The Impact of Climate Change on Pikas Regional Distribution

Climate Change and Biodiversity WG Use Scenario Engineering Report
GEOSS Architecture Implementation Pilot, Phase 2

Version <1.1>
## Revision History

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Climate Change and Biodiversity Use Scenario

1. Introduction

1.1 Scope of this document

This AIP-2 Engineering Report (ER) will briefly describe the use scenario entitled "Pika Distribution" of the Climate Change and Biodiversity WG. The ER describes how the GEOSS-based system was tested to predict the impact of climate conditions on biodiversity for the Pika specie distribution in the Great Basin area (North America). The architecture of the developed system is described, focusing on the GEOSS standard components and services utilized by the demonstration. Persistent Exemplars services identified are listed.

1.2 GEOSS AIP

The GEOSS Architecture Implementation Pilot (AIP) leads the incorporation of contributed components consistent with the GEOSS Architecture using a GEO Web Portal and a Clearinghouse search facility to access services through GEOSS Interoperability Arrangements in support of the GEOSS Societal Benefit Areas. AIP is a GEO task for elaborating the GEOSS Architecture under the purview of the GEO Architecture and Data Committee.

This ER is a key result of the second phase of AIP, namely AIP-2. This was conducted from July 2008 to June 2009. A separate AIP-2 ER describes the overall process and results of AIP-2 and thereby provides a context for this Community SBA ER.1

2. Community SBA Objectives

Predicting how biodiversity will change with climate is critical to understand the implications of climate change, and one of the key biodiversity changes will be how the distribution of individual species changes. This is currently a topic of great interest and many studies have been done looking at such changes. The value of these studies covers part of the continuum from pure research to pure applied work. The research end includes understanding what factors actually control the distribution of a species, such as physiological limitations relative to weather and climate. This work, along with occurrence information, can be used to predict how future changes in climate will effect that distribution. Moving further towards the applied end of the continuum then includes developing approaches that allow the implications of changing climate to be assessed.

The main objective of the Climate Change and Biodiversity Working Group is to demonstrate how the GEOSS Common Infrastructure allows to facilitate interoperability between the resources (i.e. data, services, models, semantics, best practices, etc.) managed by two important communities: Climate Change and Biodiversity Communities.

In this Use Scenario, Climate Change and Biodiversity datasets and services are searched, discovered and accessed in a homogeneous way. The goal is to use these resources for generating predictions of the future distribution of the Pika specie by applying statistical modeling and publish the achieved results as a new GEOSS resource.

This scenario is driven primarily by scientific research on the distribution of Pikas and how it is changing. This demo makes use Pikas observations over the last 20 years, plus existing modeling demonstration systems, to model Pika distributions and how they may change with climate.

From the GEOSS infrastructure perspective, an important objective is to investigate the interoperability process to determine valuable predictors for the impact of climate change on biodiversity.

While this particular scenario focuses on Pika in the US Great Basin region, a similar approach could be taken for any species or geographical region.

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1 A listing of all AIP-2 Engineering Reports: http://www.ogcnetwork.net/AIP2ERs
3. Scenario

3.1 Actors

The main involved actors in this Scenario are:

- **Scientist**: end user of the developed system;
- **Environmental, Climate Change and Biodiversity Data/Service Providers**:
  - Government Agencies;
  - Academic and Other Research Institutes;
  - International Organizations;
- **Model Providers** (Ecological Niche Model).

3.2 Context and pre-conditions

The following demonstration aims to predict how Climate Change effects will impact on Pikas distribution in the Great Basin region (North America). This is the Area Of Interest (AOI) of the specie demonstration. In general, this Scenario might occur in any geographic AOI. As well as for AOI, the species of interest might be other than Pikas (which is the species of interest of the specific demonstration).

One type of critical data is the observation data for the species of interest. These can be provided by GBIF or other sources such as, in this example, the research scientist studying Pika (provided by the demo scientific patron: Dr. Chris Ray of the University of Colorado -US). The availability of good data over a range of dates may be of particular value because they can support model validation. This particular use scenario benefits from over two decades of data on Pika observations, including data on both presence and absence. Data on locations where the species once occurred (or was suspected to occur) but is now absent are quite rare, because developing such a dataset involves time-intensive ground surveys by a professional familiar with the habitat and habits of the species. The availability of these data on Pika absences will allow the development of habitat models with finer resolution than is typical of models based on presence data alone.

Another type of critical data involves environmental parameters important for species survival. Even though species distribution may be controlled by just a few environmental parameters, it is common to predict distribution based on a variety of parameters because it is often not known a priori which parameters are most significant to the species. Again, this particular use scenario example benefits from previous modeling of environmental factors (climate metrics) that can explain recent extinctions of particular Pika populations within the Great Basin –based on the studies of Dr. Chris Ray. The two most explanatory climate metrics are the number of cold days and the average summer temperature over the previous 60 years at a given location. These two environmental parameters have been successful in explaining over 70% of the variance in Pika population persistence within this region. Knowing these parameters a priori should reduce reliance on potentially spurious predictors of species presence—a potential source of error in predicting climate-related changes in species distribution.

Important processing functions fall mainly into two categories. The first is the models that generate the environmental parameters. One of these, called WORLDCLIM, can generate data grids for about 30 parameters at 1 km. Another example of model that can generate data grids with the same scale is TOPS (Terrestrial Observation and Prediction System), which also publishes such data on a WCS Server.

IPCC scenarios may provide input for statistical downscaling of climate predictions. WORLDCLIM and IPCC scenarios data were published on the ESSI Lab WCS Server.

The second important processing function is that which correlates species occurrence to environment, often called an Ecological Niche Model (ENM), or species distribution model.
This software, of which there are a variety of different types that each use different techniques, identifies a quantitative relationship between observations and environment that can be used to predict distribution. When provided with future environmental data it can produce predicted distributions. In this example a niche modeling system, based on the OpenModeller technology, provides the niche modeling engine. OpenModeller is an open-source project used within the context of the GEO GBIF IP3 demonstration system developed earlier. IP3 extended the OpenModeller system coupling it with the IP3 Community Distributed catalog/broker system.

The following datasets and services are assumed to be available before the scenario begins:

- **GEO Portal**, through this portal the end user will be able to search, find and access the services which are needed for the Scenario execution (ESA GEOPortal will be used);
- **IP3 Client Application** is registered on the Components and Services Registry (CSR) and accessible through the GEO Portal;
- **IP3 Brokering&Mediation Service**. This is a distributed catalogue which federates several services (exposing them through the CSW-ISO interface). Federated services publish the following datasets:
  - Environmental datasets concerning the AOI (WCS);
  - Climate Change datasets concerning the AOI (WCS);
  - Species presence datasets concerning the given species and the AOI (GBIF);
- **Ecological Niche Model Server** (WPS);
- **WCS-T**

### 3.3 Scenario Events

At summary level, the Scenario proceeds as it follows:

1. The user access GEO Portal, finds IP3 Client Application and accesses to it;
2. Through the IP3 Client Application the user searches, discovers and accesses presence datasets;
3. Through the IP3 Client Application the user searches, discovers and accesses historical environmental datasets;
4. Through the IP3 Client Application the user searches, discovers and accesses Climate Change datasets;
5. Through the IP3 Client Application the user generates an Ecological Niche Model (ENM) using the discovered datasets (presence and historical environmental);
6. Through the IP3 Client Application the user projects the generated ENM using the discovered Climate Change datasets;
7. Projections are published on a WCS-T;

The steps which have to be performed in order to compose the Scenario are detailed in Table 1 where the different colors are to be interpreted as it follows:

- **AIP-2 Components and Services in blue**
- **AIP-2 Products in red**
- **AIP-2 Actors in orange**
### Table 1 – Steps in the Use Scenario

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Trans. Tech Use Case</th>
<th>Specialized Use Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td><strong>Scientist accesses GEO Portal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>01.1</td>
<td><strong>Scientist</strong> accesses the GEO Portal and searches for “Biodiversity Analyzing Systems”</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01.2</td>
<td><strong>Scientist</strong> selects IP3 Client Application</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01.3</td>
<td><strong>Scientist</strong> accesses IP3 Client Application</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02</td>
<td><strong>Scientist selects species of interest</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>02.1</td>
<td><strong>Scientist</strong> uses IP3 Client Application to submit a query to the IP3 Brokering&amp;Mediation Service and discover the presence datasets for a given species</td>
<td>UC #4 – Client Search of Metadata</td>
<td>Species Presence Query</td>
</tr>
<tr>
<td>02.2</td>
<td>IP3 Brokering&amp;Mediation Service mediates the query request distributing it to the GBIF Web System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02.3</td>
<td><strong>Scientist</strong> selects one or more presence datasets returned by the query</td>
<td>UC #5 – Presentation of Reachable Services &amp; Alerts</td>
<td></td>
</tr>
<tr>
<td>02.4</td>
<td><strong>Scientist</strong> gets the selected dataset(s) using the IP3 Brokering&amp;Mediation Service, which mediates the access request distributing it to the GBIF Web System</td>
<td>UC #6 – Interact with Services</td>
<td>Species Presence Access</td>
</tr>
<tr>
<td>03</td>
<td><strong>Scientist selects historical environmental data</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03.1</td>
<td><strong>Scientist</strong> uses IP3 Client Application to submit a query to the IP3 Brokering&amp;Mediation Service and discover historical environmental data</td>
<td>UC #4 – Client Search of Metadata</td>
<td>Environmental and Climate Change Query</td>
</tr>
<tr>
<td>03.2</td>
<td>IP3 Brokering&amp;Mediation Service mediates the query request distributing it to the WCS where the datasets are published</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03.3</td>
<td><strong>Scientist</strong> selects one or more datasets returned by the query</td>
<td>UC #5 – Presentation of Reachable Services &amp; Alerts</td>
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</tr>
<tr>
<td>03.4</td>
<td><strong>Scientist</strong> gets the selected dataset(s) using the IP3 Brokering&amp;Mediation Service, which mediates the access request distributing it to the WCS</td>
<td>UC #6 – Interact with Services</td>
<td>Environmental and Climate Change Access</td>
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<tr>
<td>04</td>
<td><strong>Scientist selects Climate Change data</strong></td>
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<tr>
<td>04.1</td>
<td><strong>Scientist</strong> uses IP3 Client Application to submit a query to the IP3 Brokering&amp;Mediation Service and discover Climate Change data</td>
<td>UC #4 – Client Search of Metadata</td>
<td>Environmental and Climate Change Query</td>
</tr>
<tr>
<td>04.2</td>
<td>IP3 Brokering&amp;Mediation Service mediates the query request distributing it to the WCS where the datasets are published</td>
<td></td>
<td></td>
</tr>
<tr>
<td>04.3</td>
<td><strong>Scientist</strong> selects one or more datasets returned by the query</td>
<td>UC #5 – Presentation of Reachable Services &amp; Alerts</td>
<td></td>
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<tr>
<td>04.4</td>
<td><strong>Scientist</strong> gets the selected dataset(s) using the IP3 Brokering&amp;Mediation Service, which mediates the access request distributing it to the WCS</td>
<td>UC #6 – Interact with Services</td>
<td>Environmental and Climate Change Access</td>
</tr>
<tr>
<td>05</td>
<td><strong>Scientist generates the Ecological Niche Model (ENM)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05.1</td>
<td><strong>Scientist</strong> uses IP3 Client Application to ingest the</td>
<td></td>
<td></td>
</tr>
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</table>
selected species presence and historical environmental datasets into the ENM Server

| 05.2 | Scientist uses IP3 Client Application to select the appropriate algorithm for the prediction and to set the algorithm parameters |
| 05.3 | IP3 Client Application sends a request to WPS Server for generating the ENM | WPS Request |

06 Scientist generates projection of the Ecological Niche Model

| 06.1 | Scientist uses IP3 Client Application to ingest the Climate Change datasets into the ENM Server |
| 06.2 | Scientist uses IP3 Client Application to select the ENM to be projected |
| 06.3 | IP3 Client Application sends a request WPS Server for projecting the ENM | WPS Request |

07 Result Publication

| 07.1 | IP3 Client Application sends a transaction request to the WCS-T for publishing the generated projection | UC #6 – Interact with Services, WCS-T Transaction Request |

3.4 Post-Conditions
After the execution of all the steps of the Scenario, a prediction of future species distribution in the AOI has been generated. Such prediction is also immediately available through an OGC Web Service –i.e. it is published by a WCS component.

4. System Model of the Scenario

4.1 Components Diagram
The following diagram (Figure 1) shows a components view of the developed system, underlining the components external and internal to GEOSS.
4.2 Activity Diagrams

In this section activity diagrams concerning the main steps in Table, that is: retrieving datasets, generating an Ecological Niche Model, projecting an Ecological Niche Model and Publish the result of the projection.

The diagram depicted in Figure 2 shows the activities which are performed for retrieving the presence datasets for the species of interest. The diagram shows, in a graphic format, the step 02 of Table 1.

Diagrams concerning the steps 03 and 04 (Retrieving Environmental and Climate Change datasets) are omitted since they have the same structure of the diagram in Figure 2 with one only difference: the GBIF Web System is replaced by the ESSI Lab WCS Server.

Diagrams concerning steps 05, 06 and 07 are depicted respectively in Figure 3, Figure 4 and Figure 5.
Figure 2 - Species of Interest

<table>
<thead>
<tr>
<th>Scientist</th>
<th>IP3 Brokering &amp; Mediation Service</th>
<th>GBIF Web System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submits Query to IP3</td>
<td>Mediates Query Request</td>
<td>Receives Request</td>
</tr>
<tr>
<td>Receives Query Response</td>
<td>Mediates Response</td>
<td>Generates Response</td>
</tr>
<tr>
<td>Selects Datasets</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Requests Selected Datasets</td>
<td>Mediates Access Request</td>
<td>Receives Access Request</td>
</tr>
<tr>
<td>Receives Requested Datasets</td>
<td>Forwards Access Response</td>
<td>Provides Requested Datasets</td>
</tr>
</tbody>
</table>
Figure 3 - Generation of Ecological Niche Model

Figure 4 - Projection of Ecological Niche Model
Figure 5 - Result Publication

<table>
<thead>
<tr>
<th>IP3 Client Application</th>
<th>WCS - T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generates a CoverageDescription Document for the Generated Projection</td>
<td></td>
</tr>
<tr>
<td>Sends a Transaction Request (Add)</td>
<td></td>
</tr>
<tr>
<td>Receives Transaction Request</td>
<td></td>
</tr>
<tr>
<td>Performs Transaction Request</td>
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</table>

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5. **Specialized Use Cases**

The following sections describe the Specialized Use Cases that were reported in Table 1.

5.1 **Species Presence Query**

IP3 Client Application communicates with the IP3 Brokering&Mediation Service through the CSW-ISO AP 2.0.2 interface. The submitted query contains both geographic (i.e. the envelope characterizing the specific AOI) and Full Text (i.e. the scientific name of the targeted species) constraints.

5.2 **Species Presence Access**

IP3 Client Application sends the access request to the IP3 Brokering&Mediation Service which mediates the request and passes it to the GBIF Server (“Search for Records”). The GBIF Server gets the requested presence records and sends them to the IP3 Brokering&Mediation Service.

5.3 **Environmental and Climate Change Query**

IP3 Client Application communicates with the IP3 Brokering&Mediation Service through the CSW-ISO AP 2.0.2 interface. The submitted query contains geographic ((i.e. the envelope characterizing the specific AOI) and Keywords/Full Text (i.e. the name of the targeted parameters/fields) constraints.

5.4 **Environmental and Climate Change Access**

IP3 Client Application sends the access request to the IP3 Brokering&Mediation Service which mediates the request and passes it to the WCS Server (GetCoverage request). The WCS Server gets the requested datasets and sends them to the IP3 Brokering&Mediation Service.

5.5 **WPS Request**

IP3 Client Application sends an Execute request to the WPS Server.

5.6 **WCS-T Transaction Request**

IP3 Client Application generates a “CoverageDescription” document describing the prediction that was generated by the model run. Then, it sends a transaction request (of type “Add”) to the WCS-T component.

6. **AIP-2 Implementation of SBA Scenario**

6.1 **Demonstration**

The demonstration that was prepared deals with the species known as Pikas (whose scientific name is “ochotona princeps”). The AOI is the Great Basin Area in the North America. The used datasets were the ones published on GBIF (concerning Pikas presence) along with those provided by the demo scientific patron, Dr. Chris Ray of the University of Colorado. Concerning the environmental historical data, we used the datasets downloaded from the http://worldclim.org website; we published them on a WCS 1.1 server. Climate Change data (published on the same WCS server used for the historical data) are the IPCC 3rd Assessment data for 2050, Climate Model CCCMA, Scenario A2a. Projections are published through a WCS-T server.

A demo video was prepared showing the Use Scenario execution, it is available on both the GEOSS AIP-2 demo web page and ESSI Lab server.
6.2 Next Steps

To make this Scenario fully operational the only need is a further testing of services which compose it. After this testing phase such services should be identified as persistent exemplars.

The first and immediate steps which can be performed to further develop the Scenario are the following:

- characterize more biodiversity data providers, this would allow to use these new data both for creating new Niche Models and for validating the existing models;
- test with other animal species distribution;
- test with different models for the downscaling of environmental and Climate Change data;
- test with different algorithms for Ecological Niche Model computations.

A more complex development of the Scenario concerns the IP3 Brokering&Mediation component. We are extending it in order to federate not only heterogeneous data provider services, but also model provider services – i.e. WPS.

7. References


