Predicting the impact of climate change on biodiversity – a GEOSS scenario

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While some two million plus species have been described, and many millions more remain to be discovered, climate change threatens to commit 15 to 37 per cent of these to extinction by 2050, accelerating a dangerous trend that land use change has already set in motion. An extinction episode of this magnitude would likely severely degrade the quality of vital ecosystem services, such as nutrient cycling, atmospheric regulation, soil formation, water purification, and pollination, upon which the human enterprise relies. Scientists are presented with the formidable challenge of assessing likely impacts of unprecedented interactions between rapid climate and land use changes, predicting how those impacts will unfold into the future, and providing policy options to decision-makers. These issues have been highlighted in stark terms in the newly released Fourth Assessment Report of the Intergovernmental Panel on Climate Change.[1]

In short, global change requires a monumental scientific response, drawing on infrastructure that integrates the enormous volumes of data available from biodiversity research, earth observations, and climate models. Components of this megascience infrastructure already exist, having been established by the IPCC and Global Biodiversity Information Facility (GBIF). Integrating these disparate components will require great effort in terms of metadata development and related service coordination. However, the Global Earth Observation System of Systems (GEOSS) provides the basis for realizing these goals through its clearinghouse registry of registries system.

Here, we describe the results of linking the biodiversity and climate change research infrastructures to enable scientists to conduct new, broad-scale ecological analyses. We describe a generic use scenario and a related modelling workbench for studying the impacts of climate change on biodiversity. A scenario, as described here, provides a basis for predicting biodiversity impacts of climate change into the future by demonstrating recent impacts of anthropogenic changes in the 20th century. Models such as this are built using the infrastructure being developed by GEOSS and provide an essential benchmark against which forecasts for the future might be constructed. This development has been conducted in the framework of the GEOSS Interoperability Process Pilot Project initiative.

Scenario definition

One of the most widely used techniques for large-scale biodiversity data analysis is Ecological Niche Modelling (ENM), which was pioneered by Peterson et al.[2,3] and refined subsequently by many others.[4] ENM is now employed in a range of global change and macroecological applications.[5,6] GBIF has promoted this approach and organised several international workshops on the topic.

A scenario for predicting the impact of climate change on biodiversity involves several steps[7]:

Step one — Identify the species for which sufficient data exist: such data should span at least 30 years. There are many biodiversity datasets that satisfy these stringent criteria, and although they are usually patchily distributed (for example, birds from the United Kingdom, butterflies from Canada, and so on), ENM can be applied to them. However, identifying the existence of the datasets is a challenge. If multiple datasets are cached in a repository somewhere, cluster analysis and data mining can be used to discover the most suitable datasets. If caching or other central repositories do not exist, expert human advice is needed to select the datasets.

Step two — Assemble biodiversity datasets and map their spatial and temporal distributions, after which gaps in data become clear. Such gaps can provide new data sharing opportunities within and among countries, and the need for more and better data can be communicated to policy-makers. Presentation of such spatial trends can also encourage additional data providers to permit access to their data holdings.

Step three — Determine which environmental characteristics are most likely to influence target species' niches. High resolution land cover and climate data are commonly required for this purpose. Although satellite data have not yet been widely or effectively used, GEOSS infrastructure will enhance access to high quality earth observation datasets of relevance to ENM.

Step four — Determine which historical and future scenario climatological data are needed for ENM of the selected group of organisms. This may include measurement of how the species in question has/have responded to recent climate changes, thus strengthening any inferences related to how typically spatial ENMs will change temporally.[8]

Step five — Determine which modelling algorithms will most accurately and precisely predict shifts in distribution and abundance for the selected group of organisms. Identify the reporting needs in terms of data accuracy and error propagation.

Step six — Download the selected species occurrence data (eg from GBIF) and environmental and climate data (eg from IPCC) to the modelling workbench.

Step seven — Run the models and present the outputs as a series of maps and predicted species' ranges or abundances, as appropriate. Measure uncertainty in model outputs under the range of desired scenarios so a realistic depiction of policy options is available to policy-makers. This approach resembles that of the IPCC in presenting different climate change scenarios depending on variations in emission reduction efforts.

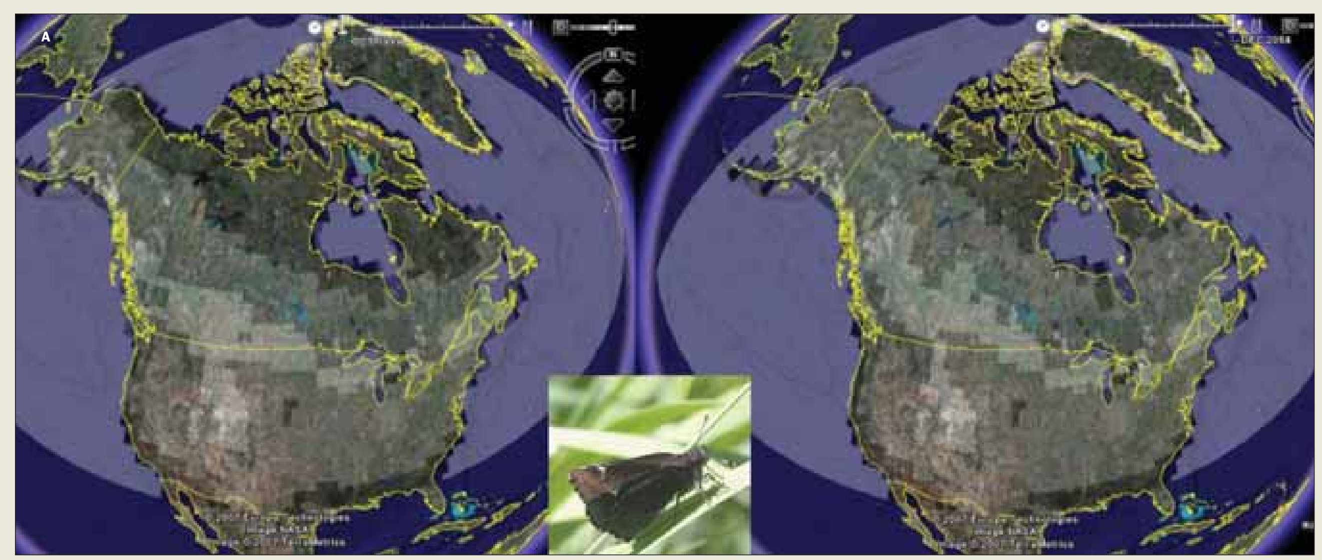
This scenario is but one example of a broad-scale application for biodiversity data. Biodiversity is also affected by other factors such as tropical deforestation, for which other scenarios can be produced. However, these additional scenarios also build on the same pool of primary biodiversity data as the described climate change scenario.

The overall prediction system architecture comprises several components from the biodiversity and climate change Societal Benefit Areas, as follows.

A biodiversity data provider, such as the GBIF Data Portal (http://data.gbif.org) provides unified access to some 130 million primary species-occurrence records (both specimens and observations) from some 1000 databases and 200 data providers around the world, and covering a diverse range of taxa and ecosystems. A high proportion of these records are geo-referenced, and ongoing efforts in the data providing communities promote the necessity and value of providing an accurate geo-location for records. The GBIF virtual database represents a unique resource for Earth observation studies which require ground-truthing data, whether historical (to study change over time) or contemporary. GBIF exposes the data through a web site and several web services.

A climatological data provider, such as the National Center for Atmospheric Research (NCAR) Geographic Information System (GIS) portal provides web access to free, global datasets of climate change scenarios. These data (spanning 50 years from 2000 to 2050) have been generated for the 4th Assessment Report of the IPCC by the Community Climate System Model (CCSM). Climate models are an imperfect representation of the earth's climate system and climate modellers employ a technique called ensembling to capture the range of possible climate states. A climate model run ensemble consists of two or more climate model runs made with the exact same climate model, using the exact same boundary forcings, where the only difference between the runs is the initial conditions. The NCAR portal provides several climate change scenarios. Of these, the constant 20th century scenario shows the least increase in future surface temperature, the B1 and A1B scenarios displays moderate increases and the A2 scenario results in the

Tests using the common roadside skipper butterfly



a) The *Amblyscirtes vialis* distribution projected for the year 2000; b) The *Amblyscirtes vialis* distribution projected for the year 2050 under the IPCC B1 climate change scenario. Light markers corresponds to 100 per cent of presence probability; gray markers to 50 per cent of probability

Source: Peterson et al. 2004. *Amblyscirtes vialis* photo by Erik Nielsen largest response. The interoperability experiments mainly considered the A1B scenario, which is represented by the five ensemble members.

A catalogue, such as GI-cat[9,10] allows discovery of, and access to, the available biodiversity and climatological datasets. GI-cat provides a consistent interface for querying heterogeneous catalogues and accessing servers that implement international geospatial standards. In addition, GI-cat implements a mediation server, making it possible to federate non-standard servers by specifying 'special interoperability arrangements'. GBIF portal services were registered at GI-cat, which required a formal mapping of the GBIF data model to the ISO 19115 core metadata profile, and the adaptation of GI-cat to the GBIF service protocols.

A model provider is a component which is able to run an ecological niche model on the selected biodiversity and climatological datasets. It supports selection of datasets, setting of parameter values and specifying the algorithm to be used. For example, the open source OpenModeller (http://openmodeller.sourceforge.net) software which is available as a stand-alone application (OpenModeller Desktop) and as a modelling kernel that is accessible through specific modules implementing external interfaces.

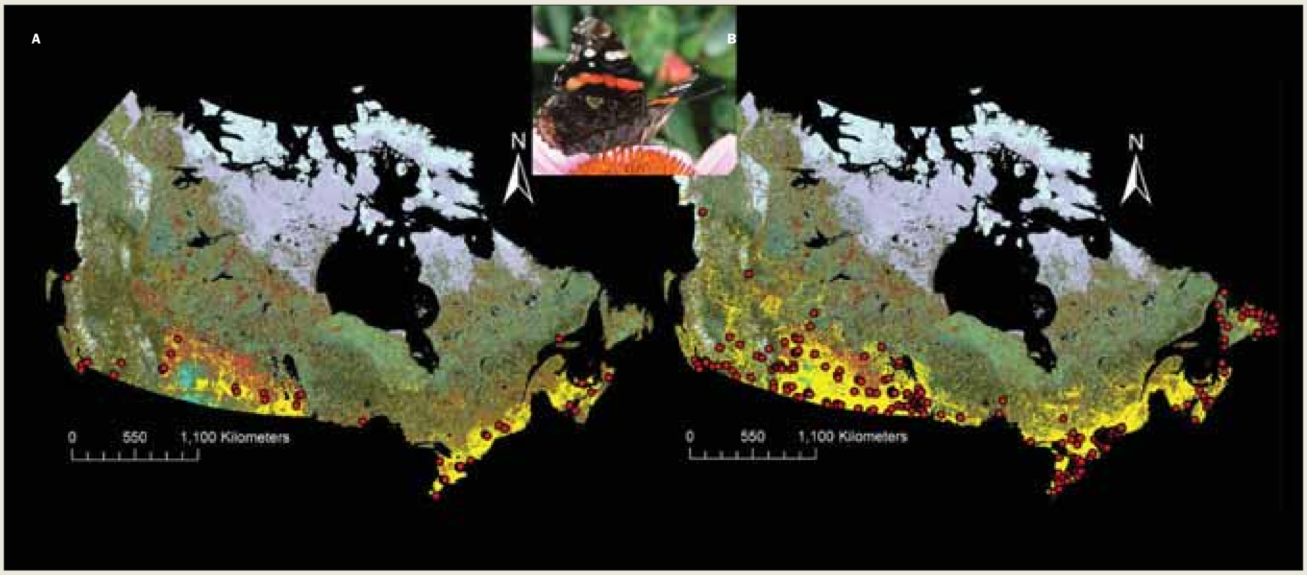
A Web-based Graphical User Interface (GUI) for the model provider. This component acts as workflow controller; it allows the access to the GEOSS Clearinghouse to identify other needed services, implements the business process of the typical biodiversity scenario to be run and controlled by the user through the GUI. We have developed a client application running in a web browser environment using AJAX web framework technologies (www.w3schools.com/ajax/default.asp). With this tool, the user is guided through the process of discovering data (by submitting queries to GI-cat), accessing selected data (through GBIF and Open Geospatial Consortium Web Coverage Services and NCAR data servers) and running ENM projections.

These components play the three typical roles of a Service Oriented Architecture (SOA) where 'Consumers' discover 'Providers' through a 'Registry'. In the example framework data and model providers are the 'Service Providers'; the GUI-controller pair acts as a 'Consumer' and the catalogue plays the role of the 'Registry'.

In this paper we have described how the distributed components needed for global change research can be linked together. In this scenario the GI-cat catalogue service has fulfilled the discovery and linking functions of the GEOSS clearinghouse and the portal, as these were not available at the time this work was done in early 2007. The GIS portal and GBIF Data Portal were accessed directly. In the near future, these data services will be registered and discoverable directly through the GEOSS clearinghouse, as well. GI-cat has been registered as a GEOSS component implementing a GEOSS international standard service, making it interoperable with other GEOSS components.

Our experiment demonstrates the role played by international standards in supporting interoperability and the effectiveness of establishing special interoperability arrangements where these standards are not fully supported. This is particularly important in establishing crosswalks among different information communities. The catalogue has proven valuable in managing linkages and integration of highly distributed resources.

Tests using the Canadian butterfly species Vanessa atalanta



a) The distribution of *Vanessa atalanta* based on historical observations of climate, land use, and species location from 1900-1930. b) The distribution of the species has expanded over the course of the 20th century, as shown here from models run on the same data from the 1960-1990 time period. This use of the GEOSS framework demonstrates that species can be highly responsive to climate change and that forecasts for IPCC scenarios in the future are viable and can usefully inform policy

Source: Peterson et al. 2004. *Vanessa atalanta* photo by Jeremy T. Kerr