



Vinecology: pairing wine with nature

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Keywords

New world mediterranean; vineyard; footprint; winelands; working landscapes; best practices; viticulture.

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Received

1 May 2012

Accepted

25 December 2012

Editor

Phil Levin

doi: 10.1111/conl.12011

Abstract

With some of the highest biodiversity on the planet, the Mediterranean Biome is experiencing a conservation crisis driven by high human population density, development, and habitat fragmentation. While protected areas safeguard some critical habitat, economic realities require conservation efforts in human-dominated landscapes to maintain biodiversity in practice. As an essential component of food security for a growing human population, agricultural landscapes must play a key role in such efforts because they occupy large areas of land, are adjacent to critical habitat, and both depend on and provide ecosystem services. Winegrapes are a high-value specialty crop that can both benefit from and contribute to conservation, as producers and consumers increasingly value environmental stewardship. At the same time, potential expansion of cultivated areas, either to meet future wine demand or in response to climate change, means that decreasing the environmental impact of viticulture is critical for biodiversity conservation. We propose that vinecology—the integration of ecological and viticultural practices—can produce win-win solutions for wine production and nature conservation, where the goal is a diverse landscape that yields sustainable economic benefits, species and habitat protection, and long-term provision of a full range of ecosystem services.

Introduction

The past 50 years of conservation science have relied on protection of intact ecosystems as the primary method to stem the loss of biodiversity. With the increased scale of human impact across the globe, there is a growing awareness that conservation of biodiversity, ecosystems, and the goods and services ecosystems provide to people will depend on how we manage agricultural areas in addition to traditional protected areas (Vandermeer & Perfecto 2005; Fischer *et al.* 2008; Phalan *et al.* 2011). This shift in attention toward human-altered landscapes requires a broader perspective on what it means to do conservation. Working in the agricultural landscape should be part of this emerging paradigm because this land

use affects vast areas, is essential for food security and human well-being, and is dependent on many of the same ecosystem processes that sustain native biodiversity (Foley *et al.* 2011).

Engaging the agricultural sector in conservation requires finding members of the industry that are poised to benefit from the ecological benefits of conservation, and ideally from the positive public image that comes from being perceived as environmentally friendly. The wine industry is well-positioned in both of these arenas. Because wine is defined in large part by geographic origin and the local climatic and edaphic conditions of where the grapes were grown—captured in the term *goût de terroir* or “taste of the earth”—consumers can easily make the connection between product quality and

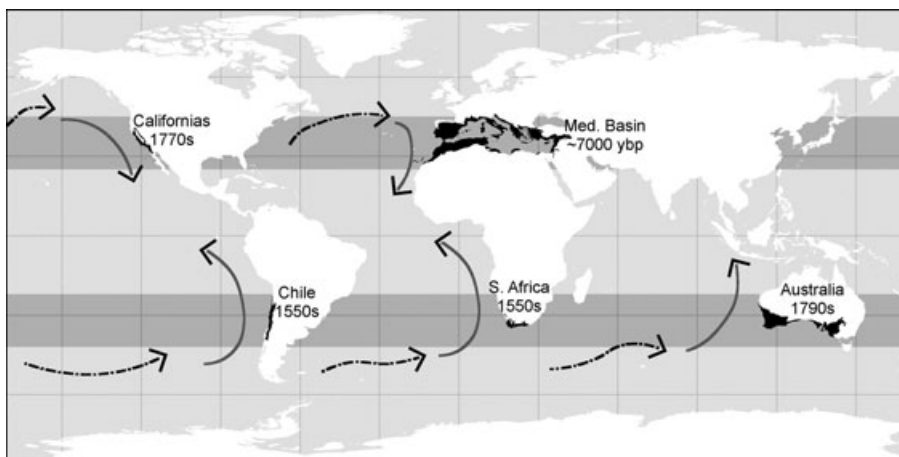


Figure 1 The Mediterranean Biome is mapped in black. Cultivation of winegrapes spread throughout the Mediterranean Basin starting ca. 7000 ybp (McGovern 2004), and then into the NWM in the more recent past ca. <500 ybp; the first recorded date of cultivation is shown for each region (Unwin 1996). Major cold ocean currents (solid arrows) and Hadley Cells (not shown) are dominant features of NWM climate regimes (adapted from Pidwirny 2006).

environment (van Leeuwen *et al.* 2004; Wilson 2001). As such, it is an industry with many environmental leaders, and one that has recognized the marketing advantages of going “green,” as demonstrated by the many sustainability and associated marketing programs established globally (Bisson *et al.* 2002; Warner 2007; Shaw *et al.* 2011).

The winegrape, *Vitis vinifera*, is native to the Mediterranean basin, and is ideally suited to being grown throughout the Mediterranean biome—temperate regions on the western side of continents with cool, wet winters, and hot, dry summers promoted by atmospheric circulation (Figure 1). This biome, which also includes Australia, Chile, South Africa, and the Californias (California, USA, and Baja California, Mexico), is renowned for having some of the highest concentrations of biodiversity and species endemism of any place on Earth (Cowling *et al.* 1996; Myers *et al.* 2000; Olson & Dinerstein 2002). The four areas outside of Mediterranean Basin are collectively known as the New World Mediterranean (NWM), and are of particular interest here because they have both high potential for vineyard expansion, and have sizable extents of natural habitat remaining outside of protected areas. These regions, most of which are densely populated or are experiencing rapid population growth (Williams 2012), may also experience biologically significant changes in climate in the coming years (Hannah *et al.* 2002; Lin *et al.* 2008; Klausmeyer & Shaw 2009). As such, the NWM will be an important testing ground for either conflict or opportunity, in terms of how agricultural production and biodiver-

sity coexist (Underwood *et al.* 2009b; Cox & Underwood 2011).

NWM protected areas and working landscapes

Mediterranean regions have suffered alarmingly high rates of habitat conversion and fragmentation that when coupled with relatively modest habitat protection, give them one of the lowest ratios of protection to habitat conversion of any biome (Hoekstra *et al.* 2005; Underwood *et al.* 2009b) and an insufficient protected areas network (e.g., Tognelli *et al.* 2008). High human population density and growth, expanding urban areas, climate change, and pressures to sustain productive agriculture suggest that additional protected area set-asides will be limited (Wilson *et al.* 2007; Underwood *et al.* 2009a,b). However, an increase in protected areas is unlikely to solve the current array of conservation challenges (Cox and Underwood 2011) or conserve the full range of NWM biodiversity (Fischer *et al.* 2006). As a result, to sustain the unique biodiversity of the NWM, there is a clear need to undertake conservation beyond protected area borders and to broaden the reach of conservation values into the frontier where natural habitat and agriculture meet (Cox & Underwood 2011). The vinecology approach recognizes that the agricultural sector plays a primary role in managing the largest remaining portions of privately held land in the NWM.

In the NWM, the decisions made concerning agricultural production (which crops, where, and how much land to cultivate for each) and which management approaches to use will largely determine the fate of biodiversity and ecosystem services, including regulating and supporting services such as soil formation and nutrient cycling, provisioning services such as providing food, fuel, and fiber, and cultural services such as tourism, livelihoods, and aesthetic value (Swinton *et al.* 2007). Whether it is vineyards or other agroecosystems, the ecological processes that sustain these services often require coordinated management and landowner integration over large areas, such as the maintenance of stream conditions in the wine-growing region of California's Central Valley that promote annual salmon runs and related biogeochemical cycling (Merz & Moyle 2006) or the demonstrated value of managing alien invasive species in the south African wine lands as a key water and fire management strategy (Cowling *et al.* 1996). Working landscapes can also buffer protected areas and safeguard endemic species from exogenous threats such as invasive species (Seabloom *et al.* 2006), or allow for coordinated management of natural disturbance regimes such as fire (Cowling *et al.* 1996) or flood (Gasith & Resh 1999).

NWM vineyard footprint

Agriculture is a dominant and widespread land use with a long history in the Mediterranean biome. Vineyards and wine have been part of the landscape in each of the NWM regions as long as there has been a European influence, and as far back as 7000 ybp for the Mediterranean Basin itself (Figure 1; McGovern 2004). In the late 1990s, global demand for high-quality wine spiked, causing a substantial increase in the vineyard footprint of each NWM region (Figure 2). Although estimates vary slightly, the aggregate winegrape footprint in the NWM added approximately 15,000 ha of vineyards annually for the period 1988–2010, increasing by 70% from ~400,000 to over 684,000 ha (Figure 3), sometimes exceeding 20% expansion per year within a given region (Figure 2). Although much of this increase can be attributed to crop switching (i.e., converting orchards or annual crops to vineyards), a substantial portion came from conversion of natural and seminatural habitats to winegrape production (e.g., Heaton & Merenlender 2000; Fairbanks *et al.* 2004; Schulz *et al.* 2011). Global data lack the resolution for precise estimates of natural habitat converted, but each of the NWM regions has experienced natural habitat conversion to winegrape production to some degree. A general upward trajectory of vineyard area in the

NWM has translated into increased global market share for these regions, despite occurring during a period of global declines in production and consumption (Labys & Cohen 2006). If, in fact, this growth trend is linked with global economic cycles, as suggested by Labys and Cohen (2006), we may expect that rising standards of living in emerging economies, such as China and India, may be accompanied by a concomitant wave of vineyard development to meet future demand.

Vineyards and their effect on biodiversity and natural habitats

As a monoculture often located on floodplains of streams or rivers or sensitive hillsides, vineyards pose a threat to biodiversity by occupying key habitats and simplifying the structure and composition of ecological communities. This phenomenon has occurred in South Africa, where vineyard development has threatened plant species in the Cape Floristic Province by converting irreplaceable patches of fynbos and renosterveld, both of which are fire-adapted vegetation types exhibiting a high degree of endemism and species richness (Fairbanks *et al.* 2004). Likewise in California, vineyard development has been shown to be a major driver of habitat conversion of grasslands, savannah, and oak woodlands (Merenlender 2000). In Chile's Central Valley, winegrape production together with avocados is also strongly associated with conversion of hillsides and habitat loss (Armesto *et al.* 2010; Schulz *et al.* 2010). These results are not especially surprising, given that as with any conventional cropping system where complex habitats are replaced with a single nonnative species, the partial or entire loss of guilds and trophic levels is expected to cause significant ecological impacts (e.g., Woodcock *et al.* 2009).

Habitat conversion may be the most noticeable impact of vineyards on natural systems, but habitat degradation, while less obvious, also results in loss of ecosystem function and can have detrimental impacts on biodiversity. In Portugal for example, the simplification of previously complex vineyard landscapes has been shown to both decrease native insect communities, and increase vine insect pest abundance (Altieri & Nicholls 2002). In northern California, withdrawals of surface and groundwater by vineyards and alterations to aquatic habitat and water quality have had negative impacts on native salmon populations (Deitch *et al.* 2009). Hilty and Merenlender (2004) detected higher numbers of mammalian predators in vineyards near wildlands than those surrounded by additional vineyard lands, while Laiolo (2005) found

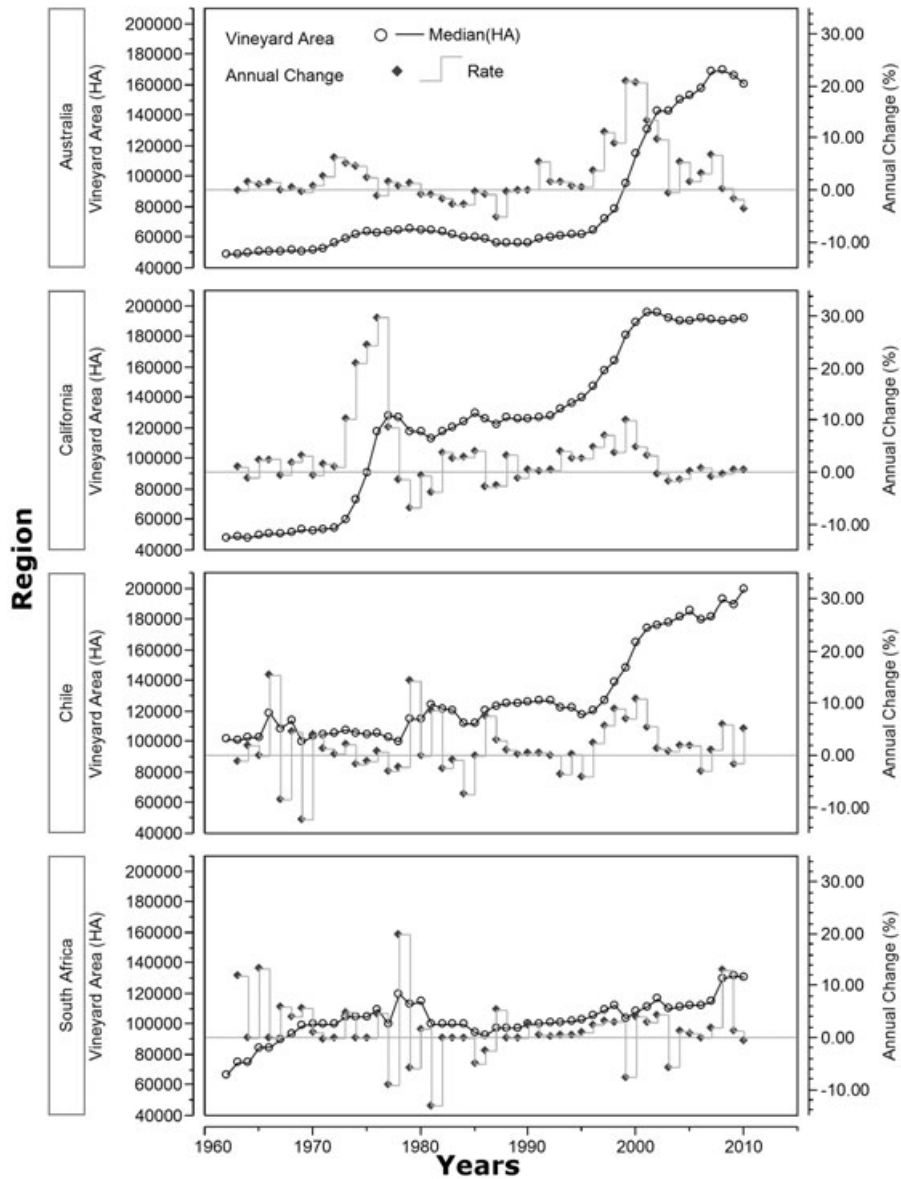


Figure 2 Median footprint trend estimates for vineyard plantings (hectares) for years with data in each of the NWM regions (1962–2010). California has maintained the largest vineyard footprint in the NWM for the past decade, and has experienced two periods of rapid growth, first in the 1970s and then in the late 1990s. Australia and Chile have followed similar trajectories, with rapid expansion over the last decade resulting in a doubling of vineyard area; it remains to be seen if another period of rapid expansion is ahead. South Africa’s vineyard expansion has been more gradual. Data sources: ANRA/CSIRO (<http://www.anra.gov.au/topics/agriculture/statistics/index.html>); BWI(<http://www.bwi.co.za>); CWI (<http://www.wineinstitute.org/files/WorldVineyardAcreagebyCountry.pdf>); FAO (<http://faostat.fao.org>); OIV (<http://www.oiv.int/oiv/info/frstatoivextracts2>); USDA-NASS/CDFCA (<http://www.nass.usda.gov/ca>).

bird diversity decreased with the loss of native grasslands and woodlands around vineyards. Similarly, Schmitt and others (2008) found butterfly diversity and abundance to be higher in vineyards that maintained land in various states of fallow nonproduction (from grassland to secondary forests). Thus, while native biodiversity may

prefer undisturbed natural habitat to vineyards, there are nevertheless important qualitative differences of habitat in and around vineyards that can have positive or negative impacts on biodiversity and/or its movement across the landscape, depending on the management practices employed.

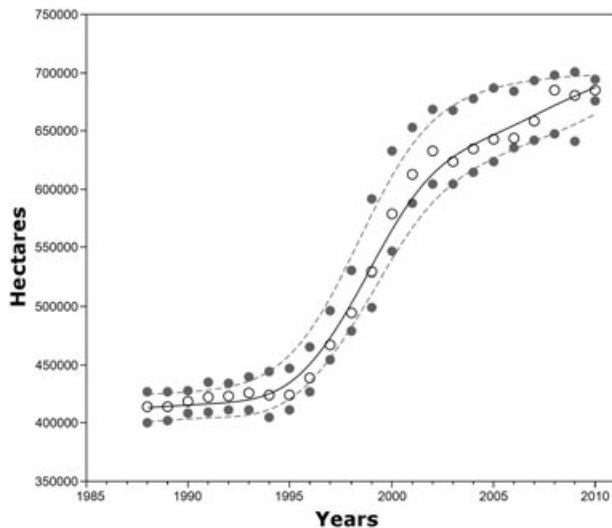


Figure 3 Estimated footprint trend in total hectares of NWM vineyards from 1988–2010 (years with multiple area estimates for each region), shown as aggregated quartiles with spline-fitted response curves. Medians of summed annual hectares are shown as open circles; closed circles represent lower (25%) and upper (75%) bounds of aggregated sums. Estimates are from multiple sources and may include vineyards used for other purposes and may include table grapes, or winegrapes intended for other purposes. Sources: as in Figure 2.

The vinecology era

In this article, we develop the concept of *vinecology*, especially as it applies to the agricultural regions and natural habitats of the NWM biome. Vinecology is the integration of ecological and viticultural principles and practices; it contextualizes sustainable land management within a specific agricultural sector and serves as an entry point to biodiversity conservation in an economically and biologically important biome. For vineyards and biodiversity to coexist, it is essential to integrate land and water conservation with ecologically compatible agricultural practices on productive lands (Vandermeer & Perfecto 2007; Norris 2008). Here, we review vineyard ecology and provide a justification for the role that vinecology can play in minimizing the negative effects of agriculture, vineyard development, and viticultural management (Merenlender 2000). Now it is critical time to promote the concepts of vinecology because the NWM wine industry is in transition in terms of production: the area planted to vineyards grew rapidly from 1995 to 2010, but now appears to be leveling off (Figure 3). By engaging the industry in conservation now, there is time to couple sustainable management practices with land conservation objectives before the next wave of demand for wine and other specialty crops drives further losses in

the unique flora, fauna, and ecosystem services of these regions.

Vinecology considers the agricultural landscape in the context of the surrounding natural habitat and the full array of ecological processes and functions that support that habitat. It further seeks to integrate formerly separate disciplines, where topics relating to agronomy, ecology, hydrology, and social sciences, such as human ecology and resource economics, for example, are considered together, rather than in isolation (Smukler *et al.* 2010). As such, vinecology focuses on the working landscapes of the NWM, where production in the form of winegrapes is made compatible with the conservation of species and natural communities, provision of ecosystem services and the support of other activities, such as tourism, outdoor recreation, the creative economy, and commerce in rural communities (Porter *et al.* 2009). The goals are that, through on-farm and landscape-scale management techniques, surrounding natural habitat is preserved, and the ecosystem functions upon which vineyards and the related tourism economies ultimately depend are maintained. In other words, these ecosystem services benefit the vineyards themselves by providing a source of natural predators for pest control, buffering weather conditions such as wind and temperature, promoting aquifer recharge and minimizing erosion, maintaining soil fertility through practices that minimize tillage and limit chemical inputs, and contributing to the aesthetic value of the vineyard for tourism.

A confluence of emerging trends in applied research on soils, water use, and other low-impact management practices, such as integrated pest management, and action on behalf of producers to implement these practices has resulted in a new era of winegrape growing (see review by Ohmart 2011). Producers of high-value specialty crops such as winegrapes are leading the way in sustainable agriculture because of the visibility and economic importance of their crop. They are also conscious of their image, using sense of place to sell their product, and thus embrace and capitalize on the concept of *terroir* and place of origin. These image-important qualities represent a fortunate coincidence, in that the very environmental components that are perceived to help create high-quality winegrapes—diverse soils, microclimates, and topography (Jackson & Lombard 1993)—are also those that give rise to biodiversity in the NWM.

Finding ample niche space for biological communities, including humans, requires that winegrape growers and the conservation community cooperate at multiple scales and across disciplinary domains (Table 1). Vineyard landscapes are now the base for emerging research showing connections between ecosystem function, agricultural practices at multiple scales, and response of

Table 1 Vinecology integrates across domains, such as natural habitat, water, and soil, and at multiple scales to address conservation issues and seek ecosystem benefits

Vinecology domain (scale) and mode of engagement	Conservation challenges	Vinecology practices	Ecosystem benefits	Supporting studies
<i>Wildlife habitat (H1)</i>				
Growing regions, appellations, winefarms, vineyards—major watersheds, catchments, riparian corridors (10 ^{>6} m ²) regional grower and sustainability groups (e.g., Biodiversity & Wine Initiative South Africa, Lodi	Conversion and fragmentation of natural habitat, especially shrublands, threatens endemic and rare species, disrupts connectivity, gene flow, and effective range size.	Maintain and conserve contiguous areas of native habitat.	Provides core native habitats and corridors to support wildlife, improves ecosystem functioning, and sustains ecosystem services.	(Heaton and Merenlender 2000; Merenlender 2000; Nicholls <i>et al.</i> 2001)
<i>Water resources (W1)</i>				
Winegrape Commission California); conservation planning tools (e.g., InVEST, Vista); water-user associations and watershed councils; land trusts and conservancies	Wine, through viticultural and oenological operations, uses roughly 1000 L of water for each 1 L of wine produced. Production practices consume water and diminish water quality.	Develop and implement a catchment level assessment of water resources (e.g., water footprint analysis to determine hydrological balance); sustain hydrological functioning through restoration of streams, riparian zones, and wetlands.	Integrates operations into more holistic catchment perspective; integrates industry operations with broader ecosystem and societal objectives.	(Hoekstra and Chapagain 2007)
<i>Soil health (S1)</i>				
	Vineyards on steep slopes accelerate erosion and loss of soil. Deep ripping of soil horizons can disrupt local hydrogeology.	Design vineyard blocks with row orientation to minimize downslope processes; employ mulching and cover cropping with (native) perennials to reduce soil exposure.	Reduces erosion, increases organic matter and infiltration rate, lowers soil temperature, and improves nutrient cycling.	(Battany and Grismer 2000; Ruiz-Colmenero <i>et al.</i> 2011)
<i>Wildlife habitat (H2)</i>				
Vineyard blocks, rows, vines—habitat patches, hedgerows, field margins (10 ²⁻⁵ m ²); conservation easements; cost-share and incentive programs; stream rehabilitation teams; alien species eradication councils	Land clearing, especially of wetlands and riparian areas, diminishes ecosystem functioning, degrades habitat, and eliminates higher trophic levels.	Maintain wetland and riparian areas, establish hedgerows and vegetation strips, and incorporate habitat islands.	Allows for wildlife movement and migrations; improves biochemical cycling; sustains trophic interactions; buffers against pesticide drift; and serves as source for beneficial insects.	(Hilty and Merenlender 2004; Baumgartner <i>et al.</i> 2006; Smukler <i>et al.</i> 2010; Jedlicka <i>et al.</i> 2011; Williams <i>et al.</i> 2011)
<i>Water resources (W2)</i>				
	Seasonal water abstraction (e.g., frost protection) can critically	Utilize seasonal storage ponds filled in winter to augment supply during	Replenishes ecosystems during seasonal dry periods; reduces impact	(Lohse <i>et al.</i> 2008; Deitch <i>et al.</i> 2009; Grantham <i>et al.</i> 2012)

Continued

Table 1 Continued

Vinecology domain (scale) and mode of engagement	Conservation challenges	Vinecology practices	Ecosystem benefits	Supporting studies
	impair aquatic ecosystems.	deficit and climatic extremes; drain in summer to prevent biological invasion (e.g., American bullfrog).	on native aquatic and riparian biota; prevents critical stream drawdowns that harm fishes and other aquatic organisms.	
<i>Soil health (S2)</i>				
	Vineyard floor management alters soil dynamics (i.e., structure, water holding capacity, and nutrient cycling).	Employ cover cropping and flower strips between rows; establish and maintain sediment barriers and traps between vineyard blocks and stream courses.	Increases organic matter, improves soil structure and water holding capacity, sequesters carbon, and accelerates nutrient cycling.	(Wheeler <i>et al.</i> 2005; Guerra and Steenwerth 2012)
<i>Wildlife habitat (H3)</i>				
Vines, berries, phenolics—lone trees, fruits, nectars, carbon, nutrients (10^{0-1} m ²); viticulture and resource management extension specialists; continuing education workshops; worker training and skill development programs	Viticulture is a monocrop often heavily managed with biocides, and thus biologically depleted.	Plant and maintain flowering strips between vine rows (can be in conjunction with cover crops and integrated pest management) as “planned” biodiversity.	Serves to increase insectary habitat as part of integrated pest management strategy; improves biodiversity by attracting pollinators and predatory insects (i.e., parasitoids).	(see Gurr <i>et al.</i> 2004)
<i>Water resources (W3)</i>				
	Irrigated viticulture can deplete local surface water stores and aquifers.	Employ improved technology, such as drip irrigation and real-time evapotranspiration and soil moisture monitoring, in conjunction with viticultural practices such as shoot thinning and leaf pulling.	Reduces consumptive use and overall water footprint; reduces mildew and weeds; reduced deficit irrigation can improve fruit quality.	(Chaves <i>et al.</i> 2007; Schultz and Stoll 2010)
<i>Soil health (S3)</i>				
	Farming practices deplete beneficial soil biota.	Mulch vine rows with pomace and other green manure.	Reduces pestilence and adds source of nutrients and organic matter; sustain microbial functions.	(Jacometti <i>et al.</i> 2007a,b; Steenwerth and Belina 2008; Steenwerth and Belina 2010)

Parenthetical notations (H1, W1, S1) refers to graphical elements labeled in Figure 4.

agroecosystems (Figure 4). Examples of such research demonstrating the **multifunctionality of vineyard systems include enhancement of insect communities, provision of bird habitat, and carbon storage** (Jedlicka *et al.* 2011; Williams *et al.* 2011; Gillespie & Wratten 2012). Addi-

tionally, the interplay between biodiversity, biogeochemical cycling, plant physiology, and vineyard management promises to be an increasing focus of vinecological research that encompasses soils, cover cropping, mulching, and grapevine performance at the vine to vineyard block

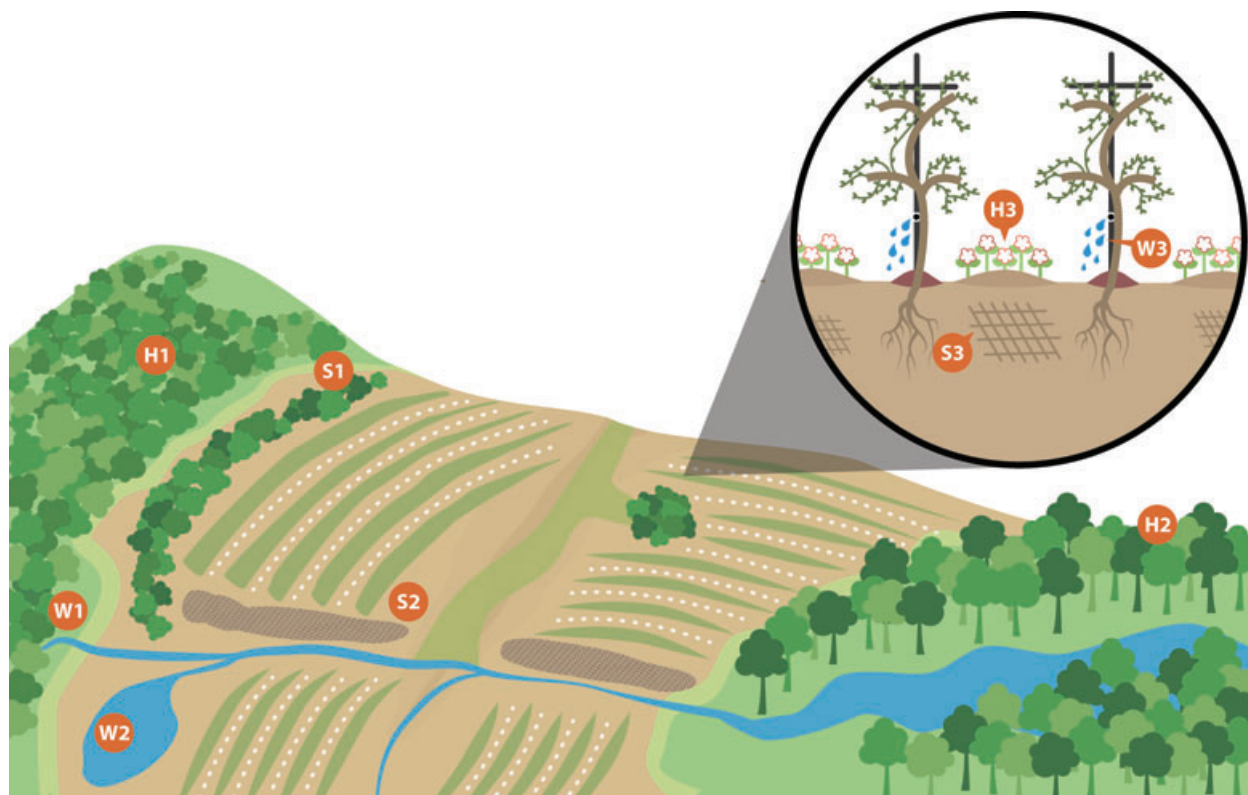


Figure 4 The working landscapes of the NWM are a mosaic of agriculture, primary forests and shrublands, riparian areas and wetlands, and modified buffer lands. Vinecology is practiced across the landscape and at multiple scales, such as between vine rows (see inset). Labels (H1, W1, S1) are indexed in Table 1.

scale (e.g., Patrick-King & Berry 2005; Jacometti *et al.* 2007; Steenwerth & Belina 2008).

At coarserspatial scales, this research is now expanding to encompass the roles of field margins, habitat patches, wildlife connectivity and corridors, and multiple trophic levels in maintaining viticultural production while enhancing biodiversity (Nicholls *et al.* 2001; Fairbanks *et al.* 2004; Hilty & Merenlender 2004; Jedlicka *et al.* 2011). **Landscape-scale effects are also apparent in disease incidence in vineyards.** For example, when vineyards are adjacent to riparian woodland, Pierce's disease—a lethal disease caused by the bacterium *Xylella fastidiosa* and spread by xylem-feeding leafhoppers—is common if the landscape contains a small proportion of riparian habitat and more vineyard, but is rare when the landscape is composed of a larger proportion of riparian habitat (Baumgartner *et al.* 2006). Viewing the landscape as a continuum of ecosystem functions and human uses is not new, but putting this perspective into practice is not yet widespread (McIntyre & Hobbs 1999; Bennett *et al.* 2006). Increasingly, however, conservation approaches have looked toward quantifying, and even monetizing,

ecosystem services across this continuum (e.g., Asquith *et al.* 2008).

An extension of this approach is landscape-scale mapping of ecosystem services to simultaneously evaluate conservation and agricultural potential under different land use scenarios (Sandhu *et al.* 2008; Nelson *et al.* 2009). **To date, most mapping exercises have focused on either vineyard potential for high-quality wine production (Jones *et al.* 2004; Diffenbaugh *et al.* 2011) or vineyard development as a threat to conservation goals (Merenlender 2000; Fairbanks *et al.* 2004). By tackling these competing views simultaneously, land uses can potentially be identified and sited to generate both high biological and economic returns (Polasky *et al.* 2008).** Similar approaches to prioritizing restoration of degraded habitats, efficient water use, and watershed management are underway (e.g., Deitch *et al.* 2009). Such landscape-scale applications of vinecology are also providing evidence to growers of natural habitat value, such as the study by Williams *et al.* (2011) that showed standing carbon in patches of natural vegetation was 10 times greater than in managed vineyards. As agriculture of the NWM looks to move

toward more sustainable forms of production, identifying and quantifying natural capital will be increasingly important. This new era points toward win-win-win solutions benefitting biodiversity and ecosystem services outcomes, grower economic outcomes, and end products for consumers that can be fully considered sustainable.

Green industry trends

As a leading high-value specialty crop, NWM winegrapes are being used to promote environmentally friendly farming practices that confer both conservation benefits and a positive image to the product (Fischer *et al.* 2008), which is evidenced by a growing number of sustainability programs (Shaw *et al.* 2011), including an industry-wide program in South Africa (Von Hase *et al.* 2010). Land set-asides may be done in the context of agricultural and conservation easements, which offer potential tax benefits for vineyards that agree to protection of natural habitat on their property or long-term agricultural use (i.e., prevention of urbanization and maintenance of marginal habitats) (Rissman *et al.* 2007). High-value crops tend to be more sensitive to public perception of social responsibility, and may use wildlife- or nature-friendly images to add shelf appeal within the increasing use of “green” marketing within the wine industry (Delmas & Grant 2010). While the potential pricing premium for certified wines has thus far proved elusive in California (Delmas & Grant 2010), South African vintners participating in the Biodiversity and Wine Initiative have benefited from a global marketing campaign championing the floristic diversity of the Western Cape region and the winegrowers championing its conservation through land set-asides (McEwan & Bek 2009).

The South-African industry-wide program is noteworthy for extending the vinecology approach beyond mutually shared sustainability objectives to include levels of compliance (Figure 5). At its base, the industry engages in self-regulatory compliance through various authorizations and technical guidelines and is widespread, though diffuse in methods. With more direct engagement and formalization, the next tier of industry efforts is focused on moving beyond minimum compliance toward better practice by identifying key ecological risks and promoting best practices (see Table 1 for examples). The upper tier of implementation, with focused engagement and formal means of compliance, is focused on conservation of biodiversity, high-value habitats, and ecosystem functions through the implementation of stewardship agreements that are either financial (e.g., tax rebates) or nonfinancial (i.e., in-kind labor and material) in means. These tiers are more fully integrated

for the public by combining tourism to winefarms and nature reserves, much like the Green Mountain Eco Route (<http://www.greenmountain.co.za/>, accessed 2012-12-12) in the Western Cape, which also coordinates conservation activities through a land owner conservancy.

It is important to recognize, however, that biodiversity-friendly viticulture, and sustainable agriculture more generally, depends on a sophisticated understanding of the ecosystem that is more complex than conventional farming systems, and may require additional capital inputs (Lockie & Carpenter 2010). As Delmas and Grant (2010) discuss, it is not the eco label that drives the willingness-to-pay for premium wines, but rather it is the additional human and natural capital invested into the certified production process that results in a better valued product. In other words, activities inherent to achieving a sustainability certification often require producers to utilize practices that are more labor- or capital-intensive than those in conventional practice. While practices vary depending on geographic setting and certifying body, activities might include installing drip irrigation to reduce consumptive water use, for example. Similarly, mulching with pomace (grape pressings) is a viable alternative to the conventional practice of applying fungicide to reduce *Botrytis cinerea* fungus in grape clusters (Jacometti *et al.* 2007). When finely tuned, some practices, such as cover cropping, can yield synergistic benefits between human and natural capital (e.g., forage for honey bees). Cover cropping between vine rows can reduce erosion, improve soil conditions (e.g., water holding capacity), regulate vine growth, and ultimately yield higher quality wine (Guerra & Steenwerth 2012). Sustainability practices alone may not directly result in better wine, but the additional attention and capital invested in the production process can yield a better end product.

Climate change adaptation trends

The cool, wet winters and warm, dry summers of the Mediterranean Biome, which are fundamental to winegrowing, may shift or become more variable as anthropogenic climate change increases average and maximum air temperatures and alters the amount and timing of seasonal and annual precipitation (Klausmeyer & Shaw 2009). While historical warming up to this point has been associated with some increases in wine quality, especially in cool winegrowing regions (Jones *et al.* 2005), further warming is likely to decrease both winegrape yields and desirable compounds in wine and its price in regions such as California and Australia (Lobell *et al.* 2007; Webb *et al.* 2008; Nicholas *et al.* 2011). Further, changing climate conditions may favor an increase in the frequency of diseases such as downy mildew (Salinari *et al.* 2006),



Figure 5 The South African wine industry employs a scaled framework to achieve widespread sustainability, where conservation protection status is focused on prioritized areas through formal agreements and direct engagement by field representatives. A broader base of engagement is achieved through voluntary compliance and adoption of the best management practices.

increase the range of pests such as vine mealybugs (Gutierrez *et al.* 2008), and increase the transmission rate of Pierce's disease by xylem-feeding sharpshooters (Daugherty *et al.* 2009).

Winegrape producers will likely seek to adapt to new climatic conditions, undertaking a continuum of responses from those that are easier and less expensive to implement, such as changes in farming and winemaking practices, to those that are more expensive but effective, such as changes in planting decisions such as rootstock and variety, and ultimately changes in vineyard locations (Nicholas & Durham 2012). Efforts to quantify the amount of adaptation needed to offset losses under various climate scenarios, and a comparison of the effectiveness of various adaptation strategies in the wine industry are just beginning (Difflenbaugh *et al.* 2011).

Vinecology principles can help inform climate adaptation. For example, trellising architecture can be selected in warm regions to provide more shade for vines, resulting in a substantially cooler microclimate and grapes higher in desirable compounds (Nicholas *et al.* 2011), rather than relying on evaporative cooling in water-scarce regions. There is significant potential for changes in winemaking and farming practices to respond effectively to climate change, and vinecology principles can be used to sustain vibrant winegrowing in current vineyard areas and lessen the pressure for vineyard expansion into new areas.

Conclusions

The emerging discipline of vinecology offers a synthesis of ecological and agricultural research and practices that come together in the production of winegrapes. While many studies bridging winegrape production with conservation objectives have emanated from NWM, vinecology as a discipline is not restricted by geography. The discipline proposes a re-envisioning of the agricultural landscape as one that contains natural habitat and crops in an integrated matrix, which provides economic output together with a range of widely beneficial ecosystem services. It is a data- and practice-driven approach that continues to evolve as new research is brought to bear on winegrape production. Widespread adoption would be very timely, given that wine consumers and producers are increasingly attuned to the environmental impacts and image of wine, and that new vineyard development has slowed down for the moment, and thus corrective action could be taken before it picks up.

Vinecology provides a useful paradigm for such action, even if it represents a bit of a departure from conservation's historical focus on protected areas. It promotes biodiversity conservation in the winelands of the NWM by engaging producers and consumers alike in cooperative solutions, by promoting sustainable practices at multiple scales over large areas, and by embracing the ecological, cultural, and economic values that make

these places desirable. Beyond these reasons, the concept of vinecology supports the tenet that it is possible to make a healthier environment and enjoy the fruits of the Earth at the same time.

Acknowledgments

This work was supported in part by The Nature Conservancy—California and CONICYT-Chile (Award# PFB 23/2008), and is a result of three international workshops held on the subject (Stellenbosch, South Africa 2008; Santiago, Chile 2009; and Davis, California 2011). We are grateful for the contributions and suggestions of many affiliates, not limited to Pierre De Villiers, Louise Jackson, Matthew Hoffman, Rodd Kelsey, Kirk Klausmeyer, Mark Lubell, Cliff Ohmart, Pablo Marquet, Scott Morrison, Jason Pelletier, Jeff Parrish, Todd Rosenstock, Rebecca Shaw, Emma Underwood, and Steve Wratten. Sydney Vickery assisted with figures. We would also like to thank the many winegrape growers that have provided a valued perspective, and leadership within their industry.

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