Climate-Adaptive Viticulture

Sustainable Farming and Changing Climates

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Vineyard Health

- ‘Health’ – the state of being **free** from illness or injury

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- No way to be **totally free** of illness or injury

Vineyard Health

- ‘Health’ – the state of being **free** from illness or injury
- No way to be **totally free** of illness or injury
- The next best option is to keep illness or injury to a minimum

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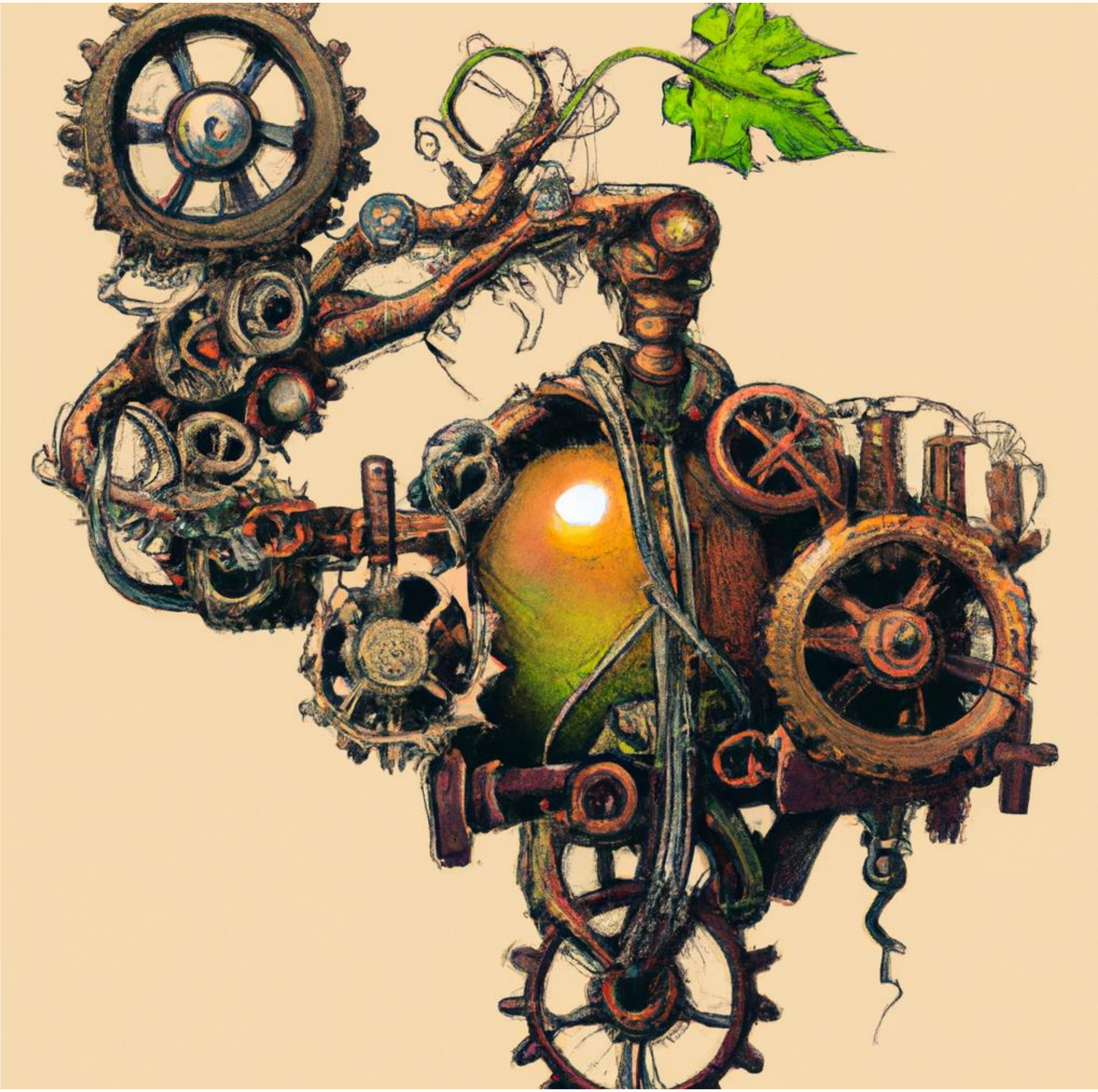
Vineyard Health

- **Vine Function ≈ Vine Health**

- Important Vine Functions
  1. Photosynthesis
  2. Vascular system
  3. Reproductive efficacy
  4. Available Nutrients



Changing Climates

- Climates are changing and impacting the factors that affect vine health.

  i. Temperatures
    - Affects all aspects of vine health
  ii. Precipitation
    - Affects all aspects of vine health
  iii. Extreme weather events
    - Heatwaves, fire, and late frost events
    - Impacts photosynthesis and reproduction
  iv. Pests and Diseases
    - Directly limits vine health

Changing Climates

Temperatures

- Impact all living things
- Alter physiology
- Ideal range differs by species
- Range differs by cultivar too

Changing Climates

Precipitation

- Mediterranean climates with unique precipitation patterns
- Changing with the climate
- No precipitation in late-Summer
- Limits Summer diseases

Changing Climates

Extreme weather events

- Affects regions differently
- Impacts dependent on microclimates
- Existing infrastructure matters
  - Heatwaves
    - More damaging in coastal regions
  - Spring Frosts
    - More damaging inland

Climate Concerns

Frost damage, heat, and drought

Vine susceptibility ~ abiotic stress

No natural immune system

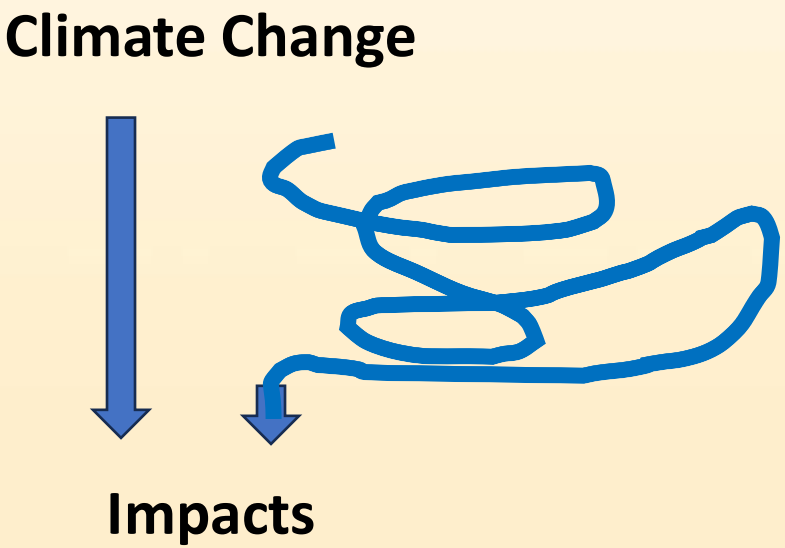
- Additive resistance
- Defense compound synthesis
- Abiotic stressors redirect resources

Can tolerate pests/diseases under best conditions

Climate Impacts

- Must consider both **direct** and **indirect** impacts of changing climates

  1. Change in growing season length
  2. Earlier or later budbreak and ripening
  3. Resource scarcity (i.e., water/fertilizer)
  4. Increased soil salinity
  5. More extreme weather events

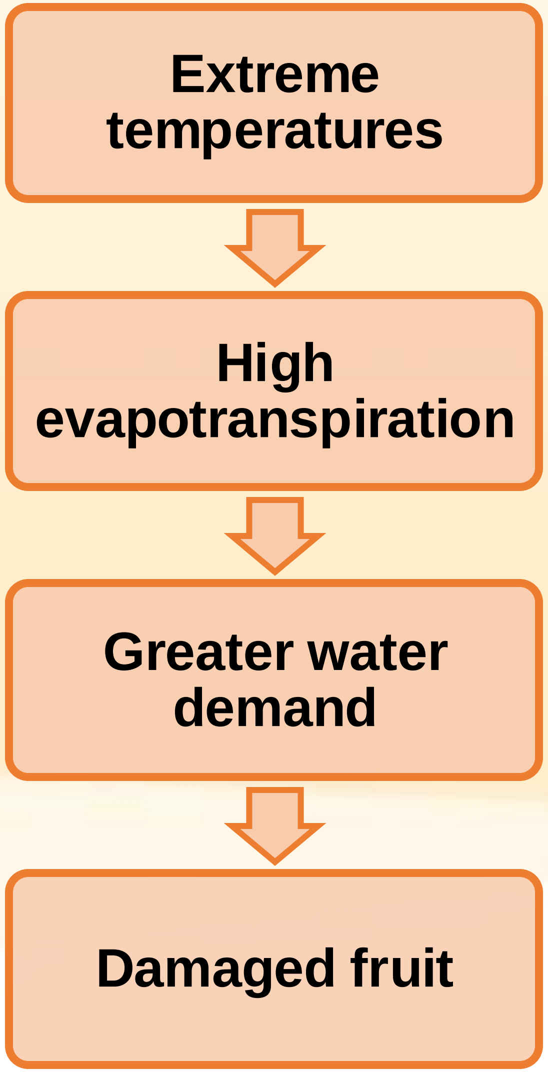


Climate Change

Impacts


66.6
°F/°C

Extreme Heat

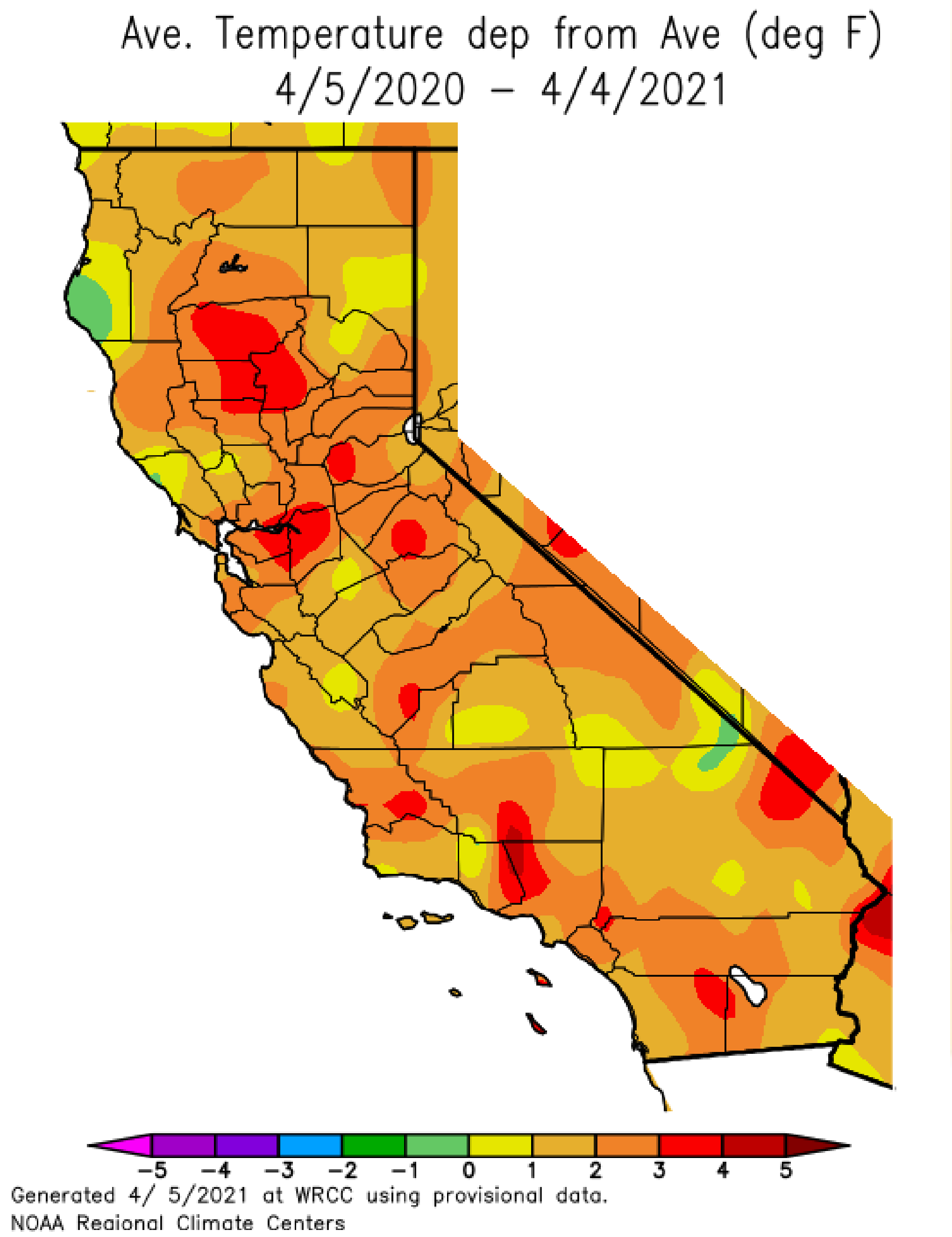


Extreme temperatures

High evapotranspiration

Greater water demand

Damaged fruit



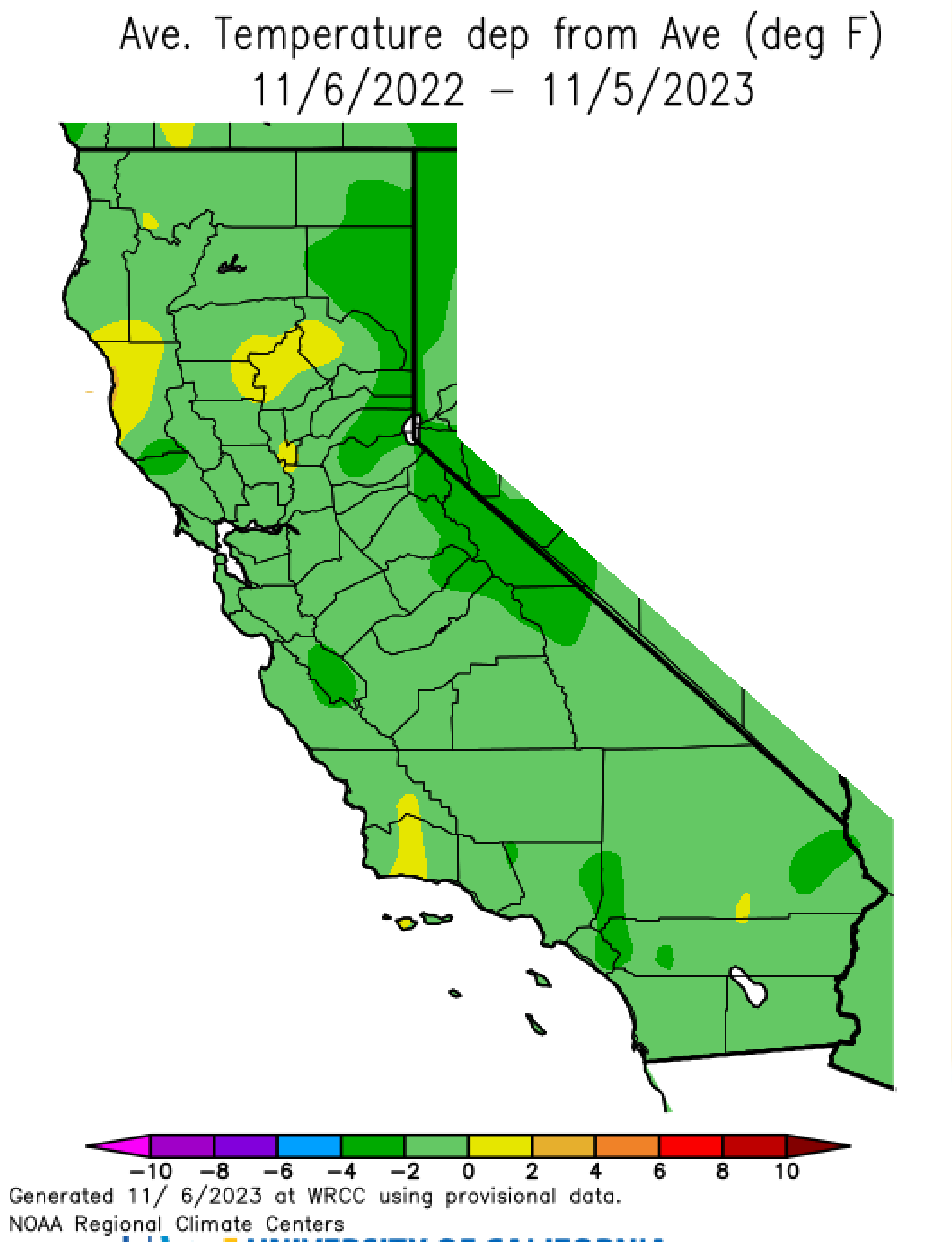
Ave. Temperature dep from Ave (deg F)
4/5/2020 – 4/4/2021

Generated 4/ 5/2021 at WRCC using provisional data.
NOAA Regional Climate Centers

Credit: California Climate Data Archive (2021)

Extreme Heat?

Average temperatures in the 2023 growing season were notably lower across the state compared to average



Ave. Temperature dep from Ave (deg F)
11/6/2022 – 11/5/2023

Generated 11/ 6/2023 at WRCC using provisional data.
NOAA Regional Climate Centers

Credit: California Climate Data Archive (2021)

Station	Year	Final GDDs	Winkler Zone
Ukiah	2023	3301.5	III
Ukiah	2022	3475.5	III
Ukiah	2021	3679.1	IV
Ukiah	2020	3604.9	IV
Ukiah	2019	3470.4	III
Ukiah	2018	3602.5	IV
Ukiah	2017	3640.7	IV
Ukiah	2016	3344.6	III
Ukiah	2015	3656.8	IV
Ukiah	2014	3635.5	IV
Ukiah	2013	3326.1	III
Ukiah	2012	3285.4	III
Ukiah	2011	2965.9	II
Ukiah	2010	3136.9	III
Ukiah	2009	3572.9	IV
Ukiah	2008	3516.6	IV
Ukiah	2007	3392.1	III
Ukiah	2006	3666.2	IV
Ukiah	2005	3335.1	III
Ukiah	2004	3575.9	IV
Ukiah	2003	3509.8	IV

🟥 Hottest

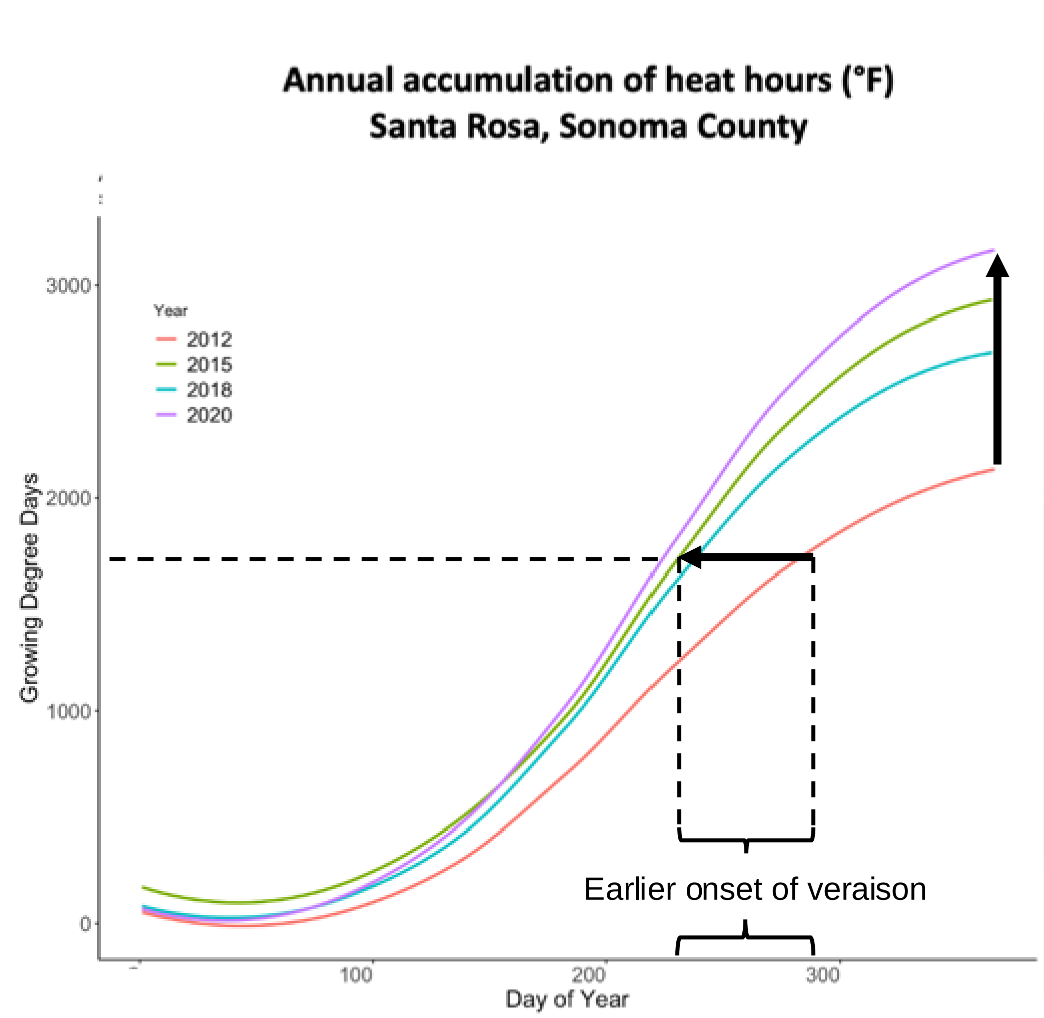
🟩 Coolest

Increasing Temperatures

In Central Europe the impact of warming climates has been documented in Bernáth et al. 2021

Between 1985 and 2018

- Budbreak: 5-7 days earlier
- Flowering: 7-10 days earlier
- Berry maturity: 18 days earlier
- Harvest: 8-10 days earlier



Cumulative heat accumulation in Santa Rosa, California in 2012, 2015, 2018, and 2020. (Data from https://cimis.water.ca.gov)

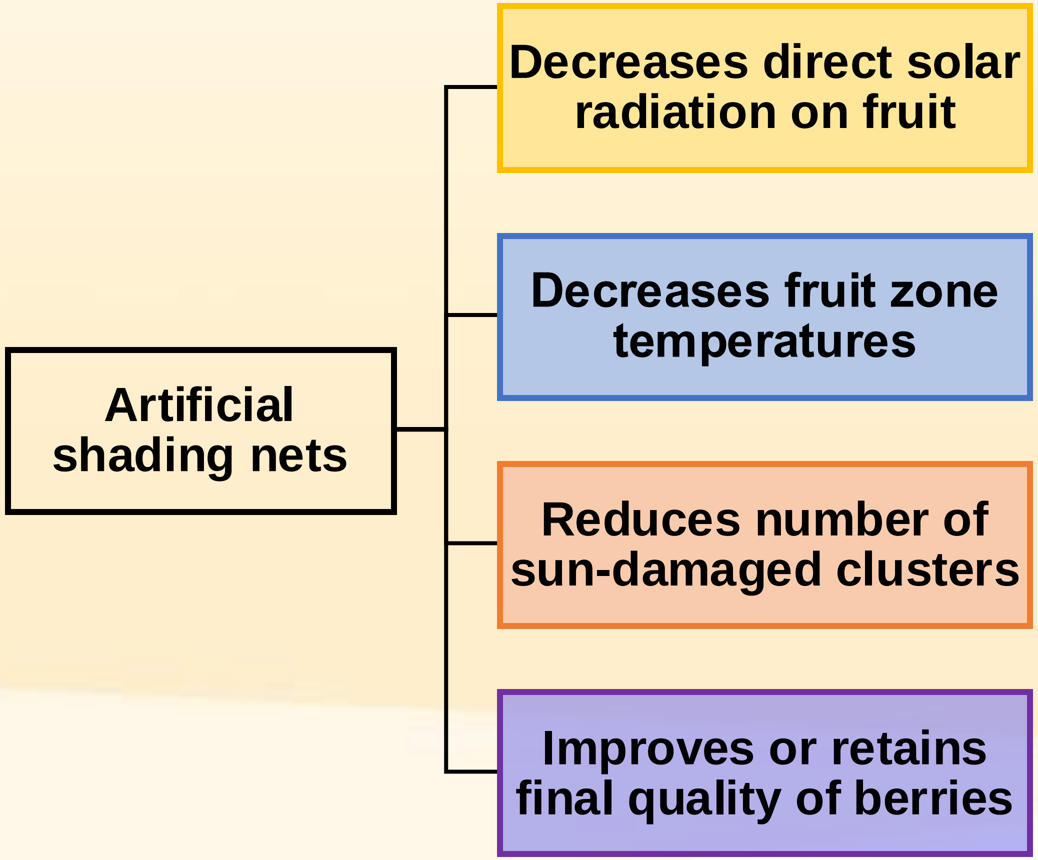
What can we do?

- Vineyards need tools to address extreme weather conditions and other impacts of climate change

- Concerns of note:
  1. Shorter time between budbreak and harvest
  2. Increased risks of heat damage
  3. Increased risks of cold damage
  4. Limited water availability
  5. Pest acclimation to climate and beneficials
  6. Soil salinization

Heat and Solar Radiation

Shade nets to mitigate heat and solar radiation damage



Artificial shading nets

- **Decreases direct solar radiation on fruit**
- **Decreases fruit zone temperatures**
- **Reduces number of sun-damaged clusters**
- **Improves or retains final quality of berries**

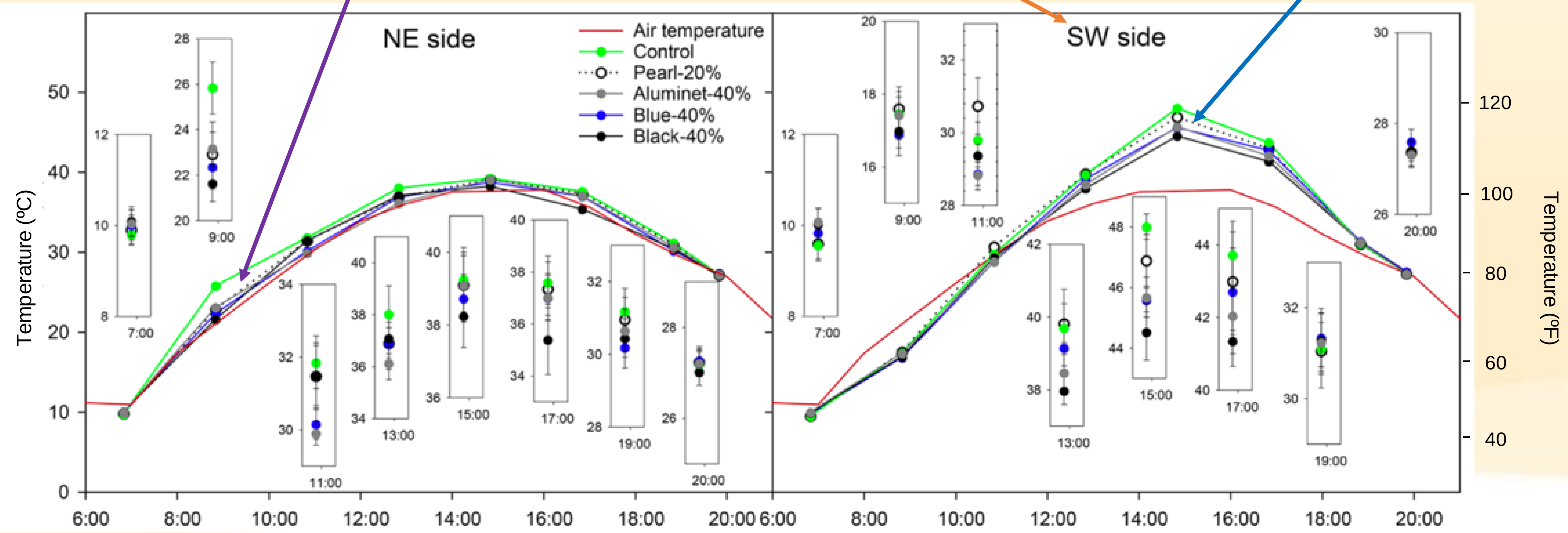
Different colored shade nets applied to Cabernet Sauvignon in Oakville, CA in 2017.

Effects of Shade Netting on Berry Temperatures

Very effective when either side is in direct sunlight

Impact last longer on the more exposed side of the canopy

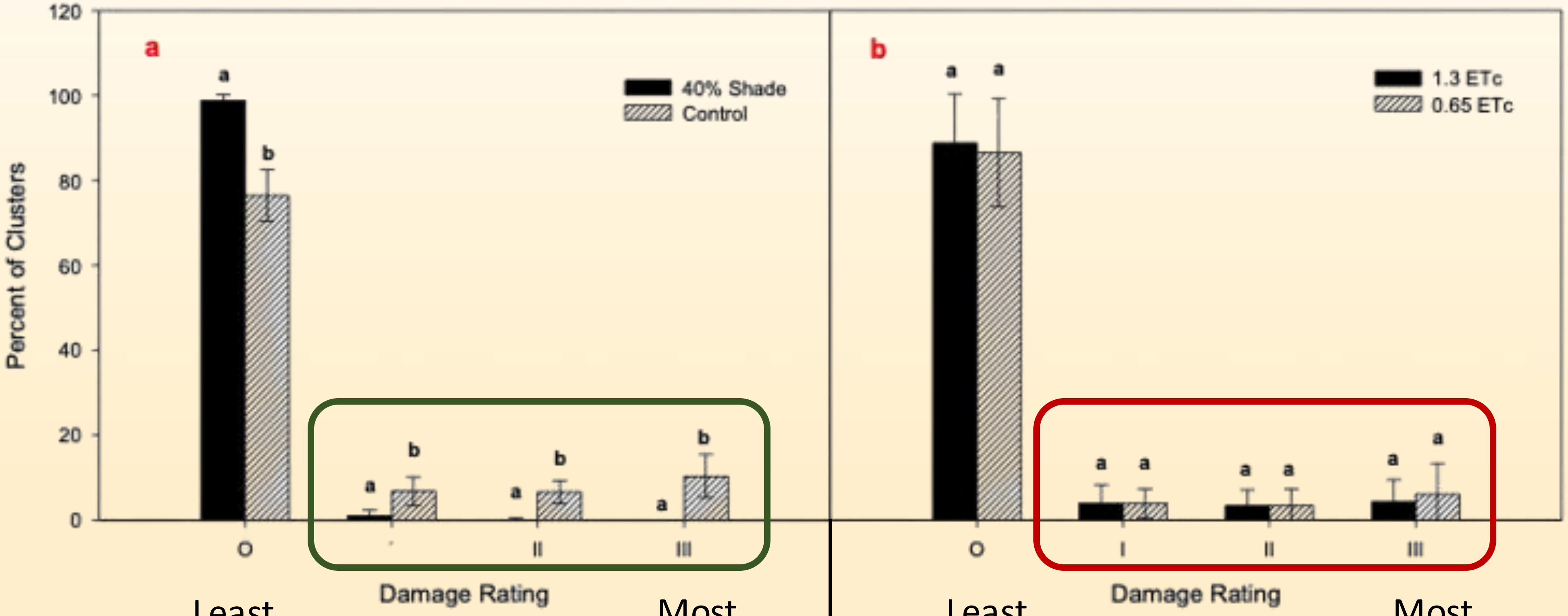
Can be up to **5 ºF cooler** under the canopy [2]



Cabernet Sauvignon fruit zone air temperatures measured under different colored shade nets in Oakville, CA in July 2016 (figure from Martínez-Lüscher et al. 2017)

Black shade net applied

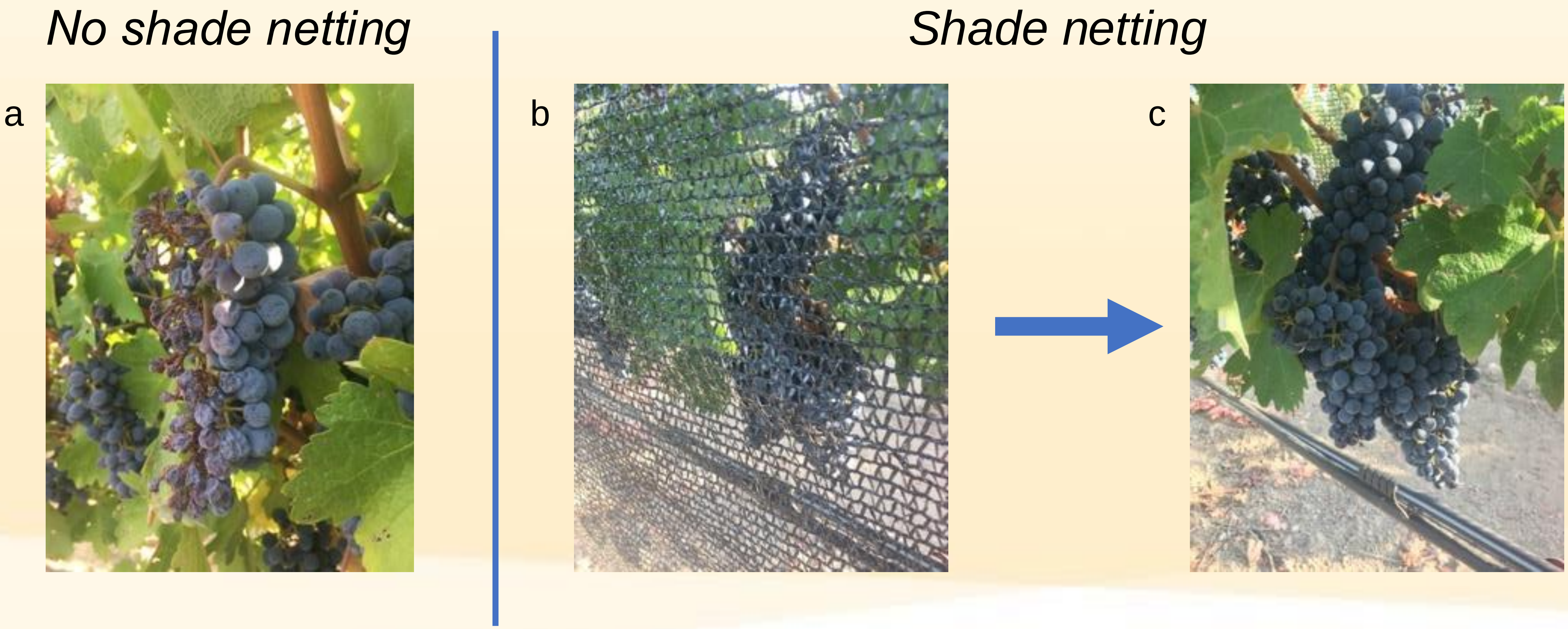
Modified Irrigation



Least Damage → Most Damage

Least Damage → Most Damage

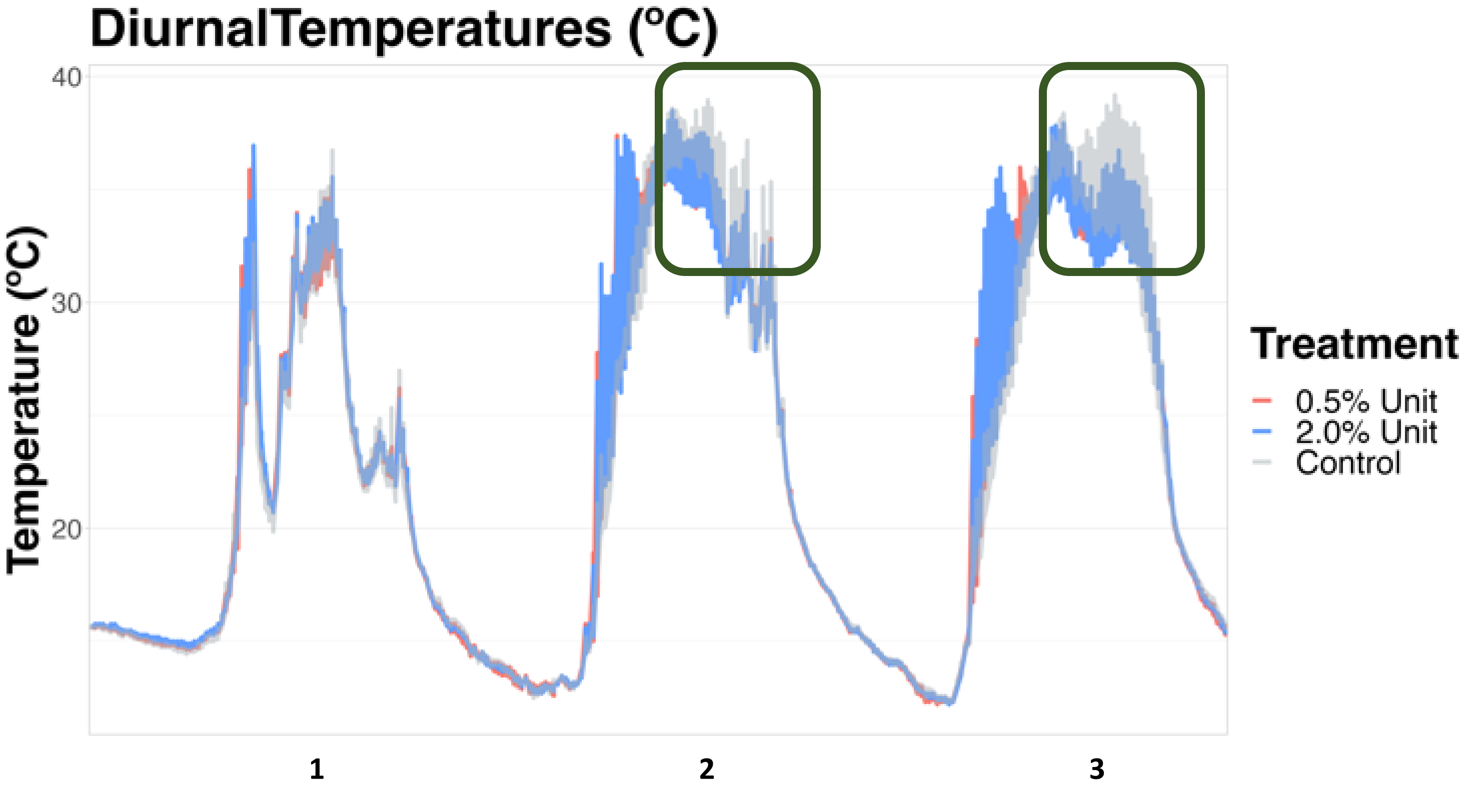
Increasing Temperatures

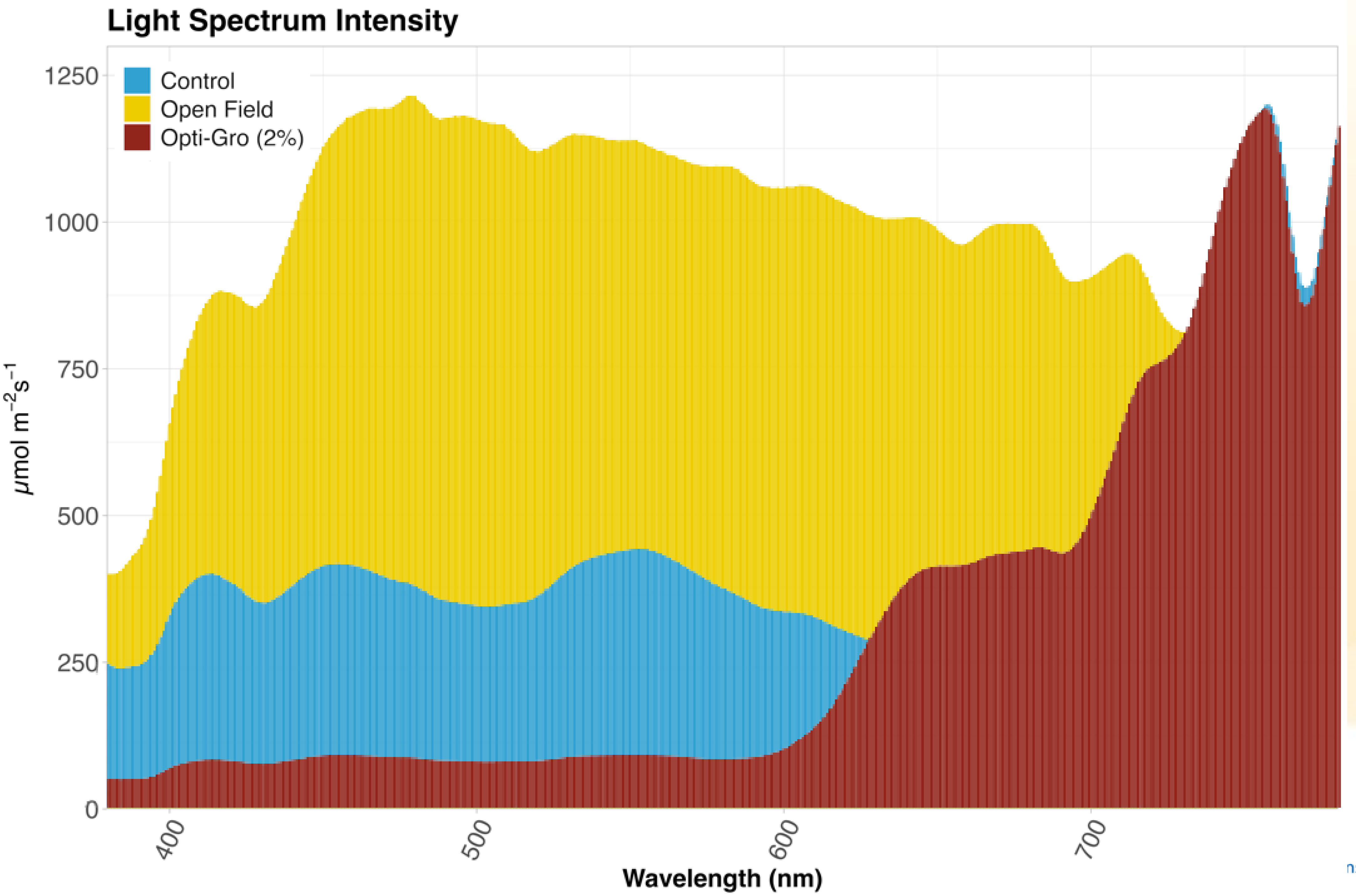

No shade netting

Shade netting

Left to Right: (a) no shade net applied; (b) example of black shade net applied following fruit set; (c) resulting cluster protected by shade net; all images were taken on the same day in Oakville, CA in August 2017.

Light Modification in Other Forms




Light Spectrum Intensity
Control
Open Field
Opti-Gro (2%)
1250
1000
750
500
250
0
μmol m⁻²s⁻¹
400
500
600
700
Wavelength (nm)

nsion

Pests and Diseases

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Worldwide Temperature Increases

Heatwaves have increased in frequency, severity, and length

Fungi tolerance to high temps is bookended

- Unless they can adapt to hotter climates; opening more niches for themselves
- *Candida auris* – human fungal pathogen simultaneously emerged

Viral temperature ranges are similarly problematic

- However, viruses can adapt rapidly to new conditions

Pest and disease responses to climate change

As a result of the indirect impacts of:

1. Increased average temperatures
2. Higher atmospheric CO_2
3. More environmental pollutants
4. Changes in distribution and range of host plants

We expect to see changes in:

1. Pest and disease migratory behavior
2. Over wintering success
3. Species interactions
4. Effectiveness of pest predators and parasitoids

Pest and disease responses to climate change

Both the pest and host can respond to changing climates in unpredictable ways (5)

Changes in temperature and atmospheric CO_2 levels have impacted the timing of generational cycles of insect species in vineyards (6, 7, 8)

- Resulting in some asynchrony between pest and predator/parasatoid

5. Rumbidzai Katsaruware, Paramu Mafongoya, and Augustine Gubba. Responses of insect pests and plant diseases to changing and variable climate: A review. Journal of Agricultural Science, 9:160, 11 2017. doi: 10.5539/jas.v9n12p160.
6. Diego Tomasi, Gregory V Jones, Mirella Giust, Lorenzo Lovat, and Feder- ica Gaiotti. Grapevine phenology and climate change: Relationships and trends in the veneto region of italy for 1964–2009. American Journal of Enol- ogy and Viticulture, 62:329, 9 2011. doi: 10.5344/ajev.2011.10108
7. Amelia Caffarra, Monica Rinaldi, Emanuele Eccel, Vittorio Rossi, and Ilaria Pertot. Modelling the impact of climate change on the interaction between grapevine and its pests and pathogens: European grapevine moth and powdery mildew. Agriculture, Ecosystems Environment, 148:89–101, 2012. ISSN 0167-8809. doi: https://doi.org/10.1016/j.agee.2011.11.017.
8. Sandra Skendˇzi´c, Monika Zovko, Ivana Pajaˇc Zˇivkovi´c, Vinko Leˇsi´c, and Dar- ija Lemi´c. The impact of climate change on agricultural insect pests. In- sects, 12, 2021. ISSN 2075-4450. doi: 10.3390/insects12050440.

Insect responses to climate change

Insects can respond to climate change in several ways, however three major responses that have been cited are (9) :

1. Moving to a climate more suitable to them
2. Shifting their phenology to correspond with the local changes in environmental conditions, or
3. Adapt to the new conditions and the associated impacts on the ecosystem

9. Deepa S Pureswaran, Audrey M Maran, and Shannon L Pelini. Chapter 18 - insect communities, 2021.

Insect/pathogen migration in response to changing climates

A migration of insects and pathogens is expected to move northward as climates change. (15)

- This is the case for more crops than grapevines

Temperatures and elevated CO_2 levels are essential components to estimate the potential for pest/disease migration (20)

20. Holly A. Ameden and David R. Just. Pests and agricultural production under climate change, 2001.

Disease Expression

- Host-Pathogen interaction is broadly impacted by environmental conditions
- Certain abiotic stressors can increase susceptibility of grapevines to pathogens or trigger symptomatic expression of the pathogen (10)
- Fungal trunk diseases
  - Have expressed more symptoms in vines than usual in N. Coast
  - Two years of extreme drought followed by late spring frost and summer rains

10. A Songy, O Fernandez, C Clément, P Larignon, and F Fontaine. Grapevine trunk diseases under thermal and water stresses. Planta, 249:1655– 1679, 2019. ISSN 1432-2048. doi: 10.1007/s00425-019-03111-8.

Overwinter Recovery – *Xylella fastidiosa*

Overwinter recovery from Pierce’s Disease relies on cold Winter temperatures < 53 ºF for prolonged periods (11)

Warmer winter temperatures could impede the phenomenon of overwinter recovery

Winter temperatures in California have risen around 2 ºF since the 1970s (12) and made overwinter recovery of *X. fastidiosa* less likely to occur in hotter regions.

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11. Helene Feil and Alexander H. Purcell. Temperature-dependent growth and sur- vival of xylella fastidiosa in vitro and in potted grapevines. Plant Disease, 85 (12):1230–1234, 2001. doi: 10.1094/PDIS.2001.85.12.1230
12. Tapan B Pathak, Mahesh L Maskey, Jeffery A Dahlberg, Faith Kearns, Khaled M Bali, and Daniele Zaccaria. Climate change trends and impacts on california agriculture: A detailed review. Agronomy, 8, 2018. ISSN 2073-4395. doi: 10.3390/agronomy8030025.

Susceptibility of stressed vines to pests and diseases

Water stress has been shown to increase transmission of *Xylella fastidiosa* in grapevines (13)

Combined biotic and abiotic stress responses in plants often involve numerous signaling pathways

Plants can tailor their response to specific stress combinations through hormone signaling, receptors, and transcription factors (14)

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13. Celia Del Cid, Rodrigo Krugner, Adam R Zeilinger, Matthew P Daugherty, and Rodrigo P P Almeida. Plant Water Stress and Vector Feeding Preference Mediate Transmission Efficiency of a Plant Pathogen. Environmental Ento- mology, 47(6):1471–1478, 09 2018. ISSN 0046-225X. doi: 10.1093/ee/nvy136.
14. Venkategowda Ramegowda and Muthappa Senthil-Kumar. The in- teractive effects of simultaneous biotic and abiotic stresses on plants: Mechanistic understanding from drought and pathogen com- bination. Journal of Plant Physiology, 176:47–54, 2015. ISSN 0176-1617. doi: https://doi.org/10.1016/j.jplph.2014.11.008.

‘New’ diseases in vineyards

Often can be difficult to identify:

- Lime disease on the West Coast or GRBV in vineyards

Grapevine Red-Blotch Associated Viruses

- Flagship example for grapevines
- Not known until 2008 (Oakville, CA)

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Case Study: GRBV

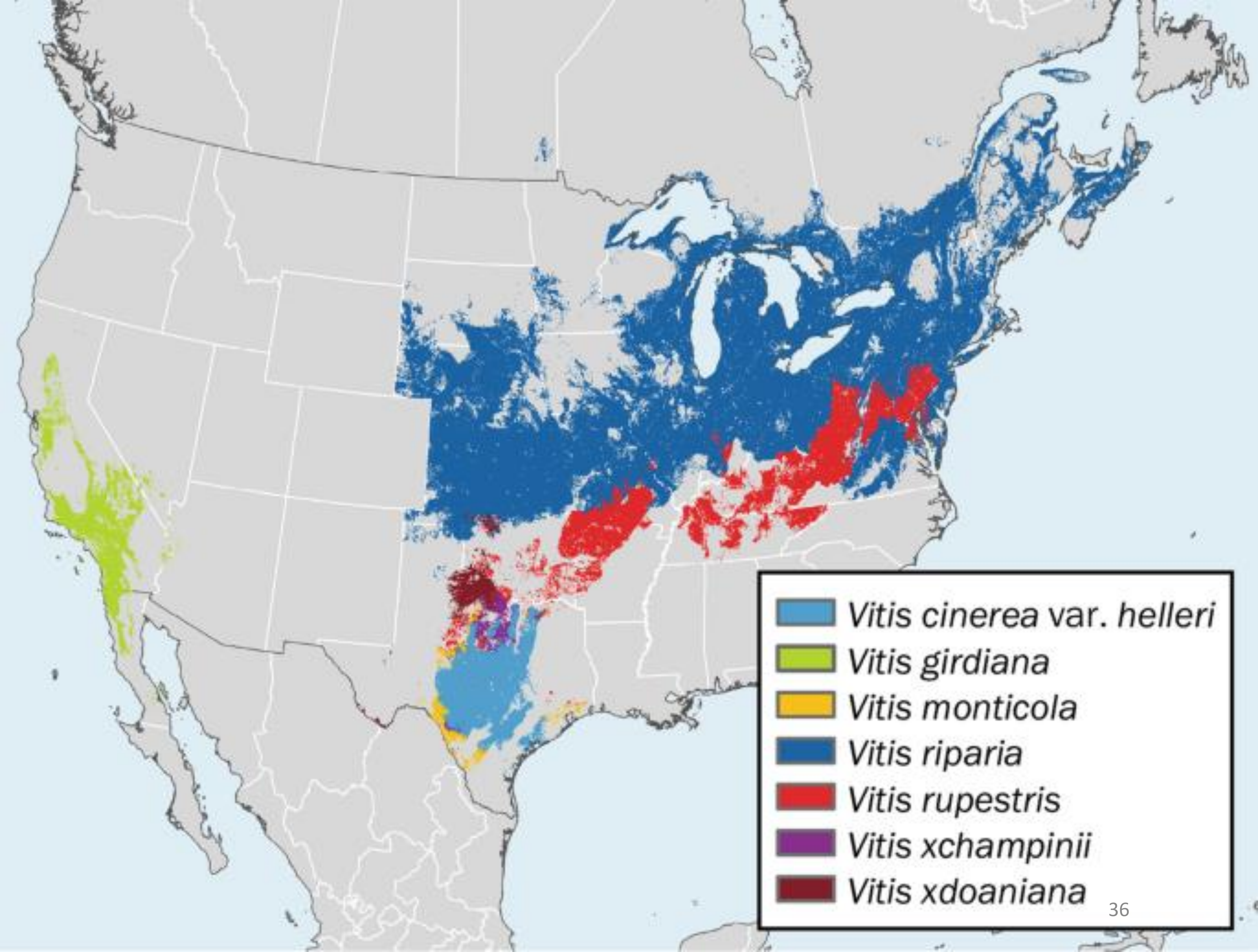
Red blotch was an unknown disease in grapevines for decades and likely was already present in the north coast during the 20th century.

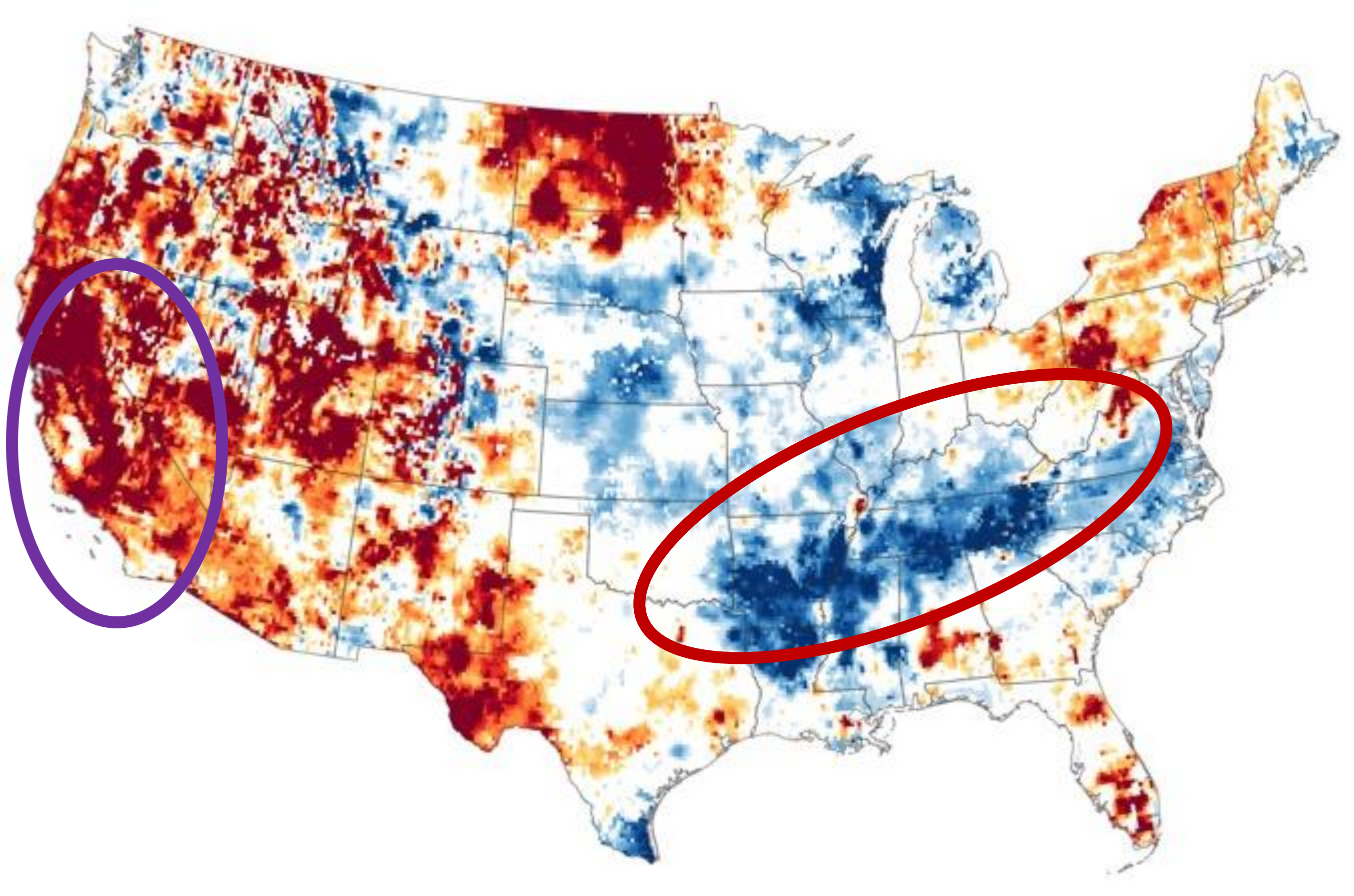
Large, clean-material vineyards used to source pathogen-free material did not know it existed and thus, did not know what to test for.

The future of our climate may increase the likelihood of new diseases we cannot test for or expression of existing pathogens becoming more problematic

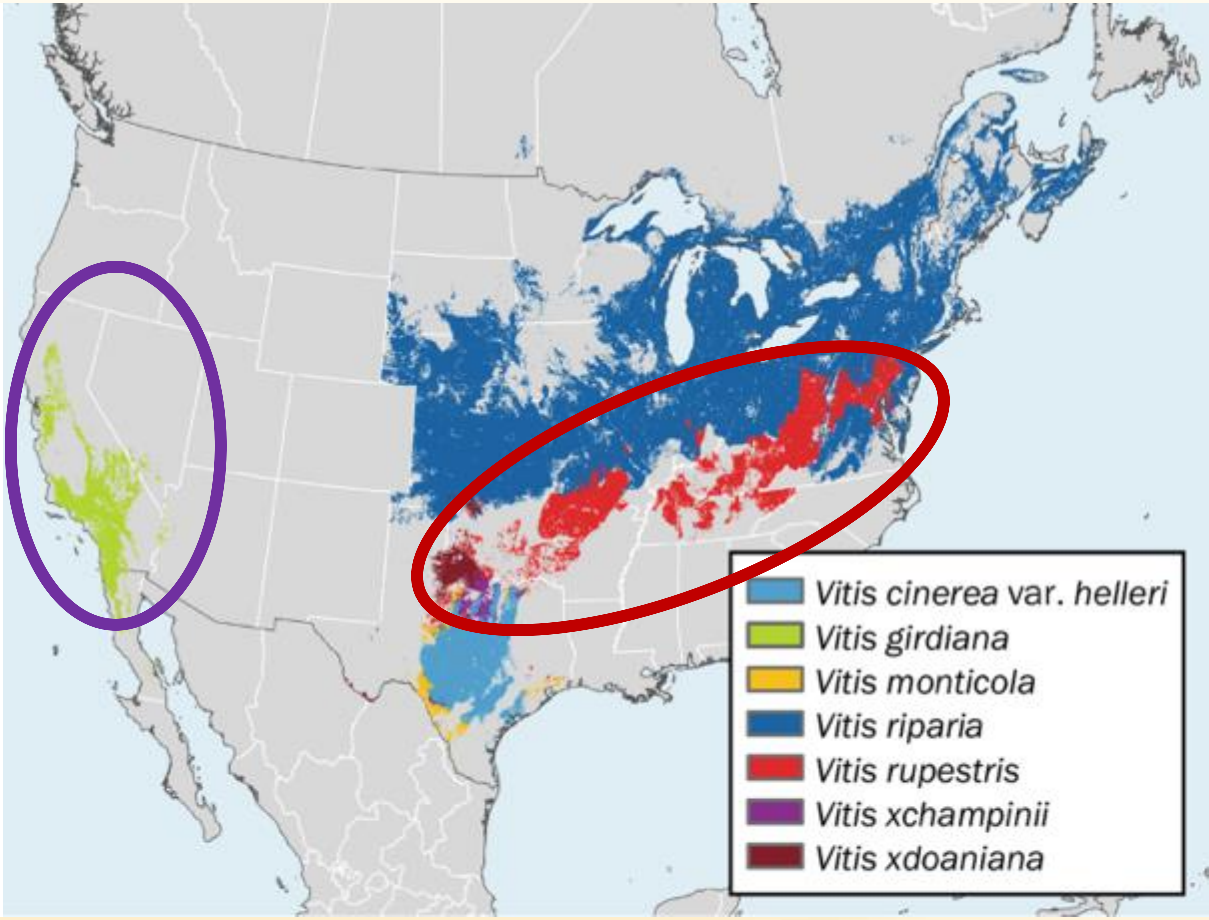
Trait sourcing

Wild vines





Drought conditions – 2021 (NASA)

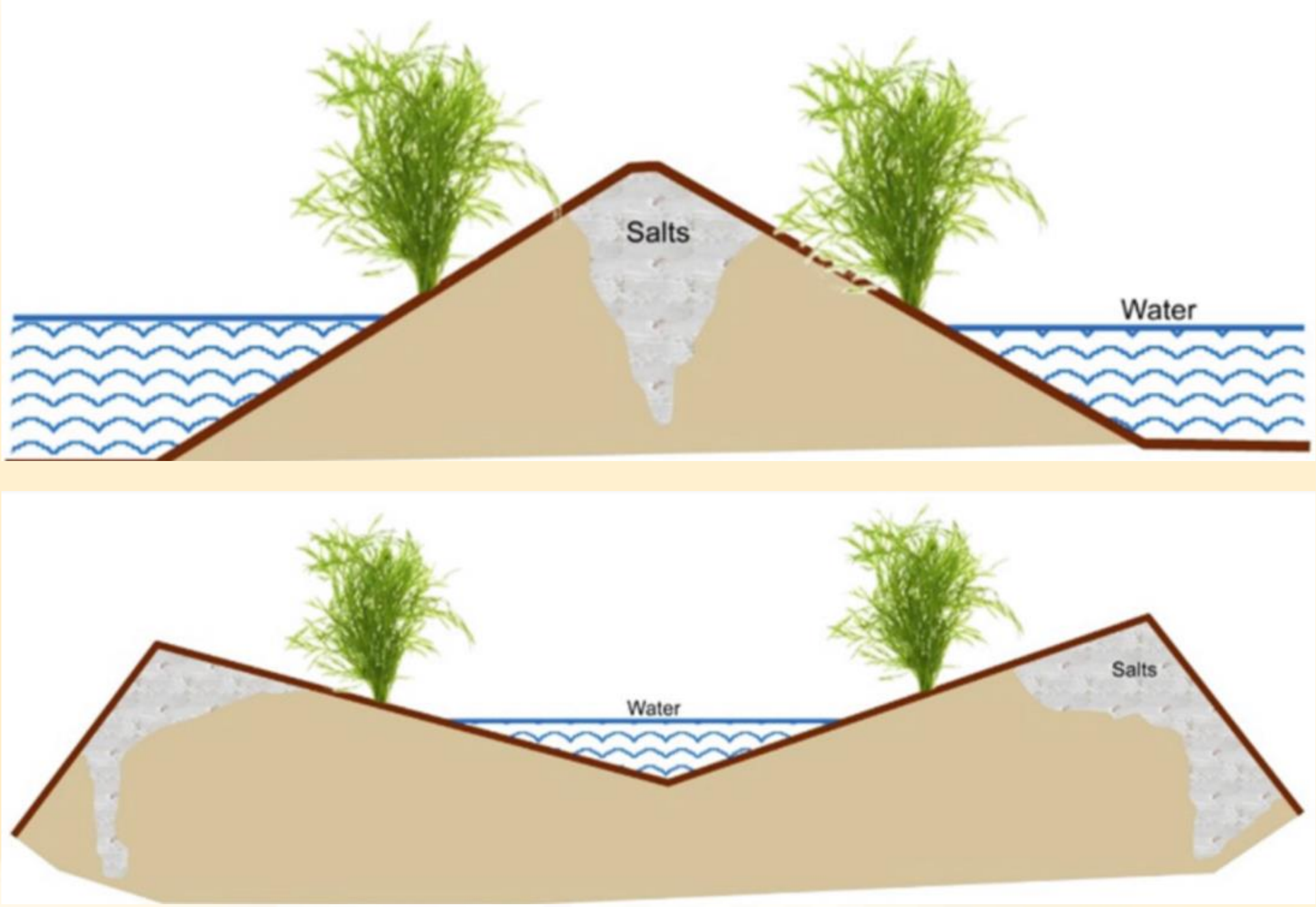


Heinitz et al. 2019

Salinity

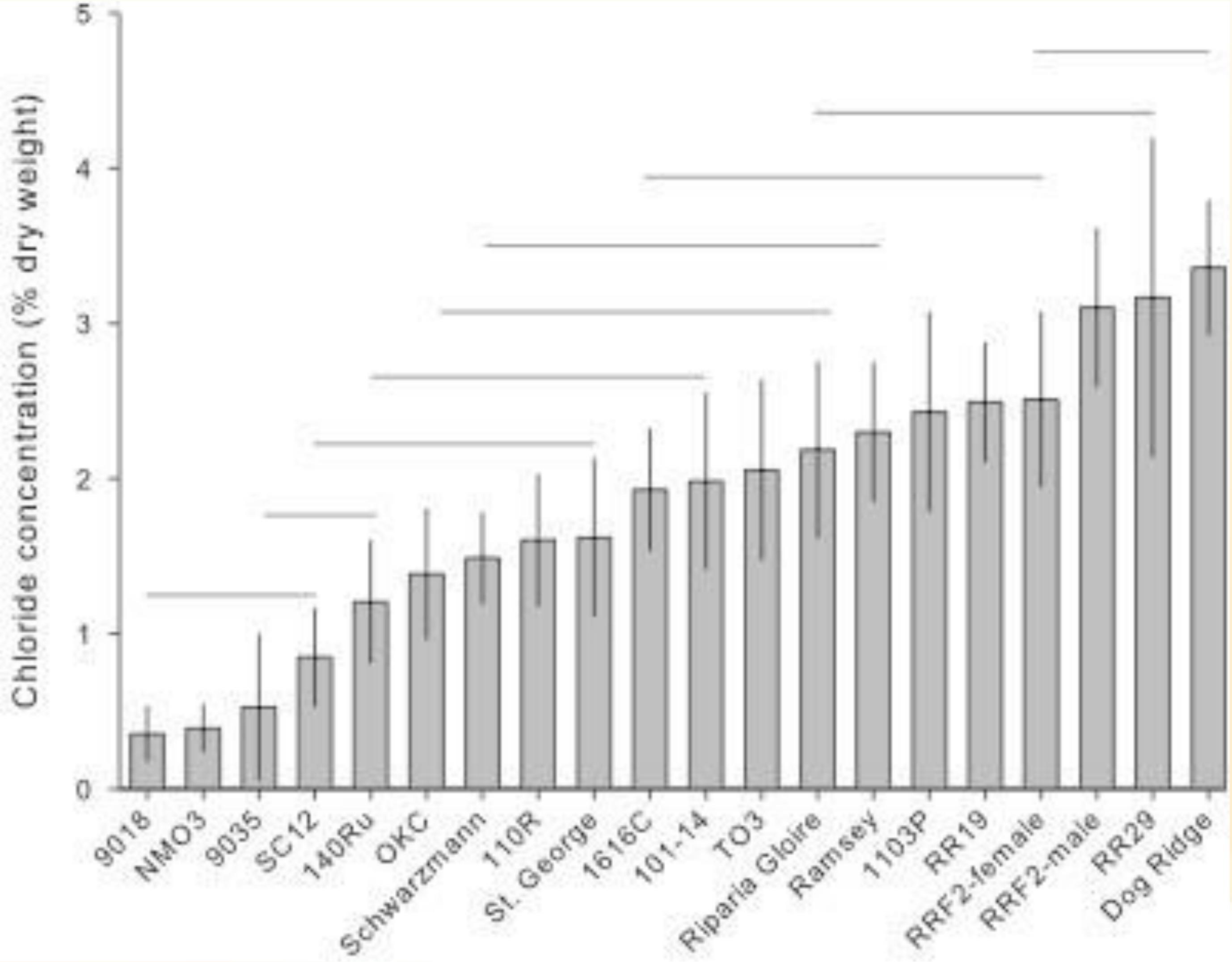
Management strategies

- Sloped furrows
  - Can help redirect salt deposits away from roots
- Leaching salts
  - Clean water
  - Expensive
  - Reduce NaCl buildup around roots
- Monitoring
  - For increases in soil and water salinity



Examples of sloped furrows to direct salts to periphery of the root zone as soils dry and salts are deposited [5].

Chloride concentration in leaves (% dry weight)



Heinitz, C. C., Fort, K., & Walker, M. A. (2015, 2015/4//). Developing drought and salt resistant grape rootstocks. Acta Horticulturae,

Salinity Tolerance

- Salinity tolerance is one of the traits we might seek in new phenotypes or species
- From 2018-2021 we tested wild grapevines to find a candidate
- Required to tolerate up to 12.5% the average NaCl concentration in seawater

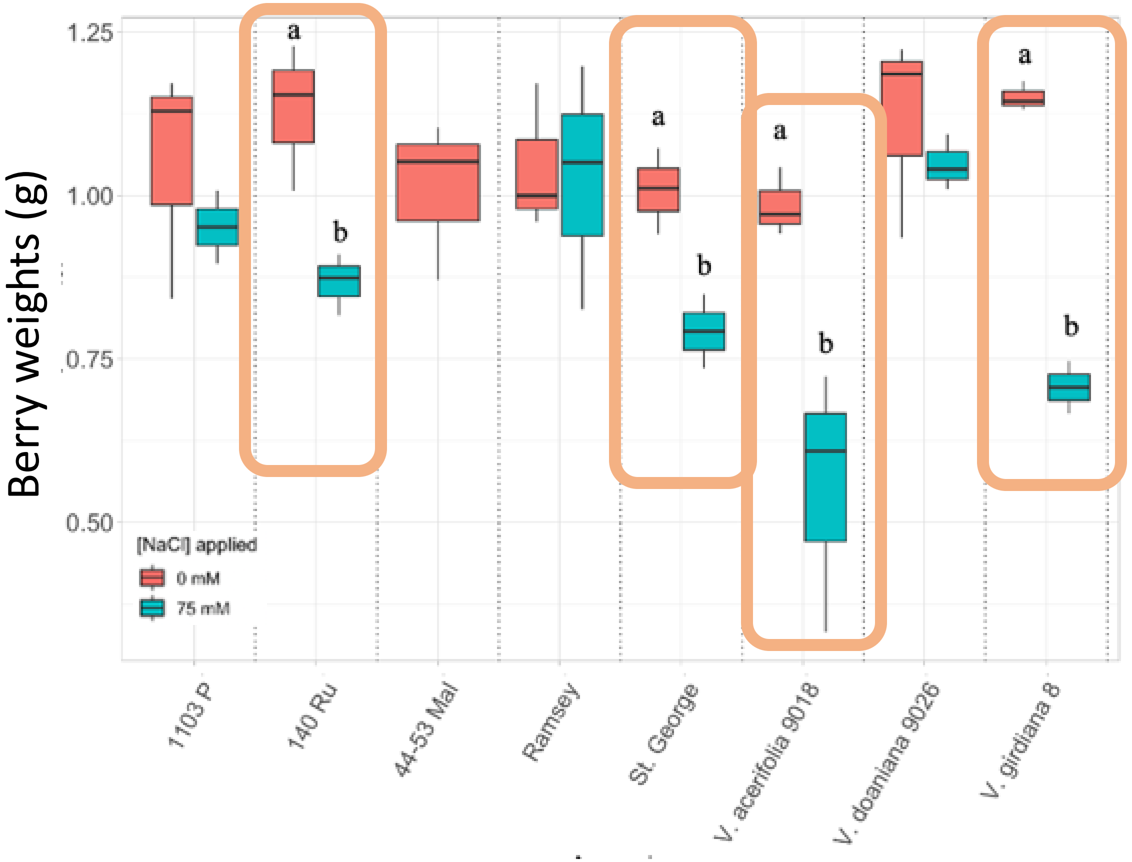
New Agronomic Traits

Unexpected problems

In some of the promising candidates we found that some agronomic traits were missing

- Up to 40% Smaller berries
- Poor vigor
- Low graft success rates

Individual berry weights

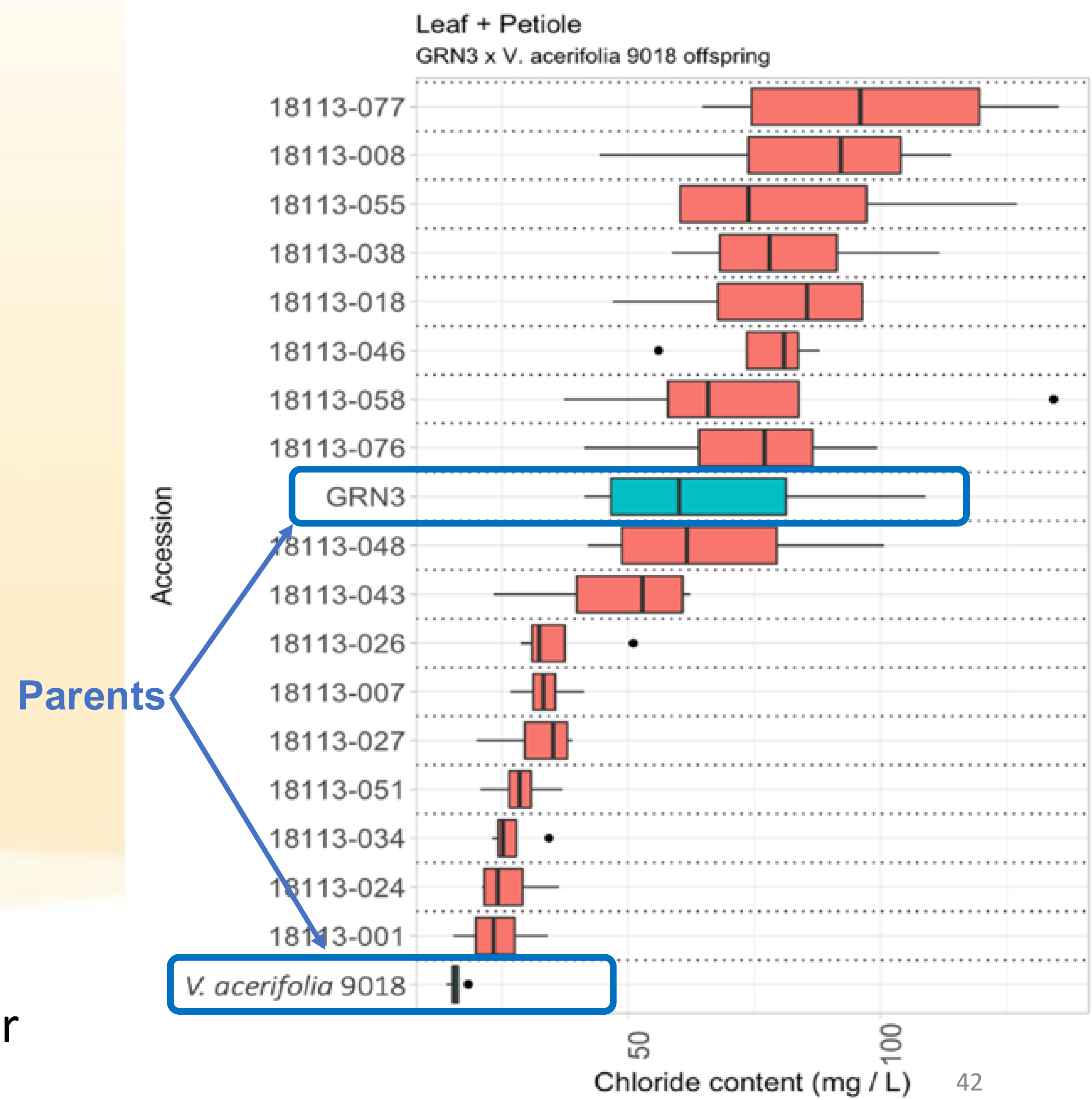


Rootstock
(grafted to Cabernet Sauvignon)

New Agronomic Traits

Breeding new cultivars

- Long term solution
  - Can take decades
- Utilize wild grapevines
  - Huge gene pool
  - Potential for high salinity tolerance
  - Largely unexplored
- Incorporate existing traits
  - Preserve other traits of existing rootstocks
  - Rootability, drought tolerance, vigor

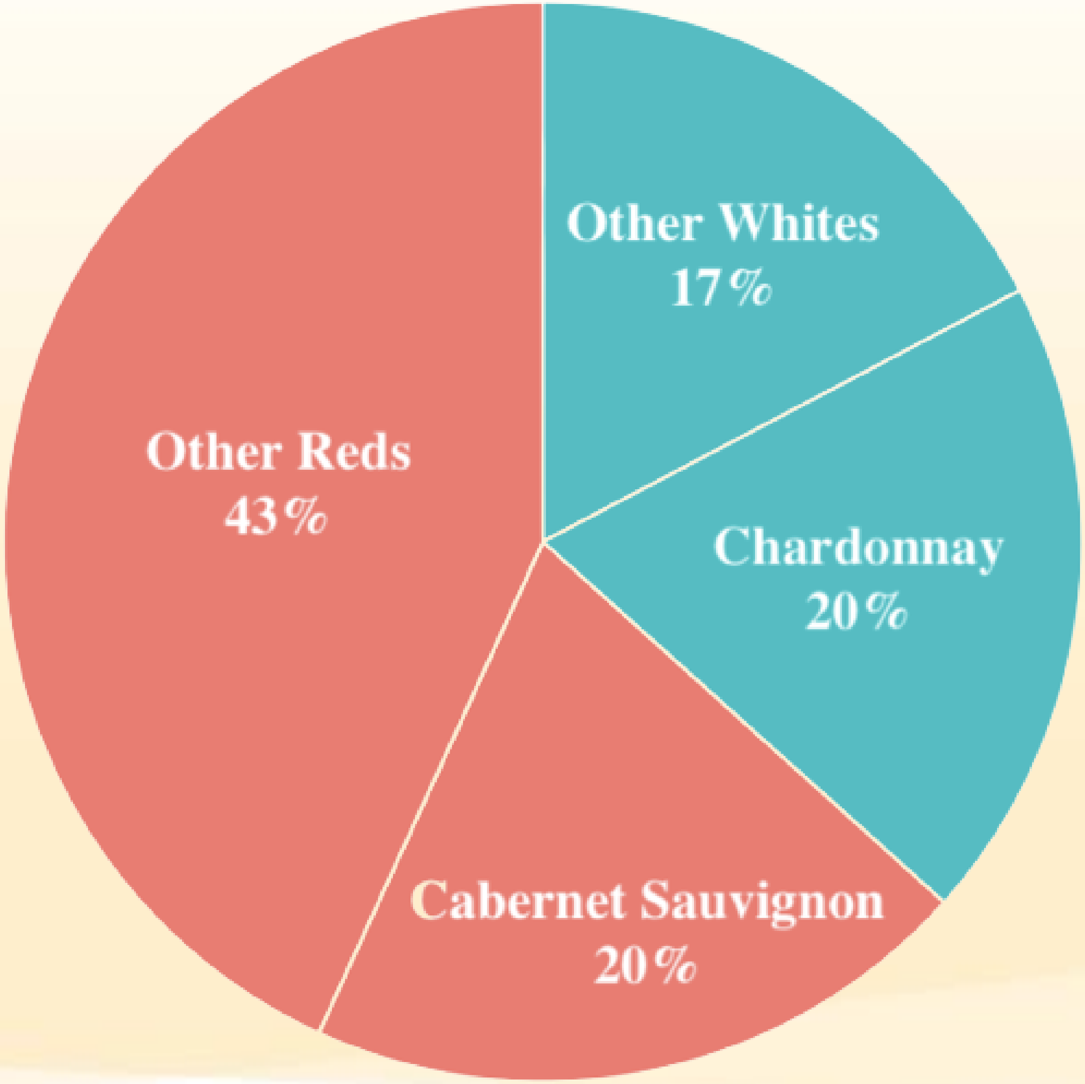


Scion Variety Bottleneck

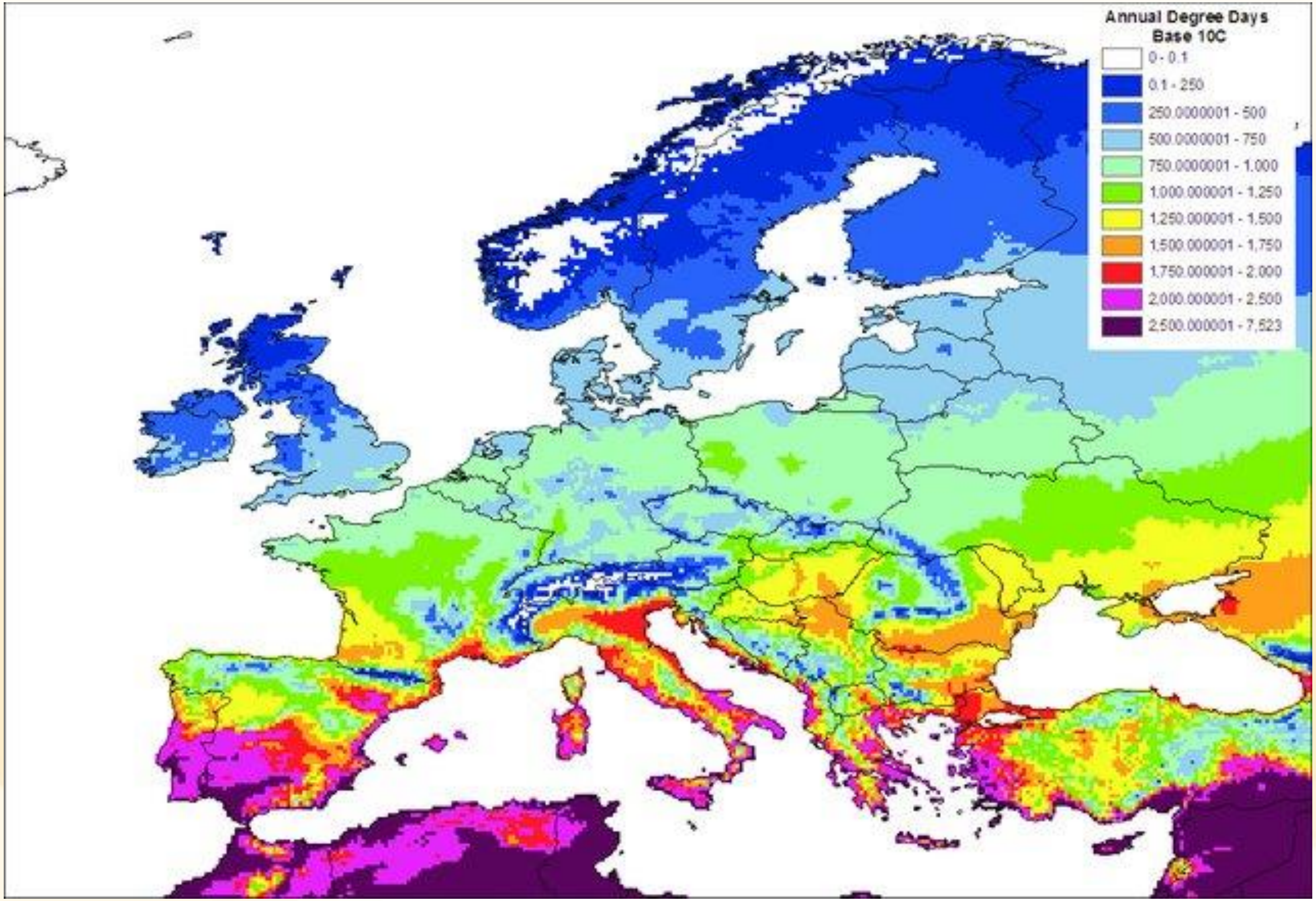
- Market limitations on profitable cultivars
- Bottleneck down to two scions
- Wide range of climate adaptation in scions

Examples of desirable characteristics:

  i. Late budbreak (avoid frost)
  ii. Moderate vigor (less water demand)
  iii. Early fruit maturity (maybe)
    e.g., Sémillon; Tempranillo



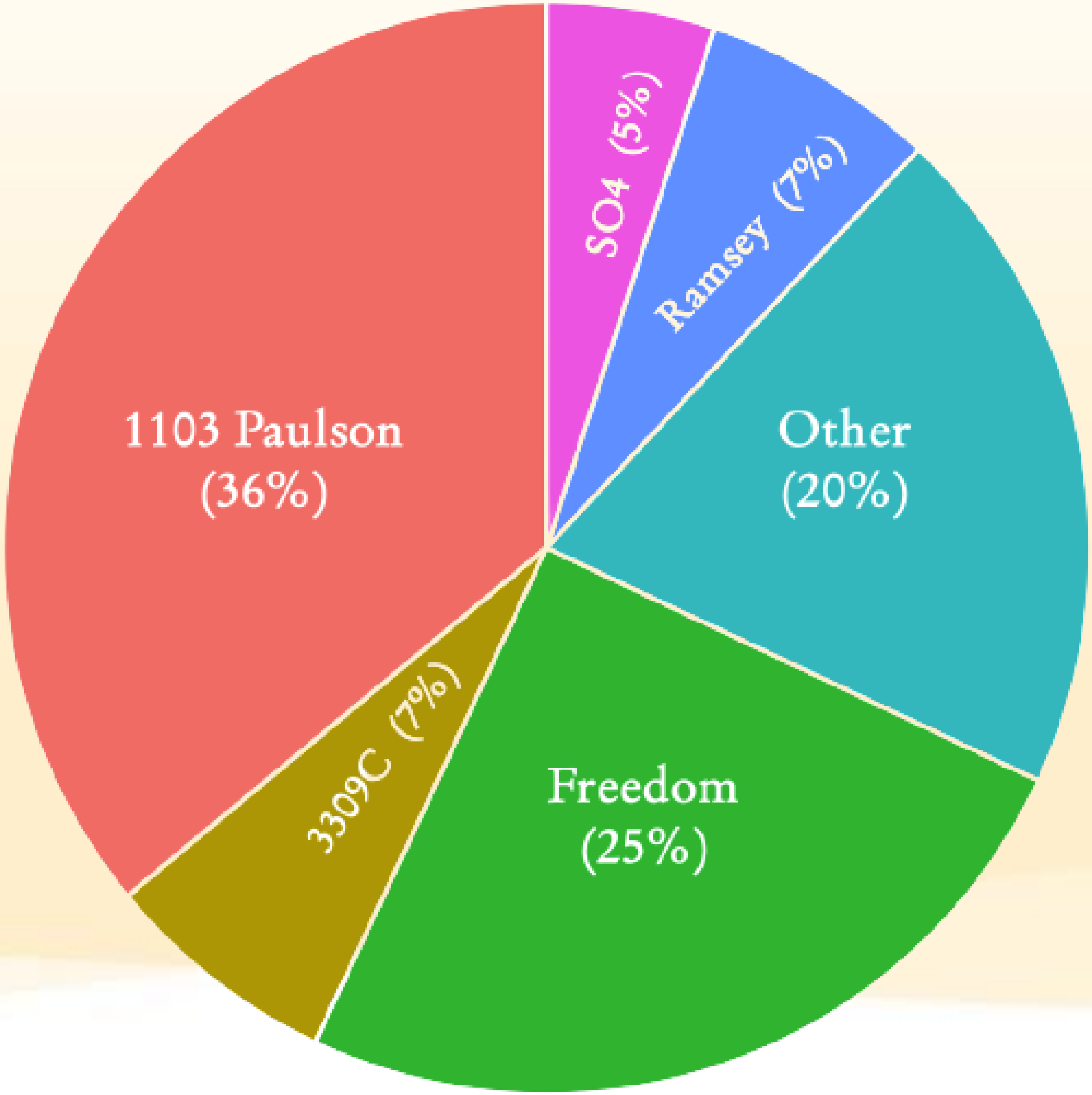
CA Grape Acreage Report (2020)



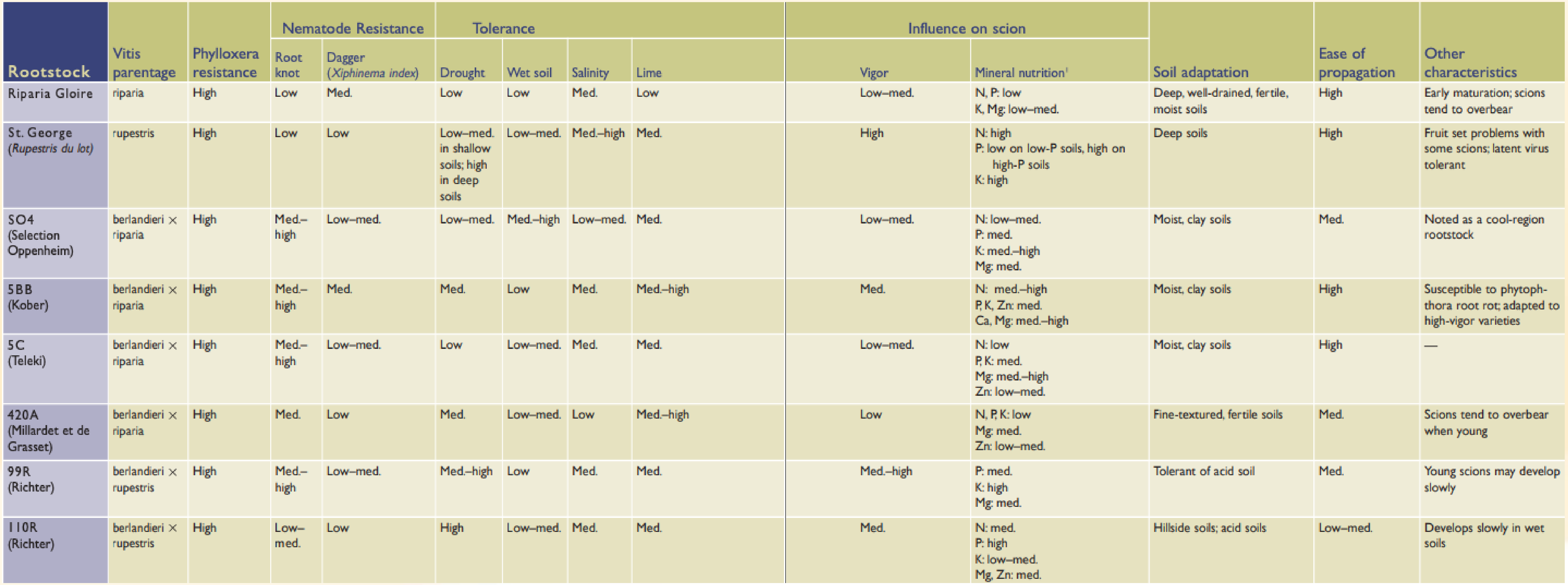
Annual Degree Days
Base 10C
0 - 0.1
0.1 - 250
250.0000001 - 500
500.0000001 - 750
750.0000001 - 1,000
1,000.000001 - 1,250
1,250.000001 - 1,500
1,500.000001 - 1,750
1,750.000001 - 2,000
2,000.000001 - 2,500
2,500.000001 - 7,523

Limited Rootstocks

- The trend observed in scions appears to hold true for rootstock varieties as well
- Data is sparse for rootstocks
- In 2022, we identified the most planted rootstocks across California



Rootstocks by Usage



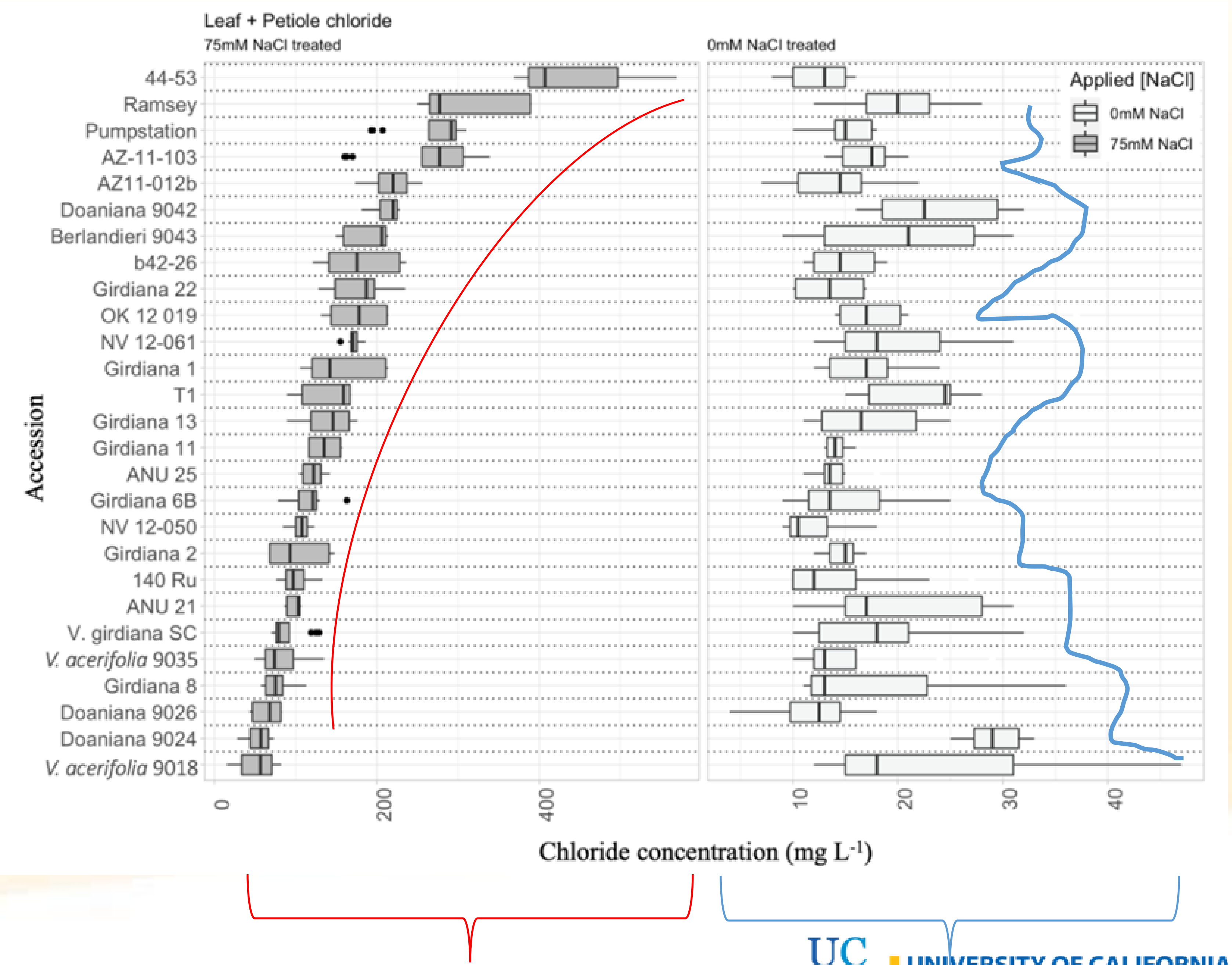
Rootstock	Vitis parentage	Phylloxera resistance	Nematode Resistance		Tolerance				Influence on scion		Soil adaptation	Ease of propagation	Other characteristics
			Root knot	Dagger (*Xiphinema index*)	Drought	Wet soil	Salinity	Lime	Vigor	Mineral nutrition[1]			
Riparia Gloire	riparia	High	Low	Med.	Low	Low	Med.	Low	Low–med.	N, P: low K, Mg: low–med.	Deep, well-drained, fertile, moist soils	High	Early maturation; scions tend to overbear
St. George (*Rupestris du lot*)	rupestris	High	Low	Low	Low–med. in shallow soils; high in deep soils	Low–med.	Med.–high	Med.	High	N: high P: low on low-P soils, high on high-P soils K: high	Deep soils	High	Fruit set problems with some scions; latent virus tolerant
SO4 (Selection Oppenheim)	berlandieri × riparia	High	Med.–high	Low–med.	Low–med.	Med.–high	Low–med.	Med.	Low–med.	N: low–med. P: med. K: med.–high Mg: med.	Moist, clay soils	Med.	Noted as a cool-region rootstock
5BB (Kober)	berlandieri × riparia	High	Med.–high	Med.	Med.	Low	Med.	Med.–high	Med.	N: med.–high P, K, Zn: med. Ca, Mg: med.–high	Moist, clay soils	High	Susceptible to phytophthora root rot; adapted to high-vigor varieties
5C (Teleki)	berlandieri × riparia	High	Med.–high	Low–med.	Low	Low–med.	Med.	Med.	Low–med.	N: low P, K: med. Mg: med.–high Zn: low–med.	Moist, clay soils	High	—
420A (Millardet et de Grasset)	berlandieri × riparia	High	Med.	Low	Med.	Low–med.	Low	Med.–high	Low	N, P, K: low Mg: med. Zn: low–med.	Fine-textured, fertile soils	Med.	Scions tend to overbear when young
99R (Richter)	berlandieri × rupestris	High	Med.–high	Low–med.	Med.–high	Low	Med.	Med.	Med.–high	P: med. K: high Mg: med.	Tolerant of acid soil	Med.	Young scions may develop slowly
110R (Richter)	berlandieri × rupestris	High	Low–med.	Low	High	Low–med.	Med.	Med.	Med.	N: med. P: high K: low–med. Mg, Zn: med.	Hillside soils; acid soils	Low–med.	Develops slowly in wet soils

140 Ru

140 Ru – deep rooted

101-14 mgt

101-14 mgt – shallow rooted



Difference in scale

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Research into combined stress responses

Plant responses to combined stressors may be unique to the specific combination of stressors.

- e.g., drought and *Xylella fastidiosa*

Changes in morphology and physiology are greater with combined stressors:

- Heat and drought in combination decrease plant growth and yields more so that each stressor individually.

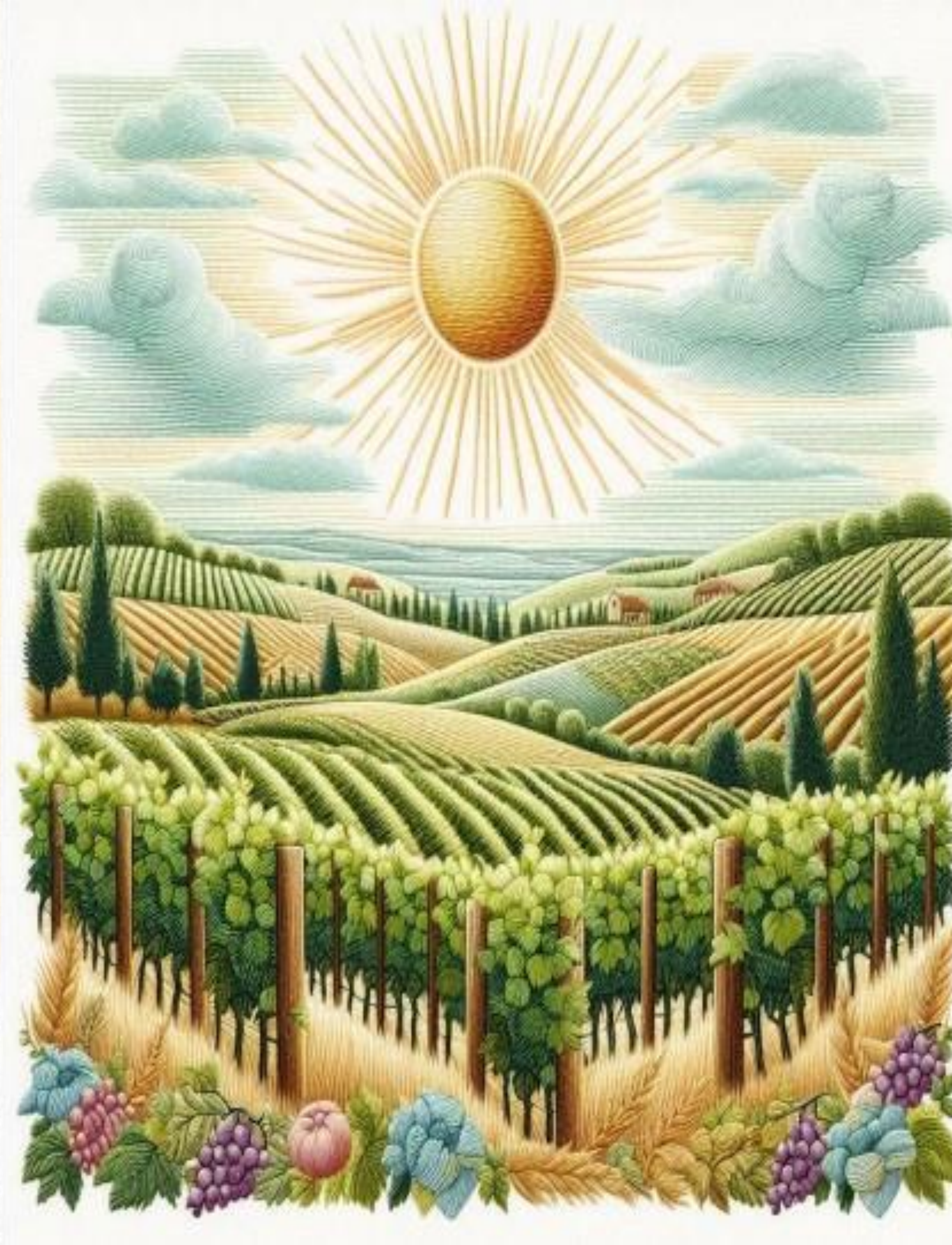
Combined stressors may be thought of as a third-type of stress beyond biotic and abiotic

Study: Climate-Adaptive Rootstocks

- Conducted 2022-2023
- Two Scions
  1. Cabernet Sauvignon
  2. Chardonnay
- Five Rootstocks
  - Most common rootstocks sold in past five years
- Nine locations
- Three Mesoclimate Classifications

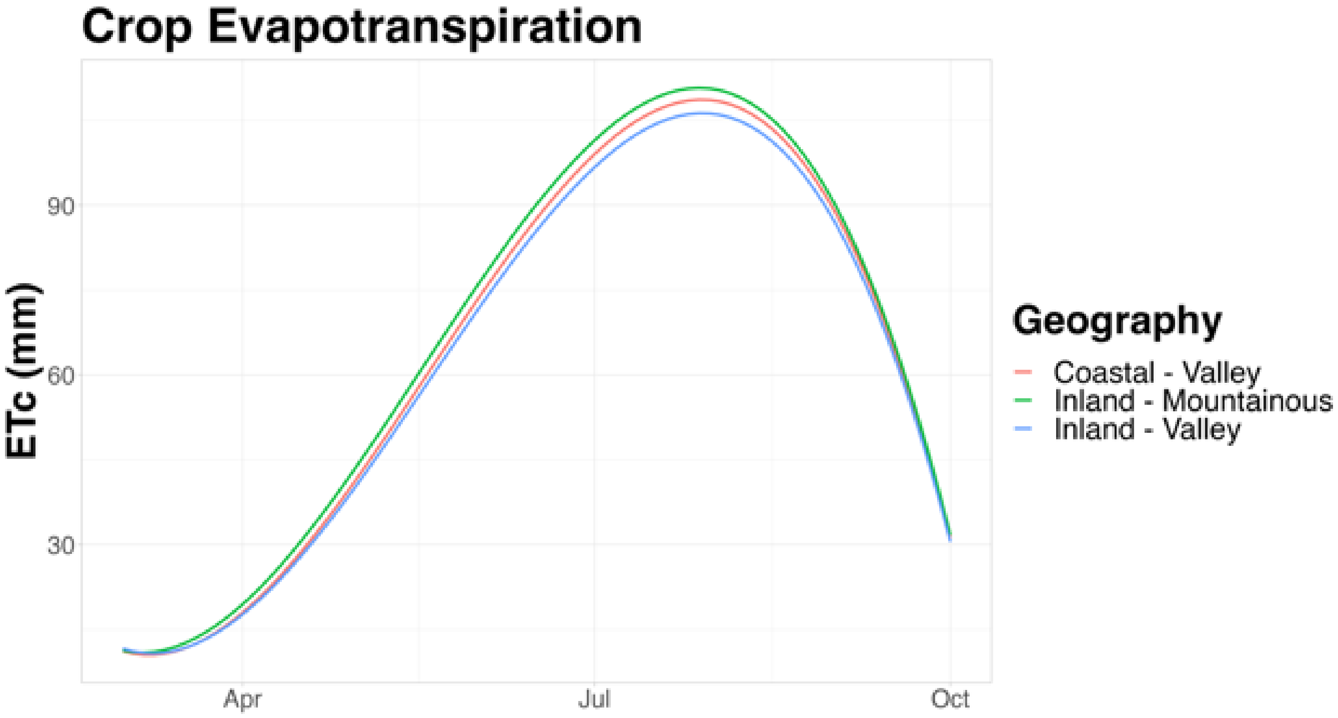
Mesoclimate Classification

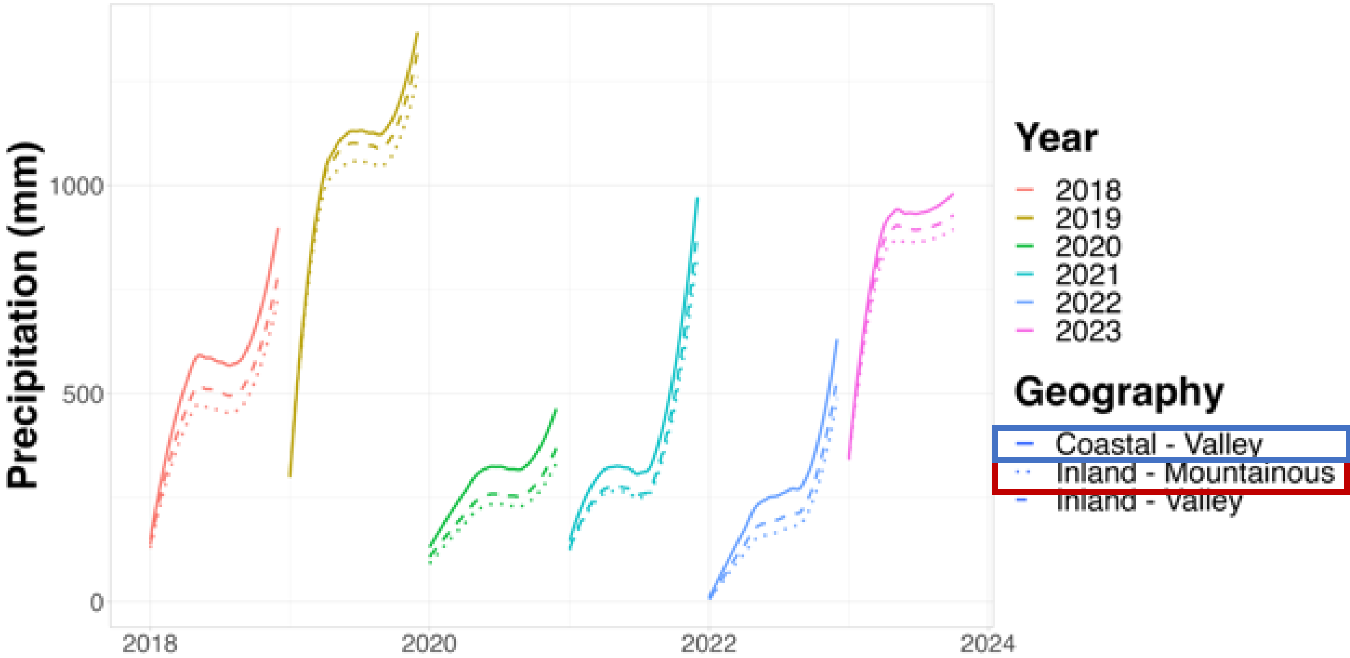
- Three classifications
    1. Coastal Valley
    2. Inland Valley
    3. Inland Mountainous
- Based on
    1. Proximity to coast
    2. Average temperatures
    3. Precipitation
    4. Geographic Location



Water Use by Mesoclimate

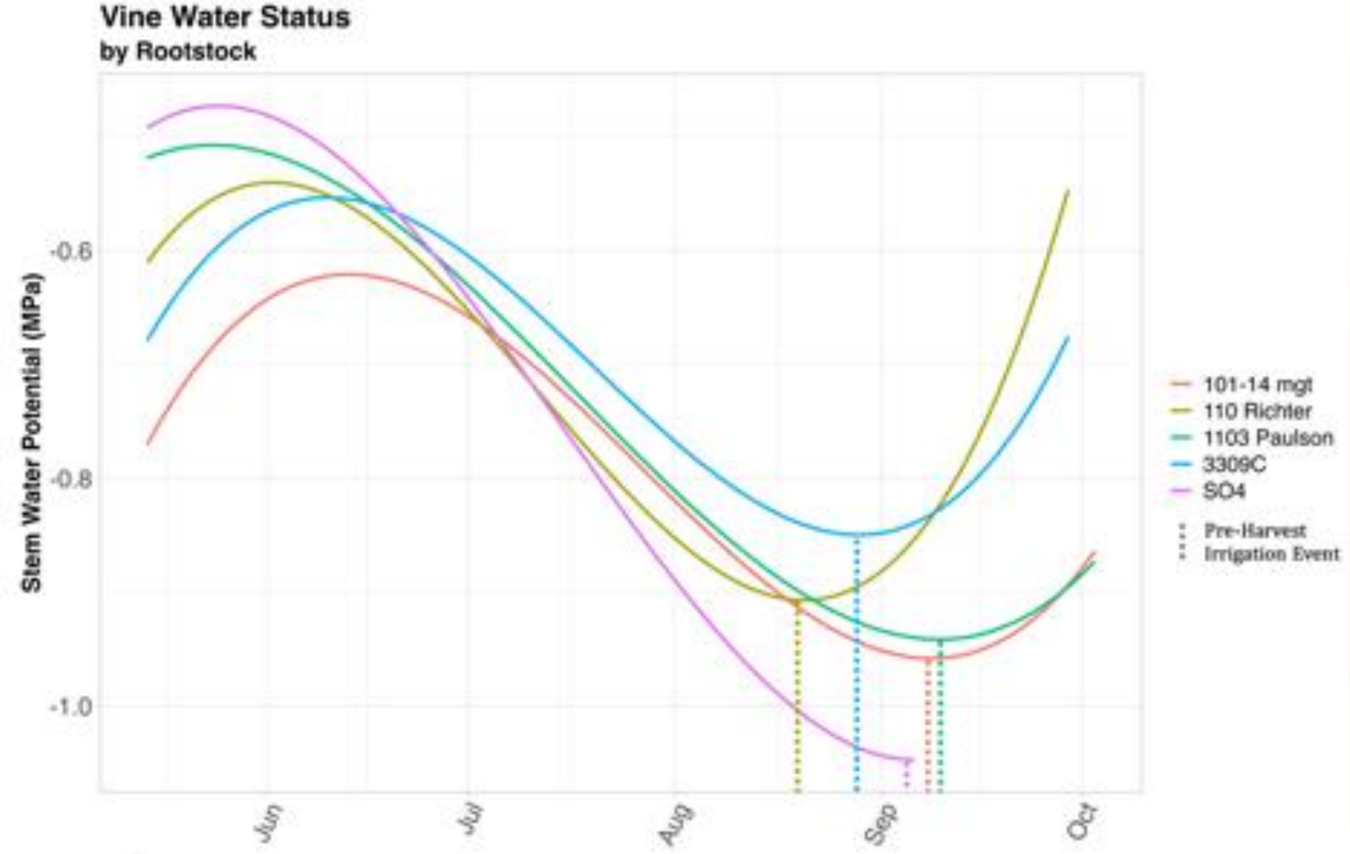
- Water use is important
- Crop evapotranspiration by geographic classification was not significantly different
- Precipitation was consistently highest in coastal valleys and lowest in inland mountain regions
- Inland mountains also lost more water to ET_c than other regions

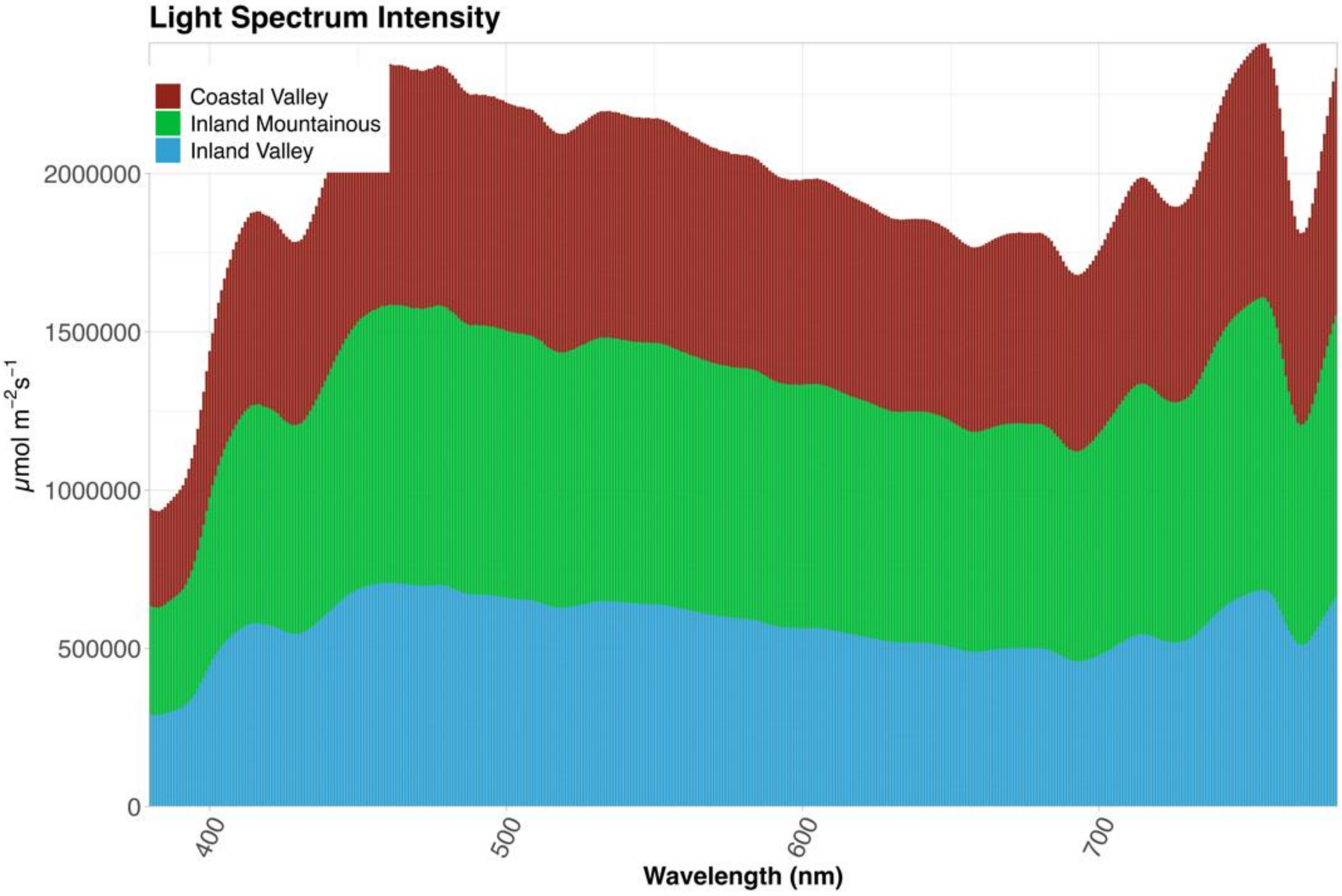




Water Use by Rootstock

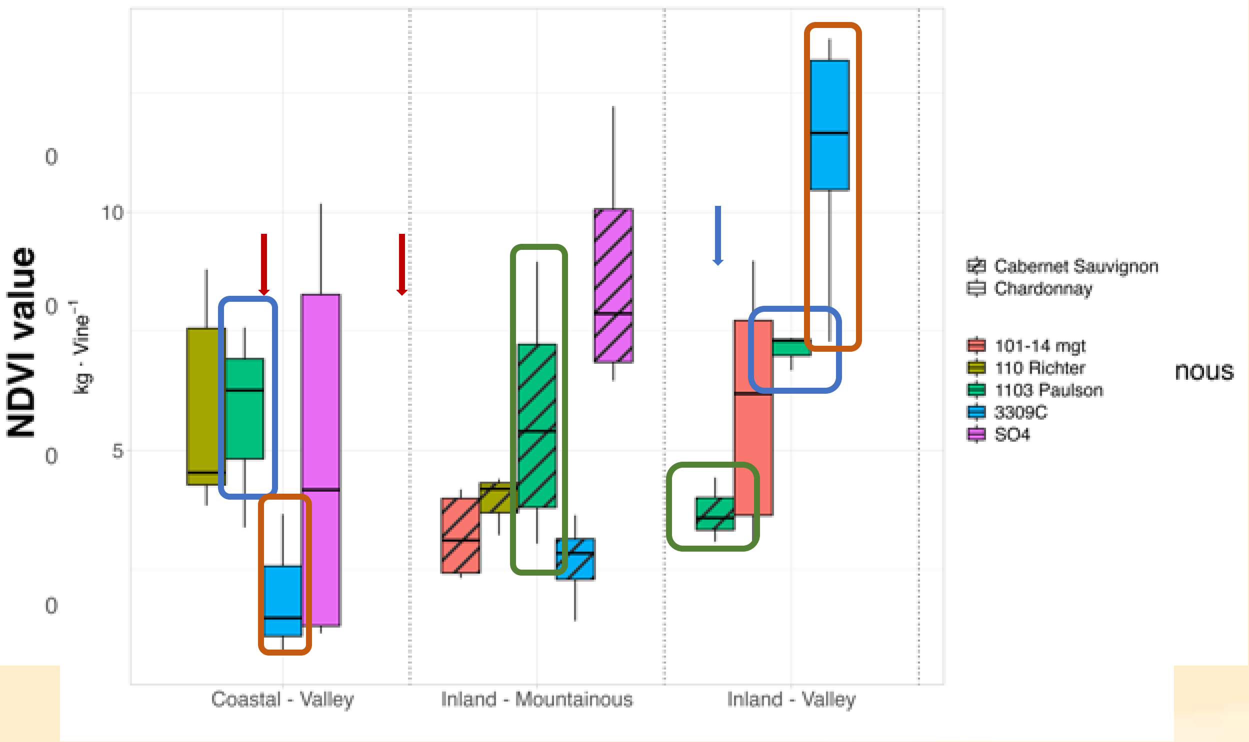
- Vine water stress varied by rootstock as well
- These data represent both scions for each rootstock listed
- Rates of vine water stress increased at consistent levels as SWP dropped in summer
- Vine recovery varied by rootstock
    - 110R recovered fastest with pre-harvest irrigation event
    - Other rootstocks recovered at a slower rate




Light Spectrum Intensity
Coastal Valley
Inland Mountainous
Inland Valley
2000000
1500000
1000000
500000
0
μmol m^{-2}s^{-1}
400
500
600
700
Wavelength (nm)

Agronomic Performance

- Factors that were significantly different by rootstock or site
    1. Growth rate (NDVI)
    2. Clusters per Vine
    3. Yield per Vine
- Some rootstock ~ scion combinations performed consistently regardless of site
- Other combinations were influenced by site significantly



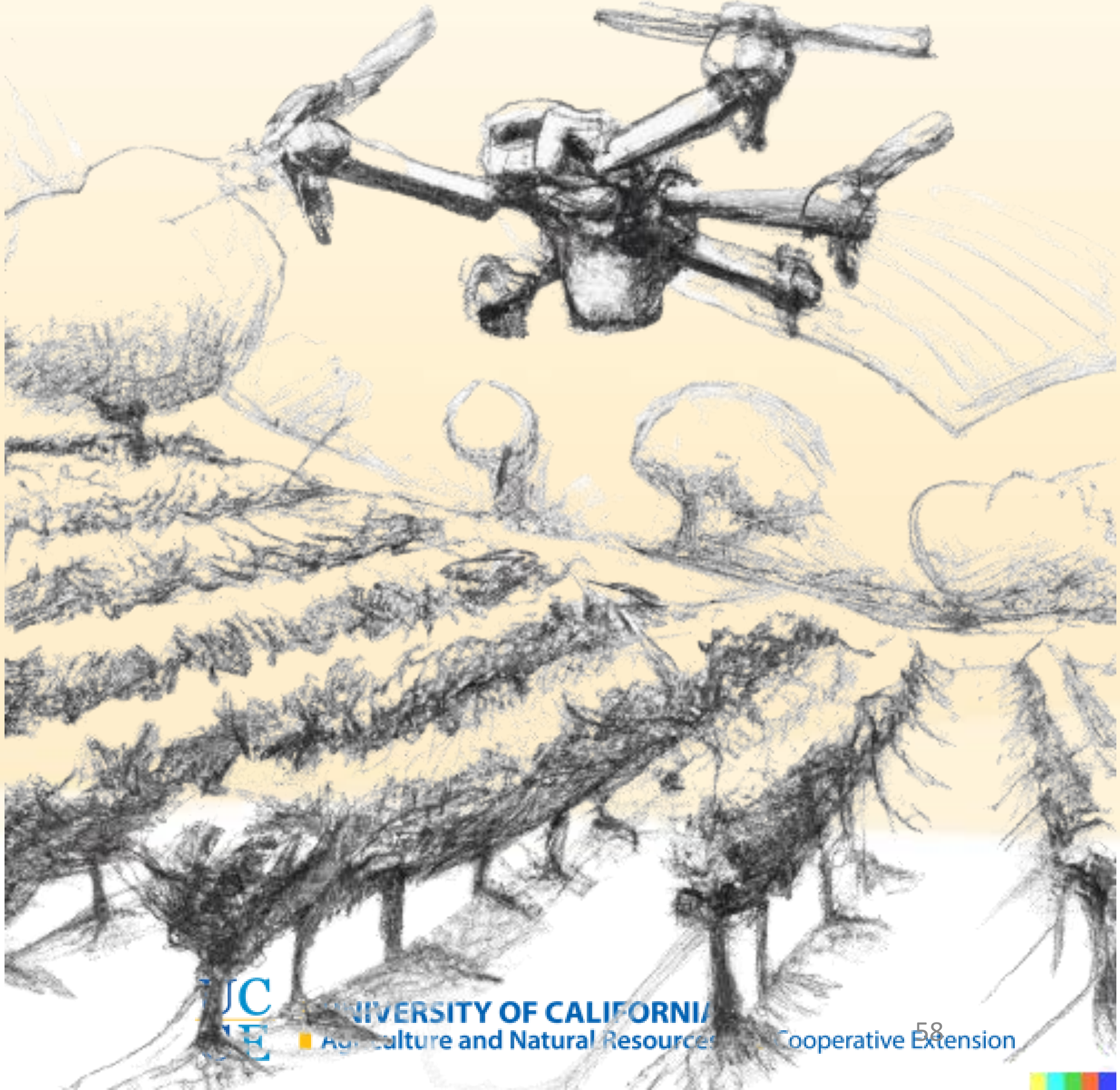
Site Conditions or Rootstock?

- It’s both
- Site influence > Rootstock influence
- Rootstock alone impacted:
  - Yields
  - Individual Cluster Weights
  - Vine Water Status
  - Cluster Counts per Vine
- Site/Geographic classification impacted
  - Yields
  - Individual Cluster Weights
  - Berry Size
  - Vine Water Status
  - Cluster Counts per Vine
  - Sugar Accumulation

The Climate-Adaptive Vineyard

The Climate-Adaptive Vineyard

1. Water Use Efficiency
    - Drought tolerant cultivars
    - Precision irrigation methods
    - Water-efficient cultural practices
    - Better soil-water dynamics
2. Heat/Drought tolerant varieties
    - Research and testing
    - Available and adopted
3. Pest-tolerant rootstocks
    - Identify future pest risks
    - Select for current pests
    - Available and adopted

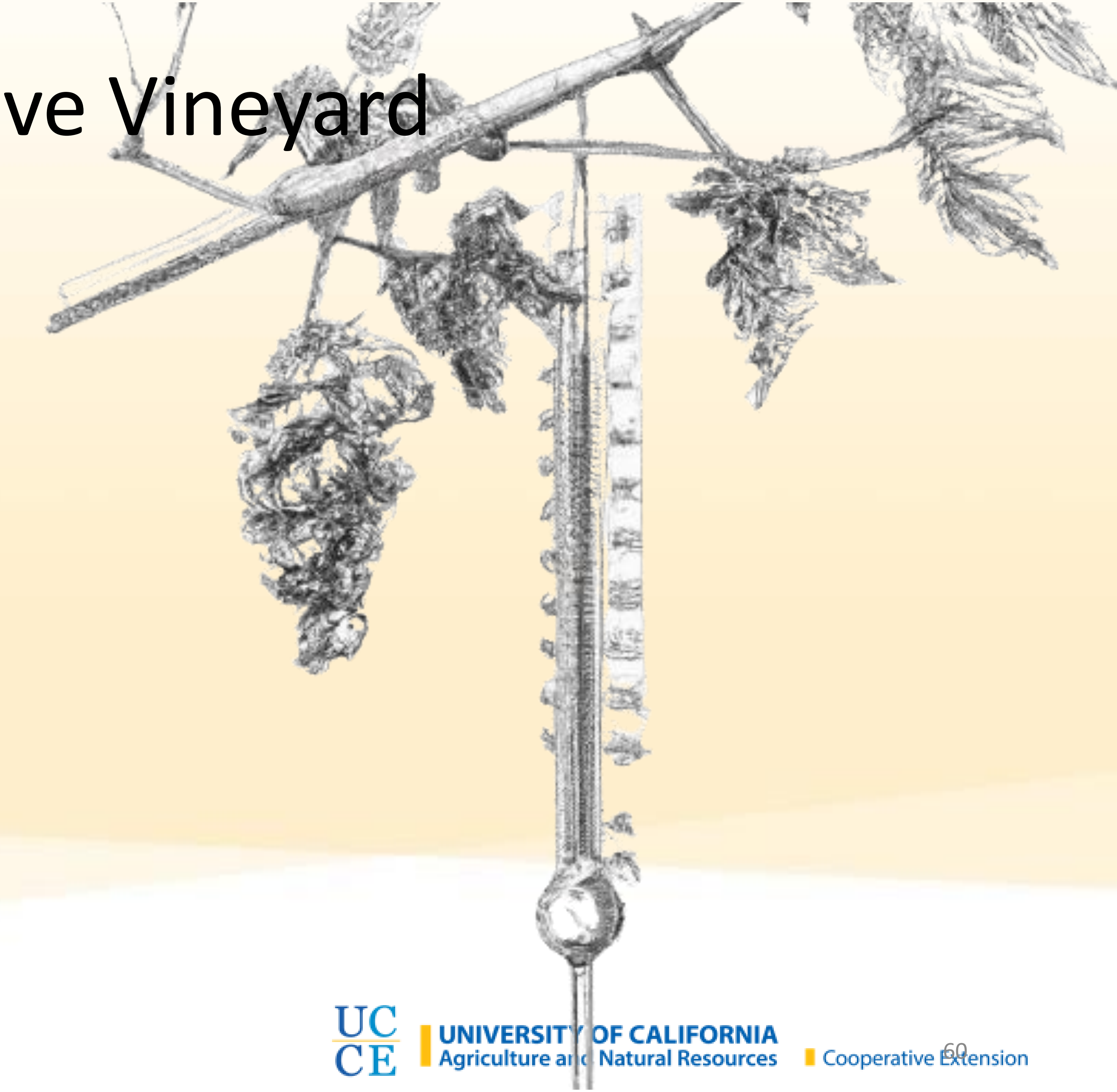


The Climate-Adaptive Vineyard

4. Efficient management practices
    - Precision irrigation
    - Optimize canopy design
5. Improving soil health
    - Increasing water infiltration
    - Improve water retention
    - Improve nutrient retention
    - Promote mycorrhizae health
6. Desirable employment
    - Make jobs desirable
    - Improve employee retention and well-being
    - Keep skilled labor

The Climate-Adaptive Vineyard

7. Adaptable Infrastructure
   - Dynamic trellises
   - As-needed devices
8. Consistent monitoring
   - Observe and record patterns and trends
   - Get ahead of challenges before they become costly
9. Ready adoption of new practices
   - Growers willing to try out new concepts and practices
   - Increase our climate-resilience greatly



Other Challenges

There are many more challenges when considering adapting vineyard systems to climate change that must be addressed:

Adaptable Infrastructure Labor Supplies Site Suitability

Smoke-taint in Fruit Wildfires 'New' Pests

Changes in Beneficials Alternative Chemical Controls

How to Assess Climate at Your Vineyard

- CIMIS / Weather Stations
- Temperature loggers
- Soil ~ Water interactions
- Other soil characteristics (i.e., texture)
- Resource access and availability
- Spectrophotometers

Use Online Resources to Assess your Site

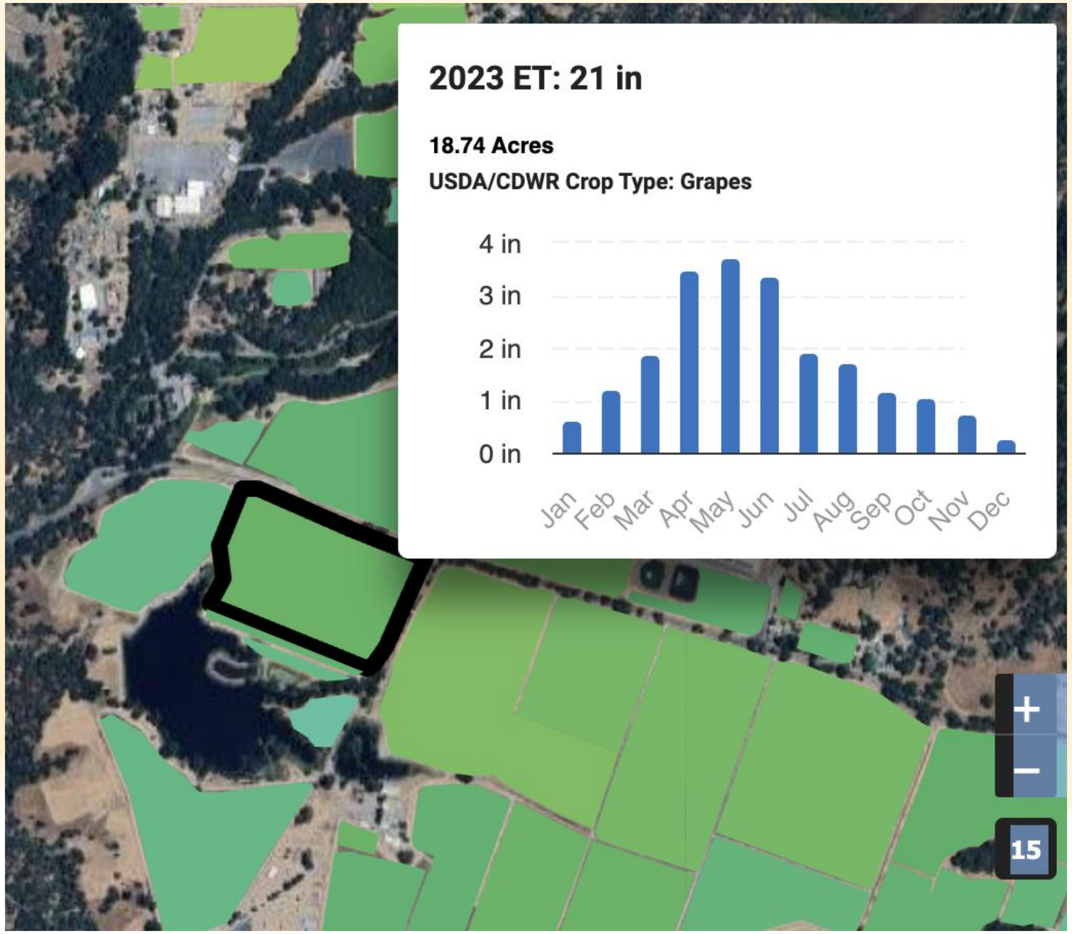
- CropManage

  https://cropmanage.ucanr.edu/
- OpenET

  https://etdata.org/
- CIMIS

  https://cimis.water.ca.gov/
- UC IPM

  https://ipm.ucanr.edu/



2023 ET: 21 in

18.74 Acres

USDA/CDWR Crop Type: Grapes

Summary

1. Climate challenges may be addressed with beneficial traits present in existing cultivars
2. The **direct** and **indirect** challenges of climate change will impact both vines and pests
3. Short-term solutions, like artificial light modification, may be useful when cultivars are locked in
4. Site Conditions > Rootstock
5. There are many ways to improve the climate-resilience of your vineyard; choose the methods that are suited to your site

Thank you

Special thanks to the organizations who provided funding for the data presented (2016-2023)

AMERICAN VINEYARD FOUNDATION

CALIFORNIA GRAPE ROOTSTOCK COMMISSION

Opti-Harvest

Contact me: codchen@ucanr.edu

UC CE | UNIVERSITY OF CALIFORNIA Agriculture and Natural Resources | Cooperative Extension

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