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IMPACT ASSESSMENT FOR THE BARENTS SEA REGION: A GEODATA INFRASTRUCTURE APPROACH

Lars Bernard, Nicole Ostländer, Claus Rinner

Institute for Geoinformatics, University of Münster, Robert-Koch-Str. 26-28, 48149 Münster, Germany, {bernard,ostland,rinner}@ifgi.uni-muenster.de

1. INTRODUCTION

The concepts of geodata infrastructures (GDI) and distributed geoinformation services (GI services) are getting established. Current GDI efforts concentrate on the dissemination of geoinformation by use of services for cataloguing, mapping, and accessing geodata (Abel et al. 1999, Groot and McLaughin 2000, Bernard et al. 2001, Bernard 2002). Time has come to add more functionality to GDI and make GI services more *intelligent*. This paper discusses first steps by trying to incorporate techniques from the spatial decision support domain into GDI.

An overview of the BALANCE project which stimulated the idea of combining spatial decision support and GDI is followed by an outline of first ideas of how to design a GDI-based Assessment and Decision Support System.

2. THE BALANCE PROJECT

Current results of Global Climate Models indicate a global climate change and predict an increased warming for most of the circumpolar North. Without discussing the quality of model results most experts agree, that the northern ecosystems are highly sensitive to a possible future warming. Resulting positive or negative feedback has impact on the ecological system as well as on the socio-economic system of the northern regions.

The EC-funded research project *Global Change Vulnerabilities in the Barents Sea Region: Linking Arctic Natural Resources, Climate Change and Economies* (BALANCE) is conducted by a consortium of 15 research institutions from six European countries. The BALANCE project focuses on the integrated analysis and assessment of the impacts on the environment and society in the Barents Sea Region that might be expected from future climate changes. The Barents Sea Region (fig. 1) has one of the highest population densities throughout the Arctic and comprises a number of economic sectors that are partly dependent on renewable, vulnerable resources such as timber and fish. Following current research results these resources might heavily be influenced as a consequence of global climate change.

The major goal of the BALANCE Project is "to assess the vulnerabilities of the Barents Sea Region to climate change based on a common modelling framework for major environmental and societal components as well as on the quantification of linkages between these components through an integrated assessment model" (BALANCE 2002). The project will address terrestrial ecosystems, marine ecosystems and the hydrological regime as well as major societal/socio-economic sectors, i.e., forestry, fisheries, aquaculture, and reindeer husbandry in the Barents Sea Region to achieve a holistic approach.

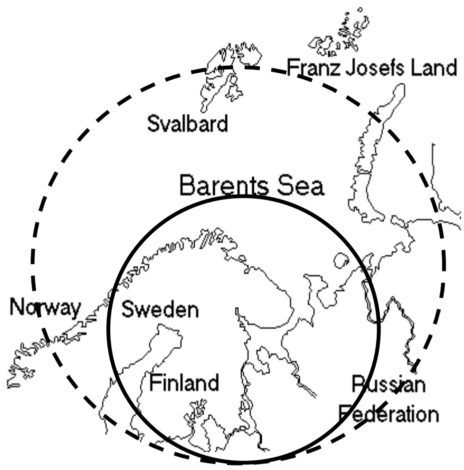

Fig. 1 Greater study area of BALANCE (dashed circle) and present priority area (solid circle) *(BALANCE 2002)*

The developments for the BALANCE project conducted by the Institute for Geoinformatics have two major goals:

1. The dissemination of model results developed in this project through a distributed web-based infrastructure of GI services. Making these results available for all stakeholders through an easy to use medium - the WorldWideWeb - will increase awareness.
2. The assessment of climate change impacts by providing an online Assessment and Decision Support System (ADSS). This will enable a better understanding of climate change impacts and vulnerabilities and the underlying processes for all stakeholders.

To achieve these goals a GDI will be set up for the BALANCE project to provide all project partners with the results of the applied climate, ecological and socio-economic models. Based on this BALANCE GDI and the specification of environmental and societal vulnerability indicators as provided by the project partners, the ADSS will be developed. Examples of such indicators include: sustainable stock sizes; decline in employment and population; changes in average age and out-migration.

3. BALANCE GEODATA INFRASTRUCTURE

The objectives of developing the BALANCE GDI based on distributed GI services are (1) to ensure the most up to date information, (2) to stimulate the partners to provide their results, which will be immediately available for all partners and stakeholders and (3) to enable project partners to manage and publish their geoinformation autonomously. The BALANCE GDI will be developed based on standardized GI services, thus enabling the integration of the evolving national and international GDI throughout Europe (e.g. INSPIRE, http://www.ec-gis.org/inspire). This facilitates stakeholder involvement with regard to the formulation of policy recommendations.

The architectural design of the BALANCE GDI will follow the General Service Model proposed by the OpenGIS Consortium (OGC, http://www.opengis.org/). The following Web-based GI services will be used:

- Web Catalogue Services to enable search for geodata and GI service, also being linked to other evolving European and national GDI

- Web Feature Services (WFS, (OGC 2002a)) and Web Coverage Service (depending on its future development within the OGC) to allow access on geoobjects,
- Web Map Services (WMS, (OGC 2002b)) providing maps and also offering a rendering engine for the above mentioned WFS,
- Web Clients that realize Web-based user interfaces to the BALANCE GDI applying standard Internet browsers.

Based on this BALANCE GDI a prototype of an *Assessment and Decision Support System (ADSS)* for BALANCE will be developed.

4. ASSESSMENT AND DECISION SUPPORT SYSTEM

Evaluation techniques within environmental impact assessment (EIA) are closely related to techniques in multi-criteria decision-making (MCDM, (Morgan 1998)). MCDM is a set of methods that aggregate attribute values into a ranking of decision alternatives. Instead of MCDM, we prefer the notion of multi-criteria *evaluation* (MCE) to avoid the impression that decisions could actually be calculated. MCE-based (spatial) decision support systems are used to suggest alternatives with high scores to human decision-makers.

A well established MCE method that is simple as well as powerful, is *weighted linear combination* (WLC, also known as simple additive weighting). WLC requires an initial standardization (or normalization) of variables to acquire commensurate factor values. Standardization can be done using common operations such as linear scale transformation or score range transformation. Variables can also be standardized using subjective utility functions to be specified by the decision-maker. Next, importance of factors is defined through factor weights. WLC finally adds weighted factor values of each alternative into a score by which alternatives can be ranked.

Within the BALANCE project MCE methods are used for the purpose of vulnerability assessment. Here the evaluation methods are used to determine areas that are more or less vulnerable to climate changes. The resulting vulnerability depends on user-specified weighting of vulnerability indicators (climate change impact factors). For instance a stakeholder may weight change in forest stands higher than change in average fish population based on the personal background.

As Morgan (1998) points out, the mathematical MCE methods require quantitative factors. This poses a problem for use in EIA which usually include qualitative information. Within the BALANCE project, this problem should be avoided by the compilation of quantitative vulnerability indicators. These indicators could be used as factors in a MCE procedure. Another requirement of MCE methods is that factors are non-redundant, thus statistical independent. This condition is hardly to prove considering real applications and therefore often stays unverified.

Our first approach for the BALANCE ADSS will be based on WLC. Each spatially represented vulnerability indicator is multiplied by the corresponding factor weights. The resulting weighted factor maps are aggregated into a single map that displays scores of vulnerability, corresponding to the stakeholders' preferences.

4.1 Design of GDI-based Assessment and Decision Support

The ISO/TC 211 abstract geoinformation service model distinguishes six main categories of geographic services (ISO/TC-211 and OGC 2002):

1. Human Interaction
2. Model and Information Management
3. Workflow and Task Management
4. Processing
5. Communication

6. System management

The existing (partly draft) OpenGIS Web Service specifications fall into category two (Web Catalog Service, Web Coverage Service, Web Feature Service, Web Map Service) and six (Geographic Markup Language). Several client applications (category one) based on these services are available today. The use of multi-criteria evaluation methods in the ADSS creates a need for services of category four (i.e. processing) in addition to existing services:

- statistical calculation services, to find minimum and maximum criterion outcomes for standardization
- coverage processing services to aggregate feature or grid coverages that contain criterion outcomes and factor weights (these could be called *map algebra services*)
- vector to grid, and grid to vector coverage conversion services

Interface specifications for such services allow developers to create sequences of services. Combining services is called service *chaining*. ISO/TC 211-19119 defines three possible architectures for service chaining:

1. user-defined (transparent) chaining
2. workflow-managed (translucent) chaining
3. aggregate service (opaque chaining)

In the first variant, "user defines and controls the order of execution of the individual services" (ISO/TC-211 and OGC 2002) and the details of services are transparent to the user. In the second variant, "execution of the chain is managed by a workflow service" (ISO/TC-211 and OGC 2002). The service chain is pre-defined in the workflow service and the execution is translucent to the user. Finally, an aggregate service appears as a single service "which handles all coordination of the individual services" (ISO/TC-211 and OGC 2002). Service chaining behind an aggregated service is opaque to the user.

By proposing architectural designs for an impact assessment service for the BALANCE project, we want to prepare the road for a technical solution of project goals. At the same time, we are using the project background as a means of examining geodata infrastructure specifications for specific geoprocessing services such as spatial multi-criteria evaluation in environmental impact assessment.

With respect to architectural approaches, two design options are proposed and described in the following paragraphs:

- A specialized MCE client that uses a transparent chain of information management services for which web service interface specifications already exist (coverage and feature services, catalogue services)
- An aggregate MCE service chain that adds appropriate processing services (statistical calculation services, coverage processing services) to the information management services

A first distinction of these architectural approaches has been presented at an OGC technical committee meeting (Simonis et al. 2002).

4.2 MCE Client Approach

Fig. 2 shows a transparent chaining approach to spatial multi-criteria evaluation. In step 1, a stakeholder in BALANCE uses a client to access a catalogue service requesting a list of available services for accessing coverages of the Barents Sea Region. Based on this list, the stakeholder selects datasets from different information management services to be used in his/her vulnerability analysis. The datasets represent remotely collected information on individual impact factors. The sequence of services and service chains for data access replace some common steps of data pre-processing in a stand-alone multi-criteria evaluation tool.

For example, in step 2 and 3, the client requests coverages from remote services for immediate use in the evaluation. In step 4, the client uses a map service to access topographic maps that are used as background layers. The client submits a query for the desired map layer to a map access service (step 4a). This service requests the geographic features from a feature access service (step 4b), renders these, and delivers the map image to the client.

At his point, the client has collected the raw data for an impact assessment using its local multi-criteria evaluation methods. The coverage data is in the same spatial reference system, but may need standardization. Standardized coverages are combined on a cell-by-cell basis using an evaluation method that calculates an overall vulnerability coverage, which is displayed to the user. The user may be offered ways to influence the assessment, e.g. by specifying different importance weights for the impact factor coverages.

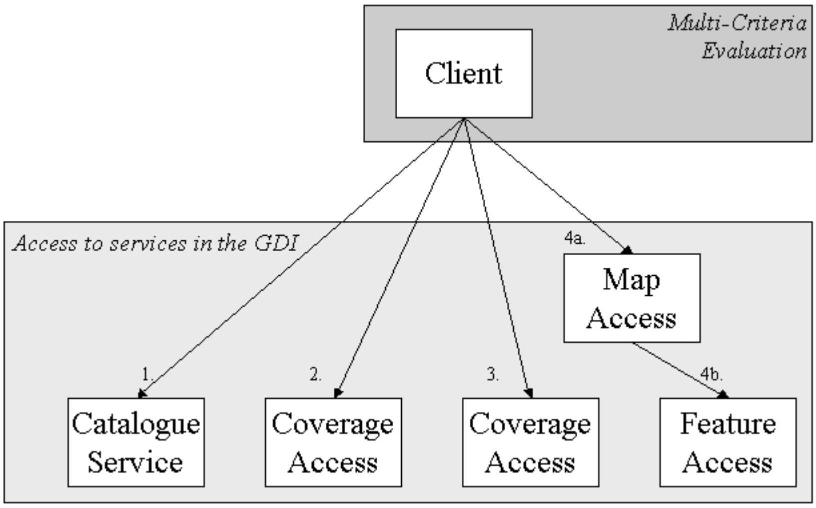

Fig. 2 User-defined, transparent service chaining for distributed data access to feed a multi-criteria evaluation client

Alternatively, this service chain might also be combined by an aggregate service instead of the above described 'thick' client approach. Consequently, this aggregate service can be accessed with a thin viewer client. We will follow this approach in our implementation approach (section 4.4). In the following section, we propose a slightly different design that further decomposes the MCE function into services.

4.3 Aggregate MCE Service Approach

Fig. 3 shows an opaque service chaining approach to spatial multi-criteria evaluation. The human user has thin client software that displays results of a single *aggregate multi-criteria evaluation service*. In step 1, the client accesses the aggregate service requesting a climate change vulnerability assessment. The aggregate service may offer users to analyse different areas within the Barents Sea region, or it may allow users to define certain parameters such as evaluation criteria.

Steps 2 to 4 are similar to those described above. In a sequence of data access and pre-processing services, datasets are prepared for use by subsequent services. Data is not actually collected by the aggregate service (as in the case of user-defined service chaining), but the aggregate service just collects references to currently available datasets and to pre-processing results. The remaining parts of the service chain replace some common steps of multi-criteria evaluation that have been performed on the client side in the first architectural design above.

Step 5 represents calculation of statistical data about coverages, which is required for subsequent standardization. In step 5a, the aggregate service accesses a statistical calculation service providing references to the results of coverage access and pre-processing services. These are in turn accessed by the statistical service in step 5b resulting in minimum and maximum cell values for the coverages in the assessment.

Statistical parameters of coverages are used in step 6 to standardize the coverages to a common range of cell values. Standardization is a coverage processing service that requires references to the statistical calculation service (step 6b) and to the data access and pre-processing services (step 6c). Coverage processing can also be used to multiply vulnerability indicator maps by a weighting factor. The weighted standardized coverages are aggregated using an evaluation method such as WLC (see above) on a cell-by-cell basis (step 7). This combination of thematic data across coverages is an instance of the ISO 19119 geoparameter calculation service category.

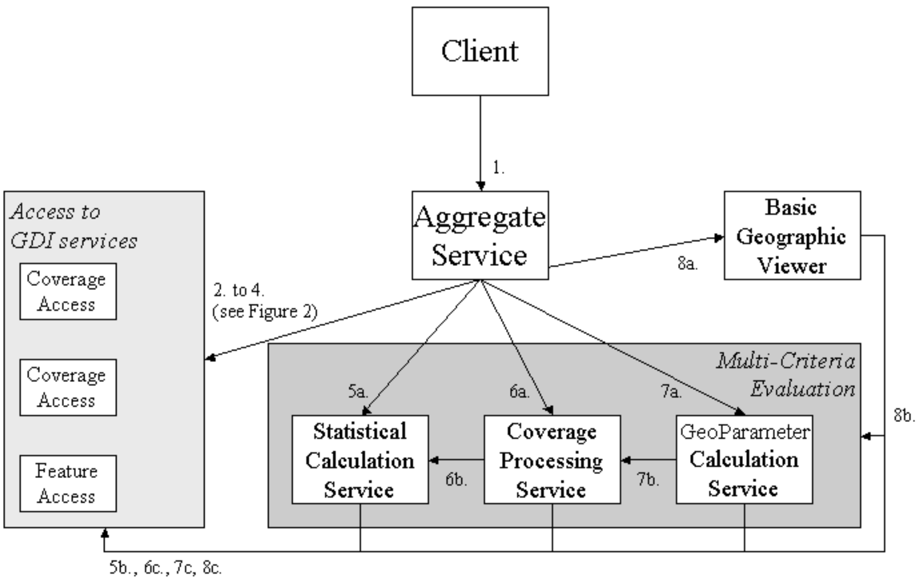

Fig. 3 Opaque service chaining with an aggregate multi-criteria evaluation service accessed by a viewer client

Steps 5 through 7 represent a multi-criteria evaluation method where climate change impact factors are used as criteria, and the evaluation provides an assessment of climate change vulnerability. The results of this service chain are sent to the client using a map service (step 8) that renders the resulting map as in the sequence described in the previous section.

4.4 Towards Service Implementation

This section proposes a way to implement the aggregate MCE service architecture of the previous section using the current and already often implemented Web Map Server specification (OGC 2002b). A client accesses the aggregate multi-criteria evaluation service as if it was a *regular* OpenGIS WMS. This is a first guess approach to realize a *Web MCE*

Service without the urgent need for a new specification to describe the interface of an evaluation or decision support service. Fig. 4 sketches the architecture of this approach.

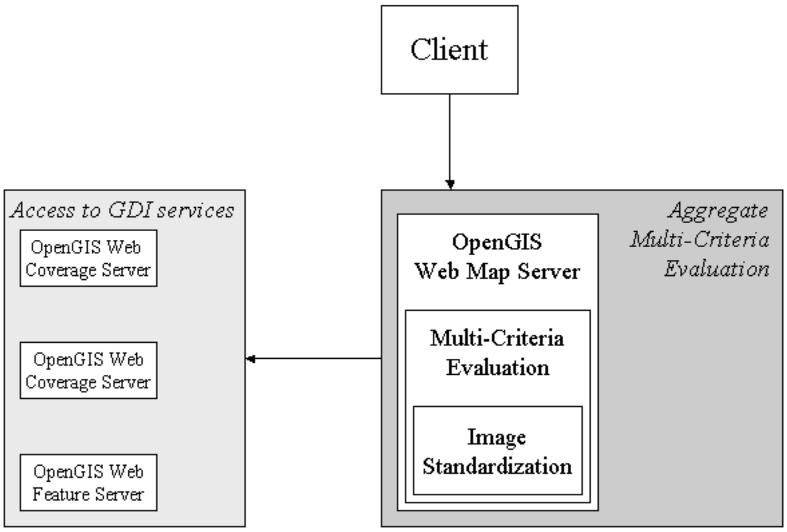

Fig. 4 Aggregate multi-criteria evaluation service using OpenGIS Web services specifications

Among the most important features of a WMS is its ability to provide a list of map layers that it can deliver using the *getCapabilities* interface, and to actually deliver a map image consisting of a graphical overlay of selected layers via the *getMap* interface. With a client request, a WMS cannot receive parameters that could be used to specify user preferences such as criterion weights or choice of an aggregation rule (see above). Therefore, we propose to use pre-defined categories of criterion importance and a fixed decision rule, WLC. Image layers representing criteria would be represented as three instances. These would be included in the list of layers to be served by the WMS. Different layers for the same topic represent different degrees of importance for the user, ranging from low over medium to high. For example, "forest-low" is a coverage representing forest areas and the coverage would be used with low importance in an evaluation.

Layer name as used in the WMS	Initial Weight	Importance Weight
forest-low	1	0.125
species-high	3	0.375
water-medium	2	0.250
soil-medium	2	0.250

Table 2 Names of layers indicating criterion importance, and derived importance weights

Criterion importance weights are defined using heuristics that depend on the importance categories of layers chosen by the user. Layers with low, medium, and high importance level are given initial weights of 1, 2, and 3, respectively. Initial weights are divided by the sum of all distributed weights to get valid weights with a sum of 1.0. Table 1 provides an example for criterion importance selection by the user and derivation of importance weights for the subsequent aggregation.

To answer a client request, coverages are retrieved from data access services. Cell values in coverages are then standardized to a common scale. Finally, coverages are aggregated with a MCE method using the derived importance weights. For example, according to the WLC method, cell values are multiplied by the importance weights and added to corresponding weighted cell values of the other layers. The resulting coverage has to be rendered and transferred to the client in a WMS-compliant way.

5. CONCLUSION

The assessment of climate change vulnerability of the Barents Sea region involves a large number of disciplines that are represented in the BALANCE project. In order to collect geodata created throughout the project, and make it accessible to partners for visualization and modelling purposes, we aim at providing a GDI-based solution including OpenGIS-compliant Web services.

One of the modelling tools to be developed in the project is an assessment and decision support system for climate change. In this paper, we presented different approaches to multi-criteria impact assessment based on the GDI architecture. The most feasible approach includes a regular OpenGIS Web Map Server that is set up to overlay indicator maps according to a user's selection. The resulting map displays a stakeholder's environmental impact assessment based on his/her personal weighting of vulnerability indicators.

The project background helped us develop a general approach to interoperable geoprocessing services that goes beyond currently available OpenGIS specifications. The multi-criteria evaluation methods used for vulnerability assessment require advanced coverage processing services. We plan to contribute to the specification and testing of such services.

6. ACKNOWLEDGEMENTS

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