Ecological Indicators 70 (2016) 460–465

Contents lists available at ScienceDirect

Ecological Indicators

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

A novel approach for assessing factors affecting biodiversity based on networks analysis

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ARTICLE INFO

Article history:
Received 4 November 2015
Received in revised form 3 June 2016
Accepted 6 June 2016

Keywords:
Networks
Path analysis
Trends
Least square method

ABSTRACT

We propose in this work a novel approach aiming at assessing cause and effect relationships between variables that can affect target biodiversity issues. These cause–effect relations are used to build a network whose nodes represent variables linked by directed arcs. The arcs have associated a value that represents trends of cause–effect relations. An important novelty of this approach is the use of product and addition operations between trends of cause–effect relations for assessing factors that can affect target variables. For the analysis of the network we use the concept of paths. Paths are defined as sequences of cause–effect relations from source variables to target variables. For example, the path from population increment that causes effects on the increment of transport routes, which in turn causes effects on the loss of vegetation cover. This approach was applied to the assessment of vegetation cover in the Morelos State, México during the period 2000–2010. The results show a promising practical alternative to assess the potential effects on biodiversity issues based on the analysis of the paths represented in the network.

1. Introduction

This work deals with a novel approach whose main objective is to assess sequences of cause–effect relations between variables that can affect biodiversity. In particular, we use the population increment as a driving force variable that causes effects on forest fires and on construction of transportation routes. Thus, forest fires and construction of transportation routes exert effects on the loss of vegetation cover, causing, in turn, the application of mitigation measures such as the protection of natural areas. This assessment approach was applied to the State of Morelos in México for the period 2000–2010.

The biological diversity, in the state of Morelos, is mainly attributed to the variations of terrains as well as its geographic position between two regions considered centers of endemic species. Such regions are the Neo-volcanic axis and the Balsas basin (Navarro and Benítez, 1993; Flores et al., 1994). Based on the estimation by Guerrero et al. (2015), in Morelos state, the following species have been described: 664 vertebrates, 29 fishes, 38 amphibians, 93 reptiles, 394 birds and 110 mammals. Thereof, 124 out of 664 vertebrates are protected by the SEMARNAT (the Mexican Minister of Environment and Natural Resources) under the NORM-059-SEMARNAT-2010. The northern part of Morelos is dominated by coniferous forest. While, a low deciduous forest covers part of the center and south. Both of them are important because they provide human settlements with environmental services, such as: water catchment, carbon fixation and oxygen generation.

Present patterns in global biodiversity reflect the extensive changes brought about by humans (Hooper et al., 2012). Neither, the marine nor the terrestrial habitats are free from human impact and large areas have been totally transformed or lost (Sanderson et al., 2002; Mora and Sale, 2011). As is already known, the increment of human settlements in forestlands brings about changes of the hydrologic cycle and causes soil erosions, invasive species and forest fires. Consequently, the distribution and abundance of many wild species have declined and some have become extinct (McKee et al., 2004; Lenzen et al., 2012). As we can see, owing to the fact that human activities cause effects on variables such as forest fires, continuous assessments are needed to know the levels of damage to biodiversity issues. The vegetation cover plays a protagonist role in biodiversity conservation as shown by several

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http://dx.doi.org/10.1016/j.ecolind.2016.06.006
1470-160X/

studies. For instance, Gould (2000), Lindborg and Eriksson (2004), and Gerlach and Musolf (2000) affirmed that species richness and genetic variability reach a maximum in areas of large forested areas with high landscape heterogeneity.

For the approach presented in this work, we deal with relations between the population increment and variables that cause effects on the loss of vegetation cover. The variables involved in this study are: the population increment, as driving force variable; forest fires; construction of transportation routes; and loss of the vegetation cover, the target variable. Then, we build cause–effect relations that take place over time, during 10 years (2000–2010). These relations are used to build a network whose nodes represent variables and whose arcs have associated a value that represent upward or downward trends of such relations. The trends of relations can reveal important factors that can affect the biodiversity issue under analysis.

In order to assure an adequate analysis of trends of relations, the network to be built should be immersed in a conceptual framework able to handle the dynamic characteristics denoted by the sequences of cause–effect relations (OECD, 1998; Niemeijer and de Groot, 2008). To cope with this problem, we have adopted the Driving Force-Pressure-State-Impact-Response components (DPSIR). The DPSIR framework is a conceptual dynamic framework able to host causal networks (OECD, 1998, 2001; Smeets et al., 1999). The DPSIR framework is derived from the classic Pressure-State-Response (PSR) conceptual framework (OECD, 2001).

Some practical applications of the DPSIR framework are found in Rasi Nezami et al. (2013), and Shao et al. (2014). In particular, in the work by Niemeijer et al., an enhanced DPSIR is proposed, where the complexity of real situations, mainly due to multiple interactions between variables of the DPSIR components, is tackled using causal networks (Niemeijer and de Groot, 2008). Important works related with the study of biodiversity affectation have been developed using the DPSIR model. For instance, as shown by Omann et al., the driving forces of climate change are energy use and transportation, and other potential changes of climate, which can cause changes on biodiversity (Omann et al., 2009). In order to capture the diversity of positive and negative human–natural interactions and make explicit the benefits to society, Kelble et al. (2013) proposed to merge the DPSIR model with ecosystem services, which yielded a conceptual model named Ecosystem Based Management/Driving Force-Pressures-State-Ecosystem service and Response (EBM-DPSER). The analysis of biodiversity loss and the development of preservation strategies is proposed in Spangenberg et al. (2009). Approaches based on cause–effect actions are typical in domains that take into account uncertain aspects associated with problems under study. Despite the present work is not related with uncertain aspects inherent to some cause–effect relations, we could mention the work by Cordoba et al. (2010), who proposed an index to measure water quality based on probabilistic tools. In order to demonstrate its applicability it is compared with classical deterministic indices; Drouineau et al. (2012) developed an indicator based on a Bayesian framework by taking into account the combination of different core metrics and the uncertainty of the assessments. This indicator was applied to transitional French water bodies. Cardenas and Halman (2016) identified techniques to cope with uncertainty involved in the environmental impact assessments (EAI), specially in decision-making steps highlighting its importance in activities that could have environmental impacts.

As mentioned before, the approach proposed in this work is applied to the loss of vegetation cover in the State of Morelos, México, during the period 2000–2010. In addition, we aimed at paving the way toward a methodology that can be applied to the assessment of other biodiversity issues in the State of Morelos.

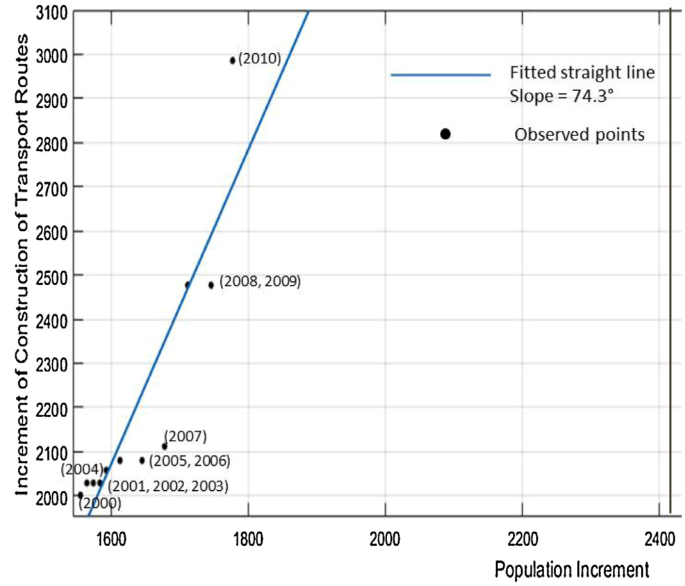

Fig. 1. A relationship between the variables of population increment and the increment of construction of transportation routes. The slope of the straight line indicates an upward trend of this relationship.

2. Methods

The effects that some changing variables exert on others can be modeled through a mathematical relationship. Hence, when pairs of observations are available a fitted straight line can be built by using the least square method (LSM) to examine data and draw meaningful conclusions about dependency relationships that may exist (Draper et al., 1966).

A straight line is formally expressed as $y = mx + b$, where y is the affected variable and x the variable that affects y, m is the slope value of the straight line and b the value of y, where the straight line intersects the y-axis. In this work, we use Matlab to calculate the fitted straight lines and their slopes.

The slope of the fitted straight line could represent either upward or downward trends of the built relationship. For instance, the slope of the fitted straight line illustrated in Fig. 1 determines a numerical value of the relationship between the population increment and the increment of the construction of transportation routes. For this case, the slope value is 3.5614, whose equivalent angle value is 74.31°. This angle value represents an important upward trend of the relation as shown in the graphics of Fig. 1. In practical terms, the population increment is causing an important increment of transportation routes, which could cause other effects, such as the loss of vegetation cover.

2.1. The network of relations

The relationships defined in this work are used to build a network of relations immersed in the DPSIR framework as illustrated in Fig. 2. As we can see, the **DRIVING FORCE** exerted by the population increment (*Pop_Inc*) produces **PRESSURES** represented by the Construction of Transportation Routes (CTR) and the Increment of fires (FIRES). The node FIRES is composed of Fires of Adult Trees (FAT), Fires of Renewed Trees (FRT), Fires of Grass Lands (FGL) and Fires of Bushes and Brushes (FB/B). For the reasons explained later in Section 3, we will only take into account, in this work, the Fires of Adult Trees (FAT). These pressure variables affects the **STATE** of the vegetation cover producing **IMPACTS** on the Biodiversity. Such impacts cause society to **RESPOND** with policy measures such as natural protected areas (NPA). We have considered the **Loss of Vegetation**