High-resolution geomatics tools: Sustainably managing commercial vineyards to address the UN SDGs

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Abstract. The UN 2030 Agenda for Sustainable Development provides a shared blueprint for peace and prosperity for people and the planet. Consisting of 17 Sustainable Development Goals (SDGs), it calls for action in a global partnership. Geographical Information Systems (GIS) have been proposed as an advanced tool for managing variability in commercial vineyards, gaining a high-resolution spatial perspective on crop performance distribution and its underpinning reasons. Recent evolution of open- source GIS software democratized access and provided an easy and affordable way for vineyard managers to combine a «big picture» with zooming in at each individual plant, in representing diverse datasets and performing complex calculations in geographic representation. Newly available sets of climate, soil, water, ecosystem and biodiversity data are contributing to the capacity to integrate conservation management in commercial vineyards, making geomatic technology an essential tool to measure and manage sustainable development indicators. In our study, we demonstrate the use of geomatic technologies in the management of a commercial vineyard by combining traditional management blocks with segmentation of geophysical and ecosystem characteristics and using those tools to design efficient drainage and measure non-crop areas for nature conservation. We propose those technologies to assess contributions for SDGs 12, 13, and 15.

1 Introduction

The 2030 Agenda for Sustainable Development[1], adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership. They recognize that ending poverty and other deprivations must go together with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

The document stresses the importance of system-wide strategic planning, implementation, and reporting to ensure coherent and integrated support for the implementation of the agenda. In this aspect, the business sector is called upon to contribute to changing unsustainable consumption and production patterns, including through the mobilization, from all sources, of financial and technical assistance to strengthen scientific, technological, and innovative capacities towards more sustainable patterns of consumption and production.

For the grape and wine sector, among the 17 SDGs, three are particularly relevant for its potential contribution through their integration in strategic planning.

SDG12 (Ensure sustainable consumption and production patterns) focuses on (i) sustainable management and efficient use of natural resources, (ii) environmentally sound management of chemicals and all wastes throughout their life cycle, (iii) adoption of sustainable practices and integration of sustainability information into reporting activities, and (iv) implementation of tools to monitor sustainable development impacts.

SDG13 (Take urgent action to combat climate change and its impacts) calls to (i) strengthen resilience and adaptive capacity to climate-related hazards and natural disasters and (ii) improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning.

SDG15 (Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss) requests to (i) ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, (ii) combat desertification and, restore degraded land and soil, (iii) ensure the conservation of mountain ecosystems, including their biodiversity, (iv) take urgent and significant action to reduce the degradation of natural habitats and halt the loss of biodiversity, (v) promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, (vi) integrate ecosystem and biodiversity values into national and local planning and development processes, and (vii) increase financial

[1] https://sdgs.un.org/2030agenda

resources to conserve and sustainably use biodiversity and ecosystems.

In this paper, we demonstrate the use of freely available open-source geomatic software in the context of a large wine company to combine multiple sets of climatic, soil, water resources, genetic resources, biodiversity, and ecosystem data in an integrated management model meant to support decision-making in the scope of short-term and long-term strategic planning, addressing those three SDGs.

2 Background

Making patterns of consumption and production biodiversity-friendly is a requirement for ensuring sustainability. For the much-needed transformational shift to sustainable production (SDG12), it is imperative to maintain a rich biodiversity and healthy ecosystems. Ecosystem services further mitigate adverse impacts of production: intact river catchment areas provide reliable water supply while hedges and green belts provide habitats for pollinators. Terrestrial ecosystems play a vital role in conserving ecological diversity and biodiversity, which are crucial in addressing the urgent need to counteract climate change and its effects (SDG13). Biodiversity and ecosystem conservation (SDG15) emerge as multipliers of co-benefits across all other SDGs, and further serve to buffer negative interactions, while entailing relatively small risks of trade-offs [1].

Vineyards, when managed sustainably, have been shown to promote a biodiversity-rich eco-mosaic featuring both cultivated and spontaneous biodiversity, countering ecosystem fragmentation and preserving the ecological value of the landscape [2-4] thus contributing to the sustainable use of resources, while providing valuable ecosystem services that reduce pest pressure, conserve water, recycle nutrients, and limit soil erosion [5]. Sustainable management of vineyards, however, requires a good understanding of its ecosystem functions, promotion of ecological infrastructures and assertive biodiversity conservation. It entails the capacity to evaluate the risks and trade-offs needed to sustain economic viability from production with essential environmental and social protection.

For example, the European Union 2030 Green Deal formulates an urgent need to bring back at least 10% of agricultural area under high-diversity landscape features. These include, *inter alia*, buffer strips, rotational or non-rotational fallow land, hedges, non-productive trees, terrace walls, and ponds. These landscape elements help enhance carbon sequestration, prevent soil erosion and depletion, filter air and water, and support climate adaptation. Furthermore, EU countries will need to translate the 10% target to a lower geographical scale to ensure connectivity among habitats. Farmers are thus, required to identify and measure their areas dedicated to such landscape features to assess their contribution and to evaluate the ecosystem services they are providing [6].

Geographic information systems (GIS), the Global Positioning System (GPS), and digital photography (satellite and aerial) are just a few of the data collecting and processing technologies that make up geomatics. All of them may be used in some way to evaluate vineyard terroir units at different scales, from the smallest field plot to the largest farm levels. It's crucial to take many of these levels into account while studying zoning [7]. Additionally, other works have developed their application to ecosystem evaluation and management, including landscape [8] and wildlife habitat [9], respectively in the scope of cultural services and of conservation conflicts arising from viticulture.

3 Material and methods

This analysis was performed over a 118-ha viticultural property located in the wine region of Bucelas (PDO Bucelas), near Lisboa, Portugal.

Climate data

Climate data were obtained from a single location within the vineyard. The automated weather station comprised sensors (Campbell Scientific, Logan UT, USA) for temperature, relative humidity, precipitation, wind speed and direction, solar radiation and leaf wetness. Sensors were powered by a local solar panel, a battery conserving excess energy for night-time operation. Data were recorded every 15 minutes and wirelessly transmitted to a central server for unsupervised and supervised validation and restitution through a proprietary web interface (INEGI, Porto, Portugal). Sensor maintenance and, where appropriate calibration, was done four times every year.

Soil data

Soil data were obtained by performing a microzoning study of the whole property. On a first approach a soil electric conductivity/resistivity survey was conducted by using an EM38 sensor (Geonics Ltd., Mississauga ONT, Canada) at 0.5 and 1.0 metre depths. The Basic Terroir Unit method [10, 11] was applied by taking soil samples using an auger at 211 locations (approximately 2 samples per hectare) and down to a depth of 1.2 metres. The samples were observed and characterized in terms of texture, soil depth, drainage, and geological facies. The site of each sampling was further characterized in terms of topography, slope rate, and aspect, landscape overture. These data were combined to produce a model of 22 spatialized terroir units. For each unit, a 2-meter-deep pit was dug to make a detailed description of the soil profile, horizon organization, and soil aptitudes and constraints (regarding rooting, chlorosis, water availability, plant vigour). Finally, all identified horizons were sampled and analysed to apparent density and mechanical resistance to penetration. Several spatialized indices were obtained:
soil water holding capacity, plant vigour and precocity potential, rooting constraints, erosion risk, and chlorosis potential.

Geomorphology data

High-resolution orthophotos were obtained by drone-based visible and near-infrared imagery at a resolution of

10 cm/pixel, planimetric resolution of 30 cm and absolute accuracy of 1.5 m. The obtained images were processed to produce a digital elevation model (DEM) of the property. Geomatic algorithms were applied to the DEM to derive elevation isoline shapefiles as well as altitude, slope rate and slope aspect raster maps [12].

Water and erosion data

A map of maximum soil water holding capacity was obtained by processing soil data as described above. Further, models of surface and subsurface hydrological processes, linear drainage erosion, and slope instability were created using high-resolution DEM (40 cm/pixel). Correlations between lithology and electrical resistivity were analysed and models SIMWE (Simulated Water Erosion) [13] and SHALSTAB (Shallow Stability Model) [14] were applied. The Topographic Wetness Index [15] weighed by electrical resistivity (TWI_w) was used to quantify the trend of water distribution, as influenced by the topography of the property. Raster files of surface drainage flow, maximum saturated hydraulic conductivity, TWI_w and sediment flow were produced. Combining these data with geological and orography interpretation, risk areas were mapped.

Crop data

Normalized difference vegetation index (NDVI) [16] and normalized difference red edge (NDRE) [17] were computed from five spectral band images (red, green, blue, infrared and red edge) after processing by software, using vine and row spacing matrices, into a point shapefile where every point represented a grapevine. Spectral images were obtained from a S20 micro-drone (Spin.Works, Lisboa, Portugal).

Biodiversity and ecosystem data

Biodiversity and ecosystem data were surveyed during three field missions scheduled for Spring (April), Summer (June) and Fall (October). A first field reconnaissance (Spring) surveyed the main ecosystem features and mapped areas for further, detailed, data gathering. The two following missions (Summer and Fall) were dedicated to surveying systematic inventories of flora and fauna to establish an ecosystem status baseline against which a matrix of indicators and risks could be established, and an ecosystem and agroecology management plan would be developed. Additionally, specific situations requiring detailed approaches were identified and mapped, and land use cartography was validated.

Hardware

A HP Z420 workstation (Hewlett-Packard, Palo Alto CA, USA) was dedicated to run the geographical information system software featuring an Intel(R) Xeon(R) CPU E5-1620-0 running at 3.60 GHz with a x64-based processor using 4 cores and 8 logical processors, 16 GB RAM, 500 GB SSD drive, a NVIDIA Quadro K2000 2 GB graphics card and running Windows 10 Enterprise.

Software and data model

A geomatic data model comprising raster files and shapefiles was created using Quantum GIS 64-bit 3.20 (Odense) version (18) under a GNU General Public License. The Coordinate Reference System was World Geodetic System 1984 (WGS84).

4 Discussion

SDG12 - Ensure sustainable consumption and production patterns

SDG12 set the target to, by 2030, achieve the sustainable management and efficient use of natural resources, i.e., soil, water, genetic, biodiversity, and landscape. The mapping of these resources in the space of the property targeted by our work is the first step towards an efficient, sustainable management.

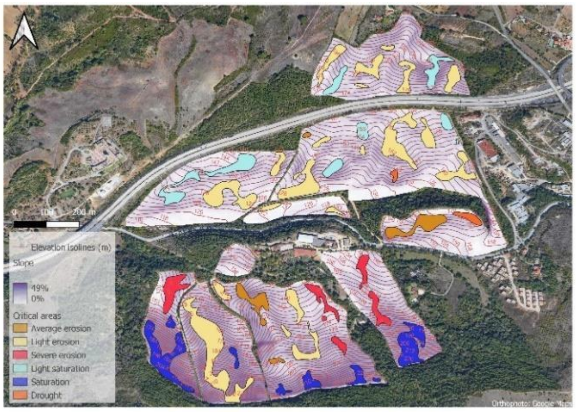

Figure 1. Distribution of altitude (lines) and slope intensity (shading). Coloured delimited zones represent critical areas (because of drought, erosion or water saturation) identified from visual map assessment and historical Google Earth imagery.

Visualizing the geomorphology of the terrain by combination of elevation isoline shapefile with slope rate raster file (Fig. 1) provided a 3D perspective of the ecosystem under management. This view allowed for a general understanding of the main landscape features and how they may be affected in terms of water (runoff) and soil (erosion) loss, providing a coarse initial assessment of the main areas to be potentially affected and requiring special care to conserve those resources. Critical areas were identified relating to potential soil saturation in water, erosion or drought. These areas boundaries were further visually confirmed by using historical satellite imagery available in Google Earth (Google LLC, Dublin, Ireland) since June 2002.

Mapping the high-resolution data obtained from SIMWE model allowed for more detailed assessment of water flow along the slopes (Fig. 2) and the identification of trend water distribution (Fig. 3), while providing essential information on water-driven sediment flow responsible for erosion (Fig. 4).

Figure 2. Cartographical representation of superficial water drainage flow. Darker shades represent higher flow rates.

Figure 3. Cartographical representation of the Topographic Wetness Index weighed by lithological resistivity. The index represents the spatial tendency of soil water distribution as affected by topography and soil materials' compaction. Darker shades represent higher wetness.

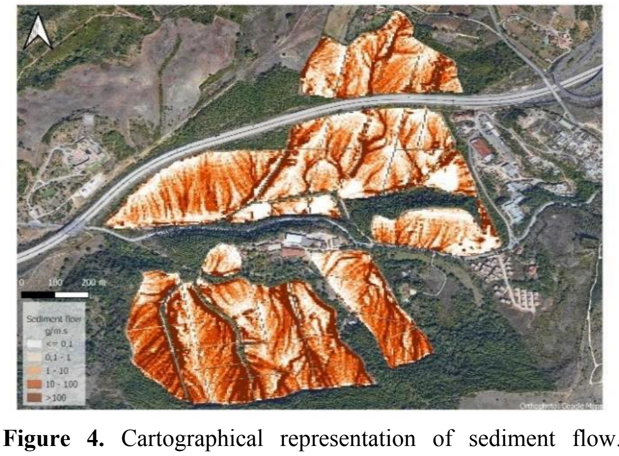

Figure 4. Cartographical representation of sediment flow. Darker shades represent higher erosion potential.

To preserve soil, management of these areas required specifically designed drainage systems able to drain rainwater while retaining soil matter. The gauge of drainage piping and canals was adapted considering values of water flow in each place. Catch basins and culverts were installed in areas with higher TWI_w to divert excess water away from cultivated soil.

The analysis obtained from the SHALSTAB model calculated the potential susceptibility to translational soil landslides relating critical rainfall values with soil properties and transmissivity. In this way, it was possible to map that potential across the property area and identify areas at higher risk of landslide (Fig. 5) as a function of daily rainfall rate.

Figure 5. Cartographical distribution of SHALSTAB risk classes, indicating areas where risk of soil translational movements may occur if a daily rainfall threshold is exceeded. Some areas are stable (bright green) or unstable (bright red) regardless of rainfall.

Performing a geomatic analysis on the higher risk classes to measure their area, it was found that 17 hectares were at risk of translational movements for rainfall rates lower than 50 mm over 24 hours (a threshold already recorded in the local weather station) and that 1.3 hectares were unconditionally unstable.

Higher risk areas were chosen to be left non cultivated and reserved for high-biodiversity areas by promoting the development of local endemic plants, with a positive discrimination for those with higher provision of ecosystem functions and those at a higher level of conservation threat. These non-cultivated areas will also play an important role in retaining water from surface runoff, soil moisture and in preventing erosion. The performance in terms of water damage and soil erosion between high-risk and low-risk areas will serve as indicators of SDG12.

SDG13 - Take urgent action to combat climate change and its impacts

Given the dangers posed by climate change and their functions in adaptation and mitigation, protecting biodiversity and ecosystems is essential to the establishment of climate resilient communities. Recent analyses, based on a variety of lines of evidence, suggest that maintaining the resilience of biodiversity and ecosystem services on a global scale depends on effective and equitable conservation of roughly 30% to 50% of Earth's land, freshwater, and ocean areas, including currently near-natural ecosystems [19].

Strengthening resilience and adaptive capacity to climate-related hazards and natural disasters is a major target of SDG13. Increasing our capacity for climate change mitigation, adaptation and impact reduction

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requires identification of the most vulnerable areas but also of those areas with higher potential for reduction of critical impacts and effective mitigation through carbon sequestration.

Visualizing the geomorphology of the terrain by combination of elevation isoline shapefile with slope aspect raster file (Fig. 6) provided an estimation of how much area face higher heat load aspects (i.e., south, and west), potentially those to become more affected by increasing temperatures and direct solar radiation.

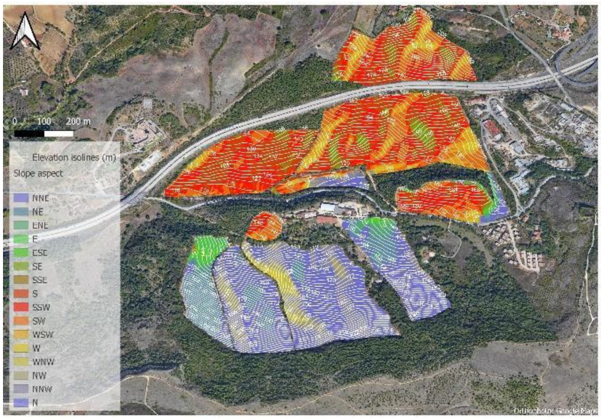

Figure 6. Slope aspect spatial distribution. Each labeled quadrant represents an angle of 22.5° of the azimuth circle. The higher heat load quadrants are yellow, orange, and red.

Geomatic analysis allowed for mapping the area of vineyard affected by the risk of increased heat load and estimated its total area to be 41 hectares. The analysis of soil water holding capacity in this area (Fig. 7) has shown that a subset of 16 hectares has a maximum soil water holding capacity of over 200 mm, potentially mitigating heat impacts in soil moisture, provided there is sufficient annual rainfall. To manage future climate risk, heat tolerant rootstocks, grape varieties, and genotypes (clones) are advisable in those areas with higher heat load and lesser water holding capacity to maintain production and quality of wines under a warmer climate, while decreasing irrigation water allocation, thus sustaining the economics of the property's output and its inherent land value.

Figure 7. Spatial distribution of the soil water holding capacity values.

Finally, the geospatial ecosystem analysis (Fig. 8) has identified significant areas on the property with potential for long term carbon storage. Woods and forests with high-value native species, occupy 34 hectares. whereas other areas with carbon stockage capacity (ecological corridors, water lines and gardens), if managed for that purpose make up for a further 14 hectares. The long-term carbon stockage capacity in those areas, representing 41% of the total property area will contribute to the local effort of climate change mitigation.

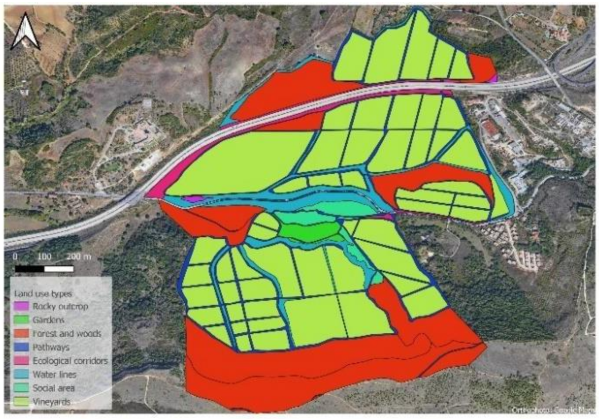

Figure 8. Spatial occupation of the property land use classes.

Climatic data from the local weather station coupled with yield, grape quality and vegetation indices (NDVI, NDRE) data will supply indicators of resilience to climate change and inform on the success of adaptation options. Land occupation evolution will provide data on local carbon storage which will be an indicator for climate mitigation feeding the analysis of contribution to SDG13.

SDG15 - Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Nature is essential to human life since it supplies our food, raw materials, and oxygen and controls our weather patterns and crop pollination. The health of ecosystems on which we and all other species depend is deteriorating more quickly than ever, having an impact on the very foundations of economies, livelihoods, food security, health, and quality of life globally. Approximately 1 million animal and plant species are threatened with extinction, many within decades [20].

Eleven natural habitats were identified in the property, ranging from riparian galleries to dryland woods and oak forests.

A total of 147 flora species were found during the field inventory missions, of which 1 considered very rare (*Scrophularia peregrina*, Fig. 9), 8 rare (*Allium guttatum* subsp. Sardoum, *Argyrolobium zanonii*, *Bromus rubens*, *Carduus broteri*, *Medicago sativa*, *Ononis natrix*, *Phalaris aquática* and *Schenkia spicata*) and 10 with protected status.

Figure 9. *Scrophularia peregrina*, the Mediterranean figwort, a species with «very rare» conservation status in Portugal, found in the property's ecosystem [21].

Concerning diurnal fauna, 25 species of butterflies, 8 species of dragonflies, 31 avian, 4 amphibian, 6 reptile, and 8 mammal species were found including one endemic to the Iberian Peninsula, *Podarcis virescens* (Fig. 10).

Figure 10. *Podarcis virescens*, the Geniez's wall lizard, an Iberian endemic species (photograph by Akhil Kesaraju distributed under a CC-BY 4.0 license).

Using the above information, a plan for the management of ecosystems and agroecology was proposed. The plan identified 8 intervention areas and defined specific actions to avoid degradation of natural value and boost ecosystem services. Among those actions, it was proposed to reduce (i) vegetation density to restore some wooded areas, by eliminating invasive species while protecting native tree and shrub species; (ii) planting several late-blossoming species known for promoting grapevine auxiliary insects; (iii) restoring water lines and their hydric functions by eliminating invasive species and promoting the development of native ones by spontaneous renewal; (iv) recovery of riparian galleries and their connectiveness through total elimination of invasives and high-density plantation of native species for soil retention; (v) install functional and protective hedges using drought-tolerant species, and (vi) colonize runoff lines with adequate species for their protection and maintenance.

The overall goal is to make the property nature-positive, i.e., to present a net gain in biodiversity as soon as possible. The plan was conceived for a maximum 5- year term to manage the property ecosystems away from risks of degradation and towards stability. Periodical biodiversity assessments in all 11 habitats will be used to compare with the baseline characterized in this work and monitor progress under SDG15.

5 Conclusions

Available open-source GIS software has the power to accurately represent and perform geomatic calculations of large, diversified and complex datasets of soil, geomorphology, hydrology, and biodiversity of vineyards.

They provide farmers with the ability to identify, map, segment, and analyse specific features and characteristics relevant for their viticultural management, allowing for general overviews of the whole property and the analysis of highly detailed representations that may attain the resolution of individual grapevines.

The usage of such tools enables both smallholders and large landowners to assess the state of their properties on cultivated and non-cultivated areas, providing tools to assess, measure, and communicate their performance towards the United Nations' Sustainable Development Goals.

The grape and wine sector has a global footprint comprising many diverse ecosystems and habitats, from temperate through subtropical zones, islands, and mountains. Additionally, wine is a high-profile cultural product associating responsible consumption with healthy lifestyles, namely under the context of the Mediterranean diet. The global wine sector is highly specialized in consumer communication, raising the product's tangible value with intangible value-adding dimensions such as geographical indications, landscape conservation, cultural heritages, brands, and lifestyles. The development of the segments of fine wine and wine tourism during the last decade testify to the relevance consumers confer on those aspects.

Using GIS tools, winegrowers may easily create communication content to share good practices and demonstrate their SDG contributions, including for markets and consumers. These tools may thus become valuable additions for vineyard managers, winemakers and marketeers alike, raising the world's awareness for this sector's commitment for overall sustainability.

Further research, however, is needed to measure the level of adoption of these technologies by grape and wine farmers and identify barriers and incentives to adoption, the existence of gender, age or other gaps and define training programs, for both students and professionals with the goal of promoting their proficiency in geomatic analysis and representation. Findings can be used to improve both the available open-source geomatic softwares and public funding programs promoting training, high-specialized precision agroecological management and networks enabling growing contributions for the UN SDGs.

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