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ORIGINAL ARTICLE

The dispersion of climate change impacts from viticulture in Ticino, Switzerland

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Abstract

Climate change is having complex impacts on agriculture worldwide, including viticultural systems in mountainous areas such as the canton of Ticino in southern Switzerland. Here, socio-ecological qualitative research is used to examine how vignerons are experiencing and responding to climate change. Even in wealthy Switzerland, with highly developed technical capabilities and support services, the immediate climate change impacts are driving major changes across industry, community, and place. Some change is positive in the short term, such as increased rates of grape development. Negative changes are associated with more extreme droughts, storms, and wet periods, which are increasing disease and pest control requirements. Niche adaptation opportunities exist, but as vignerons adjust their behaviors, more complex socio-ecological impacts are emerging and impacting across landscapes. Professional vignerons are adjusting their phytosanitary management systems: increasing monitoring, optimizing their chemical use, and shifting the susceptible and labor-intensive Merlot variety onto the valley floors to reduce costs. Part-time vignerons are trying to adapt, but are voicing concerns about the difficulties of the new management demands. The result is that changes in climate threaten the established regional niche of high-quality Merlot production in association with terraced landscapes. As decision-makers aim to adapt to climate change, they will need to support local learning to manage the immediate risks to both Professional and Part-time vignerons, as well as the broader risks that are dispersing across society.

Keywords Climate change adaptation · Mountain · Grapes · Agriculture · Landscapes · Swiss

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1 Introduction

Climate change impacts and adaptation responses of vignerons vary according to a range of environmental and social factors (Battaglini et al. 2009; Lereboullet et al. 2014; Mosedale et al. 2016; van Leeuwen et al. 2019). As adaptation interventions necessarily alter other systemic relationships, such as those between viticulture and surrounding landscapes (Hannah et al. 2013; Costa et al. 2016; Vlahos 2020), or wine and the consumer (de Orduna 2010; Ubeda et al. 2020), multiple aspects are in flux within regions adapting to climate change. Thus, climate change impacts are not constrained to specific elements of risk within systems themselves. Rather, as vignerons, or any farmers, act to adapt to climate change, impacts disperse across social and environmental spheres depending on the social, economic, and ecological contexts within which change is experienced (Ford et al. 2013; Schlosberg and Collins 2014; Harrison et al. 2019; Poortinga et al. 2019).

Researchers have been examining agricultural adaptation to global climate change for some time (Butzer 1980; Fuhrer et al. 2006; Smit and Skinner 2002). Yet, the concept of successful adaptation remains open to interpretation in relation to cultural values and behaviors (Adger et al. 2009; Neset et al. 2019; Few et al. 2021). What might seem like an effective, resilient system to some, may to others be seen as unnecessarily rigid or conservative as farming communities strive to retain systems or landscapes in the face of overwhelming drivers of change (Brown 2011; MacKinnon and Derickson 2013; Wilson 2014; Patel et al. 2017). Even successful adaptation that leads to systemic change could be seen to undermine traditional systems, deplete cultural or ecological values, or polarize communities (Matin et al. 2018). For example, for people who prize traditional farming methods, landscapes, or products, any farmer behavior that leads to significant agro-ecological change infers losses to important cultural systems or landscapes (Bardsley 2003; Plieninger and Bieling 2012; Blythe et al. 2018; Lieskovský and Bürgi 2018).

While the physical elements of vineyard site and situation will determine many experiences of climate change (Caffarra and Eccel 2011; Bonfante et al. 2018; Neethling et al. 2019), historical cultural elements of viticulture and their interactions with society will influence how people choose to adapt and perceptions of success (Gladstones 2011; Adger et al. 2013; Tieskens et al. 2017; Bardsley et al. 2018; Bonfante et al. 2018; Grüneis et al. 2018). Here, we examine the perceived impacts of climate change on viticultural systems in the southern, mountainous, Italian-speaking Swiss canton of Ticino (Fig. 1), to analyze the broader implications of proposed adaptation responses within the context of social and landscape change. Adaptation actions and policies could enhance opportunities from climate change or reduce negative impacts. By interviewing vignerons in Ticino who manage a range of viticultural systemic forms, we examine how broadly different types of vignerons experience and respond to climate change. Professional vignerons here are defined as managing larger, more industrialized vineyards, whereas Part-time, family-run, small-scale vineyards, often on *Ronchi*, or terraced blocks, are commonly managed to meet lifestyle or cultural goals. As we interpret vignerons' perceptions and behaviors in response to environmental risk, the implications of climate change impacts on society in Ticino are analyzed in relation to what successful adaptation policy means in the context of an evolving rural landscape (Swisstopo 2022).

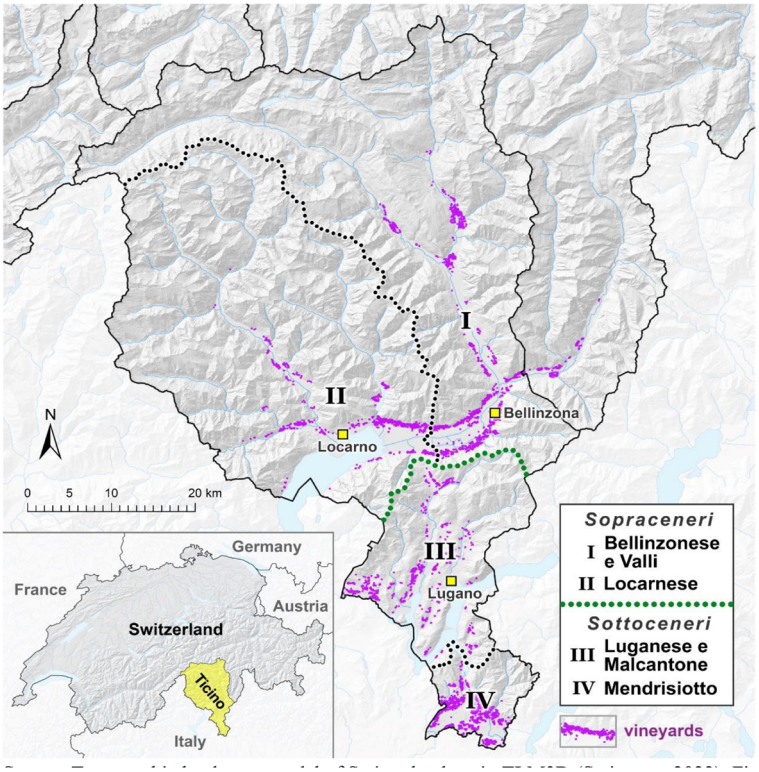

Fig. 1 Vineyards and the major sub-regions and topography of Ticino, Switzerland

2 Climate change adaptation within Swiss viticultural systems

The vineyard is a complex agroecosystem performing important roles that extend beyond grape production (Trivellone and Moretti 2017; Comino et al. 2017; Bardsley et al. 2018). The vineyards of Ticino date back to Roman times but have come under pressure over the last 150 years. Production declined from over 50,000 to 17,000 hectoliters in the nineteenth century due to the combined impacts of modern agriculture, poverty, and out-migration of many smallholders, and new diseases and pests including Downy mildew, or Peronospora (*Plasmopara viticola*), and the Phylloxera bug (*Daktulosphaira vitifoliae*) (Gessler et al. 2011; Regazzoni Jäggli 2015; Panzera 2017). The Merlot grape variety was introduced in the early twentieth century from France, partly in response to the Phylloxera threat (Cervim 2020; Ticinowine 2020). A further wave of pressures emerged in the 1950s, with a regional transition to an urban/tourism/retirement economy and rising costs for land and labor, which led to vineyard abandonment and subsequent forest expansion and urbanization (Bardsley et al. 2021). Since the 1990s, support for farmers in Switzerland has shifted from a focus on production to the promotion of social and ecological outcomes through direct payments, especially in the uplands (Lehmann and Stucki 1997; El Benni and Finger 2013; OECD 2015; BLW 2021; Metz et al. 2021). With direct payments, the Swiss state has provided encouragement for vignerons to maintain production and manage local environments (Curry and Stucki 1997), but rising land values generate an ongoing incentive to

intensify systems or transition to urban land uses (Price et al. 2015). For that reason, much of the remaining viticulture industry of Ticino has increased financial returns per hectare to remain viable (Regazzoni Jäggli 2015; Trivellone and Moretti 2017).

Irrespective of historical challenges, grapes and wine remain important in Ticino, covering nearly 1100 hectares and directly employing over 3500 people (BLW 2020). In the north of the canton (*Sopraceneri*), viticulture is imbedded in the Alps often in association with terraces (*Ronchi*) (Fig. 2a and b), whereas the southern systems in the *Sottoceneri* are associated with more open, hilly landscapes (Fig. 2c). Most production, at 99,000 hectoliters, is red wine, while just over 10,000 hectoliters are whites, and since its introduction, Merlot has become the dominant variety within the cantonal industry and key to regional marketing (Zamparini et al. 2010; Ticinowine 2020).

Climate change presents opportunities for viticulture in Ticino, but also new risks. The temperate climate of the southern Alps, with warm, wet summers and cold winters is characterized by variable temperatures and extremes of precipitation, usually exceeding 1.5 m per year (MeteoSwiss 2022). There has been a strong warming trend in the canton, but other projected changes are associated with rainfall averages and distribution, more extreme heat, droughts, frost, hail, extreme rainfall and snow events, and higher humidity levels during key growth periods (Fuhrer et al. 2006; Zubler et al. 2014; Braunschweiger et al. 2018; CH2018 2018; Ménégoz et al. 2020; NCCS 2021). Future projections suggest that climatic impacts will become progressively more severe, potentially leading to grape yield or wine quality constraints as thresholds of adaptative capacity are reached (Bernetti et al. 2012; Lereboullet et al. 2014; Fraga et al. 2018; Santillán et al. 2019).

Some climate change in Ticino is positive for viticulture, especially longer growing seasons and opportunities for grapevine and berry development (CH2018 2018). However, change itself is becoming a risk, exactly because the aesthetic and cultural distinctiveness of the only wholly Italian speaking Swiss canton is tied to the heritage of vineyards and wines (Leimgruber 1991; Lindemann-Matthies et al. 2010; Zamparini et al. 2010). Vineyards are situated either on the alluvial plains of the major rivers such as the Ticino or Maggia, around lakes and valley margins, or along hillsides on glacial terraces (Fig. 1; Petit et al. 2012; Bonardi 2019; Scapozza and Ambrosi 2020; Ticinowine 2020). Traditional vineyard structural elements such as pergolas, drystone walls, and hedgerows create important habitat for species that are not seen in the forest or on other agricultural lands (Moretti et al. 2017). Therefore, any significant changes to local viticulture threaten environments, identity, and tourism in Ticino, with people attracted to the Swiss "sunroom" because of its mild climate, biocultural landscape, and associated wine culture (Bagutti 1987; Lévy 2016).

There are several further unique aspects that frame adaptation in Ticino. The large altitudinal variation and associated climatic gradient, along with the agro-politics of Switzerland, offer opportunities for adaptation, but also generate risks (Zubler et al. 2014). Much Swiss climate change adaptation research has focused on the physical characteristics of change in agroecosystems (Finger and Schmid 2008; Lehmann et al. 2013; Rahman et al. 2015; Henne et al. 2018) and the governance regimes to support adaptation (Braunschweiger et al. 2018; Skelton et al. 2019). Yet, as mentioned, Swiss agricultural policy extends beyond physical goals, promoting farmer behaviors and socio-ecosystems that lead to multifunctional outcomes such as cultural landscapes, biodiversity conservation, and tourism (Netting 1981; Curry and Stucki 1997; Aerni 2009; El Benni and Finger 2013). In fact, much state support is now tied to popular backing for high-quality environmental outcomes from agriculture (Klein et al. 2014; Mack et al. 2021; Metz et al. 2021). For that reason, effective, long-term adaptation in Swiss agriculture must account for broad societal values, just as they account for bureaucratic and

Fig. 2 **a** Pergola on a *Ronchi* vineyard, and *Ronchi* vineyards in urbanizing landscapes in **b** Bellinzonese e Valli (*Sopraceneri*) and **c** Luganese e Malcantone (*Sottoceneri*) (source: authors)

competitive business demands (Smit and Skinner 2002; Adger et al. 2013). While such socio-cultural complexity has been acknowledged in climate change policy in Europe (Bernetti et al. 2012; FOEN 2012), it is less clear whether those challenges are being integrated into Swiss adaptation research and practice, or for viticultural systems more broadly (von Glasenapp and Thornton 2011; Braunschweiger et al. 2018; Grüneis et al. 2018; Widmer 2018; Candiago et al. 2022). We aim to examine the key narratives regarding climate change risk and adaptation in viticulture in Ticino to analyze how local perceptions could guide opportunities to evolve adaptation policy to mitigate both viticultural and broader societal risks (Paschen and Ison 2014).

3 Method

Part of the challenge of examining complex climate change impacts of adaptation responses across a system is to obtain a data sample that reflects the breadth and depth of understanding of climatic risk perceptions and behaviors (Adger et al. 2013; Elixhauser et al. 2018; Few et al. 2021). Here, we undertake socio-ecological qualitative research to examine vignerons' perceptions of climate change impacts and how those impacts are dispersing out to influence the viticultural system and associated land use decision-making. Small scale, in-depth qualitative analyses can be powerful methods for drawing out a range of viewpoints and identifying key narratives on climatic risk and opportunities for adaptation (Otto-Banaszak et al. 2011; Nielsen and D'Haen 2014; Rosenbloom 2017; Bardsley et al. 2018). Recent quantitative studies in Switzerland examining environmental perception have low questionnaire response rates of 15 to 35% (Conedera et al. 2015; Bardsley et al. 2021; Maidl et al. 2021), which raises questions of how to make sure that data is obtained from a range of respondents (Pope and Mays 1995). The qualitative approach enabled us to access different types of vignerons who welcomed the opportunity to discuss their experiences with climate change and express their stories about the ongoing challenges associated with that change (Table 1).

The interviews were undertaken by the authors with support from the Swiss research institute Agroscope in October and November, 2018. Vignerons were sent invitation emails from publicly available addresses, and 15 vignerons who responded were interviewed from a range of viticultural systems across the four wine regions of the canton: Locarnese and Bellinzonese e Valli to the north (*Sopraceneri*); Luganese e Malcantone and Mendrisiotto to the south (*Sottoceneri*) (Table 1 and Fig. 1; Zoltan and McKercher 2015; Genoud 2020; Ticinowine 2020). Although there is truly a spectrum of producer types, to support analysis, respondents from large, professional wine companies who employ staff throughout the year were defined as Professional (P), and the smaller, part-time, family-managed or hobby grape producers were labelled as Part-time (Pt) (Table 1). The face-to-face, semi-structured interviews ran for about 1 h, but respondents commonly volunteered to spend more time with us to emphasize key issues in their vineyards (Drew et al. 2022). The interviews were framed by questions on respondents' experiences of climate change (see also Reser and Bradley 2020); the impacts on viticultural systems and businesses; adaptation challenges and opportunities; and, how adaptation behaviors influence society and landscapes in Ticino. Interviews were audio-recorded and when necessary, translated into English during transcription by one of the authors, who is a multilingual, long-term resident of Ticino. The datasets generated during the current study are not publicly available due to human ethical reasons, but are available from the corresponding author on reasonable request.

Table 1 Respondents' number, gender, location, and producer type

Vigneron no	Gender	Sub-region of Ticino	Professional (P) or Part-time (Pt)
		Sopraceneri	
1	M	Bellinzonese e Valli (B&V)	P
2	F	Bellinzonese e Valli (B&V)	P
3	M	Bellinzonese e Valli (B&V)	P
4	M	Bellinzonese e Valli (B&V)	Pt
5	M	Bellinzonese e Valli (B&V)	P
6	M	Bellinzonese e Valli (B&V)	P
7	M	Bellinzonese e Valli (B&V)	Pt
8	M	Locarnese (L)	P
9	M and F	Locarnese (L)	P
		Sottoceneri	
10	F	Luganese e Malcantone (L&M)	Pt
11	M	Mendrisiotto (M)	Pt
12	F	Mendrisiotto (M)	Pt
13	M	Mendrisiotto (M)	P
14	M	Mendrisiotto (M)	Pt
15	M	Mendrisiotto (M)	P

We use narrative analysis to highlight the key themes relevant to vigneron perceptions and decision-making as they navigate climate change adaptation pathways (Hovardas and Stamou 2006; Bardsley et al. 2018). Greater evidential rigor can always be generated with more respondent interviews (Mason 2010; Weller et al. 2018) or links to other methodologies (Feola et al. 2015; Schattman et al. 2018), but the repetition of key themes in vignerons' responses suggested that important narratives had been emphasized to provide a basis for analysis (Neethling et al. 2017). Respondent quotations are used to provide evidence to support arguments presented in the text and collated to allow for key messages to be highlighted. The perceptions of respondents warrant the claims made regarding climatic impact risks in "chapter 4" and adaptation responses in "chapter 5," and guide a discussion of those changes for viticulture and associated landscapes in Ticino in "chapter 6." To maintain anonymity, exact locations and vineyard types are not identified. Rather, quotations are cited in the text according to respondent numbers, sub-region (B&V, L, L&M, or M), and producer type (P or Pt), as in Table 1, and respondents' major perceptions and activities are summarized in tabulated and diagrammatic forms in Table 2 and Fig. 3.

4 Vignerons perceptions of climate change

Climate change was recognized by all respondents (Table 2). No respondent suggested that climate change was not a concern, with about a third considering it as the biggest risk to their business.

All vignerons mentioned that weather patterns and seasonal conditions were becoming more unpredictable, with increasing variability and extreme weather events leading to a range of impacts and associated management challenges (Table 2), which we detail below.

Table 2 Key climate change impacts perceived by vignerons in Ticino

Observed climate change impacts	Respondent															
	Sopraceneri									*Sottoceneri*						Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Variable precipitation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	15/15
Disease and pest pressures	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	15/15
Fast vine/berry development	x	x	x	x	x		x	x	x	x	x	x	x	x	x	14/15
Extreme precipitation events	x	x	x		x	x	x	x		x	x	x	x	x	x	12/15
Humidity in spring/summer		x	x	x		x	x	x	x	x	x		x	x	x	12/15
Drought stress	x	x	x	x	x	x	x	x	x				x	x	x	12/15
Milder winters	x	x				x		x		x	x		x			7/15
Late frosts	x		x	x	x			x				x			x	7/15
Long growing seasons	x	x	x	x	x						x					6/15
Extreme heat	x				x	x		x		x		x				6/15
Early start to season	x	x			x				x				x			5/15
Warm nights					x			x	x		x		x			5/15

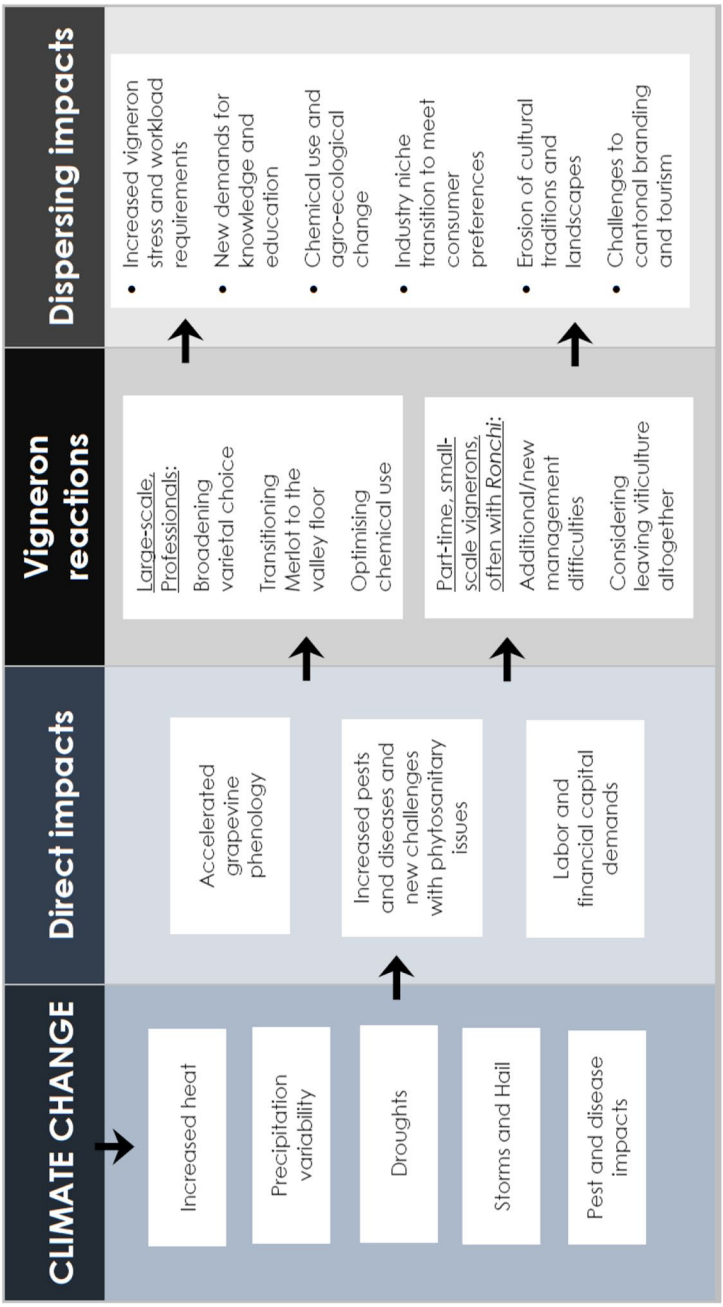

Fig. 3 The dispersal of climate change impacts from Professional and Part-time viticulture in Ticino (source: authors)

4.1 Impacts of greater climate variability

Respondents indicated that the most significant impact of climate change was greater variability in the weather and the generation of a range of more extreme conditions, particularly greater risks of drought and intense rainfall events in both sub-regions (Box 1). While most respondents had been growing grapes in Ticino for a long time, there was a sense that they were increasingly uncertain about the weather conditions and how to manage them.

Box 1 Vignerons' perceptions of climatic variability in Ticino

"We could say that there is a degree of strangeness. We see precipitation events that are much more intense and violent. The same for drought, we see much more extreme, more concentrated drought events" (V2, B&V, P).

"Each year we face something new, completely different. Perhaps in the past the climate was more consistent. Now we always seem to face new surprises" (V3, B&V, P).

"We get high rainfall here, 1800 mm a year, but it seems rainfall events are much more intense – when it rains it is almost monsoon-like. Events have always been extreme, however now they seem even more extreme" (V10, L&M, Pt).

"There doesn't appear to be any more regularity, what we are seeing are peaks" (V13, M, P).

Increasing climatic variability makes trends difficult to interpret, and places more stress on vignerons who must pay closer attention to the weather and monitor corresponding changes in the vineyard, to intervene in a timely manner as imbalances occur in the vineyard.

4.2 Impacts of warming

Respondents emphasized that conditions are warming, but not evenly across the seasons, with the prominence of shorter, colder winters; longer, hotter summers; and increasingly variable spring and autumn conditions, including early spring rains followed by damaging frosts soon after budding. Even then, many vignerons noted positive aspects of the warming trend for their wines in the short term, especially as it allows grapes to fully develop before harvest. "Grape varieties, which until some 20 years ago could be difficult to fully ripen in this pre-alpine region, are nowadays achieving different maturation results" (V2, B&V, P). With respondent V4 (B&V, Pt) highlighting the extent of the change in the growing season: "In the course of 50 years, we brought the harvest forward by one month."

As warmer conditions increase the rates of grapevine and berry development, most respondents suggested that the end quality of the wine has improved. However, the shift is creating issues with balancing sugars with other characteristics of the grapes, because there is limited time for the grapes to develop their full range of characteristics (Table 2). Respondent V13 (M, P) voiced this concern: "This type of climate as we have seen lately in our region is certainly an advantage for the viticultural sector. We see higher temperatures and we reach the degrees of maturity[1] sooner. Of course, there is also a catch, for while the quantity and quality of the product has improved, at the same time the lifestyle of the farmer has gone backwards. This is due to the fact that all the work is intensifying

[1] Refers to Degrees Oeschle, a "scale of measuring grape sugars, and therefore grape ripeness based on the density of grape juice" (Robinson 2006, 492).

and grouped into a smaller period of time, and also we've seen an increase in phytosanitary problems, more difficulties managing hired labor."

The changing maturation rates generate new management issues, such that even the positive aspects of warming require considerable skill, time, learning, and information to exploit the change effectively. For example, key activities are concentrated in shorter time periods making it difficult to manage the complexity of labor requirements and wine production, especially as the grapes themselves are often warmer during harvest, influencing wine production:

> The general management of the vineyard across the whole year is becoming more challenging. The grapes are ripening very quickly and this makes it harder to pick at an optimal point in time. […] We never needed to cool in the past, now however we need to invest energy to cool the must.[2] This year the grape must came in at 26 degrees Celsius – this is what you would expect in southern Italy, not here! Under these circumstances we start to see vinification issues such as oxidation.[3] […] I see a problem during the ripening period, as everything is happening very rapidly. Once, if I was aiming for 90 degrees Oechsle and a certain acidity[4] level, and I did some sampling and measurements once a week, I knew that when we reached 80 degrees, we would require perhaps another 10 days. Now this takes a lot fewer days (V3, B&W, P).

Traditionally, the long, slow ripening of grapes in cool conditions would lead to Merlot wine characteristics from Ticino highly appreciated by consumers, but warming is altering those qualities (Box 2). Respondent narratives from both *Sopra-* and *Sottoceneri* emphasized concerns that as the time to ripening contracts, the conditions that allow for the soft, fruity, and complex wines typical of regional Merlots will become less common, and the stronger flavor characteristics driven by tannins and acidity will dominate (Ticinowine 2020).

Box 2 Vignerons' perceptions of the impacts of warming on Merlot wines in Ticino

"It is not good to have a high sugar content and low acidity. The challenge lies in finding a point where the harvest occurs with the best possible acidity levels and a good sugar level. Therefore, I believe that, overall, the effect [of having to harvest earlier] is rather negative. This type of ripening of the fruit is not leading to the balance we are seeking, but rather to a disequilibrium where one parameter prevails over the other. This also leads to management difficulties, as we would almost have to harvest all the grapes in a few days" (V2, B&V, P).

"When it is very hot and added to that there is also some water stress, the Merlot starts to produce some very hard tannins[5]" (V3, B&V, P).

"The faster development of the grapes doesn't necessarily bring the structure and body of the wine that you want" (V8, L, P).

"It is now possible to bring all grapes to an optimal ripening – something that was not always the case until 15–20 years ago. […] We can achieve a [Merlot] wine with 12.5%, very ripe, high acidity, much fresher. The risk is that in – not sure how many years – we will tend to produce a wine here that is not typical for this region" (V10, L&M, Pt).

[2] "A mixture of grape juice, stem fragments, grape skins, seeds, and pulp that comes from the crusher-destemmer that smashes grapes at the start of the wine-making process" (Robinson 2006, 466).

[3] "Wine fault resulting from excessive exposure to oxygen" (Robinson 2006, 501).

[4] "Is a general term for the fresh, tart, or sour taste produced by the natural organic acids" in the wine (Robinson 2006, 2).

[5] "Diverse and complex group of chemical compounds that occur in the bark of many trees and in fruits, including the grape" (Robinson 2006, 680).

While grape growers are recognizing both advantages and disadvantages of the warming climate, especially for grape development and wine production, more specific elements of climate change are driving negative impacts that require complex adaptation responses (Table 2), and those changes are generating problems for individuals and production systems to near thresholds of tolerance.

4.3 Impacts of hot and dry periods

Ticino is a high rainfall region for wine grape production, so increasing dry periods have variable impacts depending on the site and soil characteristics. Dry periods are problematic on the lighter soils of the *Sopraceneri*, but most respondents noted that they were manageable, either because localized heavier soils hold sufficient water to sustain vine growth, or they have invested in irrigation infrastructure (Table 2). Respondent V5 (B&V, P) from *Sopraceneri* noted "We have light soils with little water retention, wind and prolonged warmth. If these elements combine, you can see how we go from an abundance of water to dry over a period of 10 days – we have water stress" (V5, B&V, P). As Klein et al. (2014) and Tendall and Gaillard (2015) also found for other types of Swiss agriculture, the use of permanent irrigation infrastructure is becoming increasingly important to try and ensure that extreme hot, dry periods can be negotiated effectively:

> "These extreme drought periods, which were unheard of in the past, have driven some clear choices, and in every case where there are new installations, there is investment into irrigation. […] These irrigation systems are not set up only to aid the plants to establish over the first few years after planting while the plant develops its root system, they are set up for the lifetime of the vineyard" (V2, B&V, P).

4.4 Impacts of hail and extreme rainfall

Most vignerons also highlighted the changing timing and intensity of precipitation and increasing seasonal variability was creating water management issues (Table 2). Longer and more intense hail and rainfall events impact directly on the vines. "I had a very serious hailstorm in July last year. Such a heavy hailstorm has not been seen before. The old folk say, they had seen a very serious hailstorm 60 years ago but not since. It caused total damage to the foliage and the grapes, we lost about 95 percent" (V3, B&V, P). Respondent V6 (B&V, P) emphasized how regional rainfall is changing: "It is the violence of the events that is frightening. Nowadays we get rain, but it is no longer 'rain'—we are now talking 100 L (100 mm) in the blink of an eye." The severe summer storms ensure that protective hail netting is now required on more vines to abate the risk of damage, increasing the labor demands when managing the vineyard, especially on steep, terraced landscapes. The extreme rainfall events also add to the challenges of managing diseases and pests.

4.5 Impacts of diseases and pests

The interviews made it clear that the vignerons of Ticino are very familiar with managing a range of diseases and pests, which are a normal part of managing vineyards. "In all of Switzerland, there is Peronospora, Powdery mildew and Botrytis. In this climate, the black rot (*Guignardia bidwellii*) becomes very aggressive" (V3, B&V, P). Yet, respondents also noted increased impacts of disease and insect pests that are well-adapted to the warm and/or wet conditions, raising many new or intensifying old phytosanitary concerns — a phenomenon that is not constrained to viticulture (e.g., Deutsch et al. 2018) (Table 2). As respondent V10 (L&M, Pt) emphasized, new rain

and humidity conditions are driving the change: "From mid-May to mid-June, we've had thunderstorms every day for 20 consecutive days. It rained every day – not all day, but some rain each day. Of course, this makes the management of diseases much more difficult."

Vignerons perceived that Peronospora is particularly damaging in warm, wet conditions, such that monitoring demands and the repeated, timely management of the mildew is stretching capacities of labor and machinery. "Peronospora has in the last few years developed into a stronger and more aggressive mold. The temperatures overall have risen and we are experiencing longer uninterrupted wet periods. In 2018, if I remember correctly from 10th of May until the 12th of June, approximately 30 days, in this period we experienced 28 days of leaf wetting. This happened especially at night, and the nights were warm—these are perfect conditions for mildew" (V13, M, P). Respondent V10 (L&M, Pt) noted that the increased susceptibility of vines to disease could also be a factor of the plants being weakened by hot or dry conditions for which they are not as well adapted: "With these high temperatures, the plants are under stress and are thus less likely to cope well. Their defense systems are weakened and are therefore more vulnerable."

Another emerging problem is the neophyte invasive fruit fly, spotted wing Drosophila (*Drosophila suzukii*), which is attracted to all red fruit, in part due to more regular wet weather during the late ripening phase of the grapes (Knapp et al. 2019, 2021; Wuepper et al. 2021). "Drosophila is another insect we didn't know and it creates wicked damage! First problem therefore: insects. […] It's been a while since we've had a severe winter. It's always been said that cold winters act as a disinfectant and kill all the unwanted pests. As more insects are surviving winter we find larger populations" (V10, L&M, Pt).

The range of extreme climatic conditions generate difficult phytosanitary issues that vignerons must respond to rapidly and with more extensive and precise interventions to cope with the change. Respondents articulated concerns that they struggled with the additional activities, because spraying must occur in such a timely and regular manner that it was beyond their management capacities. The complexity of phytosanitary impacts is particularly important for Merlot production, because the variety appears disproportionately susceptible to the diseases and pests encouraged by climate change (Box 3), raising important questions about opportunities for long-term adaptation.

Box 3 Vignerons' perceptions of the new phytosanitary risks to Merlot wines as driven by climate change in Ticino

"The diseases that we have known and that we have now been fighting for 100 years on the Merlot in Ticino we are no longer able to fight, because we have such extreme conditions, such long wet periods" (V2, B&V, P).

"Merlot, which appeared to be the ideal variety for Ticino—actually 80% of the grapes are Merlot—proves to be very sensitive to Peronospora, especially during flowering. The other varieties are less susceptible and this was clear to see this year (2018)—only Merlot was affected. This sensitivity of the Merlot variety becomes a disadvantage because, as so often happens now here there is rain until June during the growing season, which means there is rain during the flowering period. Moreover, with the warmer temperatures, the lifecycle of the fungus is shorter and the spore-forming cycle is also shorter. Therefore, over a two-week time span during a wet and warm spring, we could see eight or even 10 spore-forming cycles instead of five. This results in a higher rate of attack and the Merlot stays sensitive and prevention becomes more difficult and the vine is unable to fight the fungus. As such, it really becomes important to ask what the direction for the future should be. We are often not able to carry out all the treatments at exactly the right time. One such intervention that is crucial is to remove foliage around the flower. To do this work on 20,000 plants over a two-week timeframe is impossible for us" (V3, B&V, P).

"Merlot is a highly problematic variety without treatments. There are some in Ticino who are trying, but I'm not sure what the results are like. All those I know can tell you that Merlot without treatments is a grim story. We treat 7 to 8 times a year" (V6, B&V, P).

5 Climate change adaptation responses

Vignerons are pursuing different adaptation pathways to deal with the complex climate change impacts. Small-scale, systemic interventions which are manageable within the normal, palliative activities of vineyard management form the majority of actions. Yet, respondents speculated that threshold limits are being reached in management response capacities, which are leading to cascading changes and the need for more systemic interventions (Kinzig et al. 2006; Wilson 2014). The size and type of business, whether Professional or Part-time, provides an important contextual distinction in relation to how systemic changes become apparent and have broader implications for the canton (Fig. 3).

5.1 Perceptions of climate change adaptation for Professional vignerons

Large-scale, Professional producers are transforming their businesses to adapt to climate-driven phytosanitary issues by translocating Merlot production and optimizing the frequent use of phytochemical inputs, which in association with the need for netting, irrigation, and intensification of harvests, are generating new labor demands (Fig. 3). For them, phytosanitary issues are largely manageable, but the regimes require careful observation of the vineyard; more investment into the timely and targeted use of chemicals to control pests; acceptance of rising costs and more labor across the season; and less surety of a successful product without such interventions (Box 4).

Box 4 Changing phytosanitary and labor demands for Professional vignerons

"We had a month of May during which we had constant precipitation. Therefore, we had no opportunities to intervene with preventative or curative treatments for some diseases. These diseases were then able to develop, grow and take hold in the vineyard. […] We know what is right to do but we still lack the experience to know how exactly to deal with this new situation. […] During the growing phase of the vine, there is a requirement for more people in concentrated periods, whereas before we could manage the vineyard with few people spread out over the year. Now, we tend to employ large numbers of auxiliary personnel for short timeframes instead of having fewer fixed employees all year long" (V2, B&V, P).

"Pesticide is the dark side that we need to manage. There is also the health of the grape, and the health of the people. We have legal constraints, but if people, the community have the idea that we are using 3, 4, 5 substances on the grapes, then it is not enough to meet the legal requirements, we have to respect the attitudes of the customers" (V8, L, P).

"Personnel is a big issue because professional training in this sector is a big problem […] The real risk though is the stress associated…, the load one carries, the workload and especially the new competencies that are required. […] We get a bit hammered left and right. The climate is changing and that is putting a strain on us: it requires a lot of energy, both physical and mental strain, and also economic strain. On one hand, we are able to achieve high quality products, on the other hand we have politics asking us to reduce chemicals and our environmental impact. On the other side, we have consumers who are demanding excellence, but at the lowest possible cost to them. The climate changes we are seeing are not at all 'low cost'!" (V13, M, P).

Respondents highlighted that Professional producers have monitoring and response protocols in place to manage disease, but are still concerned about new labor demands and potential for chemical residues (Box 4, Fig. 3), which in turn are driving major changes in the organization of vineyards. For example, steep slopes provide advantages for disease control, because there is more ventilation than the valleys, they also provide logistical challenges. As a result, several Professional respondents noted that they will increasingly direct Merlot production to the valley floors where they can easily use tractors to manage vines:

"Vineyard renewal on the slopes happens with the thought of putting varieties that are resistant to the key pathologies there, and the restructuring of old vineyards or the creation of new vineyards on the plain is carried out with the classic varieties in mind… Merlot for the reds, Chardonnay, Sauvignon for the whites" (V2, B&V, P). While such management demands generate costs for Professional vignerons with considerable resources to adapt to the change, they are making viticulture increasingly unattractive for Part-time, small-scale vignerons.

5.2 Perceptions of climate change adaptation for Part-time vignerons

Small-scale and older Part-time producers highlighted higher stress levels associated with the need to adapt to climate change (Box 5). Several respondents, especially those who are largely managing vineyards for lifestyle values, noted that these additional management pressures mean that hobby farmers are reaching thresholds after which they will be unwilling to continue producing.

Box 5 Changing phytosanitary and labor demands for Part-time vignerons

"The majority of those active in the viticulture sector are amateurs or part-timers who are dedicating 20 or 10 percent of their time to the industry. Moreover, a number of these are retirees and older people, without specific qualifications. Professionals like me play a part, however we don't even cover half of the cultivated area. The issue with climatic change and associated problems is that ever more people are saying 'I can't do this any longer – I am stopping, *Basta*!', or 'I don't want to do this because each year there is a new thing – one year it's the hail, the next it's the *Drosophila*, one year is too dry'. The first problem therefore is to see who will actually want to take ownership of looking after the vineyards" (V3, B&V, P).

"My vineyards are cared for by my wife and myself, we have no help otherwise, but we might have to revise this in the future" (V4, B&V, Pt).

"You see the Swiss reality, small wineries and small producers who are often working on difficult terrain where mechanization is basically impossible" (V5, B&V, P).

"It is challenging at the best of times. The wine industry is such that I cannot employ staff with the number of bottles I produce, or I don't make any profit" (V7, B&V, Pt).

Due to the complexity of management challenges, climate change is affecting the traditional terraced style of production, or *Ronchi*, disproportionately. Vignerons in the mountains are netting their vines to protect them from storm damage, but that is very difficult on the steep slopes, especially over pergolas (Fig. 2a). Also, the *Drosophila* flies and diseases thrive in still air and cool shade, so traditional pergolas concentrate phytosanitary impacts (Box 6).

Box 6 Respondents' perceptions of the challenges of maintaining pergolas in Ticino

"The pergola here were used for the Americana variety, but this is not done so much now because there are many more hours of work involved and a greater risk of disease under the pergola rather than on the normal rows" (V1, B&V, P).

"The pergola is more closed, less ventilated, and therefore for diseases like Peronospora and mildew, but also for hornets and the Suzukii, this is more problematic" (V4, B&V, Pt).

"I am sorry to say, but they [*Drosophila*] have the perfect conditions under the pergolas. It is sad because the pergolas are spectacular structures. In a couple of vineyards, we have already cut the legs at a height of approximately one meter where we put the grafts and then select the best shoots. The *carash*, the stone pillars that weigh about two tons each, they sit buried 50 cm in the ground, these I leave standing to remember the elders who built these vineyards" (V6, B&V, P).

There are tangible values inherent to the terraced *Ronchi* such as grape, wine, biodiversity, and landscape production and persistence, but also a range of intangible elements of cultural history, social capital of participation and action, and the bequest values of passing on such a heritage to future generations (Bagutti 1987; Lévy 2016; Lieskovský and Bürgi 2018). As respondent V4 (B&V, Pt) noted, "The beautiful things are our vineyards. However, the *Ronchi*'s hours are numbered and the vines are set to disappear." Therefore, values of small-scale, Part-time vignerons extend beyond their immediate production by helping to maintain a distinctive, romantic image for an increasingly professionalized industry. As vignerons face new levels of production risk, it is these less-tangible elements that are also being put at risk by climate change. While larger companies can transform their production systems, improving phytosanitary responses and moving their Merlot grapes onto the valley floors, the viability of Part-time viticulture in Ticino is being brought into question. The adaptation responses in both Professional and Part-time systems are generating drivers that are weakening the tradition of high-value Merlot production on terraced vineyards in Ticino (van Vliet et al. 2015).

6 The transformation of viticulture in Ticino

The complexity of climatic change impacts and response behaviors across a relatively small geographical area suggests a range of new challenges. Climate change impacts are dispersing beyond the viticultural system itself to influence multiple social and environmental spheres, including individual costs, stress, and workloads; phytosanitary needs; ecological management; industry positioning; consumer relations; and biocultural landscapes (Fig. 3). The new tensions arising from climatic impacts and adaptation responses are leading some vignerons, and Part-time operators in particular, to question the sustainability of their activities. This raises concerns for the industry in Ticino, but also for conceptions of risk management in general, as the complex impacts of climate change drive new adaptation behaviors, which in turn threaten a range of other values of viticulture for Ticino (Pfister 2009). For example, one effective adaptation tool is the cultivation of a broader range of grape varieties, but those actions generate further problems.

Ticino's premium wines are synonymous with Merlot, as vignerons have exploited the local slow ripening conditions in the mountains to generate a unique product (Zamparini et al. 2010; Regazzoni Jäggli 2015; Ticinowine 2020). "The typical wine here is the Merlot and it is difficult to change this image. So, to put in some Cabernet Franc is not easy. […] It took us years to create this image and now it is difficult to change" (V14, M, Pt). Climate change is likely to be detrimental to the marketing niche, and even if vignerons are able to adapt by generating premium wines from alternative varieties, consumers may not necessarily recognize the quality of those wines. "We are viticulturists and we are in the business of producing grapes, we can produce table grapes, Americana, anything – the problem lies with the consumer who will consume these varieties. I believe we will need a generation at least for the consumers' tastes to change. […] If the consumer doesn't find what he [or she] likes here, they will look elsewhere" (V13, M, P).

While a range of possible disease- or pest-resistant varieties are being explored, respondents noted a lack of high-quality alternatives that are well-adapted to local growing conditions. Most respondents have focused on producing high-quality Merlot grapes/wines their whole lives and are needing to learn to develop new products and educate consumers about the importance of the transition. Respondent V2 (B&V, P) emphasized that this will

involve a period of learning: "We have a range of varieties that in turn respond differently to climatic conditions where they are cultivated. From early varieties, late varieties and a range of capacities to respond to climatic challenges. […] In our enterprise we have over a number of years now, been experimenting with these resistant varieties. […] We are confronting new situations and we are lacking experience" (V2, B&V, P).

As Alikadic et al. (2019) also found for the nearby Italian province of Trento, many problems with adaptation behavior relate to new imbalances between the adaptation of viticulture and business needs, which can be acute in the high regulatory and financial cost environment of Swiss agriculture. Respondent V5 (B&V, P) stated, "We also always want to be world champions in everything, sanitary, ecological, everything – we have very restrictive laws in this respect, in relation to the environment, to the landscape and whatever else – this means that we are expensive." Professional vignerons are being forced to rapidly change the way they do business to respond to the complexity: "There are so many things that we have to understand as a society, it is like a war" (V8, L, P). However, as introduced in Section 5.2, the need to transform systems is particularly challenging for small-scale, aging, or hobby Part-time farmers who are less likely to have the expertise, the time, or the enthusiasm to invest into sophisticated adaptation techniques. As the job requires the timely management of vineyards, including the responsible use of pesticides on steep slopes under the pressure of difficult and varying weather conditions, viticulture is losing its attraction, which in turn erodes their willingness to manage vines and the biocultural landscape. "The challenge is that the winegrower has to amplify his [or her] knowledge in an excessive way – to try and to gather information on all these things" (V12, M, Pt). To successfully adapt in Ticino, as Merloni et al. (2018) also found, vignerons will first need to be willing and able to change.

The complexity of adaptation needs across different systems was highlighted by vignerons, but they also noted that state support systems treat their community as though Professional and Part-time vignerons behave in a similar way. Respondents emphasized that while considerable knowledge on climate change is available on risks from weather or pests (e.g., Dubuis et al. 2019; Wuepper et al. 2021), they were struggling to find useful local information to guide local decision-making, a finding mirrored more broadly in Switzerland (Skelton et al. 2019). Several respondents noted that the new situation requires more focused research that is directly applicable to their conditions: "Having the substantial resources of research institutes is crucial and still there is a continuous trend to wanting to cut funds. Instead of deducting from them, we should build these institutes up to help the farmer intervene at the opportune moment. Often it really is a question of a few days, knowing that you should intervene at a certain point. Agriculture is becoming more and more a labor of precision, especially when treatments are required" (V3, B&V, P). With the rapid changes in weather and phytosanitary conditions, detailed information needs to be made available in a timely manner. "Information needs to be made available quickly and regularly. We feel we are always operating in a state of emergency. The government acts too late. The winegrower has to fend for themselves, always, there is never an early warning from cantonal authorities" (V12, M, Pt).

Adaptation research could become more directly applicable for producers in Ticino by working to filter technical knowledge through the lens of specific cultural practices (Moser 2010). In that regard, respondent V9 (L, P) noted that "Scientific research is all centralized in one location and also increasingly conducted privately. […] In South Africa I saw how there is a lot of collaboration between farmers and researchers. This part is missing a bit here." Battaglini et al. (2009), Mosedale et al. (2016), and Biasi et al. (2019) similarly conclude that research that generates system-specific information is increasingly needed

to support vignerons to iteratively learn to develop appropriate adaptation responses. That learning will involve the evolution of viticultural approaches and products to generate new, high-quality niches that will persist through a future of climate change.

Simultaneously, there is increasing pressure to define production systems to attract consumers. Respondent V8 (L, P) stated, "Today, each vineyard has to find their own way, their own history because everyone has wine, everyone is better than the other, everyone is the interesting one." To generate new or sustain resilient production and marketing niches, ongoing public and/or private investment in agriculture will be vital (Lieskovský and Bürgi 2018; Bonardi 2019). One approach that several respondents noted was to explore varieties that were widely grown in the region before the success of Merlot, to support retention of traditional agricultural biodiversity and landscapes, while generating wines that will help to introduce consumers to new and unique experiences (Bardsley 2003; Herzog et al. 2005; Biagioli et al. 2012; Burandt and Mölders 2017).

To retain the mixed viticultural landscapes in Ticino, Swiss agricultural policy will need to continue to recognize and respond to the multifunctional roles of agriculture as it adapts (Klein et al. 2014; Pröbstl-Haider et al. 2016; Mitter et al. 2019). Switzerland has provided strong support for its farming sector, and much of that has been directed through policy to protect or develop specific rural land uses in marginal regions for socio-economic and ecological outcomes (Lindemann-Matthies et al. 2010; El Benni and Finger 2013; Bardsley and Bardsley 2014; Gerlak 2014; Karali et al. 2014; Widmer 2018; BLW 2021; Mack et al. 2021). As the country aims to conserve its biocultural landscapes (Iniziativa Paesaggio 2020), in part to maintain a vital tourism sector, the cascading changes summarized in Fig. 3 highlight the challenge of supporting adaptation that will enable farmers to remain effective custodians of rapidly evolving landscapes (Matasci et al. 2014). Furthermore, new phytosanitary management demands require greater understanding of the use of agrichemicals, which in turn could make the wines of Ticino more expensive for the consumer and grape growing less appreciated by an increasingly environmentally aware public. The need to adjust systems to adapt to climate risk has the potential to contradict broader environmental goals, unless vignerons are continually supported to optimize and minimize their chemical use. The Swiss state is providing considerable assistance to vignerons, yet several respondents voiced concern that the challenges of adaptation are not being made easier by broader agricultural political change, which they feel is not fully reflecting the difficulty of their task:

> On a political level though, there is a need to recognize that if the farmer has to carry out ecological roles or tasks, then it must also be paid for. Incessantly asking [farmers] to produce more, at a lower cost is not going to work […] We are losing up to 5000 jobs within the agricultural sector each year. This demonstrates that we have been moving in the opposite direction. We should and would have liked to maintain these jobs – but no! – rationalize! – make one farm out of two. The common thought is that farmers, with help of mechanization, can manage the land anyway. Well, we'll have to see – if you are a farmer in canton Fribourg where the land is flat you can plant arable crops, however, if you are in a different type of landscape, then no! We also see the disappearance of the rural culture, the traditional rural knowledge, customs and traditions, product diversity and all that is linked to these values and traditions (V3, B&V, P).

Adaptation policies need to provide labor and land management guidance that recognizes that climate change risks to viticulture in Ticino extend beyond the production of wine, and unless shepherded carefully, will continue to disperse across society. Federal

and cantonal governments could move to respond more directly to the risks of structural changes driven by climate change (Trivellone and Moretti 2017; Braunschweiger et al. 2018). Representative farmer associations such as "Interprofessione del vino e della vite ticinese" or "Federviti" have the potential to liaise with researchers and government to provide targeted guidance during the transition, especially because many emerging risks are associated with the lack of integration of technical and local knowledge to guide timely and effective responses by vignerons, and unless broadly understood, the adaptation responses themselves may make viticulture less attractive to the Swiss public.

7 Conclusion

A new risk has emerged for agriculture — not only in Ticino but everywhere — the potential for dramatic systemic transformations in response to a changing climate. Already, there has been a warming trend in Ticino, but respondents also emphasized changes to rainfall distribution, averages and extremes, heat, hail, and snow events, and air humidity levels during key growth periods. Vignerons highlighted that increasing uncertain and extreme weather events are making their activities more difficult, costly, and stressful, and while many are adjusting to respond to immediate impacts within the confines of their own systems, viticulture in Ticino has become more complex and structural change is occurring across the socio-ecosystem. While current adaptation responses are applied within a framework of "normal" practices, we identified that social thresholds are being met that threaten to lead to cascading change (Nelson 2011). The adaptation responses are generating a range of new cost burdens for producers, including increasing financial and personal stress, and those impacts are dispersing, threatening a way of life that maintains unique systems of historical production, landscape architecture, and biodiversity stewardship.

There are lessons from the research for other high-cost agricultural systems about what could be considered "successful" adaptation. In particular, the division between Professional and Part-time vignerons could be more explicitly recognized as requiring targeted support for specific adaptation pathways. New phytosanitary requirements are generating problems for vignerons, and the chemical use, changing vineyard arrangements, and labor demands led respondents to question the future importance of Merlot within *Ronchi* landscapes. To respond, some systemic and landscape change will need to be accepted or even championed in Ticino as a way of advocating for effective adaptation by vignerons as stewards of landscape — climate change adaptation is underway in Ticino, and that is an important message in itself for other places and systems (Bardsley et al. 2018).

Different groups will need to learn to support change. Consumers may need to simultaneously adapt to a shift in the characteristics of the Merlot, varietal choice, and production systems of Professional vignerons as they adapt (De Orduna 2010; Lereboullet et al. 2014). Policy that directs payments to farmers to improve conservation has been shown to be successful in Switzerland, and could be further promoted to target assistance for vignerons who wish to maintain small holdings or focus on landscape stewardship outcomes (Wuepper and Huber 2022). For example, if vignerons are becoming more reliant on sophisticated responses to phytosanitary demands, there could be a corresponding increase in support for vignerons either to optimize their operations or develop alternative organic, biodiverse systemic pathways (Home et al. 2019; Taghikhah et al. 2020).

There is an intricate link between the risk to viticulture and the cultural identity and landscapes of Ticino. To assist vignerons to respond to the new complexity, unique adaptation niches that are framed by local values must evolve in association with technical support (Mosedale et al. 2016). Several respondents identified a particular gap in research services, which appear to be insufficiently attuned to the specific characteristics of local activities. By articulating future challenges and highlighting their goals, research that involves ongoing learning with farmers to generate knowledge of local risks and different potential adaptive pathways could help to guide behaviors that will benefit both individual producers and wider society (Pelling et al. 2008; Neethling et al. 2017; Candiago et al. 2022). Without such investment into appropriate and timely climate change research closely tied to vignerons' decision-making, the cultural relationship between people, wine, and regional landscapes could be weakened in the sunroom of Switzerland.

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