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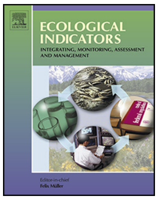

Modeling bird communities using unclassified remote sensing imagery: Effects of the spatial resolution and data period

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ABSTRACT

In this paper we assess the capacity of satellite images to explain and predict bird community patterns in farm-wood landscapes in southwestern France. Our goal is to examine the effect of the images' acquisition date and spatial resolution on the models' performance. We also seek to assess whether unclassified images provide results comparable with classified data (i.e. land-cover map). To do that we constructed species richness models (generalized additive models) based on a sample of 573 counting points and on non-classified images made up of NDVI data and digital height model (DHM), making it possible to quantify the spatial and vertical heterogeneity of habitats. To assess the acquisition date effect, we compared the performance of NDVI data acquired on four different dates (February 4th, June 24th, August 19th and October 18th, 2009) by the same sensor (SPOT-5). To assess the spatial resolution effect, we compared five NDVI images acquired over an identical period (September 2010) but by different sensors (WorldView-2, SPOT-5, SPOT-4, Landsat, MODIS) as well as two DHMs obtained from LiDAR (1 m) and radar (5 m) data. Our results show that for a constant spatial resolution (10 m) it is the NDVI data acquired at the beginning of the autumn that provide the best performance. These data better reveal the landscape requirements of birds during the breeding period. For a given period (September 2010), the higher resolution spatial data (2 m) are the highest performing. However, in view of the cost of WorldView images, we suggest that 10 m data (SPOT-5) provide a good trade-off for studying the distribution of bird communities. For the height data (DHM), the effect of the spatial resolution is not significant. The differences of performance between the spatial resolutions of NDVI data are not as great as those between the data acquisition periods. The performance of unclassified data (NDVI or DHM) is also comparable with that of land-cover maps. This suggests on the one hand that the choice of the NDVI image date is more important than that of the spatial resolution and on the other hand that the NDVI or DHM data are good alternatives to classified data when constructing a bird-habitat predictive model.

1. Introduction

Because of its capacity to observe habitats on different spatial and temporal scales, remote sensing is now an inescapable tool for many fundamental and applied ecological issues (Boyd and Danson, 2005; Cord and Rödder, 2011; Gillespie et al., 2008).

In ecology, the landscape is usually represented discretely, as a mosaic of habitat patches, corridors and barriers within a matrix. That is why the remote-sensing usage that predominates in this area remains the production of land-cover classifications from which composition and configuration metrics can be calculated (Levin et al., 2009; Newton et al., 2009). However, despite its popularity, this discrete representation of the landscape has certain limits (Fischer and Lindemayer, 2006; Southworth et al., 2004). Choices have to be made beforehand regarding the land-cover categories to be used and their level of detail, which may have significant consequences on the ability to predict the presence or diversity of species. Indeed, the perception of the habitat by the species may be very different from the landscape perceived by man and therefore from the predefined categories (Foltête et al., 2000; Laurent et al., 2005; Manning et al., 2004). Consequently,

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the species-habitat models based on the utilization of land-cover maps may be skewed by an anthropocentric vision of the landscape elements chosen and of the variables used to describe them.

Faced with these limits, the question of the most appropriate representation of the landscape for constructing ecological models has been posed (McIntyre and Barrett, 1992; Price et al., 2009). Alternative representations of the landscape integrating the notion of landscape continuum (Austin, 1985; Fischer and Lindemayer, 2006; Manning et al., 2004) or of the fuzzy membership of a category have been proposed (Arnot et al., 2004; Foody, 1996; Rocchini and Ricotta, 2007). Thus, an increasingly popular research current has emerged over the last fifteen years, based on the indirect approach to modeling biodiversity, and proposing to use unclassified images rather than land-cover maps in the models. The studies adopting this viewpoint are numerous and varied (Leyequien et al., 2007; Rocchini et al., 2010; Vierling et al., 2011).

Concerning the optical data, a great majority of the published studies have looked at using the normalized difference vegetation index (NDVI), whose relationship with the net primary productivity as well as the vegetation's biomass has largely been established (Sellers, 1987). NDVI is calculated by dividing the difference in the near-infrared (NIR) and red (R) bands by the sum of the NIR and R bands for each pixel in the image. The spectral indicators generally derived from this measure of greenness correspond to simple statistics (min, max, average, sum, range, variance) calculated from the values of the NDVI's pixels in a given vicinity (e.g. Bailey et al., 2004; Bino et al., 2008; Seto et al., 2004).

The optical data and associated metrics provide information on the primary productivity, with its variability, and on the landscape composition which have an impact on biodiversity. However they do not make it possible to characterize the vertical structure of the vegetation to which certain animal species are sensitive (e.g. birds, Erdelen, 1984). To achieve that it is necessary to resort to other types of data obtained from active sensors such as LiDAR or radar. LiDAR data (discrete return LIDAR or full-waveform) are the most frequent type of data used (Bergen et al., 2009; Bradbury et al., 2005; Goetz et al., 2007, 2010; Vierling et al., 2008). The radar data also offer the potential for describing the structure of the vegetation (Imhoff et al., 1997). Spaceborne radar sensors exist which make the radar data more readily available. However they have been markedly less used up until now, probably because they are more difficult to process (Bergen et al., 2009).

These previous results have opened up new perspectives for using remote sensing for monitoring biodiversity. However, when using remotely sensed data, ecologists are limited by the impact of the spatial resolution and of the date of the images on the quality of the community-habitat models.

Few studies have assessed the effect of the images' spatial resolution to understand community patterns (Levin et al., 2009; Rocchini, 2007; Seoane et al., 2004). Furthermore, the conclusions of these studies may be limited by the fact that they were not always carried out on images taken on the same date (Chust et al., 2004; Levin et al., 2009; Rocchini, 2007). In certain cases they were based on land-cover maps, adopting a discrete representation of the landscape and not a continuous representation (Guisan et al., 2007; Seoane et al., 2004). In addition to that, some of these analyses were conducted using images that were not obtained from different sensors but, rather, images from a single sensor whose source image had been resampled at lower spatial resolutions (Gottschalk et al., 2011). From an applied viewpoint, it is necessary to assess the effect of spatial resolution based on images acquired by different sensors in order to provide useful guidance on selecting the optimal source for habitat mapping.

Concerning the choice or existence of an optimum date, no definitive answer exists in the literature. Various authors have compared the predictive performance of species-habitat models using data acquired on different dates but these works often limit themselves to comparing images on two dates and sometimes several years apart (Bino et al., 2008; Goetz et al., 2007). A study including more dates was carried out by Levin et al. (2007), but it combined images with different spatial resolutions. Other studies have sought to go beyond the bi-date comparison by using NDVI time-series summarized in a variety of phenological metrics (Foody, 2005; Hurlbert and Haskell, 2003; Oindo and Skidmore, 2002). The results obtained show a significant potential but do not indicate what date should be preferred in the case where only a few higher spatial resolution images are available in the year.

In this paper we assess the capacity of satellite images that differ in their acquisition date or in their spatial resolution, to explain and predict the bird species richness during the breeding season in an agricultural landscape. We adopt an indirect approach, using unclassified data obtained from different sensors.

First, we examine how the image acquisition date impacts our capacity to understand bird community patterns. Specifically, we assess whether different NDVI data collected at different periods in a year reflect in the same way the landscape composition and vegetation structure that affect bird distributions during the breeding period. To do that we compare four NDVI images with the same spatial resolution (10 m) acquired by the same sensor (SPOT-5) over 4 different periods (February, June, August, October 2009). Second, we examine whether the images' spatial resolution impact the bird/habitat model's performance. As many birds are sensitive to the presence of fine vegetation structures such as hedgerows, we assess whether images with fine spatial resolutions are more effective to explain bird community patterns. To achieve that we compare five NDVI images all acquired during the same period (September 2010) by different sensors (WorldView-2, SPOT-5, SPOT-4, Landsat-5, MODIS) and in a broad range of spatial resolutions (2 m, 10 m, 20 m, 30 m, 250 m respectively). We also compare two digital height models (DHM) one of which has a spatial resolution of 1 m, derived from LiDAR data, and the other with a spatial resolution of 5 m derived from a radar sensor. Finally, we assess whether the choice of landscape representation (continuous versus discrete) impact our capacity to predict bird community patterns. To examine that we compare the results obtained from continuous raw data (NDVI and LiDAR data) with those based on classified data (a land-cover map).

2. Material and methods

2.1. Study area

The study site lies between the Garonne and Touch rivers, in southwestern France (43°16′28″ N, 0°51′11″ E, WGS 1984) and is part of the "Coteaux de Gascogne" Long Term Ecological Research site (LTER_EU_FR_003). The area is hilly (altitude 200–400 m) and dissected by north–south valleys, within a sub-Atlantic climate subject to both Mediterranean and mountain influences. Wood cover is fragmented, and currently covers some 15% of the area. Woodlands are dominated by *Quercus robur* and *Quercus pubescens*. Dominant non-wood land-cover modalities consist of a combination of crops (including maize, oilseed rape, sorghum, and sunflower), short term grasslands (including ray grass, alfalfa), permanent grasslands, scattered trees and hedgerows. Permanent grasslands are not reseeded for at least five years or more (in accordance with the Common Agricultural Policy), and are composed of a higher floristic diversity than short term grasslands. Permanent grasslands are grazes and/or mowed. Hedgerows are mostly composed of trees and sometimes shrubs, which on average are ten meters high.