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Extreme heat reduces and shifts United States premium wine production in the 21st century

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• Premium wine production is limited to those regions of the world able to grow grapes with balanced composition and varietal typicity. This requires 3 climatic conditions: 1) adequate heat accumulation, 2) low risk of severe frost damage, and 3) absence of extreme heat. Even though grape growing is possible in the absence of these conditions, the highest-quality wines require that these three conditions coexist. Thanks to the availability of high-resolution climate simulations, these authors were able to predict how anticipated climate changes will affect the distribution of the premium winegrape production regions of the United States.

• Very briefly, their approach was to use the weather database Daymet (www.daymet.org) to access daily records of maximum and minimum temperatures from 1980 to 2003 throughout the United States on a 1 km grid (pixels). Then, based on published information on grapevines' requirements to ripen a crop, they determined whether each pixel was climatically suitable for winegrape production or not. This information allowed them to draw a "*current winegrape distribution map*". From there, and using published reports on climate change, they calculated the temperature change (called ?Daymet) for each pixel for the next 24 years, and determined whether that pixel was still adequate for quality winegrape production or not ("*future winegrape distribution map*").

• But how did they define "climatically suitable"? Depending on the stringency criteria, the resulting areas where grapegrowing could happen would obviously be different. So they used **3 possible growing-suitability criteria:**
- *low stringency*: included pixels that, for the next 24 years, were within any of the 5 Winkler regions (1,111- 2,499 degree-days).;
- *medium stringency*: included the above minus what the authors called "marginal areas" (areas for which the criteria were met for at least 1 year of the 24 studied;
- *high stringency*: excluded both "marginal areas" and "extreme temperature areas" (areas with average temperatures lower than 13°C or higher than 20°C). This is the criteria most representative of consistent potential for premium winegrape quality.

• What if the grapes grown in those areas were tolerant to temperature extremes? Obviously, this would also affect the resulting map. So the authors used **4 possible degrees of varietal tolerance**: heat tolerant/cold tolerant, heat tolerant/cold intolerant, heat intolerant/cold tolerant, and heat intolerant/cold intolerant.

Winkler Grapegrowing Regions		
Region I	1,111 – 1,390 growing-degree days	Best light-to-medium body dry table wines
Region II	1,391 - 1,670 "	
Region III	1,671 – 1,950 "	Full-bodied dry and sweet table wines
Region IV	1,951 – 2,220 "	Best fortified wines
Region V	2,220 – 2,499 "	Best for table grapes, Low-quality table wines

• **Results.**

1) In the baseline current distribution map, premium winegrape production was consistently possible throughout much of the western United States, particularly the West Coast, the western slope of the Sierra Nevada, extensive areas of the Southwest, and much of the Mideastern Coast.
2) In the projected future climate map, production potential was eliminated in the Southwest and Central United States. Consistent favorable regions were reduced to coastal California. New, high-quality regions were created in coastal Oregon and Washington. Much of the Northeast was also favorable, but only for heat tolerant/cold tolerant varieties.
3) The reduction in grapegrowing area was driven by 3 main causes: the overall increase of growing-season temperatures (which allowed production areas to move northward and towards higher elevations); the increase of "hot days" in the South Central and Southwest regions (which also eliminated winegrape production from these regions); and the decline of "cold days" in the Northeast and Rocky Mountain area.
4) On average, the authors calculated that **budbreak would occur 22 days earlier**, with the largest changes along the West Coast.

• Some highlights from the authors' discussion:
_ the largest reduction in projected winegrape production area were caused by the increased frequency of extremely hot days (>35^{o}C) during the growing season;
_ projected climate changes shifted the premium winegrape production to areas with high humidity/high precipitation. This would likely require increased fungal disease control;
_ the projected maps are based on temperature changes, and do not consider moisture changes, or "terroir" changes, that is, the interaction of climate, soil, varietal, and cultural factors influencing winegrape quality;
_ the projected maps do not consider advances in viticultural technology that may be able to extend winegrape production. For instance, breeding programs will likely increase heat- and cold-resistant varieties. Also, recently, a gene was identified as responsible for the conversion of vitamin C to tartaric acid. As we know, acid is very important in the perception of wine quality and this may render certain varieties more adequate for hot climates.

In conclusion, the increase in the frequency of extreme temperatures between the late 20th century and the late 21st century may have a drastic effect on the distribution of quality winegrape production regions - more so than changes in average climate alone. When these extreme temperatures were considered, regions currently marginally suitable for winegrape production in the United States were nearly eliminated. Others which are too cold for grapegrowing today, will likely become available. Overall, the model predicts that the US area capable of producing the highest-quality, most expensive wines would be reduced by more than half in the late 21st century (2071-2099). You may want to check the colored "before" and "after" maps in the original text, particularly Fig. 1.

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