G Model
JAG-963; No. of Pages 10
ARTICLE IN PRESS

International Journal of Applied Earth Observation and Geoinformation xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

An ontological system based on MODIS images to assess ecosystem functioning of Natura 2000 habitats: A case study for *Quercus pyrenaica* forests

A.J. Pérez-Luque[a,b,*], R. Pérez-Pérez[a,b], F.J. Bonet-García[a,b], P.J. Magaña[c]

[a] Laboratorio de Ecología (iEcolab), Instituto Interuniversitario Sistema Tierra, Universidad de Granada, Avda. del Mediterráneo s/n, Granada 18006, Spain
[b] Departamento de Ecología, Facultad de Ciencias, Universidad de Granada, Avda. Fuentenueva s/n, Granada 18071, Spain
[c] Grupo de Dinámica de Flujos Ambientales, Instituto Interuniversitario Sistema Tierra, Universidad de Granada, Avda. del Mediterráneo s/n, Granada 18006, Spain

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Ontology
NDVI
Snow cover
(satellite) Earth observation
Sierra Nevada

ABSTRACT

The implementation of the Natura 2000 network requires methods to assess the conservation status of habitats. This paper shows a methodological approach that combines the use of (satellite) Earth observation with ontologies to monitor Natura 2000 habitats and assess their functioning. We have created an ontological system called *Savia* that can describe both the ecosystem functioning and the behaviour of abiotic factors in a Natura 2000 habitat. This system is able to automatically download images from MODIS products, create indicators and compute temporal trends for them. We have developed an ontology that takes into account the different concepts and relations about indicators and temporal trends, and the spatio-temporal components of the datasets. All the information generated from datasets and MODIS images, is stored into a knowledge base according to the ontology. Users can formulate complex questions using a SPARQL end-point. This system has been tested and validated in a case study that uses *Quercus pyrenaica* Willd. forests as a target habitat in Sierra Nevada (Spain), a Natura 2000 site. We assess ecosystem functioning using NDVI. The selected abiotic factor is snow cover. *Savia* provides useful data regarding these two variables and reflects relationships between them.

Introduction and rationale

European Union has developed a set of environmental directives focused on nature conservancy (Evans, 2012). Their main aims are: (1) to halt the biodiversity loss according to the Convention on Biological Diversity (CBD, 2005), (2) to promote the implementation of policies for achieving sustainable development in a context of global change.

The Birds (79/409/EEC; 2009/147/EU) as well as the Habitats Directives (92/43/EEC) seek a favourable conservation status for all listed habitats and species all throughout the European territory (Louette et al., 2011). For these objectives, it is mandatory to implement methods to assess the conservation status of habitats and species. This is a challenging task that requires taking into consideration the concept of monitoring (Lindenmayer and Likens, 2010; Pereira and Cooper, 2006). According to Lindenmayer and Likens, the protocols used to satisfy legislation requirements must be focused on identifying trends in structural and functional features of habitats. These authors assert that “mandated monitoring” (required by legislation) can help in assessing the changes in the conservation status of habitats (Lindenmayer and Likens, 2010, p. 1325).

Satellites gather huge amounts of information that could be useful to monitor and to assess the conservation status of habitats (Vanden Borre et al., 2011). Such information would be adequate to assess both structural (distribution) and functional changes (productivity, phenology, etc.) in the Natura 2000 habitats. For example, a wide set of products derived from MODIS (Moderate Resolution Imaging Spectroradiometer) sensor are useful for monitoring ecosystem function at a landscape scale (250–1000 m resolution) (Hall et al., 2002; Huete et al., 2002; Justice et al., 2002). Other satellites such as Quickbird or IKONOS provide information at a finely detailed spatial resolution (0.5–4 m resolution), which is useful to monitor habitat distribution and structure (Förster et al., 2008; Hyde et al., 2006; Wang et al., 2004). The most important

* Corresponding author at: Laboratorio de Ecología (iEcolab), Instituto Interuniversitario Sistema Tierra, Universidad de Granada, Avda. del Mediterráneo s/n, Granada 18006, Spain. Tel.: +34 958249748; fax: +34 958137246.
E-mail addresses: ajperez@ugr.es (A.J. Pérez-Luque), ramon@ugr.es (R. Pérez-Pérez), fjbonet@ugr.es (F.J. Bonet-García), pmagana@ugr.es (P.J. Magaña).

http://dx.doi.org/10.1016/j.jag.2014.09.003
0303-2434/

advantage of satellite Earth observation in relation to habitat monitoring could be its capacity to allow comparisons among different locations (Vanden Borre et al., 2011). The temporal homogeneity (the same information is gathered with a predefined periodicity) is also a key feature to implement monitoring protocols using (satellite) Earth observation. However, the information collected from satellites cannot be processed and interpreted straightforwardly by most scientists and decision makers (Kalluri et al., 2003). Both the overwhelming amount of data to process/analyse as well as the inherent complexity of the variables measured make it difficult to create an operational system for assessing habitat functioning (Xue et al., 2011).

Ontologies are knowledge-representation techniques defined as a specification of a conceptualization (Gruber, 1993) within a domain of interest (habitat functioning in our case). A conceptualization is "an abstract, simplified view of the world that we wish to represent for some purpose" (Gruber, 1993, p. 199). A computer can "understand" an ontology, because ontologies are structured according to concepts and relationships on which a computer can "reason", as opposed to unstructured files like documents (Antoniou and van Harmelen, 2004). The use of ontologies can foster comprehensive data discovery and integration (Gruber, 1993; Jones et al., 2006), adding semantic meaning to data. Thus, these techniques can promote the use of remote sensing by environmental managers and ecologists (Silva et al., 2005).

While ontologies help to represent the domain, knowledge bases are used to store facts and complex information defined according to ontologies. Consequently, an inference engine, a software tool that applied logical rules to the knowledge base, can reason about those facts, deduce implicit facts, or resolve semantic queries (Hayes-Roth et al., 1983). Although ontologies are commonly used in different disciplines (Bard and Rhee, 2004; Renear and Palmer, 2009), they are not common in Ecology (Madin et al., 2007, 2008; Williams et al., 2006), or Earth observation (Arvor et al., 2013; Fallahi et al., 2008; Hashimoto et al., 2011; Larin Fonseca and Garea Llano, 2011; Oliva-Santos et al., 2014; Wiegand and García, 2007).

In this work, we describe the design and implementation of an ontological system (called *Savia*, http://obsnev.es/ontologia/index) that combines the advantages of (satellite) Earth observation with the knowledge-representation capabilities of ontologies to create a tool that displays indicators and trends regarding habitat functioning. This work had two objectives: (a) to assess the functioning of a Natura 2000 habitat and its relationships with abiotic factors (thematic objective), and (b) to use ontologies to create a operational system that satisfies the first objective (methodological objective). Our work provides a novel case study to the body of knowledge regarding the use of ontologies in Earth observation. It is also of value because we compute temporal indicators and trends to assess the conservation status of habitats. Finally, we show how ontologies can help to bridge the gap between ecologists and remote-sensing experts.

Study area and data

Study area

Sierra Nevada (SE Spain) is a mountainous area (ranging from 860 m to 3482 m a.s.l.) covering more than 2000 km^2 (Fig. 1b). The climate is Mediterranean, characterized by cold winters and hot summers, with a pronounced summer drought.

Sierra Nevada is considered one of the most important biodiversity hotspots in the Mediterranean region (Blanca et al., 1998) and has several types of legal protection: Biosphere Reserve, National and Natural Park, and Nature 2000 site. Sierra Nevada is also a LTER (Long-Term Ecological Research) site.

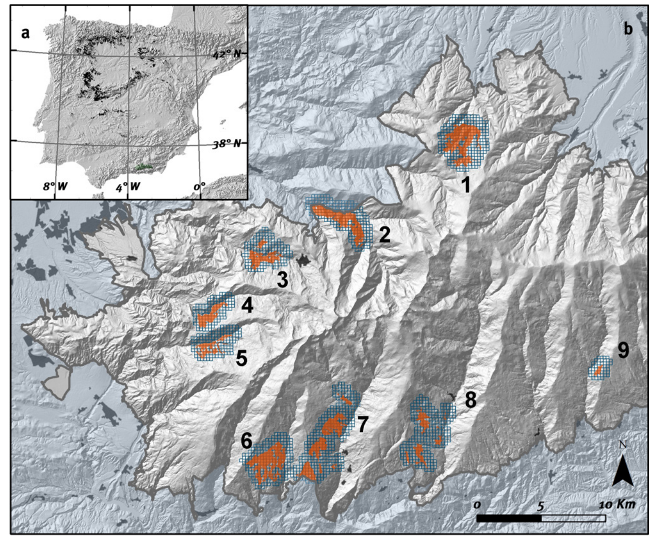

Fig. 1. Location of Sierra Nevada mountains. The distribution of *Q. pyrenaica* in the Iberian Peninsula is shown in black (a). The nine patches of *Q. pyrenaica* in Sierra Nevada are shown in orange (b). The grey line shows the boundary of the natural protected area of Sierra Nevada. The pixels used to compute the vegetation and snow indicators are included (blue grid).

We have focused this work on one habitat of Sierra Nevada: forests dominated by *Quercus pyrenaica* Willd. This habitat (EU habitat code 9230) is included in the Annex I of the Habitats Directive and its conservation status is not well known (EIONET, 2013), partly due to lack of detailed ecological studies (García and Jiménez, 2009). The Pyrenean oak forests extend from southwestern France to the Iberian Peninsula (Franco, 1990) (Fig. 1a), reaching their southernmost European limit in Sierra Nevada, where nine oak patches (2400 ha) have been identified (Fig. 1b), ranging between 1100 and 2000 m a.s.l.

Q. pyrenaica is considered as vulnerable in southern Spain (Blanca and Mendoza, 2000) and the populations inhabiting Sierra Nevada are considered relict forests (Melendo and Valle, 1996). They have undergone intensive anthropic use in recent decades (Camacho-Olmedo et al., 2002). They are also expected to suffer the impact of climate change, due to their climate requirements (wet summers): *Q. pyrenaica* requires between 650 and 1200 mm of annual precipitation and minimal summer precipitation between 100 and 200 mm. Thus, simulations of the climate-change effects on this habitat point to a reduction in suitable habitat for Sierra Nevada (Benito, 2009; Benito et al., 2011).

Data sets and derived information

We have selected two MODIS products: MOD13Q1 to assess the habitat functioning and MOD10A2 to study the behaviour of an abiotic factor (snow cover). MOD13Q1 provides information on vegetation indices NDVI (Normalized Difference Vegetation Index). The spatial resolution of this product is 250 m and the temporal resolution is 16 days. MOD10A2 provides information about snow cover extent (Hall et al., 2002). It has a periodicity of 8 days and a spatial resolution of 500 m. Each MOD10A2 pixel is labelled as snow if it has had snow on one of the previous 8 days. We selected MODIS products because both their spatial resolution and temporal resolutions are appropriate for the scope of this study.

We homogenized the different spatial and temporal resolutions in these two products to produce the final data at 500 m of spatial resolution and 16 days of temporal resolution. For the spatial resolution, we intersected the two grids to assign the identifier of any MOD10A2 pixel to its overlapping one in MOD13Q1. For

Please cite this article in press as: Pérez-Luque, A.J., et al., An ontological system based on MODIS images to assess ecosystem functioning of Natura 2000 habitats: A case study for *Quercus pyrenaica* forests. Int. J. Appl. Earth Observ. Geoinf. (2014), http://dx.doi.org/10.1016/j.jag.2014.09.003