Systems design options for linking GIS, modeling and visualization: application to forest management

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Abstract

The conceptual ideal for a manager of a complex, spatially distributed resource includes the data storage, analysis and display capabilities of a geographic information system, the availability of purpose built decision support models or procedures and realistic, real-time, interactive visualization of resource succession and the impacts of management decisions. All should work together in a seamlessly integrated environment. To create such an ideal as an industry specific system without an existing software base would be a difficult task. Separate modules already exist in the form of commercial GIS packages, industry based growth or health models and emerging visualization systems and languages. This paper presents an approach to integration of GIS and visualization using remote procedure calls (RPCs) and a message queue manager to create an integrated client-server environment. Specifically, this paper describes the development of a two-way communication between ArcView GIS and a program developed using the Performer visualization toolkits and the applications of this combined system in a forest management context. Implementation of a forest growth model in ArcView Avenue scripting language allows the model to directly drive the visualization.

Keywords: GIS, interactive visualization, integration methodology, client-server environment, forest management

1 Introduction

Environmental and natural resource management is a dynamic, multi-objective and very complex issue. It typically requires a set of tools which can be used to present current condition of resource, to predict changes over time and impacts of different management processes. GIS, environmental modeling and visualization are essential tools for resource management. During the past years, technological advancements in GIS software, computer graphic technology and improved understanding of natural resource process and modeling, have significantly changed resource management and planning.

Natural resource management is spatial in nature. GIS is widely recognized and commonly used tool for geo-reference problem solving. The usage and power of GIS in environmental management has already been proven (see Fedra 1993, 1994, Majuire et al. 1991, Knill 1993). GIS provides a wide range of functions to the users for spatial data capture, storage, manipulation and display. But GIS alone lacks the ability to provide true analytical capability and flexible display. It needs integration with other tools, such as modeling and visualization tools, to support spatial decision making.

Resource management is fundamentally concerned with evaluating of proposed management alternatives. Modeling permits simulation of likely future changes of a resource under its natural succession and proposed management processes. It is an important component of natural resource decision support system (DSS). However, the use of models as decision support is limited by their inability to handle spatial data. Therefore, it needs to be integrated with GIS to reinforce its spatial analytical abilities. A substantial body of recent research has proved the advantage of integrating GIS and forest modeling for forest decision making (for example, MacLean and Porter 1994, Peng and Apps 1997, Thorn et al. 1997).

Natural resource management involves many and diverse categories of people from different fields with different demands on visualization of data coming from the models or from data bases (Haagsma and Johanns 1995). A decision support system should not only consider their expert users (for example, forest planners) but also non-expert users (for example, general public). Therefore, an ideal system should integrate various forms of visualization (include abstract map display and realistic visualization) to make the system useable by all its users.

The formation of a spatial decision support system (SDSS) for natural resource management can be diagrammed in Figure 1.

GIS + ***Additional tools*** = ***SDSS***
such as:
resource & environmental modeling
realistic visualization, ...

Figure 1.The formation of a SDSS.

To create such an ideal system without an existing software base would be a prohibitive undertaking. In fact, modules posed above already exist in the forms of commercial GIS packages (for example ArcInfo and ArcView), industry based resource models (forest growth and yield models for example) and emerging visualization systems, languages and graphic toolkits (such as OpenGL and IRIX Performer). Integration will bring together a collection of software tools and maximize the functionality of each module. On the other hand, it minimizes the development effort and promises the rapid application design.

Detailed description of the ideal forest visualization system can be found in Tang et al. (1997), thus the following sections of this paper are devoted to the discussion of various issues relevant to general design philosophy and implementation of GIS, modeling and visualization integration in order to achieve such an ideal system.

2 Integration approaches

2.1 Levels of integration

Integration is the way of combining different systems together to provide the functionality users required. It can come in many forms and different levels. This section briefly reviews commonly used methods which integrate GIS with other modules. Lower levels of integration use data exchange method to link different modules. When GIS integrated with modeling and visualization using this method, it often serves as pre/post processor for modeling and visualization data (Figure 2). This integration methodology is implemented in many resources and environmental management systems (see Goodchild et al. (ed.) 1993, 1996). However, since it requires users to be familiar with each system's syntaxes, file formats, conversion programs and operation system procedures, it is not ideally suitable for

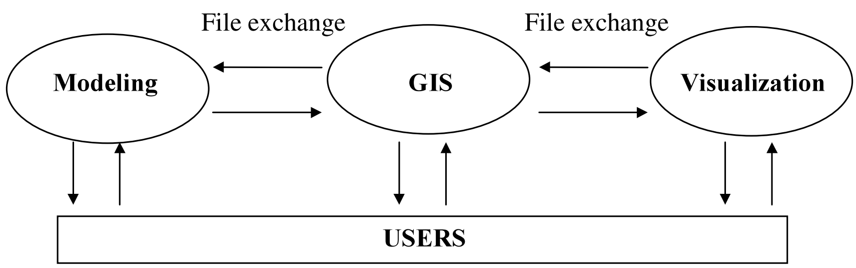

Figure 2. Lower level integration of separate programs through file exchange.

users who have limited or no knowledge of each software module. Higher levels of integration are needed to avoid this problem.

Many applications (for example Buckley et al. 1994, MacLean and Porter 1994) demonstrate closer linkages between GIS and modeling. Models written in a language other than the scripting language of a GIS (such as written used FORTRAN and C language) can be organized and activated by one or more macros in GIS as system calls. Using this integration method, users can take advantage of both GIS and existing modeling softwares, and retain a high degree of portability.

Models can also be embedded into a GIS by writing them as subroutines or commands using GIS scripting language (such as Avenue in ArcView), therefore becoming extended functions of GIS (Figure 3). In this full integration, GIS provides the framework and essential functions for the implementation of models. GIS and modeling appear to be seamlessly integrated and have the same interface to control program specifications, data conversions and output display. This type of integration achieves speed of operation and ease of use since all data conversions (or translations) between modules can be performed automatically within the system. It has been widely adopted for integration of simplified models where extensive use is made of the spatial analytical functions of GIS (Liao and Tim, 1994).

2.2 Client-server approach to visualization and GIS integration

2.2.1 Client-server paradigm

The client/server approach is an important design alternative for integrating various existing systems. It applies to any processing environment where one entity requests works to be done and another actually performs the works (Bloomer 1992). In the basic client/server model (Figure 4), a client application requests services from a server application through a communication mechanism, the server then performs those requested tasks and returns process results to its client through the same mechanism. A number of communication protocols exist for different platforms. Remote Procedure Call (RPC) is a standard communication protocol used for handling message passing activities between different software modules.

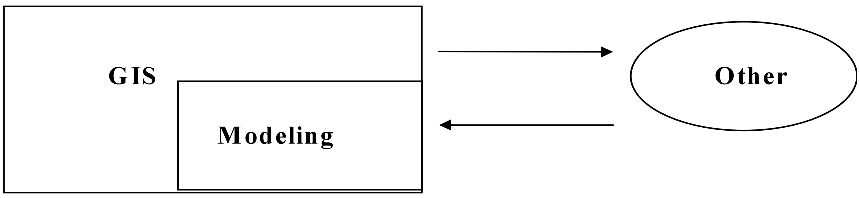

Figure 3. Model embedded into GIS, two modules share the same interface.

Figure 4. Client-Sever approach to system integration.

For GIS to take advantage of client/server technology, it requires an open GIS architecture (Open GIS Consortium 1996) that provides the interfaces and linkages necessary for integration. In recent years, GIS vendors have begun to produce GIS products which include such interfaces that allow developers to integrate GIS with other softwares using client/server technique. ArcView and Avenue support Dynamic Data Exchange (DDE) in Microsoft Windows environment, and Remote Procedure Calls (RPCs) in Unix environment for data (messages) transfer between applications (Razavi 1995).

2.2.2 Messages passing processes

An essential requirement for achieving client/server integration is communications between modules. One approach to enable this communication is using a message passing system (message queuing manager) which is formed by message queues. For each participating module there is a message queue associated with it. A system communicates with others by directing messages to the targeting system's queue using RPCs (Figure 5). The message sent is queued until the targeting system has retrieved it. The message may be a series of command or a bundle of data.

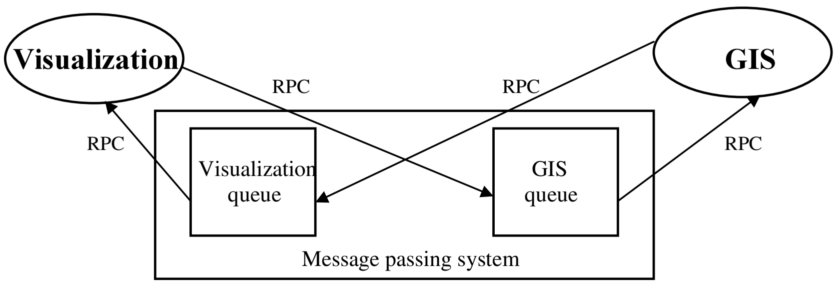

Figure 5. Messages passing processes.

3 Implementation of integration methodology

3.1 Sources of data and supported data models

Spatial data used for forest management is widely available from many different sources in many different formats. Different modules supports different data model. Data models used in our application included ARC/INFO coverages and grid, ArcView shapefile, digital elevation model (DEM) in grid form, visualization object file model (OBJ) and image data (textures).

ARC/INFO coverages include stands, roads and creeks. Among them, the stand coverage is the most important input data for forest modeling and visualization development. It describes ground vegetation (species of forest, age, treatment type, etc) and provides base data for modeling processes. In this polygon coverage, each stand has a unique polygon identification number (PID) associated with it. ArcView also supports shapefile (.shp) format which allows more rapidly display and is easier to work with. Both coverages and shapefiles can be converted to grid to enable further analysis. The grid DEM can be overlayed with other coverages in GIS and can be used together with texture to build 3D representation of forest condition in the visualization module.

Object file is an ASCII file that stores the geometry and other properties (such as textures) of physical objects in the Advanced Visualizer (Alias|Wavefront, 1995) format. It is one of the data models supported by Performer Toolkit and the forms core of our visualization. GIS data must be converted to OBJ file before it can be used in real-time visualization.

Image data (textures) include aerial photos and satellite images. Those imageries can be combined together and mapped onto DEM to present existing surface conditions in 3D. Other textures needed are the sampled textures which represent certain conditions of forest harvest or health and are used to replace the original condition in a texture mapping strategy for representation (Bishop 1994). The system can then simulate changes of appearance which are caused by management alternatives and modeling processes.

3.2 Implementation of integration methodology

In development of a forest management decision support system, we attempt to integrate GIS with forest modeling and visualization using different integration methods. Two levels of integration are adopted in respect to different characteristic of each system and relationship between them (Figure 6). Modeling process are written using Avenue scripting language and fully embedded into Arcview. Thus GIS and modeling appear to be seamlessly integrated and GIS style's interface can be used to maintain user familiarity.

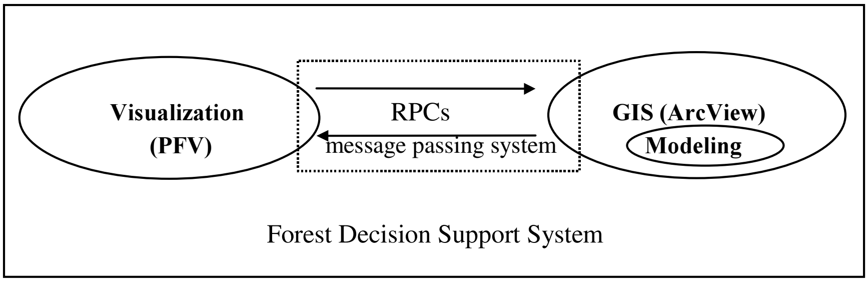

Figure 6. Different levels of integration implemented in Forest decision support system (Tang et al. 1997).

In order to fulfil a wide range of users' needs for GIS and visualization, we adopt client/server technology to integrate GIS (ArcView3.0) and a visualization module (Performer Forest Visualizer – PFV, developed using IRIS Performer Toolkits). These modules are developed independently with their own set of functionality, specification, interface, data model and data format. Therefore a message passing strategy is considered a proper way to bridge them. This integration can fully retain both visualization and GIS functionality.

In our application, both ArcView and visualization (PFV) act as RPCclients. They direct and retrieve messages while the queue manager (message passing system) acts as RPCserver and stores messages. Messages sent from origin system will be placed in targeted system's queue in queue manager and will be detected and retrieved by the targeted system when it is ready. Messages can be a single command string to activate separate modules or a bundle of data sent to another application. After retrieving message, the targeted system will then perform a series of required actions. Each client connects to its server by making remote procedure calls to it. Avenue provides a RPCClient object allowing for this type of communication with external systems. Following are fragments of Avenue script that carry out such processes.

```
aClinet =   RPCClient.Make
            ("surface",0x40000001,1)
highlight = aClient.Execute (1,"Highlight
            PID", String)
```

The first line of code creates a RPC client object connected to a specified RPC server (specified by three parameters of request Make: host name, server ID and version number). Once this client object created, it can then issue a request to its connected server and request a service by using the Execute request. Execute has three arguments: the procedure ID, the service request and the keyword STRING. It sends a message string (a command and a polygon ID) to the server which will be stored in PFV's queue and wait to be retrieved and processed.

3.3 Communication protocols

Once the communication has been established, message (data) passed must be understood by each of integrated modules. Communications protocols thus needed to be defined to achieve this common understanding. Those protocols define the structure and interpretation of the messages and are understood by the integrated systems. Types of protocols being built into our system contain a command and a polygon identification number as string. Messages passed from ArcView to visualization (PFV) include:

- *Highlight* PID highlights the forest stand(s) with selected PID (Polygon Identification Number), these polygons may be resulted from Arcview identify process;
- *Grow* Years change the height of the stand(s) to represent forest growth;
- *Harvest* PID change texture to respond to the harvest.

By sending those messages to visualization, that object (forest stand) can then be highlighted, raised or have its texture replaced in the visualization window to respond to the different actions taken in ArcView.

3.4 File conversion

The data formats supported by the two different modules are not entirely compatible. GIS data must be converted to the correct format before visualization. We select PID (Polygon ID) as the common identifier which will link different file formats. In the queue manager, there is a link to a C programmed 'PID2OBJ' converter which generates an appropriate object file (base.obj) in which data is grouped according to the stand coverage's PIDs. Hence object representation of forest stand data used in visualization are linked with stand polygon in ArcView.

In ArcView, after object construction (drawing or defining an area), it can be saved in form of a shapefile (.shp) and transferred to object file (.obj) by using another converter (ARC2OBJ) and finally passed to visualization module (PFV). ARC2OBJ needs 2 input files, naming grided topographical data (topo), grided polygon cover (cover). The later organizes grid cells into different groups according to their polygon numbers or section numbers. Output from this program is an OBJ file which represents defined area with risen edge to represent possible growth of the forest. Figure 7 is fragments of such an OBJ file. After receiving the complete object file, the visualization module can then draw, highlight, raise or replace its texture to represent different conditions.

Therefore, visualization can be driven directly by the GIS database and modeling process. The changes in GIS data base will be reflected in visualization. The growth of a stand or result of practices applied to a stand can be directly simulated thus overcoming the major problems of traditional image-based visualization, naming lack of positional accuracy and data/model coupling (Tang, et al. 1997).

```
# material library
mtllib /usr4/people/tang/from_usr23/ianb.mtl

# geometric and texture vertices
v 468230.875000 265537.458750 0.000000
vt 0.540000 0.540000 0.000000
v 468330.875000 265537.458750 0.000000
vt 0.580000 0.540000 0.000000
v 468430.875000 265537.458750 0.000000
vt 0.620000 0.540000 0.000000
...
v 468830.875000 265437.458750 311.000000
vt 0.780000 0.580000 0.000000
v 468930.875000 265437.458750 301.000000
vt 0.820000 0.580000 0.000000
...                                          1.
```

```
#material names, group names and
#elements (face) information
usemtl tximp99
g all tximp99
f 12/12  13/13  2/2
usemtl tximp99
g all tximp99
f 12/12  2/2  1/1
...
usemtl tximp2
g all tximp2
f 28/28  29/29  18/18
usemtl tximp99
g all tximp99
f 28/28  18/18  17/17
...                                          2.
```

Figure 7. Fragments of an AV OBJ file of sub-area in the forest which includes information about geometric vertices (v), texture vertices (vt), elements (f), grouping (g) and material (mtllib and usemtl).

3.5 System architecture

A few steps which involve data conversions and messages passing needed to be taken before data from one system can reach another system meaningfully. When separate systems seamlessly integrated together, this chain of complex data transformation and messages passing process can be hidden from end users' attention while still remaining transparent in term of its logic. Figure 8 presents diagram of such processes.

4 Application of integrated visualization system

4.1 Forest application

A forest manager may need to visualize existing condition in various ways. Our goal is to develop a system which provides two forms of visualization: abstract map-based

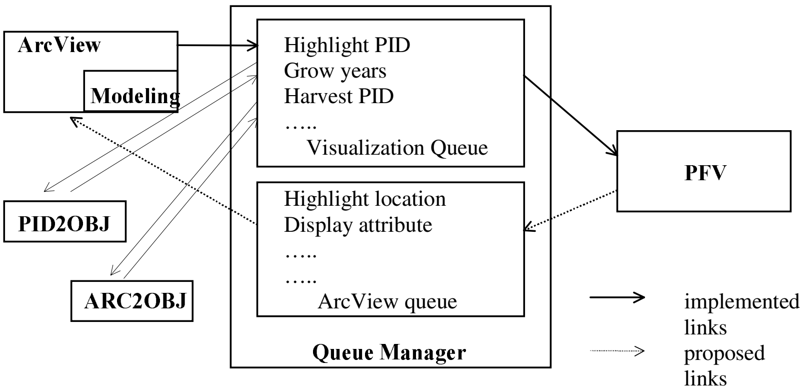

Figure 8. Data and messages passing process.

visualization and realistic image-based visualization to suit different type of users. In this system, data query, spatial analysis and modeling can be performed using traditional GIS functions and added modeling functions and the results of these can be viewed in map and realistic visualizations.

Forest management is based on evaluations of different management scenarios. Forest managers typically need to ask "What if…?" type of questions. Example scenarios may be a timber harvest schedule derived by conventional harvest planning procedures (e.g. linear programming). This will generate a table of stands with their date and type of cut. Results of these alternatives can be simulated, visualized and evaluated. Insights into the long term plans not available in the conventional planning processes may be achieved. Design and evaluation of the scenarios can be carried out interactively in real time and with immediate feedback.

The visual quality objective, amongst other forest management objectives, is gaining increasing emphasis. The aesthetics of harvest cut block shape, size and location have been of primary importance (Buckley and Berry 1997). Thus the use of integrated systems which focus on the linkage between GIS and visualization will clearly assist forest decision making.

4.2 Overview of the system

Figure 9 is the overview of the developing system. On the right is a ArcView window which has a forest

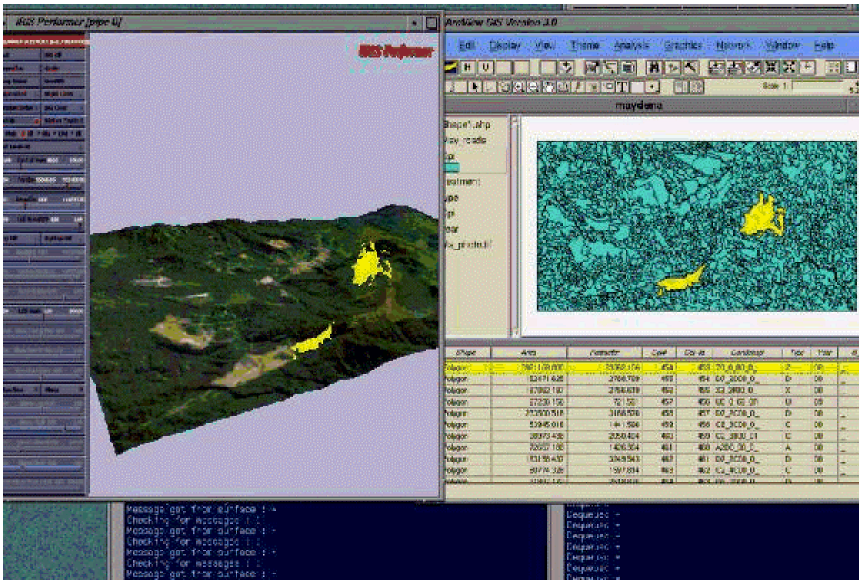

Figure 9. Overview of forest decision support system.

growth model integrated as an added function. Also presented in the ArcView window are buttons which initialize visualization or highlight, grow and change texture for appropriate polygon(s) on the PFV window. On the left is a real-time interactive 3D view visualization window (PFV) generated using IRIS Performer Toolkits. In lower part of the screen, activities of message passing are evidenced on shell windows. Friendly users' interfaces enable easy use of this system by all type of users. The PFV window includes fly/drive/walk controls so that users can use different viewing modes, travel anywhere and view any part of forest. Other viewing parameters such as view point, viewing angles and weather and light conditions can also be changed interactively to simulate the real condition of forest. Users can also take advantage of the animation function of PFV to view sequences of changes over time and the impacts caused by different management alternatives. All actions can be initialized by button clicking or mouse moving.

4.3 Two-way communications

By using RPCs and defining communication protocols, two way's communications between visualization and GIS can be achieved. System development up to date has already achieved GIS communication with visualization and directly drives visualization from GIS data base and modeling processes. Still to be implemented is communication from visualization to ArcView. This will allow GIS responds to actions taken in the visualization module. These actions include: identify forest stand(s), change of viewing location and change of view point. Function calls in Performer Toolkits permit retrieval of a specified location's PID and coordinates. This information can then be passed to GIS and activate a waiting Avenue script. Hence, attribute associated with the chosen stand can be displayed in ArcView.

5 Conclusion and future works

The successful integration of GIS, environmental modeling and realistic visualization to form a decision support system requires careful consideration of several issues which include the objectives of integration, communication methodology and data structures. Client-server and embedded approaches to such integration promise effective data communication and functionality sharing whilst maximizing the use of off-shelf softwares. The system we described here shows benefits of using such techniques in development of an interactive integrated visualization system for forest planning and management.

While such an integrated system shows promise for dramatically improving forest manager's ability to communicate complex forest planning issues with different groups of users, there is indeed need for further work to increase effectiveness and usefulness. These include:

1) generate more known scenarios to cover ranges of management planning and practices for specified application. These may include different type of harvesting, planting, treatment, etc;
2) develop more application specified functions that enable users flexibility to design unknown scenarios in real-time interactively;
3) further improve visualization realism to match users (specially non-expert users) mental images thus gain more accurate interpretation of information.

References

Alias|Wavefront Inc. 1995. OBJ File Format, Version 4.2. 530 East Montecito Stret, Santa Barbara, CA 93013, USA. p. 3.

Bishop, I.D. 1994. The role of visual realism in communicating and understanding spatial change and process. In: Unwin, D. & Hearnshaw, H. (eds.). Visualization in Geographic Information Systems. John Wiley, London. p. 60–64.

Bloomer, J. 1992. Power Programming with RPC. O'Reilly & Associates, Inc. USA. p. 1–17.

Buckley, D.J., Schreiner, F., Coughenour, M. & Blyth, C. 1994. The Ecosystem Management Model: Integrating Simulation Modeling and ARC/Info in the parks Canada (abstract). In: Proceeding of Decision Support - 2001, 17th Annual Geographic Information Systems and Resource Technology'94 Toronto, Canada, 1994. Vol. 2. p. 861.

Buckley, D.J. & Berry, J.K. 1997. GIS Visualization Techniques for Operational Forest Management. In: Proceeding of 11th Symposium on Geographic Information Systems, Vancouver, Canada, 1997. p. 209.

Fedra, K. 1993. Models, GIS and Expert Systems: Integrated Water Resources Models. In: Proceeding of Application of GIS in Hydrology and Water Resources Management, 1993, Vienna, Austria. p. 297–308.

Fedra, K. 1994. GIS and Environmental Modeling. In: Goodchild, M.F. et al. (eds.). Environmental Modelling with GIS. Oxford University Press. p. 35–50.

Goodchild, M.F., Parks B.O. & Steyaert, L.T. 1993. Geographic Information Systems and Environmental Modeling (eds). Oxford University Press, Oxford.

Goodchild, M.F. 1996. GIS and environmental modeling, GIS world, Fort Collins.

Haagsma, I.G. & Johanns R.D. 1995. Decision support systems: An integrated and distributed approach. Computer Techniques in Environmental Studies.

Knill, 1993. Geographical Information Systems: the environmental view. In: Mather, P.M. (ed.). Geographical Information Handling – Research and Applications. John Wiley & Sons Ltd. p. 8–15.

Liao, H. & Tim, U.S. 1994. Interactive water quality modeling within GIS environment. Computers, Environment, and Urban Systems 18: 343–363.

MacLean, D.A. & Porter, K.B. 1994. Development of a Decision Support System for Spruce Budworm and Forest Management Planning in Canada. In: Proceeding of Decision Making With GIS – The Fourth Dimension, GIS'94 Symposium, Vancouver, B.C. Vol. 2. p. 863–872.

Majuire, D.J. 1991. An overview and definition of GIS. In: Majuire et al. (eds.). Geographical Information system: Principle and application.

Longman Scientific & Technical, New York, Willey. p. 9–20.

Open GIS Consortium. 1996. Open GIS Consortium, Inc., http://ogis.org.

Peng, C. & Apps, M.J. 1997. A Coupled CENTURY Model-GIS Approach for Evaluation of the Sustainability of Canadian Boreal Forests Under a Changing Environment. In: Proceeding of 11th Annual Symposium on Geographic Information Systems, Vancouver, Canada. p. 316–323.

Razavi, A.H. 1995. ArcView Developer's Guide. OnWord Press, Santa Fe, USA. p. 233–243.

Tang, H., Bishop, I.D. & Yates, P. 1997. Towards an integrated interactive visualization system for forest management. In: Proceeding of International Symposium of Resource Technology 1997, Beijing, China.

Thorn, A.J., Orland, B. Y Daniel, T.C. 1997. Application of GIS and Forest Growth Models to Develop Bio-Physical Databases for New Zealand Forest Plantation Visualizations. In: Proceeding of 11th Annual Symposium on Geographic Information Systems, Vancouver, Canada. p. 185–189.

Yates, P. & Bishop, I.D. 1997. A method for the integration of existing GIS and modelling systems. In: Proceedings of Geocomputation'97, Duredin, SIRC, University of Duredin, New Zealand. p. 191–198.