



## Scenarios for land use and ecosystem services under global change



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### ABSTRACT

Scenarios provide a platform to explore the provision of ecosystem services under global change. Despite their relevance to land-use policy, there is a paucity of such assessments, particularly in developing countries. Central Chile provides a good example from the Latin American realm as the region has experienced rapid transformation from natural landscapes to urbanization and agricultural development. Local experts from Central Chile identified climate change, urbanization, and fire regimes as key drivers of change. Scenarios depicting plausible future trajectories of change were developed to assess the combined effects on carbon storage, wine production, and scenic beauty for the year 2050. Across the region, the action of the drivers reduced the total amount of carbon storage (by 85%) and wine production (by 52%) compared with a baseline scenario, with minor changes incurred for scenic beauty. The carbon storage and wine production had declined by 90% and scenic beauty by 28% when the reaction to changed fire regimes was also taken into account. The cumulative outcomes of climate change and urbanization are likely to place substantial pressures on ecosystem services in Central Chile by mid-century, revealing the need for stronger planning regulations to manage land-use change.

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### 1. Introduction

Global efforts to achieve the United Nations Sustainable Development Goals will require an understanding of how the provision of ecosystem services will be affected as a result of global environmental change (Schröter et al., 2005; Rockström et al., 2009; Nelson et al., 2010; González-Varo et al., 2013; Mace, 2013). Drivers of environmental change are factors that influence ecosystem services directly (e.g. climate change, land use change, invasive species) or indirectly (policies, science and technology, cultural factors) shaping the direction, magnitude and rate of future global change (MEA, 2005; Kosow and Gaßner, 2008). The drivers of environmental change do not operate in isolation, necessitating that the combined consequences of multiple drivers be determined (Nelson et al., 2006; Carpenter et al., 2009; González-Varo et al., 2013).

Over the past three decades, scenario analyses have played a central role in assessments of the potential effects of global envi-

ronmental change on land systems at a variety of scales (Nakicenovic et al., 2000; MEA, 2005; O'Neill et al., 2008; Van Vliet et al., 2010; Bryan et al., 2016). Scenarios explicitly incorporate uncertainty by exploring the outcomes that could arise due to multiple plausible futures. Scenarios are derived from a coherent and internally consistent set of assumptions or storylines (Peterson et al., 2003; MEA, 2005; Adams et al., 2016), which can be depicted as spatially and temporally-explicit projections of drivers such as land-use and land cover, and climate change (Rounsevell et al., 2006; Rounsevell and Metzger, 2010). Such projections enhance the communication of ecosystem services assessments and thus inform the development of robust land-use policies (Dunford et al., 2014; Lamarque et al., 2014).

There has been a paucity of studies of ecosystem services assessments under global change [but see (Oteros-Rozas et al., 2015)], particularly in developing countries of Latin America (Seppelt et al., 2011; Runting et al., 2016). The exact nature of the effect of global change in these countries is largely unknown, and their adaptive capacity is expected to be low (Sinivasan, 2010). In Latin America, the drivers assessed are climate change and deforestation, parameters that are just a limited subset of

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global change (Grau and Aide, 2008; Martínez et al., 2009; Birch et al., 2010; Carreño et al., 2012; Mendoza-González et al., 2012; Nahuelhual et al., 2014). Measuring the aftermath of a more-extensive set of global changes on ecosystem services is an important policy-relevant task in Latin American countries (Schröter et al., 2005; González-Varo et al., 2013; Oliveira et al., 2013). Rapid assessments using expert judgment and existing empirical information can be used in initial policy cycle phases to help demonstrate potential possible futures involving the drivers of change and their likely effects. Such assessments are being called for to inform initiatives such as the Intergovernmental Science-Policy Platform on Biodiversity, and Ecosystem Services (IPBES) (Brooks et al., 2014; Kok et al., 2016).

In Chile, historical trends for the past 20 years and predictions covering the next century suggest major changes in climate with a decline in rainfall and higher temperatures (Fuenzalida et al., 2007; Falvey and Garreaud, 2009). Such changes are expected to have an effect on the distribution of ecological communities (Marquet et al., 2010). Chile also has experienced a rapid process of economic development in the past 30 years, and this has resulted in the extensive urbanization of the Metropolitan Region (Cohen, 2004; Banzhaf et al., 2013). In this region, the native Mediterranean vegetation is adapted to repeated cycles of forest fires associated with high temperatures (Castillo et al., 2012b). Forest fires have increased in the past decade resulting from human activity and land use change, and as a consequence, fires have been most prolific in proximity to urban centers and roads (Castillo et al., 2012b; Altamirano et al., 2013).

We demonstrate a rapid assessment of the effects of global change on key ecosystem services in the Central Chile region, where data is sparse. Our approach translated expert-derived qualitative scenario storylines into quantitative spatial predictions of the combined impacts of climate change, urbanization and fire on the future provision of carbon storage, wine production and scenic beauty for the year 2050. The three ecosystem services evaluated are critically important for the country's environmental sustainability, its economic activity, and societal well-being (Figueroa, 2016). Central Chile provides an exemplary study case of the Latin American context as the region has experienced a long history of land conversion from forest to agriculture, rapid urbanization and a changing climate with consequent effects on fire regimes (Armesto et al., 2010; Schulz et al., 2010).

## 2. Methods

### 2.1. Study area

The Metropolitan Region of Central Chile (33°26' and 34°19'S, Fig. 1) encompasses approximately 15,402 km<sup>2</sup>, with elevation ranging from 0 to 6500 m.a.s.l. Characterized by a Mediterranean climate (warm and dry summers; cool and rainy winters) with mean temperatures ranging from 20 °C in summer to 8 °C in winter and with an annual precipitation of approximately 350 mm in the central valley, increasing with altitude (Meza et al., 2014). Central Chile is the most densely populated area of the country with almost 7 million people inhabiting the region (or 40% of the country's population), with 97% of people living in urban areas (INE, 2012) and producing, in 2014, 44% of Chile's total economic product (Central Bank of Chile, 2015). Urban development has occurred mainly on alluvial floodplains, which are also the most fertile soils for agriculture (Puertas et al., 2014), especially for fruit and wine production (Romero and Ordenes, 2004). Urbanization is also trending into higher elevation areas (Romero and Ordenes, 2004; Romero et al., 2012). The study region has a high incidence of fire events that have caused considerable material and environ-

mental losses (Castillo et al., 2012b), and their frequency has increased in the past 20 years with an average of 5000 fire events per annum (Altamirano et al., 2013).

### 2.2. Scenario building process

We developed and applied a framework for building scenarios that composed four main steps (Schwarz, 1991; Metzger et al., 2010): (1) define the scope and the focal questions, (2) identify key drivers, (3) construct qualitative scenario storylines, and (4) quantify and map the provision of ecosystem services under baseline conditions and under projections of land-use and climate change (Fig. 2).

#### 2.2.1. Scope of the scenarios

We defined the scope of the scenarios analysis as the exploration of the potential influence of key global change drivers on three ecosystem services: carbon storage, wine production, and scenic beauty, in Central Chile for the year 2050. Carbon storage in the native Mediterranean forest has been identified as an important mechanism for mitigating the burden of climate change (Gibbs et al., 2007; Caparros et al., 2011). Scenic beauty is defined as the aesthetic values derived from the appreciation of natural scenery and scenic views (Bourassa et al., 2004; Bagstad et al., 2014). The Mediterranean mountain landscapes in Central Chile are in demand for leisure activities due to scenic views (De la Fuente et al., 2006; Schirpke et al., 2013). The Mediterranean climate region is also an important region for wine production (Hannah et al., 2013), being the fifth largest exporter of wines in the world and the ninth largest producer (Lobos et al., 2014). Central Chile has a large area that is potentially suitable for irrigated high-quality wine production, particularly at the bottom of valleys (Montes et al., 2012).

#### 2.2.2. Identification of key drivers of change

We developed a list of drivers of land-use and land-cover change via semi-structured interviews with local experts (Appendix A). We initially contacted 25 experts by email and completed 10 interviews. The experts were from different disciplines (demography, economics, urban development, climate change, water, ecology, conservation, and biodiversity) and possessed both local and regional-scale expertise of the study region. The list of potential drivers was presented to the experts, and they selected and ranked drivers they considered would have the greatest effect on the landscapes of the region for the year 2050 (Appendix A). We selected the two highest-ranked drivers for the development of the storylines: climate change (specifically increasing temperature and decreasing precipitation) and urbanization. Climate change is predicted to reduce the distribution of sclerophyllous and thorny Mediterranean forest and reduce the carbon storage capacity of the landscape (Marquet et al., 2010). Urbanization is being encouraged through regional urban plans (PRMS, 2014), which seek to expand the peri-urban limits of cities, especially in the northern and southeastern sectors (Puertas et al., 2014). The ongoing expansion of urban areas is expected to lead to the loss of native vegetation and fertile soils for viticulture and could reduce the scenic beauty of the Andean foothills (Romero and Ordenes, 2004; Banzhaf et al., 2013; Puertas et al., 2014).

#### 2.2.3. The scenario storylines

To construct the storylines we developed a scenario matrix and defined assumptions about the possible trends associated with climate change and urbanization (Plieninger et al., 2013), reflecting ranges from low/weak to high/strong. The possible combination of drivers resulted in four scenario storylines (see Fig. 3 for the definition of scenarios A, B, C, and D).

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