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Normalized evaluation of the performance, capacity and availability of catalogue services: a pilot study based on INfrastruture for SPatial InfoRmation in Europe

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Geographic information has a great potential to be re-used when supported by mechanisms for its discovery. Above all, the quality of a catalogue service is the key feature supporting users in the discovery process. So far, there have been in existence various methodologies dealing with the normalized evaluation of quality with respect to catalogue services. Their biggest weakness seems to be in the depth of quality testing, i.e. some influences are beyond the scope of evaluation of these methodologies with respect to quality in catalogue services. In this study, the quality of 45 catalogue services across Europe was verified with the proposed normalized evaluation methodology originating from documents within the INfrastruture for SPatial InfoRmation in Europe (INSPIRE) framework. This paper discusses the (statistical) influence of factors that may significantly change the results of catalogue service testing. The proposals for improving the existing INSPIRE normalized evaluation procedure are applicable for any spatial data infrastructure and/or Digital Earth component using the Open Geospatial Consortium Catalogue Service for the Web as a basis.

Keywords: metadata; quality; evaluation; spatial data infrastructures; INSPIRE; Catalogue Service for the Web

1. Introduction

Geographical information, also known as spatial information, provides us with a location traditionally related to the Earth surface. Geographical information is commonly used in a wide range of human activities for different purposes. As such, it has great potential to be re-used by different institutions and companies. On the other hand, the effective (re)use of geographical information is paralysed by limited knowledge of where relevant data is stored. The term 'spatial data islands' is commonly used in this context. Discovering the localisation of geographic data storage is therefore the key to reusing (geographical) information.

The concept of Digital Earth envisages the seamless combination of geographical information. Al Gore (1998), in his speech on Digital Earth, described the concept as the '[…] representation of the planet, into which we can embed vast quantities of geo-referenced data'. Such quantities of geo-referenced data need to be organised through

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metadata, which was emphasised by Al Gore as one of the main needed technologies. In addition, metadata need to be organised since 'the ability to discover […] would be essential' for the concept of Digital Earth to be realized.

Both the concept of Digital Earth as well as the re-use of geographical information within and beyond it require reliable discovery mechanisms – namely, inventorying and searching capabilities. However, reliable metadata is not enough. It has to be published within reliable catalogue services to offer the value of metadata to as wide a public as possible. This paper therefore deals with issues relating to the reliability of catalogue services, including proposals for their normalized evaluation. The term 'normalized evaluation' is used in several scientific domains, such as economics, materials testing and computer science. Since it does not have any explicit definition, it is used in this paper to mean an unbiased evaluation that is based on rigorous testing procedures.

2. Concepts of geographical resources cataloguing

2.1. Spatial data infrastructures

Metadata for spatial data and spatial services are nowadays mostly created according to some standard. However, descriptions concerning titles, abstracts, publication dates, formats and publishers, etc. are the same across all standards. It may be even stated that the basic set of metadata items is the same for geographical data/services as for any human product known in daily life, as depicted in Figure 1.

The metadata content has then to be encoded into an exchange format. eXtensible Markup Language (XML) is the most common, since it is used, for example, by the ISO 19139, Dublin Core Metadata Initiative, and the Content Standard for Digital Geospatial Metadata. For further information on this topic, see Nogueras-Iso, Zarazaga-Soria, and Muro-Medrano (2005) or Moellering, Alders, and Crane (2005). The exchange format may be used directly for metadata transfer between organisations and/or used as an input for a catalogue service. In the end, relevant spatial data and services may be discovered through the metadata of a catalogue service within, for example, a Web browser as a client application of a catalogue service.

Catalogue services developed according to the implementation specifications of the Open Geospatial Consortium (OGC) represent today one of the most common means of metadata publication within the domain of geographic information. For more information on the details of OGC catalogue services, see Nebert, Whiteside, and Vretanos (2007).

The necessity of cataloguing in a spatial data infrastructure seems to be universally accepted. This may also be supported by experience originating from Europe. In 2003, Directive 2003/98/EC (also known as public sector information) established a minimum set of rules governing both the re-use and the practical means of facilitating the re-use of existing documents held by public sector bodies in the European Union. In the end, Directive 2003/98/EC had only a partial impact in the field of geographical information. In 2007, Directive 2007/2/ES (also known as INSPIRE – INfrastructure for SPatial InfoRmation in Europe) was established, chiefly to make it easier to discover available spatial data and services.

2.2. INSPIRE requirements on cataloguing

The INfrastructure for SPatial InfoRmation in Europe (hereinafter INSPIRE) is defined by the legal act, Directive 2007/2/EC, that came into force on 15 May 2007. Paragraph 2

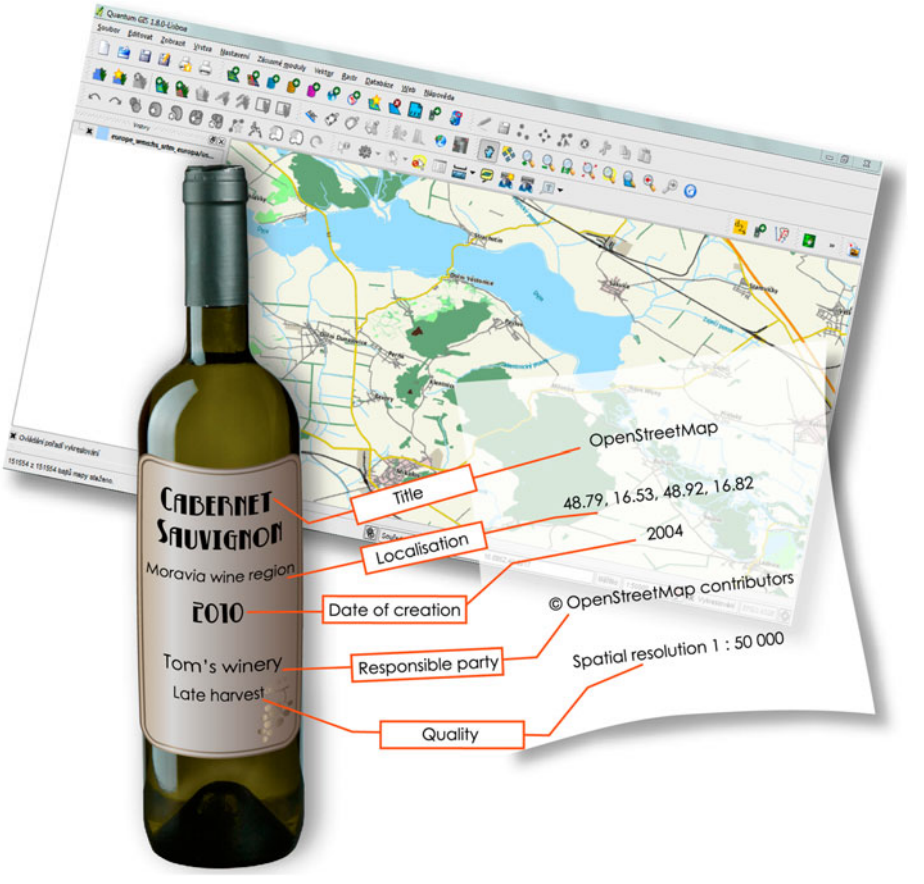

Figure 1. The basic set of metadata items required for the description of geographical information is the same for any human product known in daily life.

of the INSPIRE Directive describes the state-of-the-art of spatial data/information management in Europe: '[…] a number of problems exist regarding the availability, quality, organisation, accessibility and sharing of spatial information […]'. The INSPIRE Directive also emphasises priorities for the development of the European spatial data infrastructure:

> the infrastructures for spatial information in the Member States should be designed to ensure that […] it is easy to discover available spatial data, to evaluate their suitability for the purpose and to know the conditions applicable to their use.

It may therefore be stated that the cataloguing of geographic resources is one of the key activities in the implementation of INSPIRE. See Annoni et al. (2011) for further information on the European perspective on Digital Earth that originates from INSPIRE, Řezník (2013) for a general overview on INSPIRE, or the national point of view provided by Cetl, Roic, and Roncevic (2008). Cognitive issues of such a concept are depicted in Kubíček, Šašinka, and Stachoň (2014). Cross-domain applications when using crisis management as a pilot are defined by Konečný and Reinhardt (2010).

The INSPIRE Directive defines the concept of discovery services, which is very similar to the OGC concept of a catalogue service discussed above. Several minor differences may be defined; however, the terms 'discovery service' and 'catalogue service' may be used as synonymous in the context of this paper.

The developed catalogue services have been available free of charge within the European Member States since 9 May 2011. These catalogue services should make it possible to search for spatial datasets and services on the basis of the content of the corresponding metadata and to display the content of the metadata. The rules for the development of an INSPIRE-compliant catalogue service are defined on two levels:

- the legally binding level, i.e. defined by the Commission Regulation No. 976/2009;
- the technical level, i.e. defined by the (non-legally binding) Technical Guidance for the implementation of INSPIRE Discovery services.

The following text will outline the requirements with respect to the quality of a catalogue service developed under INSPIRE originating from legally binding as well as technical documents.

2.2.1. Quality of the catalogue service in INSPIRE

Any catalogue service within the Digital Earth concept should be reliable, i.e. its quality has to be guaranteed. The results regarding the quality of a catalogue service are given by the specifics of the chosen testing procedure. A set of so-called normalized testing procedures was developed in order to ensure the homogeneity of the assessment of the quality of catalogue services in INSPIRE.

Commission Regulation (EC) No. 976/2009 of 19 October 2009 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards the Network Services defines the functional and non-functional requirements that should be met simultaneously. Further on, this paper will deal only with the criteria that ensure the quality of catalogue services in the European spatial data infrastructure:

- *Performance*, which states how fast a request delivered to a catalogue service can be completed within that service. The response time for sending an initial response, i.e. a 'GetCapabilities' response according to OGC terminology, to a catalogue service request should be a maximum of 3 seconds in a normal situation. A normal situation represents 90% of periods out of peak load. The elementary question is how to measure the response time. It should be measured at the server side; see Section 3. Evaluation methodology for further information).
- *Capacity*, which is defined as the limit to the number of simultaneous service requests provided with guaranteed performance. The capacity criterion specifies that a catalogue service is capable of processing 30 simultaneous requests per second. A tester should issue 3 'GetCapabilities' requests and 27 'GetRecords' requests together every second within the timeframe of 1 minute. The results should be obtained within 3 seconds. The 'GetRecords' request should apply the structure of the sample reference request with the filter 'PropertyName=AnyText, Literal=dataset, and with varying BBOX requests'. There is a mismatch between INSPIRE documents dealing with the concept and the implementation of catalogue services. On the one hand, a normalized testing procedure should contain the

request with the filtering criterion 'AnyText'. On the other hand, the minimum search criteria for INSPIRE catalogue services do not include the 'AnyText' search criterion, even if it is a mandatory searching entity within the OGC implementation specification Catalogue Service for the Web (CSW).

- *Availability*, which means the probability that the catalogue service is available. The probability of a catalogue service being available should be 99% continuously during its lifetime. Also note that the Technical Guidance for the implementation of INSPIRE Discovery services (2011) counts the 99% uptime differently from the way it is commonly applied for information systems. For example, for 99% availability, INSPIRE specifies maximum downtimes of 1.7 hours a week, 7.27 hours per month and 3.63 days per year. On the other hand, 99% availability for information systems usually allows 1.68 hours a week, 7.20 hours per month and 3.65 days per year. Maximum downtime limits for a week, month and year are intended to apply for server/service failures as well as for the unavailability of a server due to maintenance or failure, for example. In any case, such strict availability criteria emphasise the need for system designs that ensure high availability.

3. Evaluation methodology

3.1. Concept of evaluation methodology

The primary aims of evaluation were to confirm or reject the following scientific hypotheses:

(1) it is possible to develop a normalized evaluation procedure for the catalogue services within Digital Earth from the performance, capacity and availability points of view;
(2) the number of metadata records in a catalogue has a statistically significant influence on the response time of an OGC-based catalogue service;
(3) the tools provided under INSPIRE may also be re-used for the catalogue services published under Digital Earth.

Several existing scientific results have been used while developing the evaluation methodology. Hošková-Mayerová et al. (2013) deal in general with aspects of quality for geospatial domains. Another kind of INSPIRE service, i.e. view – Web Map Service, has been tested by Ardielli, Horák, and Růžička (2012). In addition, Hicks, South, and Oshisanwo (1997) specify the following six types of client-side tests: test precondition data, functional testing, stress testing, test functionality, capacity testing and performance testing. The conducted tests have followed the INSPIRE requirements described above, i.e. functional testing, capacity testing and performance testing.

The requirements concerning the quality of a catalogue service should be measured at the service side exposed to the Internet and/or measured from a central network node within the infrastructure. It is desirable to measure these requirements on the server side. Unfortunately, this is not possible because of security issues. A tester usually does not have the administration rights with respect to a server providing a catalogue service. It is then almost impossible to monitor, for instance, the processing time of a response at the server side to a request delivered to a catalogue service. When evaluating the quality requirements of several catalogue services, theoretical approximation should be used to

obtain results that are as close to reality as possible. The influence of network transmissions was, for the conducted tests, minimized by measuring comparable requests to other services.

A group of 30 virtual users was created for performance and capacity testing, which sent requests each second over a 60-second period of measurement. The distribution of the requests was controlled by Throughput controller, which ensured that 10% of the sent requests matched 'GetCapabilties' requests and 90% matched 'GetRecords' requests with a dynamically changing Bounding Box, i.e. in line with the abovementioned INSPIRE requirements.

The parameters for the 'GetCapabilities' and 'GetRecords' requests were used as indicated in Tables 1 and 2.

The OGC Filter version 1.1.0 with the following structure was chosen as the constraint language used within the testing:

```
<ogc:Filter xmlns:ogc="http://www.opengis.net/ogc"
xmlns:gml="http://www.opengis.net/gml">
<ogc:And>
<ogc:PropertyIsLike wildCard="%" singleChar="#" escapeChar="\">
<ogc:PropertyName>AnyText</ogc:PropertyName>
<ogc:Literal>%dataset%</ogc:Literal>
</ogc:PropertyIsLike>
<ogc:BBOX>
<ogc:PropertyName>BoundingBox</ogc:PropertyName>
<gml:Envelope>
<gml:lowerCorner>Dynamically generated values</gml:lowerCorner>
<gml:upperCorner> Dynamically generated values</gml:upperCorner>
</gml:Envelope>
</ogc:BBOX>
</ogc:And>
</ogc:Filter>
```

Table 1. The set of parameters used for the 'GetCapabilities' requests during the conducted evaluation tests.

Parameter name	Parameter value	Cardinality
Service	CSW	1
Request	GetRecords	1
Version	2.0.2	0..1

Table 2. The set of parameters used for the 'GetRecords' operation during the conducted evaluation tests.

Parameter name	Parameter value	Cardinality
Service	CSW	1
Request	GetRecords	1
Version	2.0.2	1
ElementSetName	Full	0..1
TypeNames	csw:Record	1
ResultType	results	0..1
ConstraintLanguage	FILTER	0..1
Constraint	OGC filter value	0..1
OutputSchema	http://www.isotc211.org/2005/gmd	0..1
MaxRecords	5	0..1

All abovementioned parameters for a normalised testing procedure were chosen according to the best practices of the authors of this paper as well as limitations originating from the OGC CSW 2.0.2 implementation specification (Nebert, Whiteside, and Vretanos, 2007). Afterwards, all Catalogue Services for Web available at the INSPIRE Geoportal (see http://inspire-geoportal.ec.europa.eu) were homogenously analysed when logging the following results:

- throughput of requests within a second;
- average response time for each request.

All tests were conducted between 11 pm and 1 am in order to ensure the most relevant results – ones that were not affected by other users accessing the CSW. The availability test was conducted continuously over 1 week between 19 January 2014 and 26 January 2014.

The JMeter tool was used in order to verify the availability of the evaluated CSW. For such purposes, a ThreadGroup was created, which sent 10 'GetRecords' requests per hour to each tested CSW server. The results of the conducted availability test have only a partial value, since availability testing should be conducted continuously during the lifetime of a CSW.

From the technological point of view, the performance, capacity and availability testing of the INSPIRE Catalogue service was conducted on a virtual machine with a Windows 2008 R2 server with 8 cores and 8 GB of RAM memory based on the VMware virtualization platform. The Apache JMeter 2.10 application with Java Runtime Environment version 1.7.0_45 installed was used for the testing.

3.2. 'Queryables' testing

It is necessary to consider search parameters that further specify the searching process beyond capacity, performance and availability testing. In the OGC implementation specification as well as in the Technical Guidelines for INSPIRE Discovery services these search parameters are designated as 'queryables'. All 'queryables' supported by a catalogue service should be advertised in the 'GetCapabilities' response. Among other

means of verification, validation of the 'GetCapabilities' response may be achieved through the INSPIRE validator, which is available at the INSPIRE Geoportal (see http://inspire-geoportal.ec.europa.eu). However, the INSPIRE validator 'only' checks the availability of 'queryables' in the 'GetCapabilities' response. The functionality of 'queryables' themselves is not a subject of testing at the INSPIRE Geoportal. Testing scenarios were implemented in the JMeter application to address this limitation. Each evaluated catalogue service was evaluated through the set of 'queryables' as defined in Nebert, Whiteside, and Vretanos (2007) and Technical Guidance for the implementation of INSPIRE Discovery services (2011).

3.3. *Testing of selected parameters of the 'Get Records' request*

As stated above, the 'GetRecords' request consists of several mandatory and optional parameters that may have an impact on the results of capacity and performance testing. A virtual testing machine (Windows server 2008 R2 with 8 cores and 8 GB of RAM memory based on virtualization platform VMware) has been developed with the installed open source catalogue application called Deegree. This Java application in version 3.3.5 was used together with Apache Tomcat in version 7.0 as the application server. From the implementation point of view, Deegree enables users to search for metadata stored in a local drive in an XML file as well as metadata stored in a database. The PostgreSQL database in version 9.2 has been included together with its spatial extension, PostGIS 2.1.

The first analysed parameter was the number of metadata records in each evaluated catalogue. It was decided to test this aspect since there was wide diversification between the evaluated catalogues, starting at 5 metadata records ((PL) – Katalog INSPIREInstytutu Meteorologii i Gospodarki Wodnej – Usługa wyszukiwaniaINSPIRE) and ending at 187,487 metadata records ((CZ) – Vyhledávací služba CSW v metadatech datových sad a služeb resortu ČÚZK).

A script in the Python language was developed to create random metadata records, which were then imported into the database. Performance testing was conducted for the levels of 100, 1000, 5000, 10,000 and 50,000 metadata records when using the same parameters for the 'GetRecords' operation as described in Table 3. The definition of the bounding box was changed dynamically and randomly to achieve 100, 1000, 5000,

Table 3. The 'GetRecords' operation parameters that were evaluated in order to consider their impact on catalogue performance.

Parameter	Parameter value
ElementSetName	Full
	Brief
	Summary
OutputSchema	http://www.isotc211.org/2005/gmd
	http://www.opengis.net/cat/csw/2.0.2
MaxRecords	5
	10
ResultType	Results
	Hits

10,000 and 50,000 metadata records as the results. All the tests were conducted directly at the server to avoid the influence of network transmissions.

The second conducted test dealt with the influence of selected search parameters of the 'GetRecords' operation from the performance point of view. The parameters that were the subject of evaluation are shown in Table 3. For more information on the parameters of the OGC catalogue services depicted in Table 3; see Nebert, Whiteside, and Vretanos (2007).

At the end, 24 various settings for the 'GetRecords' request were received when combining the parameters depicted in Table 3. Performance using these sets of parameter values was evaluated at the local Deegree CSW.

4. Results

4.1. European evaluation

On 6 January 2014, 45 available catalogue services across Europe were identified at the INSPIRE Geoportal. The list of services is shown in Table 4. All 45 catalogue services were evaluated for their performance, capacity and availability. However, in the end, only 37 catalogue services were fully evaluated since the 8 remaining catalogue services were not available during the whole duration of the testing and/or the response to the 'GetRecords' request did not provide a valid response.

It may be stated that 23 of the 45 tested catalogue services fulfilled the performance criteria defined in Commission Regulation No. 976/2009. However, only 11 of the 45 catalogue services passed the performed capacity tests. Moreover, it was discovered that 23 of the 45 catalogue services supported searching based on all the required INSPIRE 'queryables'. One 'queryable' was not supported by 11 of the 45 catalogue services. The remaining 11 catalogue services did not support two or more 'queryables' and/or those 'queryables' were not available during the testing process. Only 4 out of the 45 evaluated services passed all three conducted tests – performance testing, capacity testing and 'queryables' testing.

The last conducted test dealt with the verification of the 'GetCapabilites' response. Requests to all 45 available catalogue services were made for the 'GetCapabilites' response. The obtained XML files were then saved in the local drive and validated through the INSPIRE validator at the INSPIRE Geoportal. None of the evaluated catalogue services passed this validation test. This last test was therefore repeated, unfortunately with an identical result. It was discovered that the INSPIRE validator provided various results for the same catalogue service when directly inserting the URL address during the validation process, in contrast to the validation of the 'GetCapabilites' response, which was stored as an XML file in the local drive. As a result, an improved version of the INSPIRE validator addressing procedure, resolving the discovered issue, has been publicly available at the INSPIRE Geoportal (http://inspire-geoportal.ec.europa.eu) since 15 March 2014.

The 'GetCapabilities' verification tests were again conducted on 24 June 2014, i.e. after the improvement of the validator at the INSPIRE Geoportal. It was discovered that only 10 catalogue services passed all the evaluation tests. Unfortunately, none of these 10 catalogue services matched the four catalogue services that passed the performance, capacity and availability tests. To sum up, no fully INSPIRE compliant catalogue service was discovered among the 45 evaluated catalogue services. Please see the summary statistics presented in Table 5.

Table 4. List of tested catalogue services.

Number	Name of the catalogue
1	(AT) – CSW Suchdienst der ZAMG
2	(AT) – CSW Suchdienst des BEV
3	(AT) – GEOLAND_CSW_2013
4	(AT) – INSPIREGeo-Portal Katalogservice BMLFUW/Österreich
5	(AT) – STATISTIK AUSTRIA INSPIRESuchdienst
6	(AT) – Suchdienst Schiffsverkehrsnetz – Österreich
7	(BE) – GeoCatalogue de la Région de Bruxelles-Capitale
8	(BE) – Geopunt-Metadatacenter zoekdienst
9	(CZ) – ArcGIS Server Geoportal Extension 10 – OGC CSW 2.0.2 ISO AP
10	(CZ) – Catalog Service for Web
11	(CZ) – Esri Geoportal Server 1.2.2 – OGC CSW 2.0.2 ISO AP
12	(CZ) – Metadatový katalog CENIA
13	(CZ) – Metadatový katalog Pardubického kraje
14	(CZ) – Metainformační systém Plzeňského kraje
15	(CZ) – MIcKA
16	(CZ) – Vyhledávací služba CSW v metadatech datových sad a služeb resortu ČÚZK
17	(DE) – CSW GEOkatalog NRW
18	(DE) – GeoDatenKatalog.De
19	(DE) – PortalU Metadatenkatalogdienst
20	(DK) –
21	(EE) – Estonia Discovery Service.
22	(EL) – ΚΑΤΑΛΟΓΟΣ
23	(ES) – Catàleg de Metadades del Instituto Geográfico Nacional
24	(ES) – Geoportal BCN Catàleg de Metadades CSW
25	(ES) – IDEC Catàleg de MetadadesINSPIRE
26	(ES) – Catàleg de Metadades de DGCarreteres del Departament de Territori i Sostenibilitat
27	(ES) – Catàleg de Metadades de Sant Cugat del Vallès
28	(ES) – IDEE Espana
29	(EU) – Clearinghouse of the JRC DERD unit – Demo INSPIREdiscovery service
30	(FI) – Paikkatietohakemiston CSW-rajapinta
31	(IE) – Geoportal IE – INSPIREDiscovery Service
32	(LU) – INSPIREGeoportal CSW des Großherzogtums Luxembourg
33	(NL) – Nationaal Georegister
34	(PL) – GDOŚ Geoserwis usługa katalogowa – Usługa wyszukiwania (INSPIREDiscovery)
35	(PL) – G-SIP Konstancin-Jeziorna usługa katalogowa – Usługa wyszukiwania (INSPIREDiscovery)
36	(PL) – Katalog INSPIREInstytutu Meteorologii i Gospodarki Wodnej – Usługa wyszukiwaniaINSPIRE
37	(PL) – Usługa wyszukiwania metadanych (CS-W) z Katalogu Metadanych Narodowego Instytutu Dziedzictwa
38	(PT) – INSPIRE-PT Catalog Service
39	(RO) – Serviciul de căutare al geo-portalului INSPIREal României
40	(SE) – Nationell svensk metadatakatalog
41	(SE) – Nationell svensk metadatakatalog

Table 4. (*Continued*)

Number	Name of the catalogue
42	(SI) – Slovenski Inspire metadata sistem
43	(SK) – Vyhľadávacia služba ÚGKK SR
44	(UK) – UK Location Catalogue Publishing Service
45	(UK) – Wycombe District Council INSPIREcsw service

4.2. Local evaluation

All the following additional tests were conducted only at the testing premises of the authors when using the catalogue based on the open source application Deegree. The aim of these tests was to determine whether the settings of parameters that are outside the INSPIRE normalized testing procedure would significantly influence the results of catalogue service performance.

The results of the performance and capacity evaluation based on the 'GetRecords' request parameters are depicted in Table 6 and Figure 2. These results may be classified into two groups according to the 'ResultType' parameter. The number of metadata records in the catalogue that match the search criteria is returned when setting the 'ResultType' for the value 'Hits'; the XML structure of metadata records is not provided. During the conducted tests, the response time was the shortest when setting the 'ResultType' parameter to the value 'Hits'. In other words, a catalogue in the test was capable of addressing from 85 to 96 requests per second when the response time was about 0.3 seconds. These values are considerably lower than the limit of 3 seconds defined in Commission Regulation No. 976/2009.

Table 5. Summary statistics for the 45 evaluated catalogue services that were published under INSPIRE.

Test type	Absolute values of results	Relative values (of all 45 available catalogues) (%)
Evaluated catalogue services	45	100.00
Catalogue services with the relevant response	37	82.22
Capacity (more than 30 requirements per second)	11	24.44
Average response time (within 3 seconds)	23	51.11
Catalogue services evaluated for the 'queryables'	45	100.00
INSPIRE-conformant catalogue services	23	51.11
Catalogue services not supporting at least 1 'queryable'	11	24.44
Catalogue services conformant according to the capacity, response time and 'queryables'	4	8.89
Catalogue services with INSPIRE-conformant 'GetCapabilities' response	10	22.22
Overall quality of INSPIRE-conformant catalogue services (fulfilling the capacity, response time, 'queryables' and 'GetCapabilities' response tests)	0	0.00

Table 6. Summary statistics of the throughput of the evaluated catalogue service in dependency on the setting of the 'ElementSetName', 'OutputSchema', 'MaxRecords' and 'ResultType' parameters.

Parameters			Results			
ElementSetName	OutputSchema	MaxRecords	ResultType	Number of samples	Response time (ms)	Throughput (requirements per second)
Full	Gmd	5	result	3569	495	59.2
Full	Gmd	10	result	2535	709	41.8
Full	Csw	5	result	3522	487	58.3
Full	Csw	10	result	2672	669	44.1
Brief	Gmd	5	result	4354	405	72.3
Brief	Gmd	10	result	3468	514	57.3
Brief	Csw	5	result	3800	465	63.0
Brief	Csw	10	result	3028	590	50.0
Summary	Gmd	5	result	4023	437	66.6
Summary	Gmd	10	result	3168	561	52.4
Summary	Csw	5	result	3724	476	61.6
Summary	Csw	10	result	2922	610	48.3
Full	Gmd	5	hits	5736	309	95.4
Full	Gmd	10	hits	5748	307	95.5
Full	Csw	5	hits	5469	324	90.9
Full	Csw	10	hits	5128	344	85.2
Brief	Gmd	5	hits	5785	305	96.2
Brief	Gmd	10	hits	5392	328	89.6
Brief	Csw	5	hits	5358	330	89.1
Brief	Csw	10	hits	5649	314	93.8
Summary	Gmd	5	hits	5637	314	93.6
Summary	Gmd	10	hits	5779	307	96.0
Summary	Csw	5	hits	5887	301	97.9
Summary	Csw	10	hits	5470	324	90.9

Note: 'Gmd' is an abbreviation for the OutputSchema http://www.isotc211.org/2005/gmd while 'Csw' is an abbreviation for the OutputSchema http://www.opengis.net/cat/csw/2.0.2.

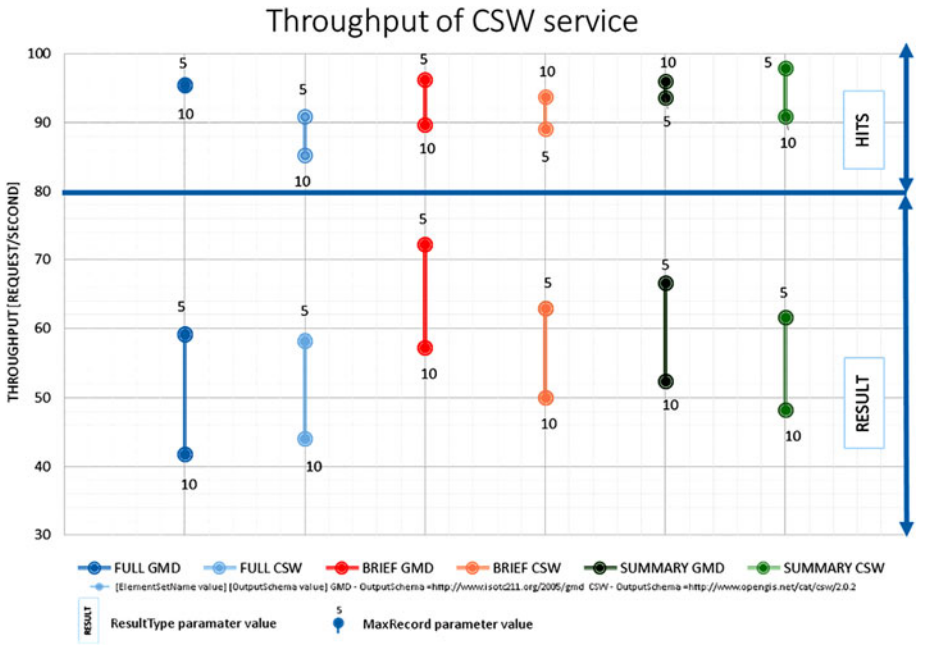

Figure 2. Throughput of the evaluated catalogue service in dependency on the setting of the 'ElementSetName' and 'ResultType' parameters.

Significantly greater differences in the results for performance and capacity were revealed when setting the 'ResultType' parameter to the value 'Results'. The main reason for such differences lies in the response, which is an XML structure. In total, the evaluated catalogue was capable of addressing from 41 to 72 requests per second with a response time of between 0.4 and 0.7 seconds.

The 'MaxRecords' parameter had the most significant impact on performance. The 'MaxRecords' parameter defines the number of metadata records that should be returned as a result of the 'GetRecords' request. In general, the higher the number of returned metadata records is, the higher the response time that is needed (i.e. the lower the performance and capacity values were).

The 'ElementSetName' parameter has a similar influence to the 'MaxRecords' parameter. The best results were achieved when setting the 'ElementSetName' parameter to the value 'Brief', when only the title, type of resource (hierarchy level), identifier, bounding box, service type (including version) and graphic overview are returned. Detailed results are depicted in Table 6.

The last evaluation determined the influence of the number of records in a catalogue on the performance of the catalogue service. This kind of test was performed at the testing premises of the authors when using the catalogue based on the open source application Deegree. It was discovered that the catalogue service's performance decreased significantly as the number of metadata records in the catalogue increased. See Table 7 for further information. The correlation coefficient reached a value of 0.67 for the dependency between the capacity criteria and the number of records. The correlation coefficient reached a value of 0.99 for the dependency between the response time and the number of metadata records in the catalogue.

Table 7. Performance and capacity of a catalogue service in dependency on the number of metadata records in the catalogue.

	Results		
Number of metadata records	Number of samples	Response time (ms)	Throughput (requirements per second)
100	4572	390	75.9
1000	3596	501	59.5
5000	1150	1589	18.8
10,000	636	2918	10.2
50,000	181	10,380	2.8

All the available CSW servers were also evaluated to support the assumptions on the dependency between the response time and the number of metadata records in the catalogue. In this case, the correlation coefficient reached a value of 0.85. On the other hand, the tests did not confirm a dependency between the throughputs of evaluated CSWs and an increasing number of metadata records. In this case, the correlation coefficient reached a value of 0.26. In this context, the value of the correlation coefficient may result from the average number of metadata records in the evaluated catalogues. The mean number of records in a catalogue was 5158 while the median was 137 records. The majority of catalogues, i.e. 43 of 45, consisted of less than 5000 metadata records. Only two catalogues contained more than 5000 metadata records: precisely 45,367 and 187,487 metadata records with throughputs of 0.6 requests per second and 0.3 requests per second, respectively.

5. Conclusions and discussion

The following conclusions may be drawn when considering the scientific hypotheses presented in Section 3 of this paper:

(1) it was confirmed that it is possible to develop a normalized evaluation procedure for the catalogue services within Digital Earth from the performance, capacity and availability points of view;
(2) it was confirmed that the number of metadata records in a catalogue has a statistically significant influence on the response time of an OGC-based catalogue service;
(3) the hypothesis that the tools provided under INSPIRE may also be re-used for the catalogue services published under Digital Earth was rejected.

It is obvious that the performance, capacity and availability testing of a catalogue service depends significantly on several factors. This statement is valid for any spatial data infrastructure as well as for the whole concept of Digital Earth. Unfortunately, so far, no complex methodology exists dealing with all the relevant factors. As a result, a tester may receive various evaluation results depending on the settings of the conducted tests. We would like, therefore, to propose an improvement to the INSPIRE normalised testing

procedure that would represent a valuable starting point. However, it is necessary to define more detailed testing guidelines for this normalised testing procedure. Otherwise, there is the risk of receiving 'valid' and 'non-valid' statements for an identical catalogue service when using the same methodology defined in the INSPIRE technical guidelines in different ways.

The following steps were proposed in order to unify the normalised testing procedure at the most detailed level. The essential requirement is to enhance the normalised testing procedure for any catalogue service by defining the following four universal parameters:

- 'ElementSetName';
- 'OutputSchema';
- 'ResultType';
- 'MaxRecords'.

Regarding the 'ElementSetName' parameter, the shortest response time is needed when setting the 'brief' value. The value 'summary' still enables the response time to be homogenously compared. On the other hand, the value 'full' does not support a unified evaluation. The response time with the value 'full' is significantly dependent on the complexity of the metadata profile of a data provider. The higher the number of descriptive items (i.e. metadata elements) is in the metadata profile, the longer the time needed for a catalogue to respond to a request.

The 'OutputSchema' parameter should follow the structure of the desired metadata records during the testing procedure. Please note that this parameter is not a subject of discussion for INSPIRE, since the obliged 'OutputSchema' should have the value 'http://www.isotc211.org/2005/gmd'. The recommendation on the 'OutputSchema' parameter is therefore valid only for catalogue services beyond INSPIRE.

The 'ResultType' parameter should be set to the value 'Results', since it will enable a set of descriptive items to be received, which is in line with the primary aim of a catalogue service for any user. The values 'hits' and 'validate' would not follow such intentions.

The 'MaxRecords' parameter may in general be set to any number. However, it is recommended that the 'MaxRecords' parameter be equal to, or lower than the maximum number of metadata records. In other words, if the smallest metadata catalogue published under INSPIRE contained 5 metadata records, it is reasonable to recommend normalizing the 'MaxRecords' parameter to the value '5'.

Moreover, current approaches like INSPIRE 'only' verify whether a catalogue service responds to the 'GetRecords' request or not. Establishing the criterion of an explicit minimum response that would include certain metadata would be a valuable step towards unifying the process.

An open question remains as to whether the number of records in a catalogue should be taken into consideration or not. According to the conducted tests, it seems that the number of records may have a significant impact on the service performance.

The results of the conducted tests should not be taken as absolute truth. First, any catalogue service is highly dynamic. The results that were obtained may be different in the following week. A service may also have been unavailable – for example, because of maintenance – during the testing process. Second, the availability testing was performed only over 1 week and not over the lifetime of a service, as required by INSPIRE, for

example. Third, even when it was attempted to minimize the influence of network transmissions by making comparative requests to other services, the measurements may have been different if the same tests had been conducted at the server side. The authors of this paper would therefore urge readers to take its findings as constructive criticism that may hopefully encourage the further cataloguing and re-use of geographic information in spatial data infrastructures and Digital Earth. The result would then be catalogue services of guaranteed and comparable quality, from which users would only benefit.

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