Environment & resources

# AN ONLINE MAPPING TOOL TO GUIDE VITICULTURE EXPANSION IN TASMANIA, AUSTRALIA

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# AN ONLINE MAPPING TOOL TO GUIDE VITICULTURE EXPANSION IN TASMANIA, AUSTRALIA

## Abstract

*As part of the Tasmanian government's AgriVision 2050 plan and a means to facilitate expansion of the Tasmanian wine industry, a comprehensive climate based assessment of the state was implemented to delineate new areas suitable for wine grape production. This paper details how climate variables concerning Frost Risk (FR), Growing Degree Days (GDD) Growing Season Temperature (GST) and Rainfall (Rfall) were spatially quantified at high spatial resolutions (30m grid spacing) and combined to form suitability maps for delineating areas accommodative to table wine grape and sparkling wine grape production (Chardonnay and Pinot Noir cultivars). Evaluation of the climate mapping showed the methods were highly accurate in delineating each climate variable with validation statistics consistent with previous studies. The resulting suitability maps also aligned to the existing arrangements of operating vineyards as well expert knowledge provided by industry. The maps were made publically available through the Tasmanian government online mapping portal, LISTmap [https://maps.thelist.tas.gov.au/listmap](https://maps.thelist.tas.gov.au/listmap) allowing for spatial interaction and querying. Since April 2018, the maps have received in excess of 27,000 'hits' in the six months to September. Further updates are scheduled into the future to include soil and climate change information into the assessment framework.*

**Keywords**: Suitability, Climate, Map, Viticulture, Wine

## Introduction

The Tasmanian wine industry is an important contributor to the Tasmanian economy that has expanded by more than 25% over the past five years (Wine Tasmania 2016). Recently, in partnership with the wine sector, there has been concerted effort by government to support targeted expansion of the industry and identify new sites for viticulture (Tasmania State Government 2014). This forms part of the Tasmanians government's AgriVision 2050 plan, which set a target for growing the agriculture sector in Tasmania to $10 billion per year by 2050 (from $2.02 billion in 2015). In this context, there is a need to provide a comprehensive climate based assessment of the state to define new production sites with the potential to facilitate sustainable expansion of the industry.

New sites for viticulture should be situated in areas where the likelihood of spring frosts are low but also take into consideration the thermal characteristics of a site to ensure sufficient warmth during the growing season (Hall and Jones 2010; Trought et al. 1999). There are many studies that have used climate based temperature indices to classify zones to determine long-term suitability for commercially viable viticulture operations. These were mainly based on heat-sum temperature indices including Growing Degree Days, Growing Season Temperature, Huglin Index and Biologically Effective Degree Days (Hall and Jones 2010; Honorio et al. 2018; Jones et al. 2010). More recently, frost risk analysis linked to viticulture suitability was also determined spatially to identify zones less prone to frost after the critical budburst period (Webb et al. 2018). However, combining an appropriate temperature index with a suitably accurate frost risk map has never been trialled to determine wine grape suitability over a considerably large land mass - the combination of which could delineate favourable growing areas according to rules that govern suitability based on low frost risk and ideal thermal thresholds.

The aim of this project was to spatially quantify individual climate variables at a high spatial grid resolution (30m) to form maps pertaining to Frost Risk (FR), Growing Degree Days (GDD), Growing Season Temperature (GST) and Rainfall (Rfall) using methods prescribed in Webb et al. (2016); Webb et al. (2018). These were combined to form suitability maps, specifically, for table wine grape and sparkling wine grapes (Chardonnay and Pinot Noir cultivars) using rules developed by industry and the existing literature. The results were published on a publically accessible spatial internet portal LISTmap (https://maps.thelist.tas.gov.au/listmap) allowing query-enabled interrogation of the layers in an easy-to-use web mapping environment.

## Methods

Tasmania is an island (68 401 km$^2$) located at coordinates 42.08°S, 146.59°E, approximately 240 km south of mainland Australia. The climate is classified as cool temperate (average air temperature range between 1°C and 16°C for winter and summer, respectively) with total annual rainfall exhibiting a trend that decreases from west (>1800 mm/year) to east (<450 mm/year) (Bureau of Meteorology 2015).

Methods prescribed in Webb et al. (2016); Webb et al. (2018) were adopted to map the climate variables concerning Frost Risk (FR), Growing Degree Days (GDD) Growing Season Temperature (GST) and rainfall (Rfall). Temperature data were sourced from the Bureau of Meteorology (BoM) (http://www.bom.gov.au/climate/data/) and the Tasmanian Government Department of Primary Industries, Parks, Water and Environment (DPIPWE). The BoM data consisted of daily minimum (Tmin), daily maximum (Tmax) and hourly air temperature (Ta) recordings from 43 long-term weather stations for years 1998-2017, whereas the DPIPWE data were based on recordings from Tinytag air temperature loggers (model no. TGP 4017, Gemini Data Loggers, Chichester, England) (Fig. 1). These represented 670 individual logging site locations across Tasmania. The loggers were periodically deployed from 2013 and were programmed to record temperature continuously every hour for 1-year. Thus, the recordings were short-term in nature and were harmonised to the long-term recordings of the BoM data series using a statistical inference procedure described in Webb et al. (2016); Webb et al. (2018). This resulted in a total of 716 temperature sites comprising of daily Tmin and Tmax temperature estimates for the 20-year period in 1998-2017; and hourly Ta estimates for the 10-year period in 2008-2017 (NB: 10 year hourly data from 1998 could only be acquired due to insufficient long-term BoM recordings prior to this date). Collectively, all aforementioned temperature data are referred to as data sites for the remainder of this paper.

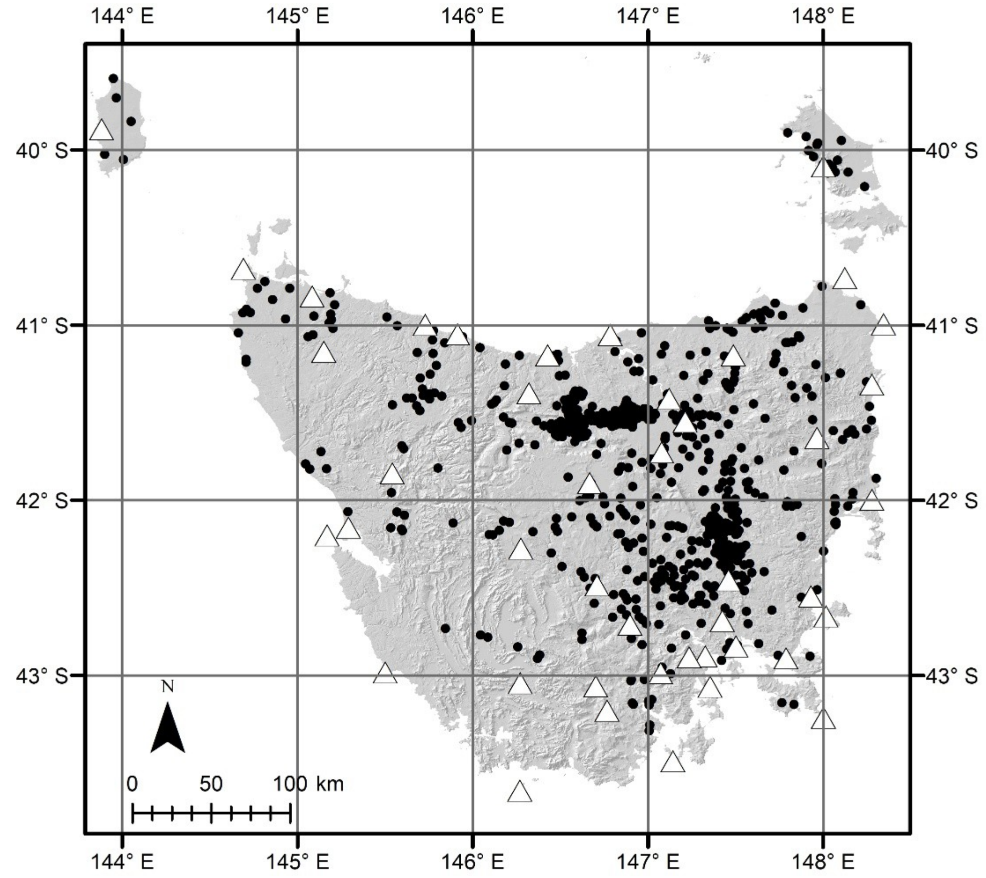


**Fig. 1** Hill shade of Tasmania with location of temperature logger (black dots) and Bureau of Meteorology (BoM) weather station sites (white triangles).

*Frost risk mapping*

Methods prescribed in Webb et al. (2018), were adopted to map frost risk for the period after budburst (the first stage of the vine's annual growth cycle where shoots begin to grow) using hourly air temperatures derived for the data sites. Air temperature occurring ≤-1°C during the post budburst was used as the threshold to identify significant frost events in combination to a budburst model developed by Moncur et al. (1989). Heat sums totalling 8200 h above a base temperature of 3.7°C from July was set as the requirement to indicate budburst. This is in the form:

$$HU = \sum_{-\,-/}^{+,}(Th - Tb) \qquad (1)$$

where HU is the heat unit (calculated from July), $T_h$ represents the temperature at the hour h, and $T_b$ is the base temperature (3.7°C). Hourly air temperature estimates were used to calculate heat sums for each data site for the 10 years leading into 2017 and noting the day of year when 8200 h was reached. Accordingly, frost risk (%) relating to modelled budburst dates to the date of last significant frost was then calculated for each data site using the following equation in each year:

$$Fr_2 = \sum_{2-9}^{8} (if\ T \leq T_7) =: \begin{matrix} 1\ if\ \text{TRUE}, \\ 0\ else. \end{matrix} \qquad (2)$$

where B is the modelled budburst date (refer to Equation 1), T is the air temperature (°C), $T_c$ the -1°C threshold and, D is the last day of spring, 30 November, i.e. the end of the frost vulnerable period leading into summer. To obtain the average value and express the yearly frost events as a proportion, the following equation was used:

$$FR_{\%\mathrm{HIJ}} = \frac{\sum_{\mathrm{MOP}}^{\mathrm{N}}(\mathrm{KL_M})}{\mathrm{Q}} \times 100 \qquad (3)$$

where $FR\%_{bud}$ is the frost risk (%) and *n* equal total number of years relevant to the analysis (i.e. 10 years). Thus, for each data site, the estimated $FR\%_{bud}$ values were then used in an interpolation exercise using regression tree interpolation (Quinlan 1986) to produce a continuous map output, as performed in Webb et al. (2016); Webb et al. (2018). This was carried out using software R (R Development Core Team 2015) along with 30 covariate raster layers (GeoTIFFs) derived from the 1-arc sec (30m resolution) Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) (Gallant et al. 2011). The raster covariate layers were spatially intersected with the geographic locations of the $FR\%_{bud}$ predictions (i.e. data site locations with $FR\%_{bud}$ values) to enable a regression tree model to be formed between the $FR\%_{bud}$ values and the intersected covariate data. The model parameters - derived using the Cubist modelling package (Kuhn et al. 2014) in R software - were subsequently used to guide the predictions across the entire covariate feature space to produce a continuous geotiff raster of $FR\%_{bud}$ of the state. In addition to $FR\%_{bud}$, another map was quantified separately for April ($FR\%_{apr}$) to determine the degree of frost risk late in the growing season. This was calculated by determining the number of years where ≤-1°C was encountered in April over a 20-year period (using the daily Tmin estimates) and expressing the final value as a proportion at each data site. Similar to $FR\%_{bud}$, the $FR\%_{apr}$ values were interpolated using the regression tree algorithm to produce a continuous geotiff raster of $FR\%_{apr}$ of the state.

*Growing Degree Days and Growing Season Temperature mapping*

Maps of Growing Degree Days (GDD) and Growing Season Temperature (GST) were produced using daily Tmin and Tmax data garnered from the data sites. Thus, GDD was calculated for each day in the growing season (October through to April) over a 20-year period using:

$$GDD = \frac{\mathrm{UVWXYUV2Q}}{+} - Tbase \qquad (4)$$

where Tbase represents a base temperature of 10°C (NB: negative GDD values were automatically reclassified to a value of 0 to indicate no thermal accumulation for a given day). An accumulated GDD unit was derived at each data site by adding all GDD units within each growing season then averaging all values over a 20 year period to produce the mean GDD value. Similarly, GST was also calculated using:

$$GST = \frac{\sum^{\mathrm{N}}_{\mathrm{OP}} [\mathrm{UVWXYUV2Q}]/+}{\mathrm{Q}} \qquad (5)$$

where *d* represents each day and *n* represents the total number of days within the growing season. GST values were then averaged over the 20 year period to represent the mean value for each data site. Both GST and GDD were then interpolated using regression tree interpolation as similarly performed with the FR%$_{\mathrm{bud}}$ and FR%$_{\mathrm{apr}}$ estimations (refer to *Frost risk mapping* methodology) to produce a continuous Geotiff raster map output of GDD and GST for the state at a spatial resolution of 30m.

### *Rainfall mapping*

March and April are typically seen as vulnerable months for wine grape production (i.e. the harvest period) where persistent high rainfall events can increase the risk of Botrytis bunch rot (Smart and Wells 2014). Hence, cumulative rainfall days (≥1mm) in March to April was calculated as a way to define to high risk areas. Daily precipitation data was sourced from 539 Australian Bureau of Meteorology (BoM) weather stations (http://www.bom.gov.au/climate/data/) for years 1998-2017 (20 years). For each station, cumulative rainfall days (≥1mm) in March to April was calculated in each year and divided by the total number years relevant to the analysis period (i.e. 20 years). Regression kriging interpolation (Odeh et al. 1995) was then used to produce a continuous state wide map of the rainfall values using the SRTM DEM and a trend map of the dominate rain shadow effect (Nunez et al. 1996). These acted as the deterministic component of the interpolation exercise prior to kriging of the residual estimates. Thus, the final geotiff raster surface was produced via the gstat package (Pebesma 2004) using R software to produce a continuous a rainfall surface (Rfall) equivalent to the resolution and extent of the FR%, GDD and GST outputs.

### *Suitability mapping*

Rulesets form the framework of the suitability mapping outputs were produced separately for table wine and sparkling wine grapes (Pinot Noir and Chardonnay cultivars). The rulesets were based on available literature (refer to Smart and Wells (2014); Webb et al. (2018)) and recommendations provided by industry experts and viticulturists. They define the climate variable ranges corresponding to suitability where limitations denote constraints to productivity. Thus, a suitability rating is governed by a most limiting factor approach where the lowest rated parameter becomes the overall suitability rating (Kidd et al. 2015; Klingebiel and Montgomery 1961). Table 1 and 2 summarises the suitability ratings for table wine and sparkling grapes, respectively, according to their climatic ranges for Frost Risk (FR), Growing Degree Days (GDD) Growing Season Temperature (GST) and rainfall (Rfall). In reference to the suitability ratings, these are defined as: 1.0 Well suited - land having no significant climatic limitations to sustained production where risks of significant crop loss due to adverse climate conditions are unlikely; 2.0 Suitable - land having only minor climatic limitations that will not significantly reduce productivity. Any risk of crop loss is inherently low; 2.1 Suitable (with frost prevention installed) - same as 2.0, however, frost prevention measures must be installed that would otherwise result in reduced productivity and crop loss; 3.0 Moderately suitable - land having climatic limitations (i.e. growing degree day units indicate a cool growing season) that is likely to impact on sustained productivity where risk of poor yield or fruit quality is possible in some years; 3.1 Moderately suitable (with frost prevention installed) - same as 3.0, however, frost prevention measures must be installed that would otherwise result in reduced productivity and crop loss; 4.0 Unsuitable - land having climatic limitations which are severe for sustained production and will so reduce benefits, or increase required inputs, that this expenditure may not justify. Risk of crop loss may be high.

**Table 1** Suitability rule matrix for table wine grapes

| **Rating** | **Rainfall (Rfall):** Cumulative rainfall days (≥1mm) in March to April | **Growing Degree Days (GDD)** (base temperature of 10°C, October-April) | **Frost risk after budburst (FR%$_{bud}$)** (≤-1°C) | **Frost risk during harvest in April (FR%$_{apr}$)** (≤-1°C) |
|---|---|---|---|---|
| 1.0 Well Suited | <20 days | >1150 | Very low risk: <1 frost per 20 year period (<5% of years) | Very low risk: <1 frost per 20 year period (<5% of years) |
| 2.0 Suitable | <20 days | >1150 or 1000-1150 | Low risk: between 1/20yr to 1/10yr period (5-10% of years) | Low risk: between 1/20yr to 1/10yr period (5-10% of years) |
| 2.1 Suitable (with frost prevention installed) | <20 days | >1150 or 1000-1150 | Medium risk: between 1/10yr to 1/5yr period (10-20% of years).<br>High risk: between 1/5yr to 1/2yr period (20-50% of years) | Medium risk: between 1/10yr to 1/5yr period (10-20% of years).<br>High risk: between 1/5yr to 1/2yr period (20-50% of years) |
| 3.0 Moderately suitable | <20 days | 800-1000 | Very low risk - low risk: <1/10yr period (<5% of years) | Very low risk - low risk: <1/10yr period (<5% of years) |
| 3.1 Moderately suitable (with frost prevention installed) | <20 days | 800-1000 | Medium risk: between 1/10yr to 1/5yr period (10-20% of years).<br>High risk: between 1/5yr to 1/2yr period (20-50% of years) | Medium risk: between 1/10yr to 1/5yr period (10-20% of years).<br>High risk: between 1/5yr to 1/2yr period (20-50% of years) |
| 4.0 Unsuitable | >20 days | <800 | >1/2yr per year (>50% of years) | >1/2yr per year (>50% of years) |

**Table 2** Suitability rule matrix for sparkling wine grapes

| **Rating** | **Rainfall (Rfall):** Cumulative rainfall days (≥1mm) in March to April | **Growing Season Temperature (GST)** (October-April) | **Frost risk after budburst (FR%$_{bud}$)** (≤-1°C) | **Frost risk during harvest in April (FR%$_{apr}$)** (≤-1°C) |
|---|---|---|---|---|
| 1.0 Well Suited | <20 days | 13.4 – 15.2°C | Very low risk: <1 frost per 20 year period (<5% of years) | Very low risk: <1 frost per 20 year period (<5% of years) |
| 2.0 Suitable | <20 days | 13.4 – 15.2°C Or >15.2°C | Low risk: between 1/20yr to 1/10yr period (5-10% of years) | Low risk: between 1/20yr to 1/10yr period (5-10% of years) |
| 3.0 Suitable (with frost prevention installed) | <20 days | 13.4 – 15.2°C Or >15.2°C | Medium risk: between 1/10yr to 1/5yr period (10-20% of years).<br>High risk: between 1/5yr to 1/2yr period (20-50% of years) | Medium risk: between 1/10yr to 1/5yr period (10-20% of years).<br>High risk: between 1/5yr to 1/2yr period (20-50% of years) |
| 4.0 Unsuitable | >20 days | <13.4°C | >1/2yr per year (>50% of years) | >1/2yr per year (>50% of years) |

To produce the suitability maps, the climate layers were reclassified according to their suitability rating thresholds and placed in a raster stack using R software. The limiting factors were then identified on a pixel by pixel basis enabling the overall suitability rating to be derived. Accordingly, the suitability rating and limiting factors were annotated via a look up table and associated to each pixel of the mapped outputs enabling interrogation of the output to occur via a Geographical Information System. The final outputs were placed on a public accessible web mapping system (https://maps.thelist.tas.gov.au/listmap) which can be spatially queried to display the suitability class and underlying climate attribute information. Areas currently designated as conservation, urban, infrastructure and water bodies were automatically classified to 4.0 unsuitable to denote areas where large scale viticulture production would be prohibitive.

## Results

### *Evaluation of the climate mapping outputs*

Each climate map was evaluated using a K-fold cross validation approach as similarly implemented in Webb et al. (2016). Specifically, 10-folds was specified where validation metrics including the root-mean-square error (RMSE), coefficient of determination ($R^2$) and the concordance coefficient ($P_c$) were calculated at each K-fold and the results averaged after K=10 (Table 3).

**Table 3** K-fold cross validation averages for modelled climate outputs for $FR\%_{bud}$, $FR\%_{apr}$, GDD, GST and Rfall.

| Climate variable | RMSE | $R^2$ | $P_c$ |
|---|---|---|---|
| $FR\%_{bud}$ | 15.9% | 0.5 | 0.7 |
| $FR\%_{apr}$ | 16.6% | 0.7 | 0.9 |
| GDD | 66.8 units | 0.9 | 0.9 |
| GST | 0.4°C | 0.9 | 0.9 |
| Rfall | 1.6 days | 0.8 | 0.9 |

Overall, the interpolation process was adequate in modelling the climate variables (Fig. 2). The most accurate climate output tended to be GDD and GST with the $R^2$ and $P_c$ registering 0.9 for both metrics, indicating excellent model predictions (NB: a value of 1 indicates perfect agreement, whereas 0 indicates no agreement with the validation data). The least accurate climate output was $FR\%_{bud}$ which produced an $R^2$ and $P_c$ of 0.5 and 0.7 respectively. Interestingly, the RMSE for $FR\%_{bud}$ was slightly lower than the RMSE for $FR\%_{apr}$ despite exhibiting superior $R^2$ and $P_c$ metrics. This suggested that the training range for $FR\%_{apr}$ was spread over a wider prediction range and thereby more prone to inaccuracies (i.e. percentiles values for $FR\%_{apr}$ were 0%, 25% and 65% at the 25th, 50th and 75th percentiles, respectively, compared to $FR\%_{bud}$ which had percentiles values of 0%, 10% and 30% at the 25th, 50th and 75th percentiles). Nevertheless, the RMSE of 15.9% and 16.6% indicated that $FR\%_{bud}$ and $FR\%_{apr}$ was within acceptable ranges and comparable to that found in Webb et al. (2016); Webb et al. (2018). The Rfall output suggested that RMSE was largely confined to 1.6 days and exhibited excellent $R^2$ and $P_c$ values of 0.8 and 0.9, respectively, thus, indicating a reliable model of cumulative rainfall days.

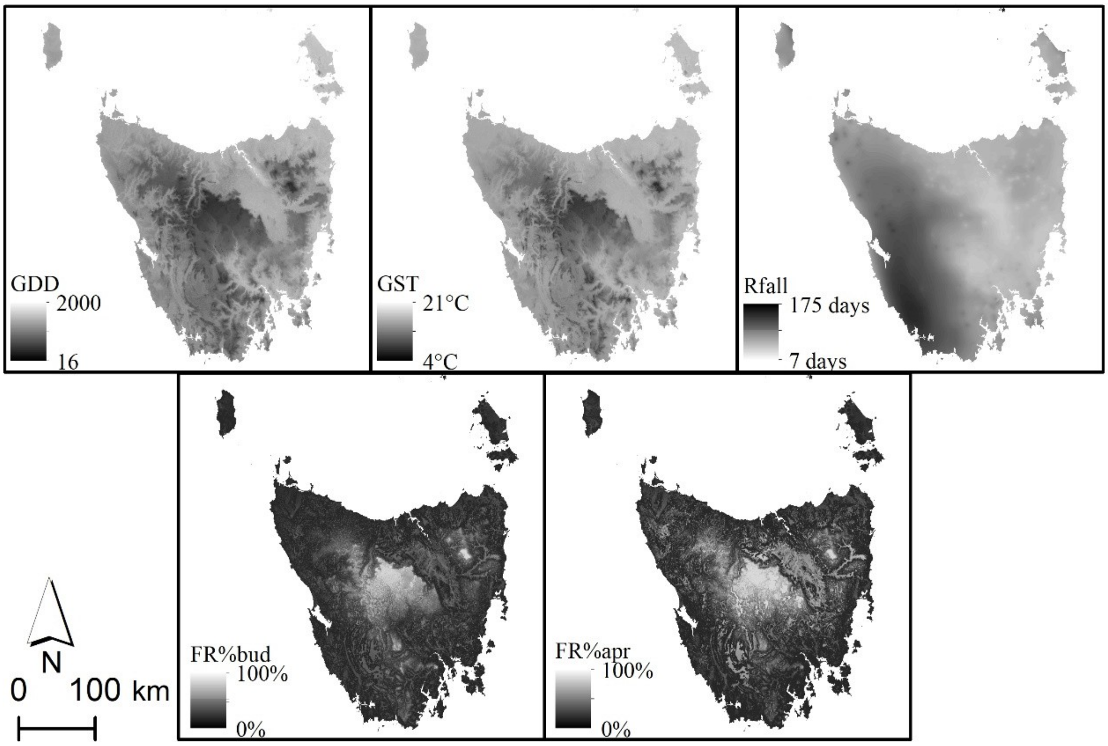


**Fig. 2** Interpolated climate outputs for FR$\%_{bud}$, FR$\%_{apr}$, GDD, GST and Rfall.

*Evaluation of the suitability mapping outputs*

Both Table wine and Sparkling wine suitability maps (Fig. 3) were assessed by comparing the mapped suitability classifications to the current plantings of established vineyard sites using mapped vineyard extents produced from the Tasmanian land-use map layer (DPIPWE 2018). This revealed that 99% of vineyards were situated in areas mapped as well suited to moderately suitability with less than 1% of sites (≤ 7.2 ha) in areas rated unsuitable (Table 4). This confirmed that the mapped suitability ratings - currently conducive to wine grape production - broadly aligns to the current locations of known viticulture sites.

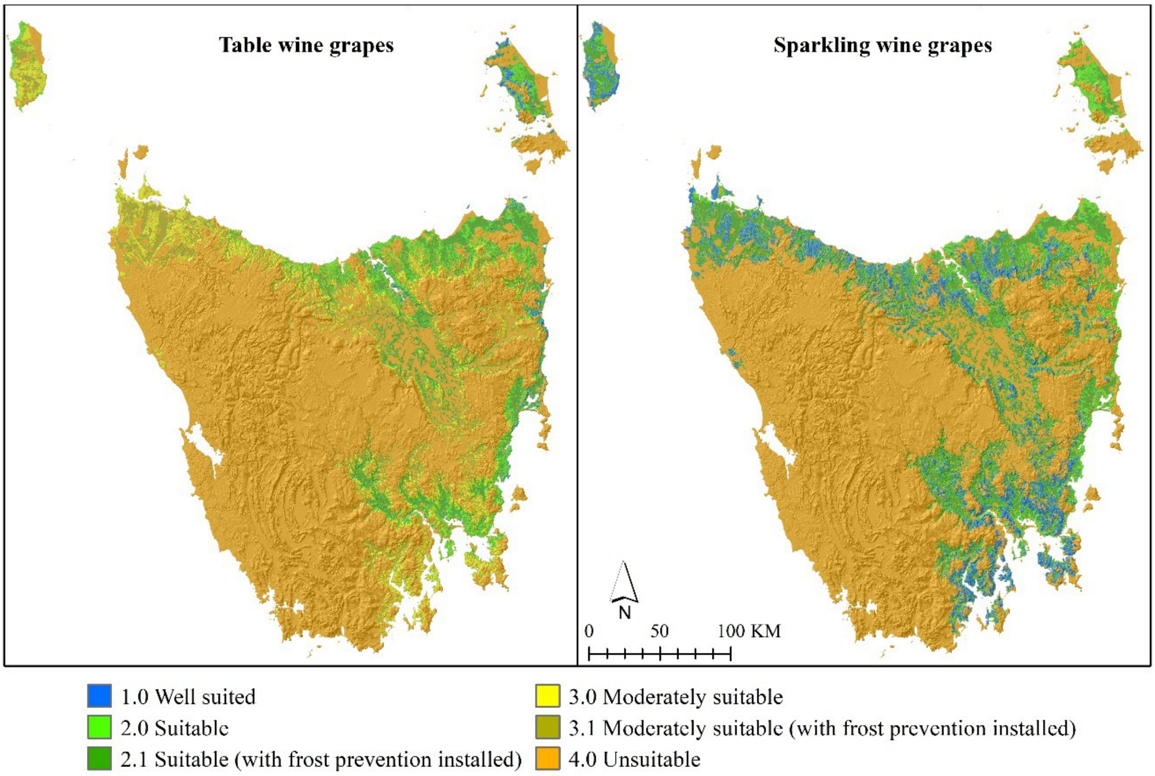


**Fig. 3** Suitability map outputs for table and sparkling wine grapes.

**Table 4** Area (ha) values for table and sparkling wine grape suitability maps versus suitability rating according to current boundary extents of established vineyard sites in Tasmania.

| Rating | Table wine grapes | Sparkling wine grapes |
|---|---|---|
| 1.0 Well Suited | 180 | 324 |
| 2.0 Suitable | 1,112 | 1,083 |
| 2.1 Suitable (with frost prevention installed) | 943 | 1,035 |
| 3.0 Moderately suitable | 114 | NA |
| 3.1 Moderately suitable (with frost prevention installed) | 92 | NA |
| 4.0 Unsuitable | 7 | 7 |

Furthermore, desktop ground-truthing conducted by industry experts verified that the mapping aligned to their expectations with regard to the existing arrangements of successful table wine and sparkling wine grape production sites (Smart, P 2018, pers. comm., 2 May 2018; Pirie, A 2018, pers. comm., 10 May 2018). This was in addition to the frost risk boundaries for $FR\%_{bud}$, which were found to be in agreement to the frost risk suitability extents identified in Webb et al. (2018). Thus, overall it was shown that the mapped suitability outputs were generally consistent across available qualitative and quantitative measures.

## Discussion

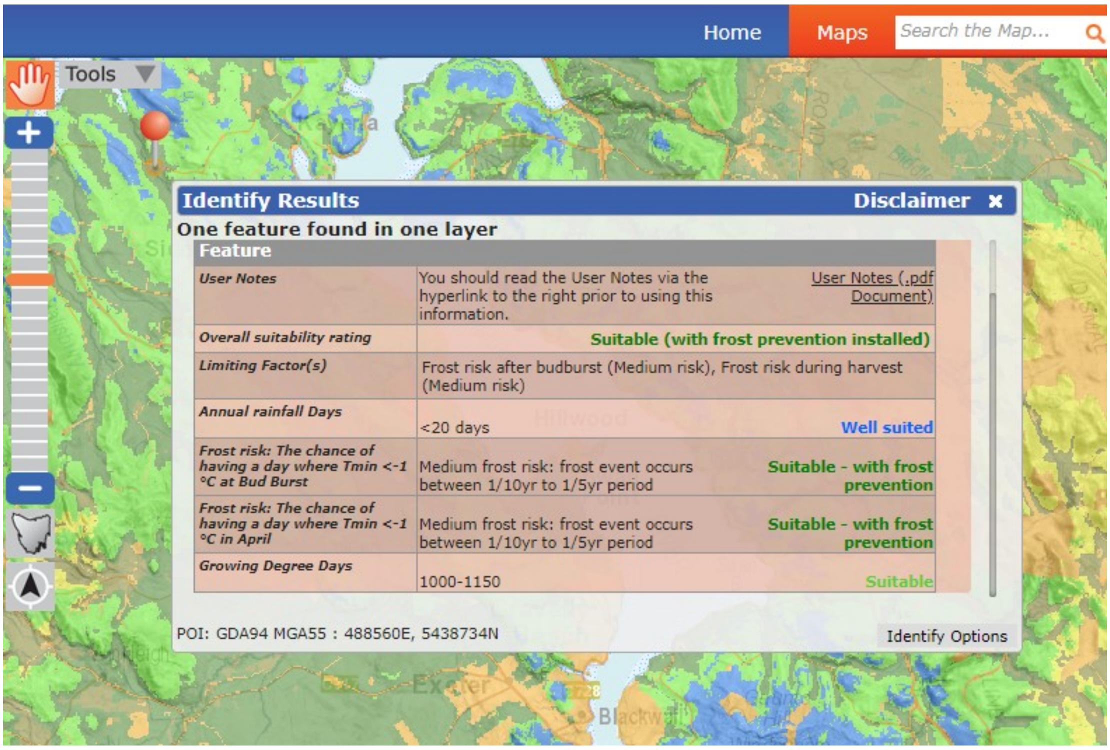
The climate maps were found to be a reliable spatial indicator of GDD, GST, FR%$_{bud}$, FR%$_{apr}$, and Rfall and were consistent with results in studies by Webb et al. (2016); Webb et al. (2018). In this regard, they were suitable for estimating specific climatic temperature requirements for wine grapes at the local scale, as advocated in Webb et al. (2016). When subjected to suitability mapping based on rulesets developed for sparkling and table wine grapes, they aligned well to the existing arrangements of operating vineyards as well expert knowledge provided by industry. The resulting suitability maps were therefore valid and reflected the current situation regarding wine grape suitability across the state. From this perspective, they were considered appropriate for identifying potential new sites suitable for wine grape production. Table 5 portrays the areal extent for each suitability class with respect to potential total land area available for table and sparkling wine grape production in Tasmania. In total, 1,835,072 ha of private freehold land (non-urban) exhibited accommodative climate properties suitable for table wine grape production, i.e. 27% of total land mass for suitability class range 1.0 – 3.1. Similarly, 1,932,387 ha was found to be suitable for sparkling wine grapes, i.e. 28% of total land mass for suitability class range 1.0 – 3.1.

**Table 5** Area (ha) values for mapped suitability ratings concerning table and sparkling wine grape suitability for private freehold land areas (excluding urban areas) in Tasmania.

| Rating | Table wine grapes | Sparkling wine grapes |
|---|---|---|
| 1.0 Well Suited | 49,918 (0.7%) | 501,493 (7.3%) |
| 2.0 Suitable | 362,372 (5.3%) | 472,935 (6.9%) |
| 2.1 Suitable (with frost prevention installed) | 414,048(6.0%) | 957,957(14%) |
| 3.0 Moderately suitable | 510,854 (7.5%) | NA |
| 3.1 Moderately suitable (with frost prevention installed) | 497,880 (7.3%) | NA |
| 4.0 Unsuitable* | 1,334,095 (19.6%) | 1,236,788 (18.1%) |

*excludes areas classified as conservation, urban and major water bodies (3,650,505 ha); Values in brackets denote proportion (%) to total land area in Tasmania.

The maps were made publically accessible through the Tasmanian government online mapping portal, LISTmap https://maps.thelist.tas.gov.au/listmap. The interactive mapping environment allows users to view or create personalised maps of Tasmania, using a wide range of environmental and authoritative land-based information. These provide planning tools for better-informed decisions and allow landowners and potential investors to determine which areas have potential suitability for development. The advantage of the online mapping system allows any point in the state (within a 30x30m grid) to be spatially queried to display the suitability class for each modelled climate parameter including the thresholds for each class and the limiting factor(s) (Fig. 4). This provides an indication to users whether a limitation maybe 'hard' (e.g. lack of GDD accumulation) and therefore prohibitive to wine grape production, or a 'soft' limitation (e.g. $FR\%_{bud}$, which can be mitigated via installation of fans or sprinklers). The mapping portal is accommodative to a further 19 enterprise crops that delineate suitability across the state in a similar fashion (refer to Kidd et al. (2015); Kidd et al. (2014))



**Identify Results** **Disclaimer**

**One feature found in one layer**

| Feature | | |
|---|---|---|
| *User Notes* | You should read the User Notes via the hyperlink to the right prior to using this information. | User Notes (.pdf Document) |
| *Overall suitability rating* | | Suitable (with frost prevention installed) |
| *Limiting Factor(s)* | Frost risk after budburst (Medium risk), Frost risk during harvest (Medium risk) | |
| *Annual rainfall Days* | <20 days | Well suited |
| *Frost risk: The chance of having a day where Tmin <-1 °C at Bud Burst* | Medium frost risk: frost event occurs between 1/10yr to 1/5yr period | Suitable - with frost prevention |
| *Frost risk: The chance of having a day where Tmin <-1 °C in April* | Medium frost risk: frost event occurs between 1/10yr to 1/5yr period | Suitable - with frost prevention |
| *Growing Degree Days* | 1000-1150 | Suitable |

POI: GDA94 MGA55 : 488560E, 5438734N

**Fig. 4** Table wine suitability map output on LISTmap demonstrating spatial query functionality to provide a transparent portrayal of the suitability rating along with the underlying limitation(s).

(Refer to: https://maps.thelist.tas.gov.au/listmap/app/list/map?bookmarkId=322935).

Future directions with regard to improving the suitability maps will incorporate digital soil map layers as developed by Kidd et al. (2015); Kidd et al. (2014), to further fine tune the products catered to favourable soil conditions. In addition, incorporating the latest developments in climate change research as similarly performed in Webb (2015), will also be conducted to spatially quantify potential change relating to predicted climate change impacts on wine grape suitability into the future. The results of this work will also be made publically accessible on the LISTmap portal. Applying the latest developments of an appropriate phenological model for improving GDD (as explained in Parker et al. (2011) will also be explored.

## Conclusions

This study has attempted to combine temperature based indices, frost risk and rainfall maps at a high spatial resolution (30m) to delineate new sites for viticulture. This represents a first attempt for producing such outputs to classify land areas over a considerably large land mass (68 401 km$^2$) to delineate suitability for sparkling and table wine grape production. The results are accessible through the Tasmanian government online mapping portal, LISTmap https://maps.thelist.tas.gov.au/listmap which can be spatially interrogated to provide location specific climate information that governs suitability of a site. A direct link to the suitability maps can be accessed here: https://maps.thelist.tas.gov.au/listmap/app/list/map?bookmarkId=322935

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