FOOD

Will We Still Enjoy Pinot

Winegrowers are trying to preserve the flavor of your favorite reds and

By Kimberly A. Nicholas

IN BRIEF

Climate change is raising air temperatures in many wine-growing regions. Because temperature drives the accumulation of chemical compounds in grapes, if it keeps rising, wine from a given region may not have the same flavor.

Higher temperature increases a grape's sugar content, which means higher alcohol during fermentation. Temperature also affects trace compounds that create aromas, crucial to our flavor perception.

Winegrowers are taking a range of steps to try to adapt, from reorienting rows of vines to rearranging leaves to provide more shade. Moving a vineyard north or even uphill to lower heat is expensive and may not duplicate flavor because of different moisture and soil conditions.

Noir?

whites as climate change alters the compounds in grapes

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IT WAS A HOT DAY IN THE VINEYARD, and I was covered in dust, sweat and sticky juice from the grapes I had been collecting for my research on how grape biochemistry is affected by light and temperature. Suddenly, I saw something that made me stop short. Tucked in one corner of this 6.5-acre plot in Carneros, in California's fabled Sonoma Valley, with row after neat row of Pinot Noir grapes, were a handful of alien vines. I had studied the arcane art of ampelography—the practice of identifying grapevines by the shape of their leaves and clusters, as part of my graduate training in viticulture—so I took an educated guess at what they were: the red varieties Cabernet Franc, Petit Verdot, Syrah and Malbec, plus a white, Sauvignon Blanc.

The next time I saw Ned Hill, an old friend from high school in nearby Napa who now managed some of the finest vineyards in the region, including this one, I asked him about those strange vines. "That's an experiment I'm doing," he said. "We're already pretty warm around here for growing Pinot. The price is good right now, so I don't want to make any changes. But pretty soon we might do better growing something else, so I'm trying out some warmer-climate varieties."

A Cabernet in Carneros? That sounded heretical. Upvalley in Napa is famous for its Cabernet, but here, where the Sonoma and Napa valleys broaden and join to meet the San Francisco Bay, it is cooler Pinot territory. The region's mild days, cool nights, fresh sea breezes and clay soils produce Pinots with the flavor of fresh red strawberries and spices like cardamom and cinnamon. It is the flavor of where I am from, and this fingerprint is what makes the wine unique and valued.

If temperatures keep rising, however, wine from those Pinot grapes will not be the same. Growers might indeed have to switch to Syrah or even Cabernet but risk ending the Carneros tradition, perhaps hurting sales. Maybe my friend could move his operation farther north, seeking cooler climates, but Pinot grapes at a different site would be influenced by the soil, humidity and rainfall there; they would not have the Carneros Pinot flavor. Or my friend could apply emerging know-how and try to adapt his growing techniques to preserve the signature flavor, a tricky task.

Climate change is beginning to affect the singular flavors that people expect from different wines from around the world—the experience you have come to know and trust from your favorite reds and whites. As a result, grape growers and winemakers are beginning to make some difficult and intriguing decisions about how to respond. Whether they can adapt enough to make sure that a Carneros Pinot retains the flavor of a Carneros Pinot or a French Burgundy that of a French Burgundy, and whether long-time wine regions fade and new ones arise, will depend on the rate of climate change and the rate of innovation.

GRAPE GROWERS can try to combat higher temperatures by increasing leaf cover or reorienting rows to enhance shade.

GREAT WINE IS GROWN, NOT MADE

WHEN IT COMES TO STAPLE CROPS such as wheat, corn and rice, scientists worry about the effects of rising temperatures on yields. For grapes, temperatures do not threaten the quantity produced so much as the quality of the grapes themselves.

Certain vineyards in warm regions are indeed looking for high volume at low cost. In California's Central Valley, for example, growers in Fresno aim for a yield of about 12 tons an acre. In 2013 they sold these grapes for an average of $340 a

ton, which mostly end up in bottles of wine costing less than $7.

The more romantic version of wine growing takes place on the cooler fringes of land hugging the California coast. Just 200 miles north of Fresno, skilled workers in Napa Valley raise grapes by hand, touching each vine up to a dozen times over the course of the growing season. Workers deliberately limit yields by pruning vines in the winter so each shoot produces only a few clusters, and they routinely pass through again in the summer, cutting any suboptimal clusters to the ground.

The intent is that the money lost in quantity will be made up in quality—that the vine will concentrate its resources in investing those few clusters with deeper, more complex flavors and aromas. The goal is to produce around four tons per acre, which fetched $3,680 a ton in 2013. Careful vineyard management certainly contributed to this 10-fold increase in price, compared with that of Fresno, but most of the premium is related to climate—a large effect from a seemingly subtle difference in annual average temperatures, just 4.5 degrees Fahrenheit cooler. As one grower told me, "Even a genius can't grow good Pinot Noir in Fresno. It's too hot."

"Too hot" is a problem because all plants are regulated by temperature. Wine grapes are especially sensitive. Wine is so shaped by the environment in which it is grown that the French have a word for it: *terroir*. Wine, like coffee and other geographically distinct products, reflects the place of its origin. The grapevine makes sugar through photosynthesis, then modifies and recombines this one starting ingredient to produce myriad compounds that might ultimately smell like raspberries or fresh-cut grass in your glass. Temperature, moisture, light and the soil itself alter how the vine orchestrates this ballet. Wine is more than 80 percent water and typically 12 to 15 percent alcohol, leaving only about 5 percent for everything else. This small fraction of other elements creates the unique flavor of a local wine, and changes in climate are putting this flavor at risk.

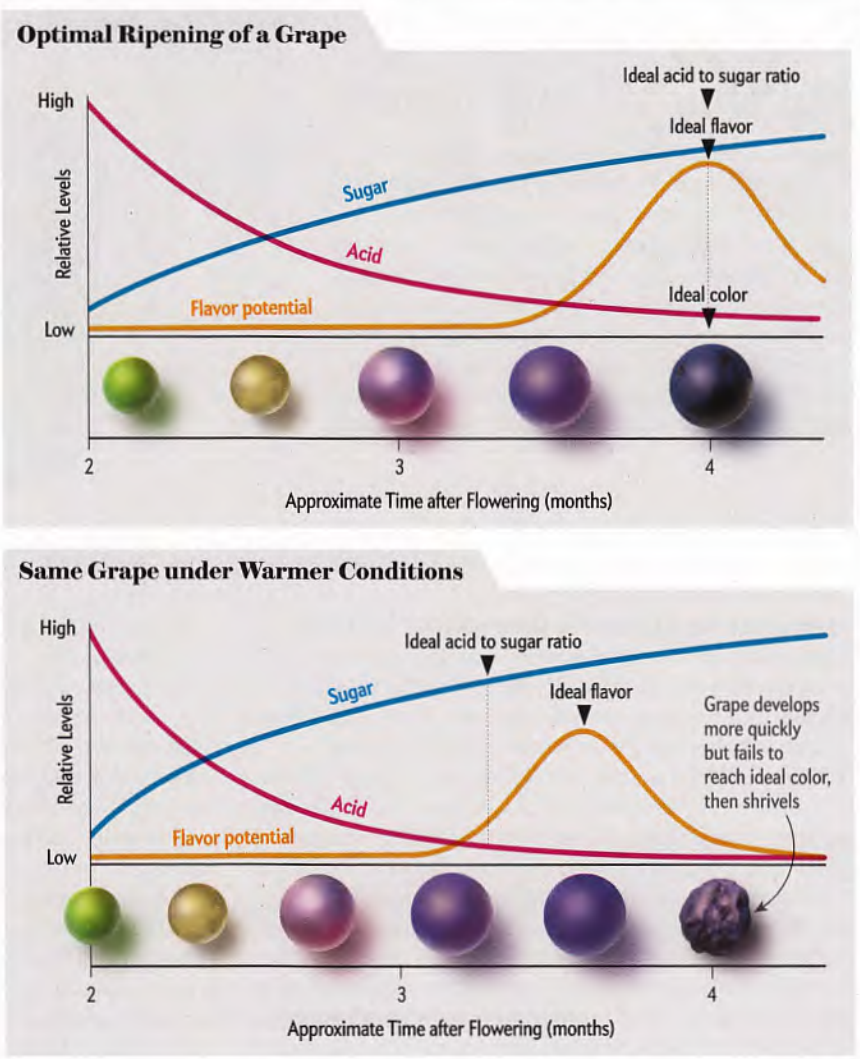
Although wine making requires great skill, nearly all the winemakers I have interviewed for my research on how the industry is responding to environmental challenges readily admit that most of the potential quality of a wine is already determined when the grapes are delivered to the winery. Some of the potential flavors come from the wine-making process, such as the yeasts used in fermentation or aging in oak barrels, but as one well-known wine-

STRATEGY

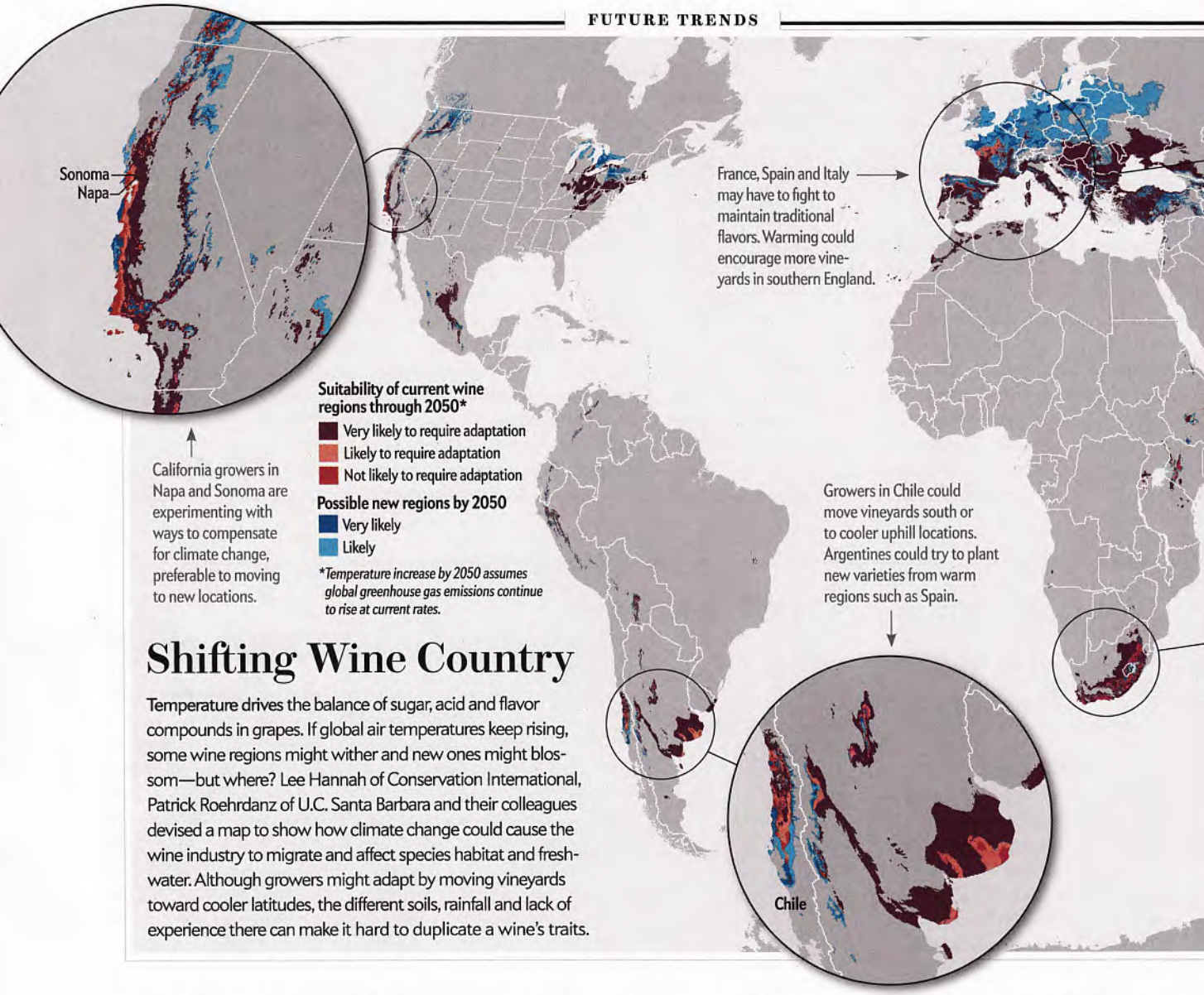
When to Pick Grapes Will Get Harder

Wine grapes take three to four months to ripen, but when to harvest them is a delicate decision. As a grape matures (*top*), its sugar level rises and its acid level falls (*blue* and *red curves*). The ideal ratio for a good wine occurs at around four months. Overall flavor (*orange curve*), influenced by other compounds, also peaks near that time, creating a tight window for the best harvest time.

The decision will get tougher. As the atmosphere warms (*bottom*), the desired ratio of acid to sugar occurs sooner in the growing season. The optimal flavor moment may occur earlier, too, but not shift as much, leaving a gap of time between ideal balance and ideal flavor and making it difficult to find the best combination. The grapes may also ripen too fast to accumulate as much potential flavor (the peak is lower in the orange curve) or to reach ideal color.



Graphic by Jen Christiansen



Shifting Wine Country

Temperature drives the balance of sugar, acid and flavor compounds in grapes. If global air temperatures keep rising, some wine regions might wither and new ones might blossom—but where? Lee Hannah of Conservation International, Patrick Roehrdanz of U.C. Santa Barbara and their colleagues devised a map to show how climate change could cause the wine industry to migrate and affect species habitat and freshwater. Although growers might adapt by moving vineyards toward cooler latitudes, the different soils, rainfall and lack of experience there can make it hard to duplicate a wine's traits.

maker told me, "If everything in the vineyard is done correctly, my job is just not to screw it up." Great wine is grown, not made.

DIFFERENT CLIMATE, DIFFERENT FLAVOR

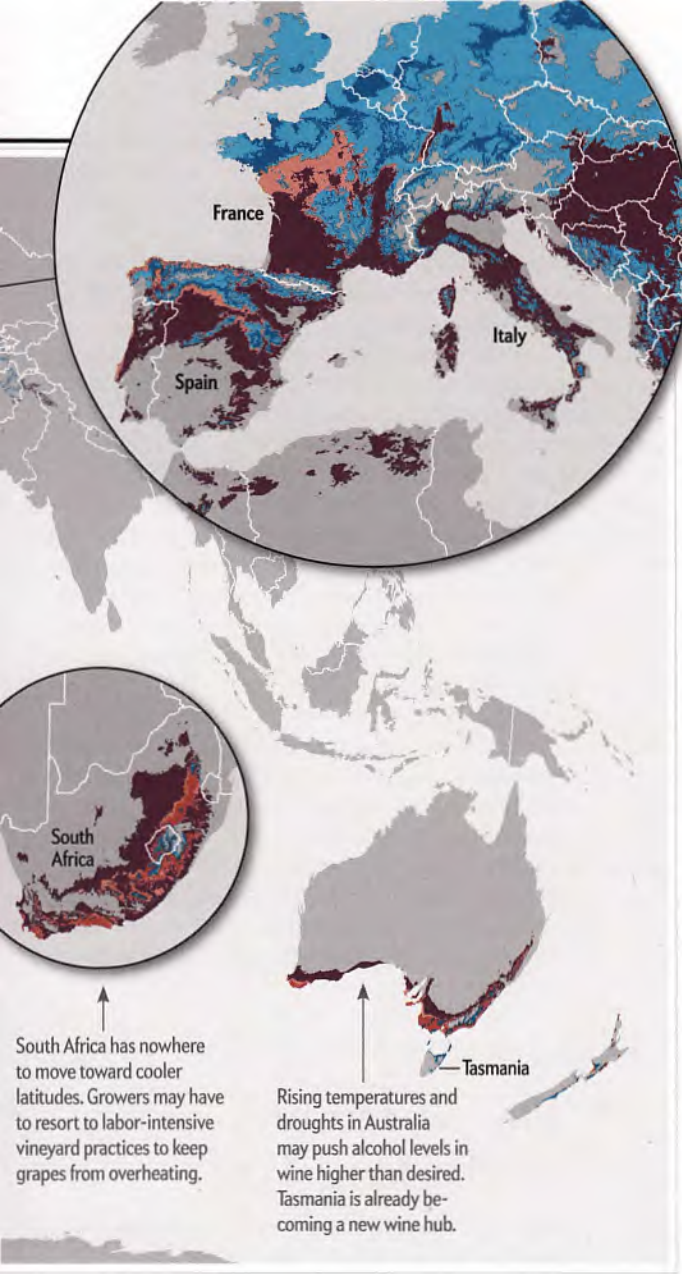
CLIMATE GREATLY AFFECTS THAT GROWING. Winegrowers think of climate on three levels: the macroclimate of a region like Carneros or Burgundy; the mesoclimate of a vineyard parcel; and the microclimate of a cluster of grapes within a canopy of leaves.

The macroclimate is influenced by broad geographical forces that set the growing season and the temperature and rainfall patterns. Temperature mostly determines which of the thousands of varieties of wine grapes can be grown optimally in a given place, from crisp whites suited to the short growing season and cool temperatures of Germany to bold reds that can maintain their flavors through a long, hot, dry summer in Spain. Temperature controls when vines wake up in the spring after winter dormancy and drives the growth and ripening process. As global temperatures rise, new regions such as southern England are becoming more suitable for wine growing, whereas some warm wine regions, notably parts of Australia, are struggling with high temperatures and regular droughts that contribute to uneven yields, overly high alcohol levels and unbalanced flavors.

Changes in the amount and timing of rainfall in a region can alter grape quality in various ways, and excessive humidity can hasten fungal rot. Drought can severely stress a plant. Many New World wine-growing areas, including California, are widely irrigated, but research I conducted in a team led by my colleagues at Stanford University showed that even in irrigated regions, natural precipitation affects yields.

How a vineyard's mesoclimate affects the taste in your glass is less obvious, but it starts with the balance of sugar and acid in the grapes, the components that form the foundation of a wine's taste. Fruits accumulate sugar through ripening, which is directly controlled by temperature. Ripe wine grapes are especially high in sugar, about a quarter by weight—twice as much as a sweet, juicy peach. Heat increases sugar at a predictable rate, usually by a percentage point or two every week during ripening. Sugar is converted to alcohol in fermentation, so sweeter grapes mean

Map by XNR Productions



South Africa has nowhere to move toward cooler latitudes. Growers may have to resort to labor-intensive vineyard practices to keep grapes from overheating.

Rising temperatures and droughts in Australia may push alcohol levels in wine higher than desired. Tasmania is already becoming a new wine hub.

higher-alcohol wines. Over the past few decades rising temperatures have influenced a global trend toward higher-alcohol wines. Higher alcohol is often perceived as "hot" and more bitter and can overpower or alter the perception of more subtle flavors.

Acids are the yin to sugar's yang. Present in large quantities in unripe grapes, they are partially broken down as the grapes ripen. Acids in wine provide a sharp, refreshing taste. Cooler wine regions have planted varieties that can ripen quickly over the short growing season yet still have pleasing acid levels that are not too high. Cool-climate wines such as German Riesling may get less refreshing with warming temperatures as the crisp taste of acids is lost with heat.

Winemakers have studied sugar and acids for a long time, but in recent years they have begun to learn more about how critical less prevalent elements in wine are to our drinking experience. For example, phenolic compounds are important for wine color. Before we sip wine, we see it in the glass, where its color inevitably shapes our overall perception. In one test, even experienced wine tasters used red wine characteristics to describe the flavor of a white wine that had been tinted red. Juice from classic (Old World) wine grapes is not pigmented; the color in the wines comes from phenolic compounds called anthocyanins in the skins. These compounds occur widely in nature; they make blueberries blue and eggplants purple. When grapes are crushed after harvest, the red varieties are left in contact with the skins through weeks of fermentation to transfer the color to the juice. White wine grapes have a lower concentration of phenolics to begin with and are usually pressed away from the skins immediately.

Phenolics in a grape are induced by sun exposure, but wines from warmer climates are generally lower in desirable color. Research suggests that changes in average temperature are not all that matter, however; an increase over certain limits can result in nonlinear consequences that will decrease anthocyanins.

That vineyard microclimate also affects tannins, which give wine texture (like "chewy" or "smooth"). Tannins are another phenolic compound and get their name from their ancient use to tan leather. Tannins are so unpalatable that they protect fruit from being eaten by animals or pests before it is ripe. In your mouth, they bind with proteins in your saliva, drying out your tongue and gums, a sensation that affects your perception of wine flavor. They also have a bitter taste. Good tannin balance helps wine compliment food; the tannins physically cleanse your palate, removing fat from taste receptors so you can taste each bite more fully. Excessive warmth or light can decrease tannins, leading to potentially less balanced wines.

RIPE FOR SMELL

AT THIS POINT, we are down to the trace compounds that account for most of a wine's unique character. These bits are crucial, most of all for smell. When we taste wine, we often swirl it first and smell the aroma. The swirling volatizes compounds in the wine so they bind with receptors in our nose, sending signals to our brain that it interprets as flavor—the integration of many sensory inputs. Most of what we commonly perceive as taste is provided by our exquisite sense of smell. That is why food seems so bland when you have a cold; your stuffy nose does not allow the aroma compounds to reach your nose from inside, at the back of your mouth. Try eating a skinless piece of firm apple and a raw potato with your nose plugged; it is surprisingly difficult to distinguish the difference. Wine tasting might better be named wine smelling, although that sounds less appealing.

Winemakers and researchers are still developing better insights into the trace flavor and aroma compounds, which can arise in many ways. Those found in grapes usually accumulate in the late stages of ripening, and we know that their formation is sensitive to temperatures at that time. This so-called flavor ripening may occur at a different rate than the predictable sugar ripening that traditionally governs harvest decisions. Instead of picking grapes when they reach a given sugar level, many winemakers are making harvest decisions based on tasting grapes in the field, looking for flavors they believe will translate into great wines. The flavors usually progress along a continuum, from tasting like green fruits and vegetables to red fruits like raspberries, black fruits like blackberries and, finally, jammy fruits like raisins.

In some regions this strategy has led to a trend toward greater "hang time"—leaving the fruit on the vine longer for better flavor ripening. Some growers may not like this approach, because the

grapes lose water, which can mean less weight and less income. The longer hang time also increases sugar levels in the grapes, perhaps forcing winemakers to later add water to the juice to ultimately get the right alcohol level.

Researchers are trying to better understand the influences that the more than 1,000 aroma compounds in wine have on flavor perception. This is difficult to predict because some compounds are present at very low concentrations, and human sensitivity to them can vary by hundreds or thousands of times among different people. For example, more than 200 compounds may contribute to strawberry smell, and your trigger for "strawberry" might be different from mine. (So don't worry that you won't get the "right" answer when tasting wines—there is none!)

Sometimes one "impact" compound is the prime force behind a characteristic smell, and understanding its effects on our senses can help growers craft a better product. In the 1980s Hildegarde Heymann of the University of California, Davis, followed a hunch and discovered that a compound called methoxypyrazine, which caused the undesirable bell pepper aroma in Cabernet Sauvignon, was destroyed by light. Growers changed their trellising practices to reduce shade on the fruit, and California Cabernet got a lot better. More recent investigation led by Claudia Wood and her colleagues in Australia, Chile and Germany identified a single compound, rotundone, as the source of the desirable black pepper aroma in Syrah, and other work suggests that rotundone accumulation is likely higher at cooler sites and in cooler years.

GROWERS FIGHT BACK

UNDERSTANDING ALL THE INFLUENCES on a wine's flavor helps growers assess possible adaptations to a changing climate. The most dramatic action would be to move between regions, say from California to Oregon, or less dramatically, move within a region, perhaps from warmer valleys to cooler hillsides. A few studies have assessed these options, but they are based primarily on predicted temperature changes, without accounting for other important environmental factors. Articles in the popular press based on these limited analyses have gone so far as to declare certain wine regions at risk, anticipating decreased grape production and quality.

Several complicating factors make the simplistic notion of moving difficult in practice. Suitable soils that provide the right nutrients and water supply are required for high-quality wines, and these may not exist in new places. Appropriate, undeveloped land may not even be available. Uprooting an entire industry and its infrastructure is difficult and expensive; new vineyards take five or six years to generate full yields and may take 20 years to make a profit. Many growers also have a strong sense of place from farming land for generations that they may not want to lose. And consumers may feel strong ties to that place. New regions that are getting warm enough to grow wine will need time to develop the cultural know-how to solve the particular challenges of planting productive sites, managing pests and disease, and developing the regional style and identity that buyers prize.

What about selecting or breeding different vines to match changing conditions? One Old World grape species, *Vitis vinifera,* accounts for essentially all the grapes used for making what most people call wine, yet it comes in thousands of strains, known as varieties. Growers have selected varieties for their desirable qualities in a particular environment, the same way that people have selected varieties of dog to pull sleds in the Iditarod or to fit in Paris Hilton's purse.

But simply taking a grape that has good characteristics in one place and growing it somewhere else often will not provide the same delicious flavor. For example, clones—genetically identical cuttings from a single mother vine—of Pinot Noir grapes from Dijon, France, were selected to ripen quickly and produce high-quality wines in cool Burgundy, where they gained a reputation for producing great wines. They have now been widely planted in warmer California, yet with faster ripening in a different environment, they do not always produce the same prized flavor profile. Planting varieties from warm regions such as Spain in new places that are warming up might produce tasty wines, but this trial and error can take many years.

Breeding new varieties to better withstand increasing temperatures is an area of active research with some staple food crops, but it has more limited potential for wine grapes. Breeding can take a decade or more, but the main limitations are cultural. French appellation law, for example, specifies that only certain varieties can be grown in certain locations, if they are to carry the protected label of the region, such as Bordeaux (although one more recently bred variety, Marselan, a cross of Cabernet Sauvignon and Grenache, was successfully legalized in the 1990s in the

DO-IT-YOURSELF

The At-Home Wine-Tasting Test

Anyone can learn to taste wine more analytically, without following professional critics. It is mostly a matter of learning to identify elements in wine and to associate them with the relevant descriptive term. Because different people may have different initial perceptions of a certain flavor, panelists in wine-tasting experiments first smell physical samples such as blackberries so they agree on what "blackberry" means. Panelists then go into individual booths, dimly lit with red light to make all wines appear the same color. A researcher slides a tray with numbered wines through the wall, and the panelists rate them on a computer screen.

At home you can simplify this procedure and make it more fun. First, tell a group of friends to bring a particular variety of wine, such as Syrah. Your job, as host, is to find samples of flavors commonly found in Syrah: black pepper, blackberries, clove. Put each one in a glass and cover it with a muffin liner to hold the aroma compounds in. Once your guests are settled, pass around and smell the standards. Then taste each wine and see which flavors you recognize and how strongly.

If you want help, consider the Aroma Wheel developed by Ann Noble. The center of the wheel establishes broad categories of aroma, such as fruity or spicy. Each category gets more refined toward the edge of the wheel: first fruity, then berry, then raspberry. Learning to experience the sensory world in more detail can make the hours a day we spend preparing and eating food a lot more enjoyable. —*K.A.N.*

WINEMAKERS at Robert Sinskey Vineyards in Napa ensure that fermenting wine stays in contact with grape skins to extract maximum color and tannins.

Côtes du Rhône appellation). Worldwide, consumers are often well entrenched in their favorite varieties, and a new breed could have a very difficult time breaking into the market.

Within an existing vineyard, growers can try to combat climate change with planting decisions. For example, they can change the direction of plant rows or how vines are trained as they grow and how they are held up by trellises to provide more shade as temperatures rise. Or growers can graft existing rootstock over to a new fruiting variety that tolerates heat better. These big decisions are usually made once, however, at the beginning of a vineyard's long life cycle.

Less dramatic decisions can still have great adaptation potential. Growers cannot control the air temperature in the macroclimate of their region, and they have only limited options for controlling the temperature at the mesoclimate vineyard scale, like overhead sprinklers or shade cloth. But they can use the number and position of leaves to cool the microclimate of the ripening grape so it better holds on to flavor and aroma compounds.

For example, in vineyards around Carneros in California my measurements revealed very high levels of sunlight (more than three times the levels previously reported) on grapes hanging from more than 500 Pinot Noir vines. All the shoots and leaves were held rigidly above the grape clusters by catch wires to provide more air circulation to reduce disease. In analyses conducted with my colleagues at Stanford and U.C. Davis, we showed that for every 1 percent increase in light, there was a more than 2 percent decrease in desirable tannins and anthocyanins. Easing off the vertical trellising style to allow more shade on the fruit could help preserve these compounds and, of course, cool the fruit.

Although most of a wine's flavor comes from the grape, winemakers can take steps in the processing phase to try to preserve a local wine's taste. If acids are lost too quickly as regions warm, they can add acid in the winery. If grapes accumulate too much sugar, which would ferment into high-alcohol levels that can overwhelm finer flavors, they can use reverse osmosis or other techniques to remove excess alcohol. These options are rather blunt tools, however; they cannot completely correct for flavors that originate in the vineyard.

Coaxing the best flavor from the land is a craft that takes years of hard work. Some industry experts think that New World regions such as Napa and Sonoma are still finding their best *terroir*. Jason Kesner told me several years ago when he was manager of a premium Napa-Carneros vineyard that the most outstanding vineyards in the region may still be generations away. It takes a generation to grow a vineyard, he said, "and then it takes your kids to figure out how to plant it differently, and it takes their kids to really get it dialed in. That's why the French have such incredible vineyards; it's just that they've had more time learning." And yet because great grapes are so sensitive to climate, if the climate changes even a little bit, the local knowledge and skills that have taken generations to hone can become less relevant, even in familiar territory.

CHANGING PLACES

EVEN IF THEY ARE RELATIVELY YOUNG, a Napa Cabernet and a Carneros Pinot have their own profiles and their own devotees. "I opened up the bottle of wine, and it smelled like Carneros," Debby Zygielbaum of Robert Sinskey Vineyards in Napa told me poetically. Climate change, if it alters the aroma and flavor of those grapes, could hurt those regions. Although warming might improve wine growing in some cooler areas, such as Tasmania, changes will most likely disrupt the major wine centers, which have tailored their industries to current conditions. For example, springtime warming greater than 1.8 degrees F is likely to reduce yields of California wine grapes, according to my research. Another example: the price of California Pinot Noir grapes drops steeply when they ripen above an optimal temperature threshold.

Growers and winemakers have some technical options for adapting, as we have seen, but whether these will always be enough remains to be tested. And at what point does applying know-how lead to a wine that is manufactured rather than one that brings out the unique flavor of a place? Ultimately there are biophysical and economic limits to adaptation.

The latest scientific reports say that if the world stays on its current trajectory of fossil-fuel use, the global average temperature will increase 4.7 to 8.6 degrees F in the next few generations. That rise may not sound like much, but consider that the low end of this range is roughly the difference between Napa and Fresno today; the high end is the difference between the Californian Central Valley wine town of Lodi and Houston. Although winegrowers are resourceful and creative, it is hard to imagine Houston becoming the next Napa Valley.

Wine is a literal message in a bottle, captured for our enjoyment. It lets us visit parts of the world we may never see in person. It reflects the fabulous environmental and cultural diversity of the planet, as well as humankind's deep reliance on nature to provide us with everything we need to live and many of the things that make life worth living. Today we are on course to fundamentally disrupt life on earth. Unless we make major changes very soon, the lost flavor of my hometown wines will likely be one of the less serious casualties.

MORE TO EXPLORE

Farm-Scale Adaptation and Vulnerability to Environmental Stresses: Insights from Winegrowing in Northern California. Kimberly A. Nicholas and William H. Durham in *Global Environmental Change*, Vol. 22, No. 2, pages 483–494; 2012.

Climate Change, Wine, and Conservation. Lee Hannah et al. in *Proceedings of the National Academy of Sciences USA*, Vol. 110, No. 17, pages 6907–6912; April 23, 2013.

FROM OUR ARCHIVES

Saving Coffee. Hillary Rosner; October 2014.

scientificamerican.com/magazine/sa