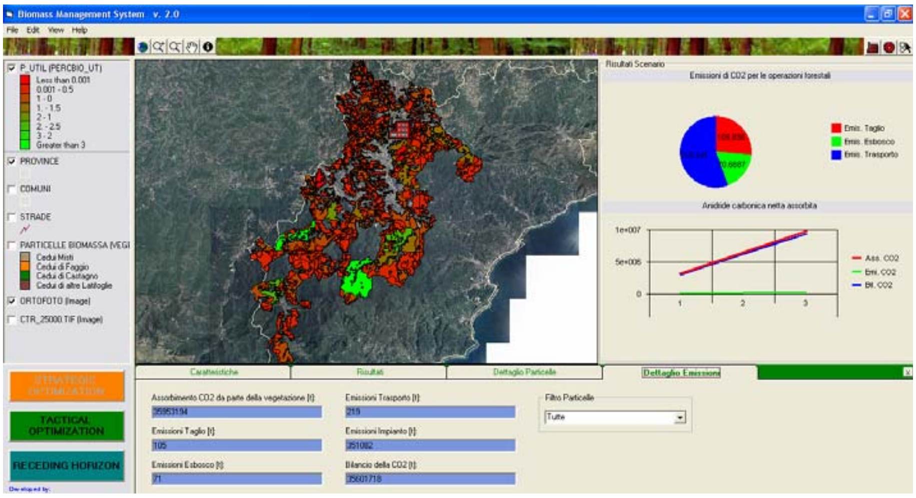

Figure 3. The optimal results for the tactical planning

5 THE REMOTE SENSING AID

5.1 The Remote Sensing Analysis

The main issues concerning forest management are depletion due to natural causes (fires and infestations) or human activity (clear-cutting, burning, land conversion), and monitoring of health and growth for effective commercial exploitation and conservation.
The analysis of the location, the extension, the health, and the productivity, the sustainability of such natural resources are critical information for natural land management. Remote sensing can reduce the cost of resource inventory and monitoring if remotely sensed data are well correlated with important field measurement, and available when needed.
The immediate advantages that Remote Sensing technology provides to a field as regards to forest management are the following: it makes possible a synoptic view of areas which otherwise should be investigated with enormous human as well as economic resource waste, it allows bypassing non-trivial obstacles, such as hard accessibility to some regions or the risk of modifying the environment by means of invasive in site inspections (Lillesand et al., 1987).
In order to manage and interpret this kind of data, it appeared to be wise to attempt to construct a data analysis system that takes advantage of keen perceptive and associative powers of humans in conjunction with the objective quantitative abilities of computers.

5.2 The Remote Sensing Module

The proposed RS module deals with the preprocessing and application of the remote sensing analysis for the exploitation of digital data in order to generate biomass information thematic maps that represents added-value layers in input to support the EDSS procedures.

With this purpose, this module will be developed to produce the following thematic layers, based on the exploitation of remote sensing data by image processing techniques, for the areas of interest:

- Archive and current satellite images for monitoring/visualization purposes;
- Vegetation species maps;
- Extension of the vegetation cover;
- Productivity Index (PI), as available wood biomass [kg]/area unit [m^2];
- Digital Elevation Model (DEM) and the related slope information.

All these kind of thematic layers have to be localized in plane geographic coordinates and updated when needed, then directly made usable in EDSS. All the layers will be stored in the database module and be available on the GIS interface (left side column, Figure 1) to be displayed on the right side, once selected.

Remote sensing, providing a detailed mapping of land at high resolution, can be an immediate decision support tool in the evaluation phase of biomass variables of the resource management and modelling, in the updating of cadastral information, in the assessment of the land, and in the evaluation of dimensions and areas of forest sites. Furthermore, the remote sensing analysis can be dynamic if multi-data images are processed with the purpose to detect natural and anthropic modifications, growth trend and so on.
Based on these considerations, the RS module aims to support both the strategic and the tactical decision approach. An example, in the strategic planning approach will be considered the possibility to "adjust" the value of a local state variable, like PI, by the correspondent RS information to obtain a *calibrated* PI value for each considered parcel by a suitable algorithm. In the tactical approach, the use of multitemporal RS data will allow the validation of the growth trend of PI in the areas of interest, for example considering at least RS data of the last 15 years.

The integration of the produced thematic layers in the EDSS is needed with the purpose to increase the reliability of the system. In this context, the use of remote sensing data, together with the extensive extraction of useful information as support tool to the management of the energy production by forest biomass, is particularly innovative.

6 THE REMOTE SENSING THEMATIC LAYERS: AN EXAMPLE

The great amount of remotely sensed data production requires to be analyzed before being available to the wide range of their customers.
With this purpose, this section aims to consider an adequate approach that makes thematic mapping by means of RS data feasible and reliable, exploiting the power of application-oriented data processing.

6.1 Application-oriented RS Data

In the case of application-oriented data processing, a brief example of RS layer generated in the RS module is showed in the following. It refers to Digital Elevation Model (DEM) obtained from radar satellite data.
Figure 4 shows a 3D-visualization of a DEM of Liguria Region, Italy, where mountainous chain is present very close to the sea. The different colours show the elevation ranges, where the red areas are the peaks.

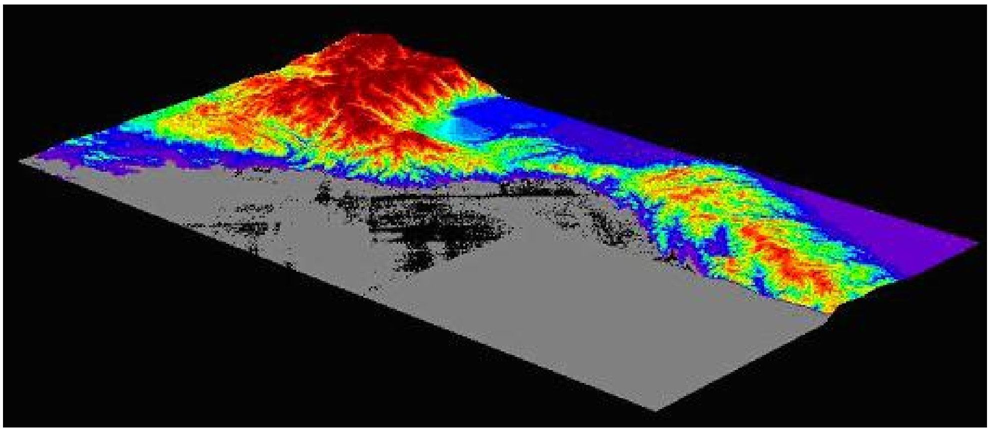

Figure 4. DEM of Liguria Region, Italy, obtained from radar satellite data.

Other information can be derived from this kind of RS product, like an elevation map where the lines at the same altitude are represented in different colour (Figure 5). From this kind of map is possible to extract the slope information.

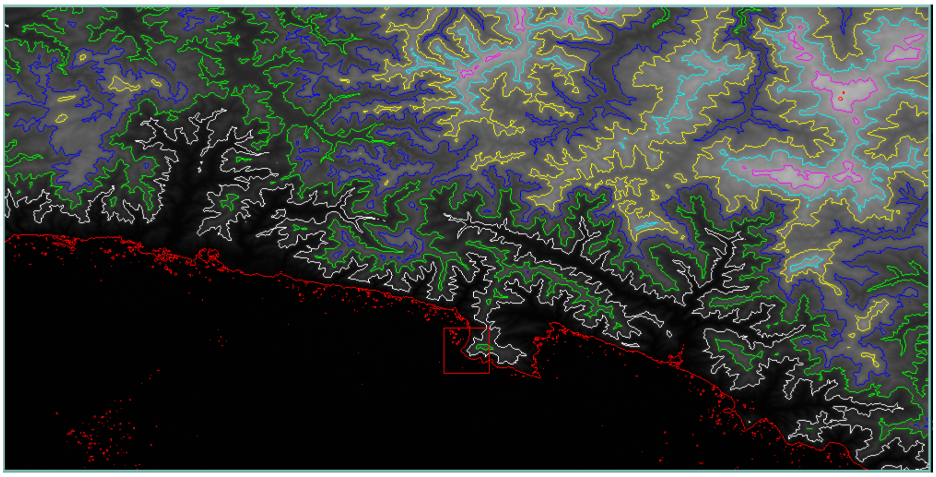

Figure 5. Altitude map obtained from radar satellite data in Fig.4.

Furthermore, it is important to note that DEM data (Figure 4) can be used in GIS interface to support the three-dimensional visualization of other available layers, like ortho-photos, vegetation and PI maps.

7 CONCLUSION

An EDSS for the monitoring and planning of forest biomass use for energy production and the features of the GIS-based interface is described in detail. The architecture includes different modules: the GIS-based interface, the database, the Remote Sensing (RS) module, and the optimization module, subdivided in strategic planning and tactical planning optimization problems. The EDSS is showed in connection with the application to a specific case study.

The main objective of the proposed work is to create a system able to transfer knowledge, data, software tools, and prototypes to the stakeholders in order to satisfy the requirements of effective monitoring, design, planning and management related to the wood biomass use for energy production.

The idea is based on the application of an innovative approach to biomass exploitation for energy production, based on a sustainable management and planning taking into account environmental, energetic, economic and social issues in order to develop a permanent market of wood production for energetic purposes that allow, on the other hand, to activate regular land maintenance to mitigate the hydrological risk and forest species degradation.

Future developments regard the implementation of the operational management optimization problem and the algorithms to process and integrate data from RS in order to generate information thematic maps that represents added-value layers in input to the described EDSS.

REFERENCES

Balzter H., Skinner L., Luckman A., Brooke R., Estimation of tree growth in a conifer plantation over 19 years from multi-satellite L-band SAR, *Remote Sensing of Environment 84*, 184-191, 2003.

Freppaz D., Minciardi R., Robba M., Rovatti M., Sacile R., Taramasso A., Optimizing forest biomass exploitation for energy supply at a regional level, *Biomass and Bioenergy 26*, 15-25, 2004.

Lillesand,T., and R.W. Kiefer, Remote Sensing and Image Interpretation, *2nd Edition*, 1987.

Saatchi,S., Halligan K., Despain DG, Crabtree, R.L., Estimation of Forest Fuel Load From Radar Remote Sensing, *IEEE Transactions on geoscience and remote sensing*, vol. 45 (6), 1726-1740, 2007.

Voivontas, D., Assimacopoulos, D. Koukios, E.G., Assessment of biomass potential for power production: a GIS based method, *Biomass and Bioenergy, 20*, 101-112, 2001.

Zheng, D., Rademacher, J., Chen, J., Crow, T., Bresee, M., Le Moine, J., Ryu, SR., Estimating aboveground biomass using Landsat 7 ETM+ data across a managed landscape in northern Wisconsin, USA, *Remote Sensing of Environment, 93*, 402-411, 2004.