Strategies for agricultural growth

ENTERPRISE SUITABILITY MAPPING:
GUIDING AGRICULTURAL DEVELOPMENT IN TASMANIA, AUSTRALIA

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Abstract

A series of new irrigation schemes in Tasmania, Australia, along with Tasmanian Government policies, is currently stimulating agricultural growth in the State. This has been supported through the Tasmanian Government's 'Water for Profit' Program, designed to provide farmers with the tools and knowledge to maximise profits on new irrigation water investments. The program includes the Department of Primary Industries Parks Water & Environment's 'Enterprise Suitability Mapping', using advanced Digital Soil Mapping, Climate Modelling and Enterprise Suitability Rulesets in consultation with industry to produce high resolution (30m) digital maps of the suitability status of a range of agricultural enterprises. The maps have been uploaded to a publically accessible internet mapping portal, and give users the capacity to interactively identify the suitability rating, soil and climate parameters and required management at any location in the State. The maps provide an indication of potential soil vulnerability and relevant management that might be required to ensure agricultural sustainability, along with combined enterprise versatility to show the areas suited to the most crops. The mapping has achieved a high level of interest in Tasmania, totalling > 143,000 internet mapping visits in the 6 months between April and September 2018.

Keywords: *Land Suitability, Digital Soil Mapping, Climate Modelling*

Introduction

Tasmania, Australia is currently undergoing a period of agricultural growth through intensification and expansion of several key industries, driven by the introduction and development of several new publically and privately funded irrigation schemes in strategic areas (Tasmanian Irrigation, 2015). Along with the Tasmanian Government's 'Agrivision 2050' aspiration to grow the value of Tasmanian agriculture tenfold to $10 billion by the year 2050(Agrigrowth Tasmania, 2015), this has been supported by the Tasmanian Government's 'Water for Profit Program' (WfP), (DPIPWE, 2015b); (UTAS, 2015).

The program was designed to provide farmers with the information, tools and skills to maximise their returns on irrigation water investment and increase profits through sustainable agriculture. The WfP Program is a joint undertaking between the Tasmanian Department of Primary Industries Parks Water and Environment (DPIPWE), the Tasmanian Institute of Agriculture (TIA) and the University of Tasmania (UTAS), and consists of four main activities;

- Farmer peer-to-peer learning networks,
- Decision-support tools for irrigated cropping,
- Irrigation soil management practices, and
- Enterprise Suitability Mapping.

The Enterprise Suitability Mapping (ESM) component was developed to address the issue of how land in the new irrigation schemes could be effectively utilised, either as intensification or diversification of existing enterprises, or development of new opportunities, specifically matching optimum terrain, soil and climate parameters to each enterprise. To do this, it was necessary to develop a methodology to produce the best soil and climate surfaces, at a useful resolution or scale, within available time and resources. This paper will focus on the ESM component development, undertaken by DPIPWE (Natural Values Conservation Branch). The ESM, or Land Suitability Mapping, is based on the FAO (1976) land suitability system, matching known soil (and climate) parameters to a range of crops, then classifying land into different suitability classes for each crop. The mapping uses a 'most-limiting-factor' approach (Klingebiel and Montgomery, 1961), where the most restrictive (poorest suitability rating) soil or climate parameter is applied to the overall rating. The mapping used contemporary Digital Soil Mapping (DSM) (McBratney et al., 2003) and climate modelling approaches to map key soil, climate and terrain parameters for a range of important and emerging enterprises, including vegetables, cereals, pharmaceuticals, pasture species, tree-crops, berries and viticulture. The DSM used strategic and statistically sound soil sampling, description and analysis, intersected with explanatory spatial datasets such as elevation, terrain, remote-sensing, existing soil mapping and geology to develop soil inference models for a range of different soil attributes and depths (e.g. pH, Clay Content, Stone Content and Drainage), as a raster-based (pixelated) 30m resolution product across the whole State. Climate parameters, such as frost-risk, growing-degree-days and heat risk, were also mapped at 30m resolution using a similar inference technique based on a network of temperature-sensors and terrain derived from digital elevation models (DEMs).

The ESM products were uploaded to the DPIPWE publically-accessible spatial internet portal, (www.theLIST.tas.gov.au) providing the ability to view and determine localised suitability, the different soil and climate values for each crop, what soil or climate properties might be economically feasible to manage to improve suitability, and potential vulnerable soil management considerations at each location required to ensure soil security and agricultural sustainability.

Methods

Study Area

Tasmania is an island state off the South-Eastern coast of Australia, covering approximately 68,401 km^2. It has a cool-temperate climate, with trending average rainfall from West (1800 mm yr^{-1}) to East (450 mm yr^{-1}) (Australian Bureau of Meteorology, 2014). Population is approximately 0.5 million people, with agriculture being one of the most economically important industries. The Tertiary basalt soils on the north-west coast and north-east are the State's most agriculturally productive, maintaining a wide range of intensive cropping. These soils are classified as Red Ferrosols (Isbell, 2002), and Nitisols or Acrisols; (IUSS Working Group WRB, 2015). They are highly fertile, well drained and high in organic carbon (Spanswick and Kidd, 2000). The Midlands agricultural area (between Launceston and Hobart) is another important farming region for cereal cropping, alkaloid poppies, and sheep grazing. The area contains mainly texture-contrast soils, many of which are considered sodic (exchangeable sodium % > 6, Sodosols (Isbell, 2002), (Solonetz or Lixisols; (IUSS Working Group WRB, 2015))).

Enterprises

Enterprises were chosen to represent a range of important and emerging crops for Tasmania. These included barley, blueberries, carrot seed, carrots, cherries, hazelnuts, industrial hemp, linseed, lucerne, olives, onions, poppies, potatoes, pyrethrum, raspberries, rye grass for dairy, strawberries, wheat, and wine grapes (sparkling and table). An additional 18 crops were also developed in consultation with TIA and industry, including perennial grasses (cocksfoot (Continental and Mediterranean), tall fescue, (Continental and Mediterranean), phalaris), perennial legumes (clover: white, red, strawberry), grass seed, clover seed, seed potato, tree crops (*Eucalyptus Nitens, Eucalyptus Globulus, Pinus Radiata*), fodder beet, maize, peas, beans and blueberries (discriminated to 'northern highbush' and 'southern highbush' varieties).

Suitability Ruleset Development

ESM rulesets based on optimal soil and climate growing conditions were originally developed by TIA using a combination of industry workshops, existing literature and trial data in a 70, 000 ha pilot area covering the Meander and central Midlands districts (Kidd et al., 2012). Soil properties included topsoil (0 to 15 cm) pH, electrical conductivity, clay %, exchangeable calcium, exchangeable magnesium, stone content (2 to 200mm, > 60mm and >200mm sizes), drainage, depth to duplex (texture-contrast) clay layer, depth to sodic layer and depth to rooting impediment (soil depth). The successful ESM pilot project was subsequently applied state-wide, at 80m resolution using the original suitability rulesets. These surfaces and rulesets were then reviewed in consultation with industry, adjusting parameter ranges to better align with existing enterprises and industry expert knowledge.

The original maps contained four suitability classes;

- Well-suited – no limitations to productivity,
- Suited – minor limitations to productivity,
- Marginally-suited, moderate limitations to productivity, and,
- Unsuited – substantial limitations to productivity.

However, the original concept was considered insufficient by many in industry, as significant areas were shown to be less than well-suited, but only being limited by easily manageable constraints, such as pH (which can be ameliorated by liming). Consequently, ESM rulesets were re-assessed to include suitability sub-classes, identifying economically feasible soil and/ or climate constraints that could improve suitability rating through applied management. These included;

- pH – managed by liming,
- Stone Content – Managed by Stone-Picking,
- Soil Drainage – managed by surface or sub-surface drainage installation,
- Frost – Managed by fans or sprinklers, or late planting,
- Heat Stress – Managed by shade or sprinklers.

A sample ESM ruleset is shown for cherries in Table 1 (Soils and Terrain) and Table 2 (Climate);

Suitability rating	**Soil Depth***	**Depth to sodic layer**	**pH* of top** 15cm	**ECse** dS/m	**Drainage***	**Stone %*** (>200mm diameter, top 15cm)	**Slope**
1.0 Well suited	>40cm	No sodic layer >100cm	6.5-7	< 1	Well drained	<10%	3-10%
1.1 Well suited with soil management	30-40cm	No sodic layer >100cm	6.0-6.5* 7.0-7.5*	< 1	Moderately Well drained	10-20%	3-10%
2.0 Suitable	30-40cm	50-100cm	6.0-6.5 7.0-7.5	1–2	Moderately well drained	10-20%	<3 or 10-15%
2.1 Suitable with soil management	20 -30 cm	50-100cm	5.5-6.0* 7.5-8.0*	1–2	Moderately Well drained	20-50%	<3 or 10-15%
3.0 Moderately suitable	20 -30 cm	30-50cm	5.5-6.0 7.5-8.0	2–6	Moderately well drained	20-50%	15-20%
3.1 Moderately suitable (with soil management)	20 -30 cm	30-50cm	5.0 to 5.5* 8.0 to 8.5*	2–6	Imperfect	20-50%	15-20%
3.2 Moderately suited (with frost/heat management)	20 -30 cm	30-50cm	5.5-6.0 7.5-8.0	2–6	Moderately well drained	20-50%	15-20%
3.3 Moderately suitable (with soil, frost/heat management)	20 -30 cm	30-50cm	5.0 to 5.5* 8.0 to 8.5*	2–6	Imperfect	20-50%	15-20%
4.0 Unsuitable	<20cm	<30cm	<5.0 >8.5	>6	Poorly drained, Very poorly drained	>50%	>20%

Table 1. Sample Suitability Ruleset: Cherries Soil and Terrain Ratings. (*Manageable Constraints)

Suitability rating	**Frost risk*** From bud swell to early bloom 15 Sept – 30th Oct, No days <-2°C	**Frost risk*** After fruit set - harvest 1st Nov – 14th Feb, No days <0°C	**Mean maximum monthly temperature (°C)**	**Mean daily maximum temperature (°C) at flowering** 1st Oct-15th Nov	**Extreme heat risk*** High temperatures at ripening 8th Dec-14th Feb, No days >35°C	**Growing Degree Days** (Oct-Apr)	**Chill hours** temperature between 2°C and 12°C (May-August)
1.0 Well suited	More than 4 years in 5	More than 4 years in 5	10-28°C	13-20°C	More than 4 years in 5	>800	>800
1.1 Well suited with soil management	More than 4 years in 5	More than 4 years in 5	10-28°C	13-20°C	More than 4 years in 5	>800	>800
2.0 Suitable	3/5 to 4/5	3/5 to 4/5	10-28°C	11-13°C	3/5 to 4/5	750-800	>800
2.1 Suitable with soil management	3/5 to 4/5	3/5 to 4/5	10-28°C	11-13°C	3/5 to 4/5	750-800	>800
3.0 Moderately suitable	2/5 to 3/5	2/5 to 3/5	8-10 or 28-30°C	9-11°C	2/5 to 3/5	750-800	>800
3.1 Moderately suitable with soil management	2/5 to 3/5	2/5 to 3/5	8-10 or 28-30°C	9-11°C	2/5 to 3/5	750-800	>800
3.2 Moderately suited (with frost/heat management)	Less than 2 years in 5 (requires frost management during frost events, e.g. Fans)	Less than 2 years in 5 (requires frost management during frost events, e.g. Fans)	8-10 or 28-30°C	9-11°C	Less than 2 years in 5 (requires heat management during hot days, e.g. sprinklers)	750-800	>800
3.3 Moderately suitable (with soil, frost/heat management)	Less than 2 years in 5 (requires frost management during frost events, e.g. Fans)*	Less than 2 years in 5 (requires frost management during frost events, e.g. Fans)*	8-10 or 28-30°C	9-11°C	Less than 2 years in 5 (requires heat management during hot days, e.g. sprinklers)	750-800	>800

4.0 Unsuitable			<8°C or >30°C	<9°C or >20°C		<750	<800

*Table 2. Sample Ruleset; Cherries Climate ratings (*Manageable Constraints)*

The new state-wide suitability maps were generated at 30m resolution by classifying the soil and climate gridded data according to the parameter rulesets for each enterprise.

Digital Soil Mapping

The DSM process for the 80m resolution mapping is fully described in Kidd et al. (2015b). The new 30m DSM effectively followed the same methodology, using additional Tasmanian soil legacy site data, newly collected data from additional sites, strategically and statistically located where uncertainties were highest in the 80m mapping through data-poor areas of the central and southern Midlands, and a range of newly generated 30m resolution spatial explanatory data (covariate). Sampling was carried out using a stratified-random approach by Fuzzy k-mean clusters of covariate data as strata (Kidd et al., 2015a). Soil cores were taken to a depth of 1.2m where possible, and analysed using Mid-Infra-Red (MIR) analysis, calibrated using 15% of samples by conventional chemical analyses (Minasny and McBratney, 2008). Soil descriptions (including drainage status) were undertaken according to Australian Standards (NCST, 2009).

DSM involved fitting mass-preserving depth splines to site data to calculate soil property values at required standard depths (Malone et al., 2009). Site values were intersected with covariates to develop soil inference models, effectively interpolating and extrapolating between sites based on the covariate soil-forming factors using an environmental correlation approach (McKenzie and Ryan, 1999). Models were developed using Cubist regression-tree modelling (Quinlan, 2005) for continuous soil property data, and decision-tree (C5) for categorical data (Quinlan, 2014). Cubist uses a data-mining algorithm to split the calibration data into a set of structured classifiers, with a tree structure formed through recursive partitioning into a series of linear models until insignificant variance in calibration results are established (McBratney et al., 2003). Covariate data included;

- Terrain derivatives from the 30m resolution SRTM-DEM (Gallant et al., 2011); e.g. slope, aspect, curvature, topographic-wetness index.
- Remote-sensing (e.g. Gamma-radiometrics, LandSat persistent greenness).

- Geology.

Modelling was undertaken in the 'R' coding environment (R Development Core Team, 2015), specifically the Cubist R package (Kuhn et al., 2013), using cloud-based high-performance computing. K-fold cross validation (where k = 10) was used (Kohavi, 1995) to reduce model sensitivity to calibration data, and a leave-one-out cross-validation within each regression-tree partition used to determine uncertainty ranges (Malone et al., 2014).

Soil Vulnerability

The DSM data was applied to DPIPWE rulesets (Kidd, 2003) to generate soil vulnerability rating maps at 30m resolution for wind-erosion, salinity, and sodicity hazards. A RUSLE (Revised Universal Soil Loss Equation) (Lu and Yu, 2002, Renard et al., 1991) approach was used to generate hillslope (water) erosion hazard mapping. Waterlogging hazard was generated by developing 30m resolution raster maps for soil drainage and soil permeability indices (Kidd et al., 2014), and multiplying these together to identify where soils were both poorly-drained with slow permeability, resulting in a high waterlogging hazard. The suitability surfaces were intersected with each soil vulnerability layer to identify areas where soil-conservation practices would be required to ensure sustainability, linked to DPIPWE soil management guidelines, for example, maintaining ground-cover through cover-crops in highly erodible areas.

Climate Modelling

Climate models for temperature and rainfall were developed using a similar predictive-spatial modelling approach through Regression-Trees. Temperature based maps were produced using 670 temperature-sensors statistically linked to 43 long-term Bureau of Meteorology (BoM) weather stations. Rainfall maps were based on 539 BoM stations. Both types of climate maps were intersected with explanatory terrain derivatives and spatially modelled, as described in Webb et al (2015, 2014, 2017).

Internet-Based Mapping Outputs

Suitability maps were uploaded to the DPIPWE spatial web portal www.theLIST.tas.gov.au to allow users to determine suitability potential for the whole state, with the ability for users to interactively query individual locations to determine suitability rating, soil and climate values, manageable constraints, potential soil vulnerability and management options. Suitability mapping could also be overlaid with other administrative, infrastructure and ecological spatial layers to better assist identifying potentially suitable locations. Land tenure, such as urban and conservation areas were identified as 'unsuitable' in each ESM surface.

Enterprise Versatility

All ESM layers were spatially combined into an 'Enterprise Versatility Index' (EVI) (Kidd et al., 2015c) to identify the areas of the state suited to the most enterprises (Figure 1), i.e. the most versatile land. Other versatility indices for grouped land use categories were also developed, including intensive rotational cropping, cereals, perennial horticulture, berries, plantation-forestry and pastures.

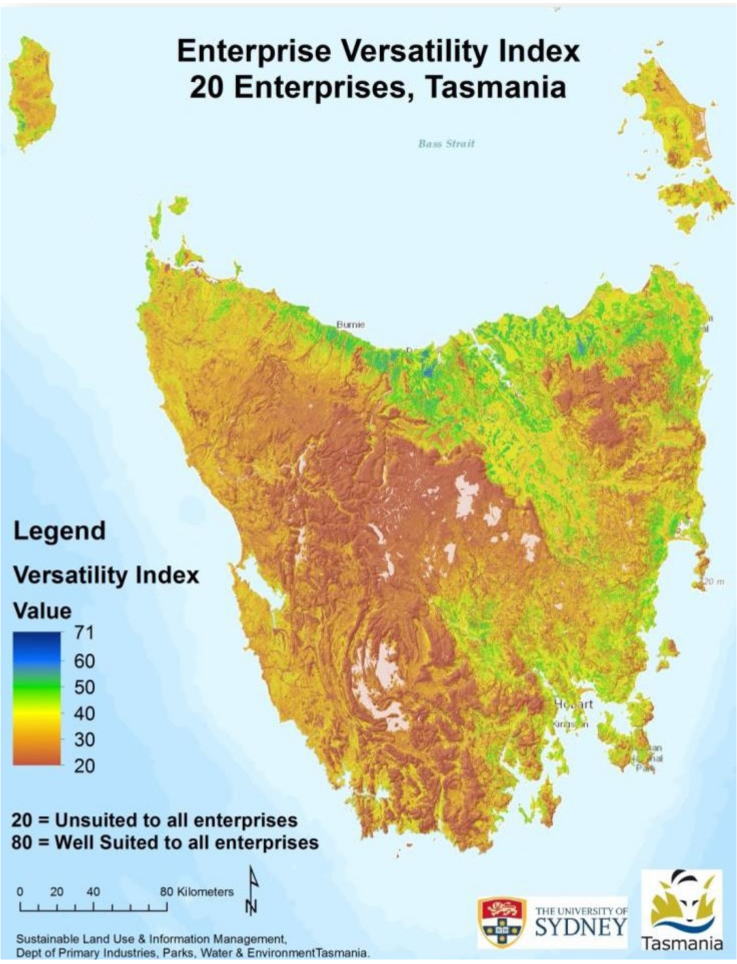

Figure 1. Enterprise Versatility Index

Climate Change Suitability

To provide additional future planning tools, climate change atmospheric models were downscaled and applied to the suitability ratings for temperature-sensitive enterprises, showing projected changes in spatial extent at 2030 and 2050, described in Webb (2015).

Results

Once acceptable diagnostics were achieved for all soil and climate grids, the resulting ESM maps were uploaded to LISTmap (www.theLIST.tas.gov.au). Figure 2 shows an example LISTmap ESM layer for cherries in the Tasmanian Midlands, while Figure 3 shows a sample of an interactive query result from the map user 'clicking' on the desired map location.

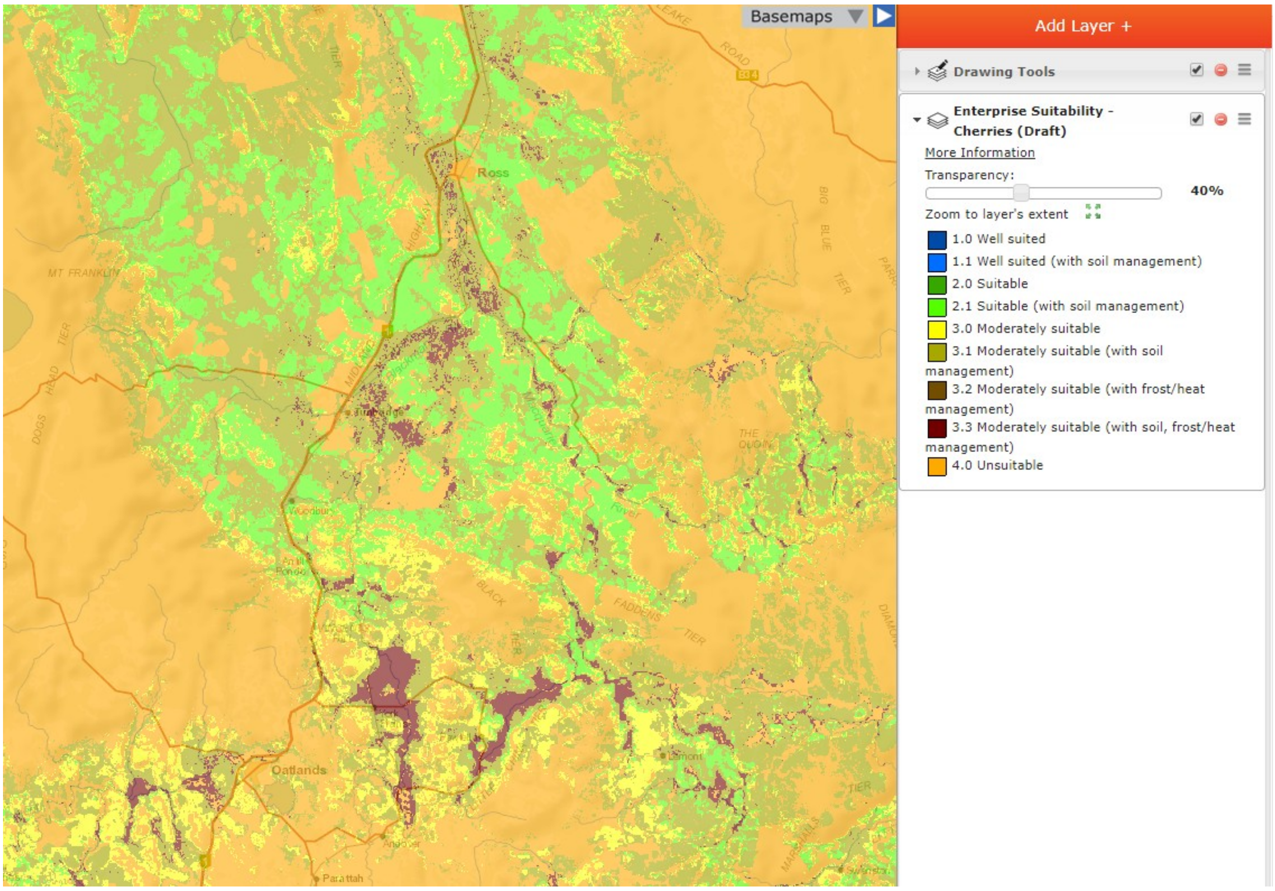

Figure 2. Enterprise Suitability - Cherries (Zoomed to Midlands Area)

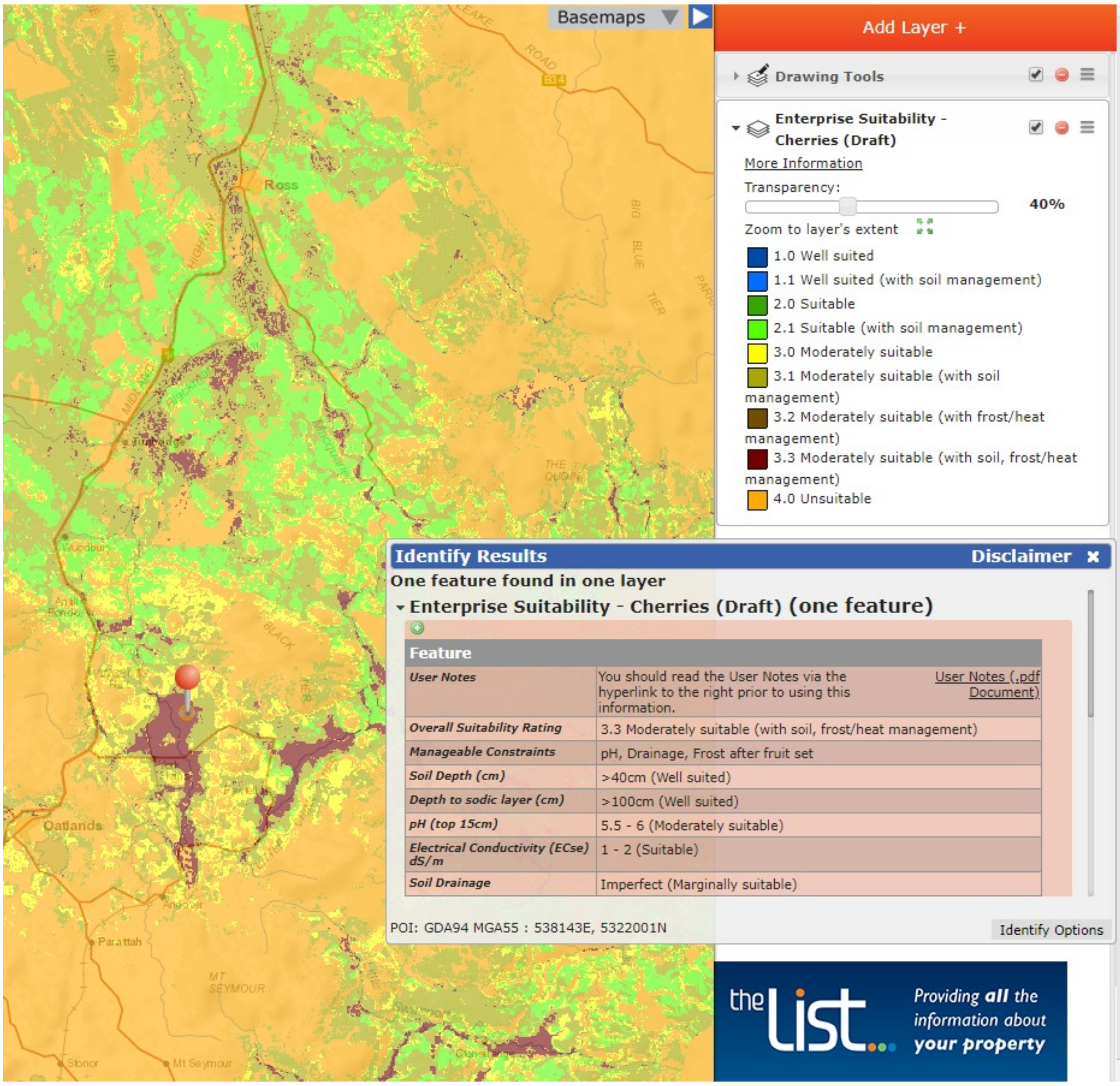

Figure 3. Interactive Map Query - Cherries

Online Statistics (Internet Map Visits)

From the six months (April to September 2018) using the previous 80m resolution Version 1.0 ESM, there has been in excess of 143,000 map visits ('hits') on the LISTmap portal for the original 20 enterprises, future climate suitability scenarios, and input soil and climate parameter maps. The most popular enterprises visited were Sparkling/ Table Wine Grapes, and blueberries during this period (Figure 4).

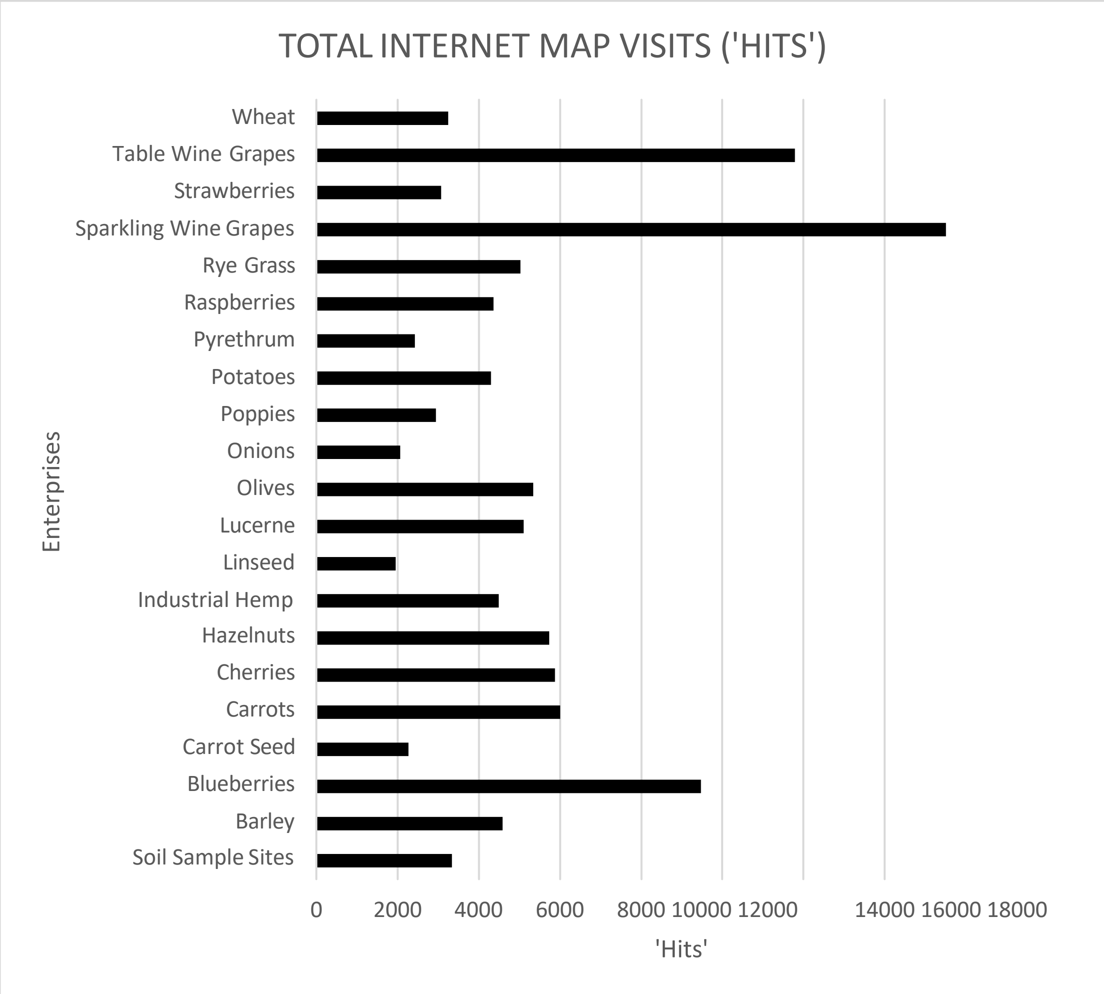

Figure 4. Total Internet Map Visits (April to September 2018)

Discussion

From the number of internet visits to the LISTmap portal in the six months, April to September 2018 (> 143,000 'hits'), it is evident that the ESM products have received good exposure and subsequent interest in Tasmania. Industry support and engagement has been manifested through the WfP program and TIA, leading to industry involvement in assessing suitability mapping for each enterprise by expert knowledge and known extent, subsequent feedback, and adjustment to suitability parameter ranges. Additional suitability parameters and enterprises have also been introduced in response to industry and TIA requests suggestions.

The ESM and Versatility mapping is intended to provide a guide to the locations and areal extents which will have the greatest likelihood of having optimum soil and climate conditions for an enterprise to succeed, and identify which soil and climate productivity constraints might require managing as an indication of potential investment inputs. It is also suggested that further due-diligence is necessary in the form of more thorough paddock or property-level investigations into soil and climate conditions, and other biophysical parameters not covered by this iteration of ESM. (e.g. wind, solar radiation and humidity). Other socioeconomic and environmental considerations will also be required in terms of zoning, neighbouring land uses, distance to processing and markets, and locations of threatened flora and fauna species.

The ESM is supported through the WfP Program by a suite of farm business planning tools, such as Gross Margins Analysis Tools for each enterprise with market outlooks (DPIPWE, 2015a). This provides basic economic analysis for any investor or farmers wishing to diversify or intensify existing farmland, and when combined with the ESM can help identify new areas for investment. The products also help new or existing industries to analyse latent agricultural growth in Tasmania by determining how much suitable land could potentially become available. The ESM could also aid in the process of locating ideal positions for new processing facilities, for example. Table 3 shows an example of potato potential, and the extent requiring some form of soil management input.

Potato - Suitability Class	**Hectares**
1.0 Well suited	25,973
1.1 Well suited (with soil management)	52,029
2.0 Suitable	1,044,955
2.1 Suitable (with soil management)	64,1906
3.0 Moderately suitable	493,629
3.1 Moderately suitable (with soil management)	170,651
4.0 Unsuitable	4,389,381

Table 3. Potential Area - Potato Suitability

The DSM, climate modelling and ESM production has provided a new digital data infrastructure for Tasmania that has and will serve a multitude of additional uses. For example, the ESM has provided inputs into the new Tasmanian State-wide Planning Scheme (Macquarie Franklin and Esk Mapping and GIS, 2017), aiding the improved identification of agricultural and rural land resources, while the DSM is informing other non-agricultural environmental analyses, such as organic soil extent in the Tasmanian remote World Heritage Areas.

The ESM framework is intended to be a dynamic process that will improve as new soil, climate and covariate data is collected or becomes available; while important agricultural areas where modelling uncertainties are highest can be targeted for new data-collection campaigns. New enterprises can be added as market opportunities emerge, or as the changing climate dictates. Future enhancements are also planned with the development of additional soil and climate input parameters, such as wind, humidity, with real-time and forecast sensor-driven spatial outputs such as temperature, frost-risk and soil moisture. The ESM will help optimise Tasmania as the ‘Digital Agriculture’ (TANG et al., 2002) future evolves, providing the framework to link, spatialise and utilise sensor-networks and remote-sensing technologies.

Conclusion

The Tasmanian Digital Soil Mapping, Climate Modelling and Enterprise Suitability Mapping has formed a high-resolution, digital, spatial resource to support farmers and investors in determining where agricultural growth in Tasmania is feasible, in terms of diversification, intensification and the introduction of new agricultural commodities. It forms part of the Tasmanian Government ‘Water for Profit’ Program to help maximise irrigation investment benefits, and has engaged industry in terms of suitability ruleset development, new crops and mapping endorsement. It provides improved understanding of the important soil, climate and terrain parameters relevant to specific enterprises and land use types, and identifies what economically feasible management inputs might be required to improve suitability, and maximise productivity. The mapping also identifies location-specific vulnerable soils information with relevant management guidelines that might need to be considered to ensure any resultant agricultural growth remains sustainable in terms of soil, food and water security.

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