An analysis of wine industry impact and risk for earthquakes in Australia and globally: Part 1: Historical Impact Analysis, Exposure and Preliminary Results

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Abstract

Wine. A multi-billion dollar industry in Australia which provides over 1% of our exports, it drives business, deal-making and is both a lifeline for those working in the business, and an important commodity. The loss of various back vintages in an earthquake can often mean that the wine is gone forever. Similarly, the loss of a harvest via steel tank failures and perhaps damage to the winery itself often can mean the end of a winery, or at least the loss of two harvests. Although there are a number of research articles centred on the dynamics of steel tanks, a holistic view of the potential impact of earthquakes on the wine industry has not been published as of yet on the basis of historical events.

A database of wineries and wine regions globally is presented with the initial scoping of their hazard and risk. In the scoping study, many wineries show high vulnerability although having a relatively low seismic hazard, thus resulting in significant risk due to non-structural and contents damage based on the previous models. Over $15 billion in losses to wineries has been found as a result of earthquakes globally. This analysis will be updated with the new 2018 Geoscience Australia model (Allen, 2018b) for the 2019 conference.

Keywords: winery risk, exposure modelling, historical earthquakes, vulnerability, global risk

Introduction

Earthquakes have caused many historical losses to wineries globally, mostly due to structures; non-structural components or simply contents losses, as shown in the CATDAT Damaging Earthquakes Database. However, there are only limited records of any impact within Australia to wineries (mostly due to bottle breakage). The probabilistic risk to wineries in Australia however is not trivial for earthquakes.

Analytical and empirical loss models have been created for components of wineries in different parts of the world for wine barrels. Empirical damage collated from the San Juan 1977, Chile 2010, Napa 2014 and other earthquakes provide useful data outside of Australia. In addition non-structural component functions for contents are shown such as wine barrels, bottles and wine cases.

Steel tank failures have been explored in the 1977 San Juan event by Manos (1991); the 2010 Maule, Chile earthquake by Gonzalez et al. (2013), the 2012 Emilia earthquakes by Brunesi et al. (2014) and the New Zealand earthquakes of 2013 by Rosewitz and Kahanek (2014); the 2014 South Napa earthquakes by Fischer et al. (2014) and the Kaikoura event of 2016 by Dizhur et al. (2017). These mostly show failure modes of buckling in the insulation panel shell of tanks; failure of base frame supports in various forms depending on being legged or flat-bedded tanks) and tank collapse and wall perforation. In the Chile 2010 event, tank collapse and support was widespread. Depending on the support type, and volume of wine within the tank, various failure mechanisms are observed. Connecting structures such as catwalks, ladders, walkways and connected racking systems are often also heavily damaged.

There have been many historic events which have affected wineries via earthquakes. Any list of events is likely an underestimate given that information about losses in the wine industry are often difficult to come by post-disaster. In order to undertake an evaluation of potential earthquake impacts the lack of damage data for wineries in Australia means that lessons need to be learned from past events in other countries in order to adapt any functions and/or create applicable non-analytical (semi-empirical or empirical) vulnerability functions.

The typical risk assessment process has been used in order to model the exposure, hazard and vulnerability associated with earthquake events for the wine industry.

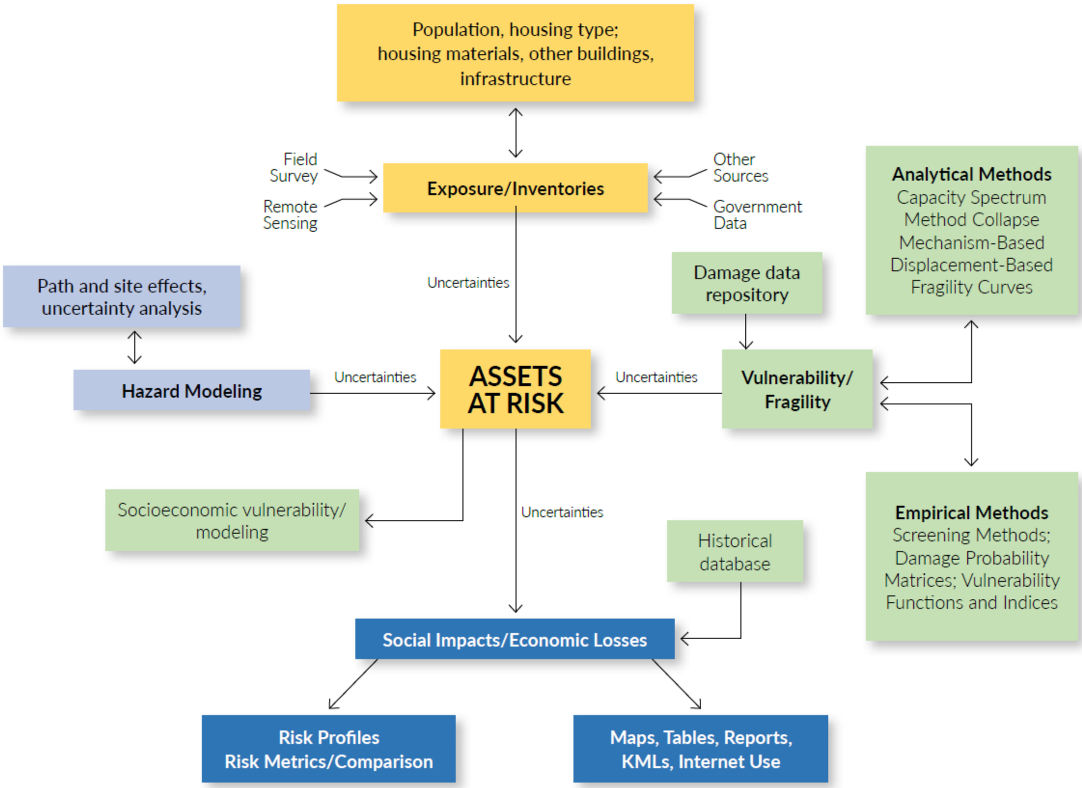

Figure 1: The risk assessment process for wineries to be used in this study

The losses globally from natural disasters have continued to increase in the past few years as shown below from the CATDAT database in country-based CPI adjusted US dollars. However, these losses below do not include the direct losses to agriculture in many cases. The losses in the wine industry in 2017 from frost exceeded 15 billion Euros from a single event in April. In addition, hail events are often not included in the overall loss estimate databases, thus causing the drought/temperature and storm losses to be less than expected.

When focussing just on earthquakes, the full sectoral impacts are often not counted for historic events meaning that in most cases, winery and wine losses have not been included in the losses seen above meaning that separate studies need to be undertaken.

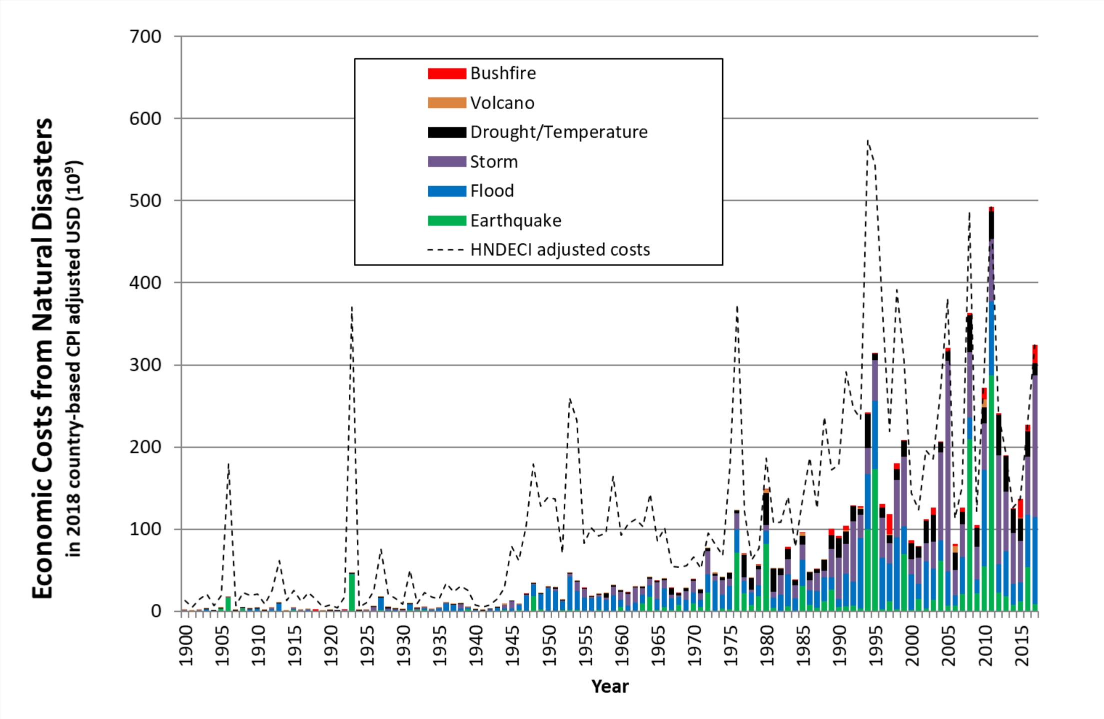

Figure 2: An updated economic costs diagram from 41,000 natural disaster events in the CATDAT Damaging Earthquakes Database in 2018 USD from 1900 to 2017 including the earthquake portion in green.

Method: Exposure

The wine industry globally produces around 30 billion litres of wine officially. By collecting data from country level assessments from the wine industry around the world, it was possible to produce a global map of wine production. This was checked against data from Anderson et al., 2017a and 2017b, where for the major markets of around 55 countries, this data has been collected annually.

The exposure datasets were developed using the following sources:-

- OSM data extraction of wineries, polygons of vineyards and landuse using QuickOSM, Osmosis, Overpass and QGIS
- Landcover dataset extraction
- Geology and soil data from local and national sources.

For the wine regions globally, the country wine authority and government websites were consulted in order to determine the names and locations. Over 7,500 regions were collected globally, allowing for the exposure to be applied at these locations in GIS using regional agency boundaries as well as GADM, SALB and World Bank boundaries for the administrative areas.

Using the database of Anderson and Aryal (2014), the grape types as well as regional naming were determined and spliced on to the wine regions. This data is important in order to create a detailed assessment of the impact of an event on production. However, for earthquakes the main issue is the structural and non-structural components of wineries rather than the production itself (given that the vineyards only in rare cases have suffered damage (lateral spreading, landslides, liquefaction, tsunami have caused issues previously).

Thus, websites of wineries, geocoding APIs as well as simple winery checks using Vivino gave the data for the sampling of winery typologies around the world. In many cases for the larger wineries, the production facilities are reasonably similar with either steel tank fermentation, or barrique style fermentation with either masonry, concrete or most commonly light steel construction. For the buildings housing rare wines as well as the cellar door, these are traditionally older and mimic well the local construction typologies, or chateau style finishing, but either out of masonry or RC.

Over 7500 grape wine growing regions globally in 131 countries in as diverse places as Tahiti, Bhutan, Lesotho and Indonesia have been mapped as part of the study – this represents the largest survey of wine regions exceeding locations known in all wine encyclopaedias. Around 100,000 official wineries (as of 2017) make up this number, with many other home-made and dormant wineries in addition to this.

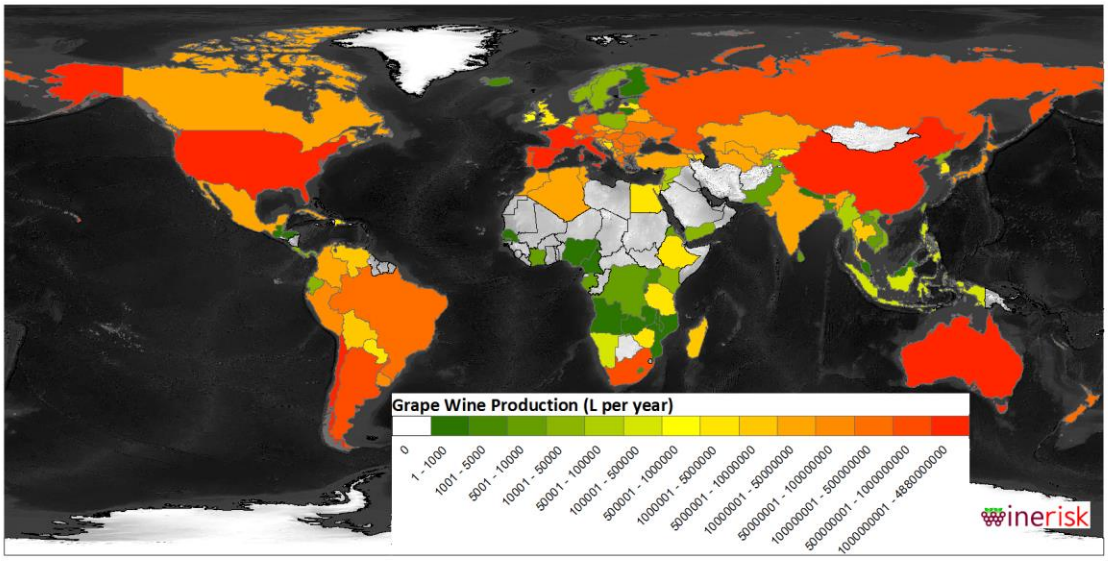

Figure 3: Grape wine production per country in litres per year (FAO, WineInstitute, OIV and own estimates)

Over $650 billion (or just under 1% of global GDP) represents the wine industry footprint, with about $300 billion of this being direct; this is a major industry, and one that impacts governments and private citizens. In terms of capital stock around $490 billion is associated with the wine industry. This was collected from capital data from wine industry websites and detailed evaluation of the investment in vines, structures and capital assets.

However, it was important to classify the exposure metrics as part of the risk analysis. Two metrics were used:- Capital stock, and GDP.

Type	Definition	Parameters included
Capital Stock (gross)	Replacement cost of all assets to the building standards at the time of the event. Improvement is not included.	Structures, tanks, wine barrels, contents, (wine), vines, infrastructure
GDP (flows)	Gross domestic product associated with the wine industry	All production and flows associated with the wine industry

It is important to characterise the capital stock and GDP outside of Australia, to see the importance of the wine industry comparatively with other countries globally. It can be seen that in terms of direct GDP, Australia ranks less than France, Chile or Portugal, when examining the wine industry. However, it is also important to note that the capital stock of Australia is very high, meaning the potential exposure to earthquakes make it significant especially given very vulnerable components with respect to earthquakes in Australia compared to other locations around the world in higher seismic regions.

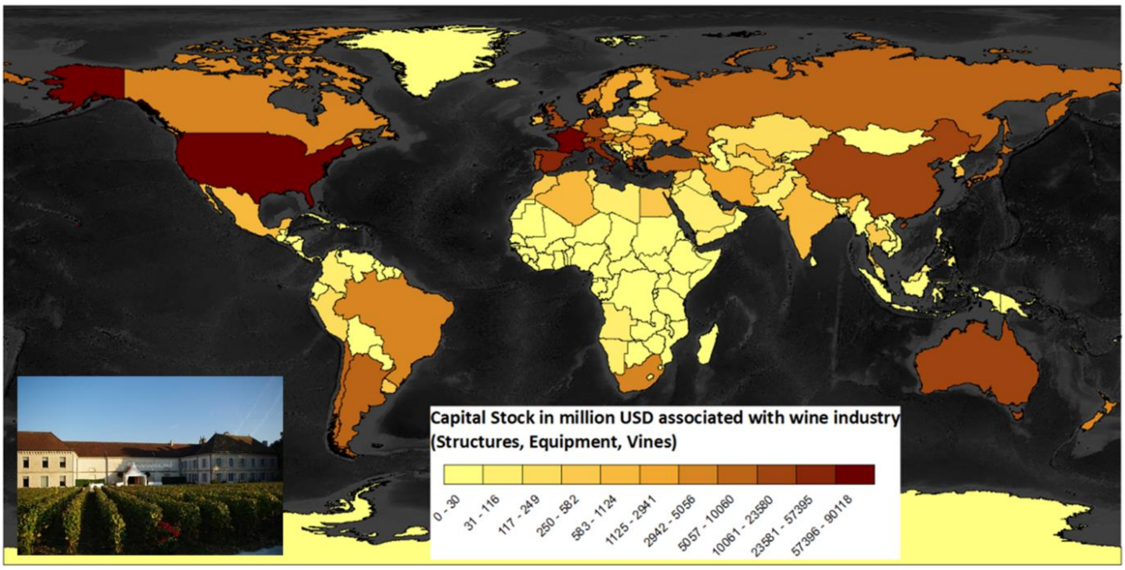

Figure 4: Capital stock per country associated with the wine industry. France and the USA have upwards of $60 billion in capital stock within the wine industry.

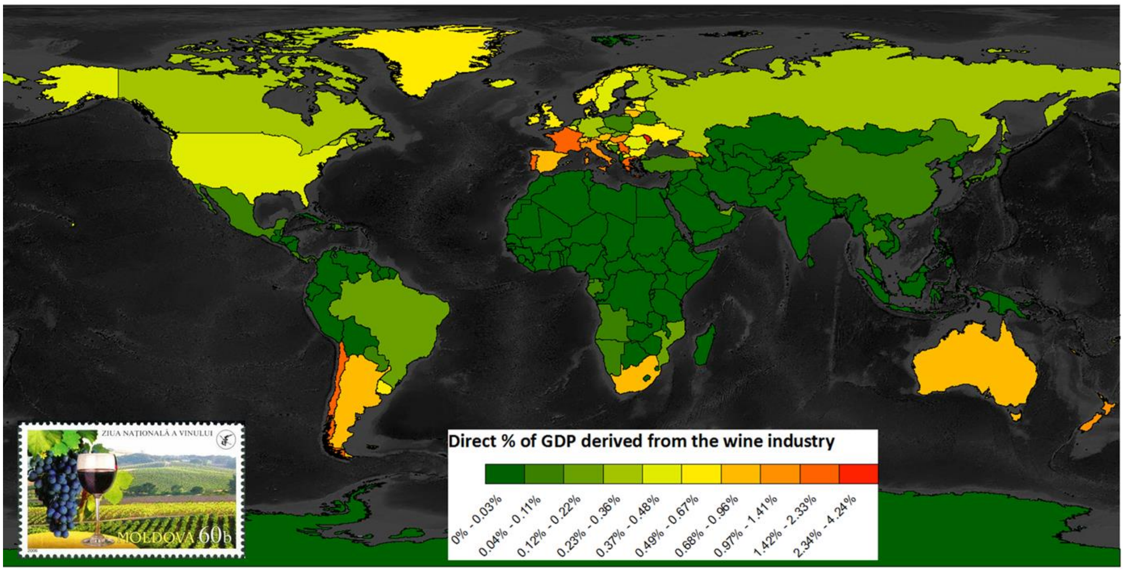

Figure 5: GDP per country derived from the wine industry.

In Australia, the wine industry produces in the order of 1 billion litres putting it within the top 10 countries globally in terms of output depending on the year and contributing about 5% of production globally.

To characterise the wine industry, the addresses of wineries were geocoded as well as layers of land use via OSM and other sources were used in order to develop a location based geodatabase across Australia in order to distribute the value of capital stock and value of stocks. Again, Anderson et al. (2014, 2015), have produced a definitive guide to the exports, value per L of wine and other metrics for many of the wine regions in Australia, so this was then spliced on to the location data in order to produce a value per winery location in terms of the flow metrics.

The values of vines, winery types and infrastructure has been determined using splits of capital stock based on wine industry data, and is valued in the order of $19.6 billion USD. The GDP associated with the wine industry is in the order of $10.2 billion USD as of 2018.

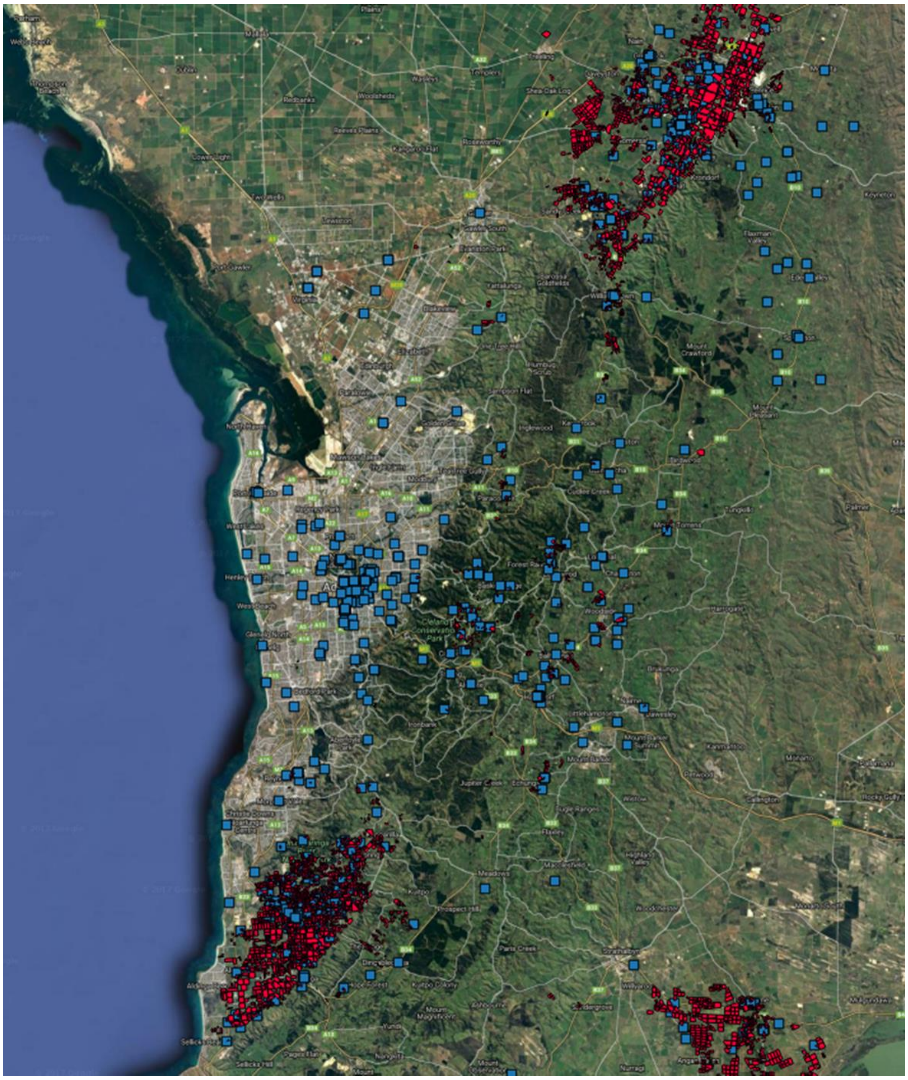

Figure 6: An example of the database across the Adelaide region showing vineyards (red) as well as the headquarters of each winery (blue). It can be seen that many of the headquarters are in the city center. This means in some cases there is a distributed portfolio for the wineries (however it should be noted that some multi-nationals also host their headquarters in Australian cities).

Historical Earthquake Event Losses to the Wine Industry

The investigation of post-disaster losses on wineries was done from a number of different sources including loss databases as well as newspapers and wine industry websites such as Decanter and Wine Spectator. The CATDAT Damaging Earthquakes Database has been used to extract earthquakes in which direct damages to the wine industry occurred. Nearly every damaging earthquake has knocked bottles off shelves etc. but in this study we have examined non-stock losses.

The 1906 San Francisco earthquake was one of the first since 1900 to occur in wine country with damage descriptions. Back in the early 1900s, the center of the wine industry in California was around San Francisco with the businesses, headquarters and storage based there. The 2010 Maule Chile Earthquake damaged winery assets and caused 125 million litres of wine to be lost, with a total bill approaching $1 billion. Napa escaped with somewhat less damage until the 2014 earthquake causing over $400 million in damage (Almufti et al, 2015).

In the last 10 years at least 25 earthquake events have caused significant damage to wineries including the 2009 L'Aquila, 2010 Chile, 2011 Christchurch, 2012 Mirandola, 2013 Marlborough, 2014 Napa, 2015 Iquique, 2016 Kaikoura, 2017 Mexico.

Although from the damaging database, only 85 events were classified as having damage to wineries from earthquakes, with some of the major ones listed in Annex A (1791 events were seen across all perils with most being hail or frost. However, when combining this with the intensity maps of the damaging earthquakes database from 1900 onwards 4,907 earthquakes are covered out of 10,312 damaging earthquakes since 1900, then 1497 of them (ca. 15%) are shown to have an intensity 6 or above for at least 1 wine region in the study. When remodelling the other events using the theoretical shakemaps (rather than observed) then this number expands to 2,209 events. (ca. 22%). This is not to say that there are observed losses, as some of these wine regions may not have existed at the time of the event (that being said, some previous wine regions may not exist now – such as in Algeria – the world's largest wine producer), but it is possible that these events caused issues.

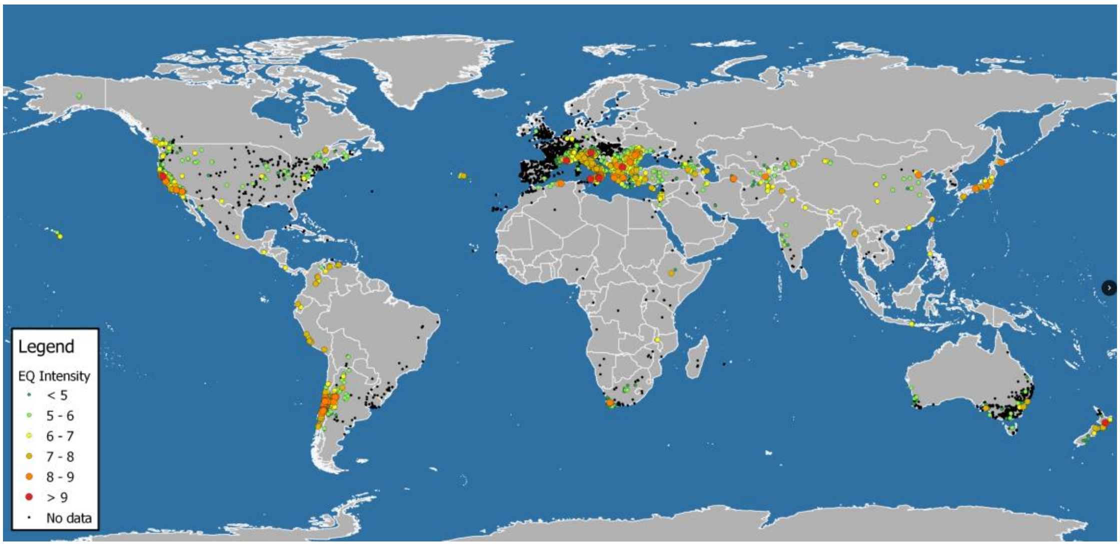

Figure 7: Every earthquake since 1900 in terms of the maximum intensity seen at each wine region.

Such a process allowed for damaging earthquakes to be identified within the series where explicit losses were not seen in literature within CATDAT. Two of these events were tested in order to see the applicability of such assumptions as to if they really did cause damage to wineries and if this is representative today.

The 1904 Plovdiv earthquake occurred in Bulgaria was centered very close to two of the big wine regions in the country, and thus a search was made as to the potential damage within the Plovdiv event however without luck as yet.

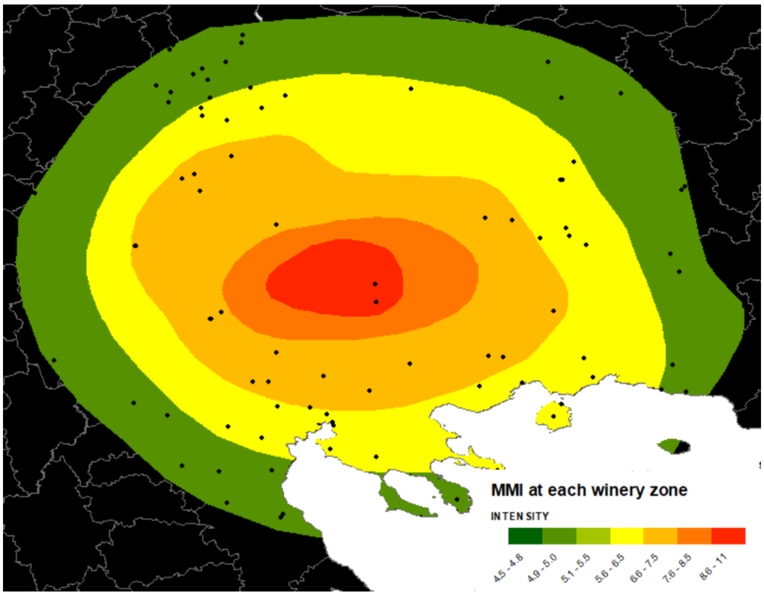

Figure 8: The isoseismal and wine region exposure (black dots) in the 1904 Plovdiv earthquake in Bulgaria.

The 1909 Lambesc earthquake in Provence caused around $14.5 million dollars damage back in 1909 ($2.2 billion in 2018 dollars via the HNDECI). It was the largest event to hit France since 1900. It can be seen that over 330 wine regions are located in the potentially damaging shaking locations and 68 in the very damaging locations. The wine industry has expanded significantly since 1909 in France, and thus, this would likely cause major issues in the wine sector today. Searching through the worded archives, many references are found towards the old Lambesc wineries/winemaking facilities, and that the entire town including them was destroyed. Today, 777ha of vines are in Lambesc within the new town.

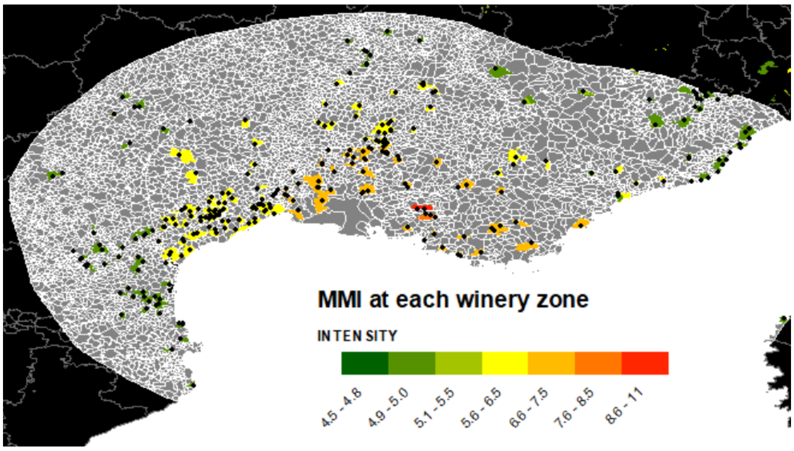

Figure 9: The isoseismal, wine region exposure and overlay of the 1909 Lambesc earthquake in France.

Historical events globally where at least 1 entire region has been above MMI8.0 shows that 65 events consisting of 96 Admin 2 wine regions (including 852 wine regions within them) have occurred since 1900 to 2010. Most vulnerable locations include the south of Italy, the Argentinian and Chilean wine regions of San Juan-Mendoza and Valparaiso-Casablanca Valley respectively. An additional 14 events have occurred since the start of 2011, leading to a total of 79 extremely damaging events for the wine industry somewhere in the world which allow for more in depth study of the most damaging effects of earthquakes on wineries and their associated structures.

Figure 10: Years of some of the most damaging events around wine regions around the world in CATDAT

When focussing on Australia, no events within the intensity VIII or above range with respect to wine regions are seen except for a few headquarters based in Newcastle as a result of the 1989 earthquake event. The 1897 Beachport earthquake would have exposed the Robe and Mt. Benson wine regions to significant shaking had they existed, as well as VI-VII shaking around Coonawarra. The expansion of wine production in Australia, has created diversification to reduce the possibility for a major hit to the entire wine industry, but has the ability to significantly impact a group of wine regions.

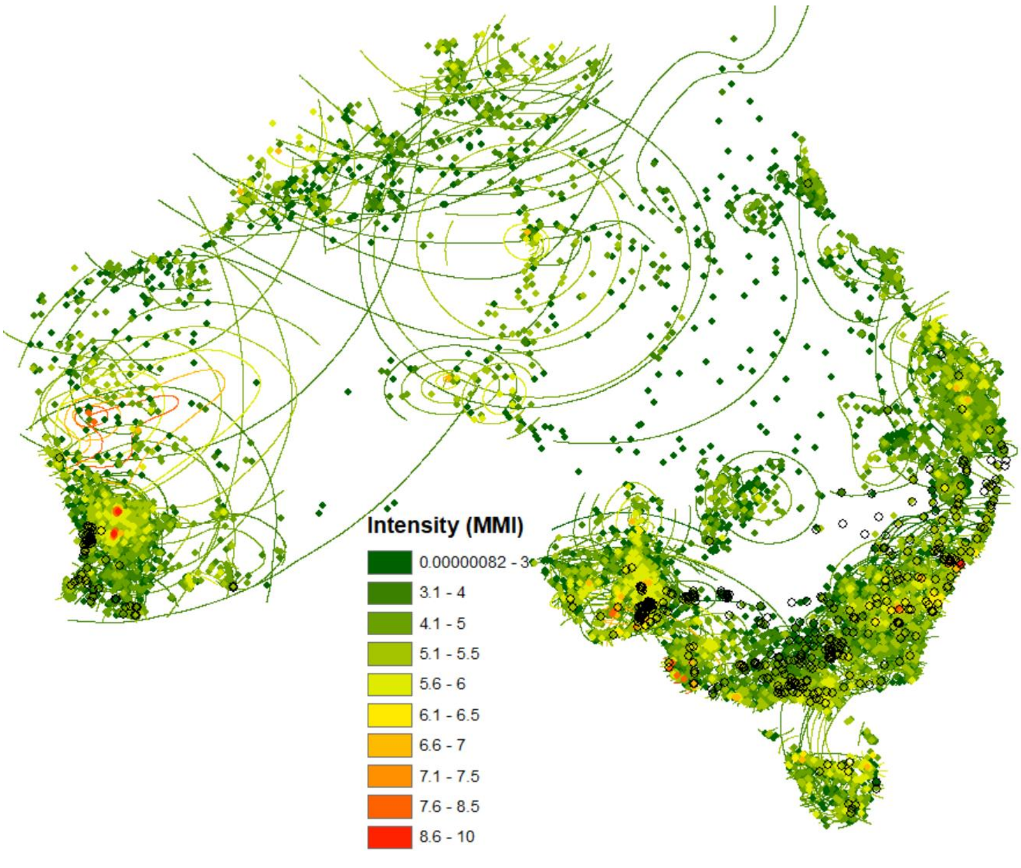

Figure 11: Intensity bounds as determined through the historical intensity maps of McCue (1995, 2013, 2014), Malpas (1991), NLA (2010) and other archives

Vulnerability and Risk of Winery Components to earthquakes

For vulnerability, a flat insurance-based curve was used based on the losses seen from Napa, Chile, New Zealand and other components, rather than the detailed vulnerability in Australia as much more research is required for the various locations in terms of code implementation and building practices within the Australian winery stock with regard to connections of steel tanks, rare wine storage practices and production chains.

The median functions vs. intensity are shown given the lack of past event PGA data.

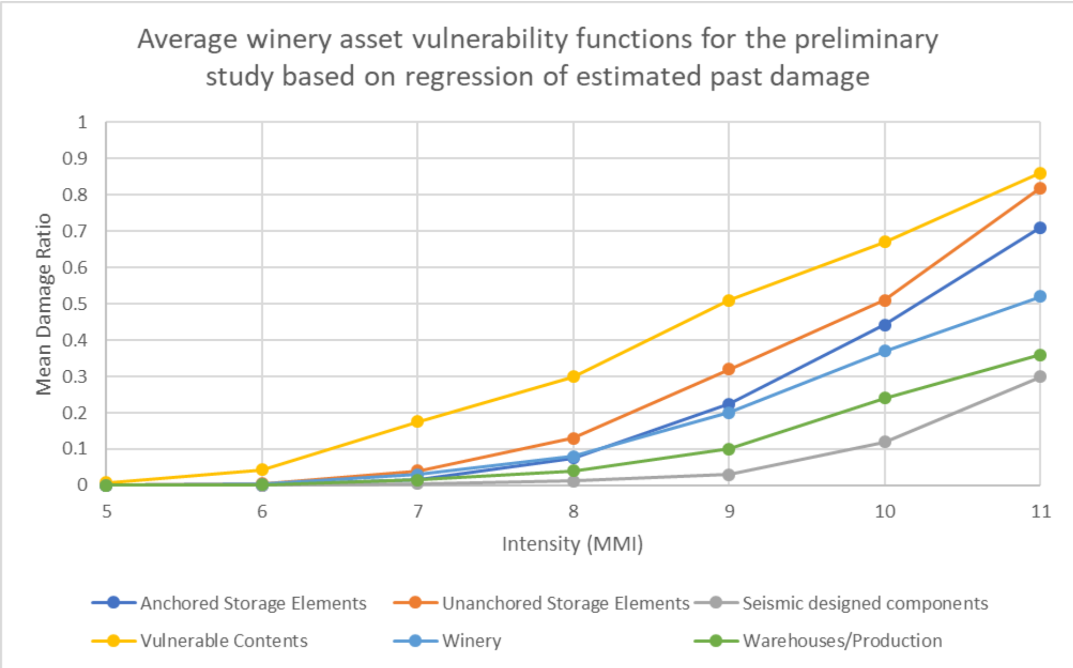

Figure 12: Vulnerability functions as determined through empirical case studies as used in the preliminary version of the model.

Given the investment in analysis from historic events, detailed vulnerability functions along each component have not as yet been included.

As an initial screening tool to examine the locations where wineries are exposed to the highest hazards, an index was formed based on stochastic event-based modelling from various entities. Where available, models were used from the World Bank, KIT and CEDIM, PCRAFI, SWIO, GEM and other entities to develop the hazard estimate. For Australia, the model of Schäfer et al. (2015) was used, however this will be re-evaluated given the improvements in earthquake catalogues as part of the work from Allen et al. (2018b). The metadata and analysis can in most cases be found on www.thinkhazard.org.

In this case, the 100-year hazard, 475-year hazard and 2500-year hazard were used as three points on the curve to examine the hazard with respect to earthquakes for each of the 7500 wine regions with a conversion used to intensity. This was the first step towards a global stochastic earthquake model for wineries which will be undertaken once the structural database is completed.

An earthquake risk index has thus been built up from various stochastic models globally (KIT/CEDIM, World Bank, GEM, PCRAFI, SWIO) and with the combined building index data and flat vulnerability curve, an initial first estimate can be made of potential losses.

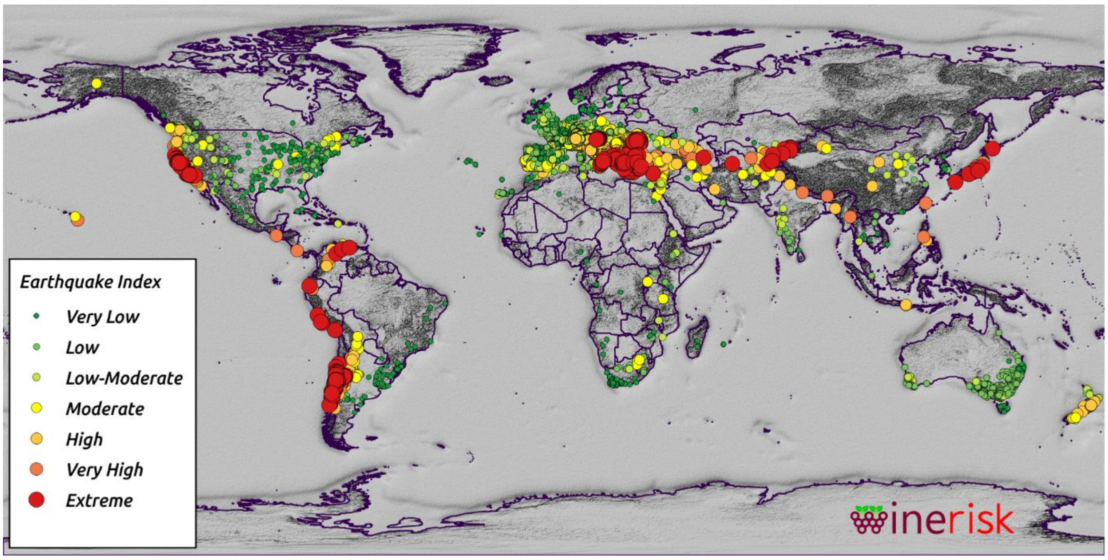

Figure 13: Earthquake relative risk index for each wine region globally.

The changing nature of the wine industry around the world has exposed wineries to the hazard although the historical event losses have not been seen. Places like Ningxia in China, are home to some of the world's largest wine manufacturing and growing, but a large earthquake has not been seen there for around 100 years. Indeed, the world's most deadly earthquake of all time – the 1920 Haiyuan earthquake caused over 273,400 deaths, and was closeby, however the 1739 M8.0 earthquake occurred right along the Helan Mountains where many of the wineries are located due optimum growing locations. Thus, the model shown above would likely underestimate locations such as Ningxia.

When checking some locations in Australia and New Zealand on the basis of this analysis, the following estimates are seen for the annual expected losses to wineries from earthquake (however, this may be influenced by the lower vulnerabilities seen through other locations).

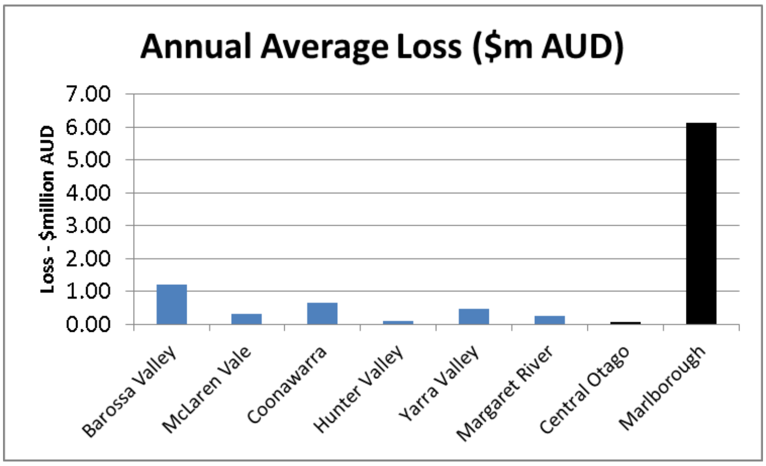

Figure 14: Annual average loss as expected from a 10,000 year stochastic run of earthquakes in selected wine regions within Australia using Schäfer and Daniell, 2014; Schäfer et al. 2015.

Conclusion

This study provides a first order analysis of global and Australian wine risk, however more research is required into a full risk analysis for Australian wineries. It can be seen that wine regions such as Barossa Valley potentially have significant risks associated with earthquakes but likely a lot less than locations like Marlborough in New Zealand which have already seen significant damaging events four times in the last 8 years.

Many events have been found as part of this study which can provide the basis for detailed analysis of the effects of earthquakes of components of wineries. Given the large asset values associated with the industry, as well as the vulnerable nature of certain components such as the cellar doors themselves, rare wine collections, barrels and steel tanks, the topic of earthquake risk in Australia cannot be discounted for wineries.

The global analysis of the wine industry risk shows a direct correlation to hazard, given that flat vulnerability functions were used globally. This will be changed in upcoming analyses using some of the detailed studies mentioned in the literature. In addition, the new hazard studies (Allen et al., 2018a, 2018b) will be used in part 2 of the study.

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Annex

Annex A: Earthquakes with a major wine industry impact as determined through CATDAT

Date	Country	Location	MMI	Mw
08/09/1905	Italy	Calabria	10	7.06
17/08/1906	Chile	Valparaiso	10.5	8.19
23/10/1907	Italy	Southern Calabria	11	5.93
28/12/1908	Italy	Messina	8.5	7.24
11/06/1909	France	Provence	11	6.2
13/01/1915	Italy	Avezzano	11	6.99
29/06/1919	Italy	Mugello Valley	10	6.18
07/09/1920	Italy	Garfagnana	11	6.48
11/11/1922	Chile	Vallenar	9	8.7
01/12/1928	Chile	Talca	9.5	7.7
23/07/1930	Italy	Vulture (Irpinia)	10	6.72
25/01/1939	Chile	Chillan, Concepcion	10	7.7
10/11/1940	Romania, Moldova	Vrancea Region, Bucharest	10	7.7
15/01/1944	Argentina	San Juan	9.5	6.8
22/05/1960	Chile	Valdivia	10	9.5

28/03/1965	Chile	San Felipe	9	7.4
15/01/1968	Italy	Belice	11	6.12
09/07/1971	Chile	Illapel,Los Vilos,La Ligua	9	7.8
05/10/1973	Chile	Valparaiso,La Ligua,Santiago	10	6.7
06/05/1976	Italy, Slovenia	Friuli	9	6.43
04/03/1977	Romania, Bulgaria, Moldova	Vrancea	7	7.5
23/11/1977	Argentina	San Juan Prov.	9.5	7.4
23/11/1980	Italy	Irpinia	10.5	6.89
07/11/1981	Chile	Valparaiso,La Ligua 6.9W	9	6.8
24/04/1984	United States	California	8	6.2
03/03/1985	Chile	Valparaiso	7	7.9
30/08/1986	Moldova, Romania Bulgaria	Vrancea region/Moldavia	9	7.1
17/10/1989	United States	Santa Cruz	8	6.9
30/05/1990	Romania, Bulgaria, Moldova	Vrancea region/Moldavia/Bulgalia 6.9W	8	6.9
15/05/1992	Uzbekistan	Andizhan oblast	7.5	6.2
26/09/1997	Italy	Marche & Umbria regions	8	6.05
03/09/2000	United States	Napa Valley	7	5
23/06/2001	Peru	Arequipa, Moquegua, Tacna, Ayacucho	8.5	8.4
31/10/2002	Italy	San Giuliano di Puglia 5.7W	8	5.78
15/08/2007	Peru	Pisco, Ica, Chincha	7.5	7.9
06/04/2009	Italy	L'Aquila	9	6.3
15/07/2009	New Zealand	Fiordland	8	7.8
27/02/2010	Chile	Curicó and Maule valleys, Rapel and Maipo	7.5	8.8
22/02/2011	New Zealand	Canterbury	9.5	6.3
11/03/2011	Japan	Northeastern Japan	10	9.1
17/04/2012	Chile	Valparaiso	8	6.7
20/05/2012	Italy	Mirandola 1	7.5	6
29/05/2012	Italy	Mirandola 2	7	5.8
16/08/2013	New Zealand	New Zealand, Marlborough	7	6.6
20/01/2014	New Zealand	New Zealand, Manawatu-Wanganui	7.5	6.2
23/08/2014	Chile	Chile, Valparaiso	8	6.4
24/08/2014	United States	Napa	8	6
16/09/2015	Chile	OS Chile, Coquimbo	7	8.3
09/02/2016	New Zealand	Marlborough, New Zealand	7	5.7
24/08/2016	Italy	Lazio, Italy	8	6
26/10/2016	Italy	Marche, Italy	5	5.4
14/11/2016	New Zealand	Marlborough	8	7.8
24/04/2017	Chile	OS Valparaiso, Chile	7	6.9
19/09/2017	Mexico	Puebla, Mexico	7	7.1

Annex B: Earthquakes with a major wine industry impact as determined through CATDAT where intensity exceeded 8 at the location since 1900 up until 2010 – the others since 2011 are shown above. Some events may be missing.

Year	**ISO**	**Admin 1 Region**	**Admin 2 Region**	**Max Intensity**	**Number of Geographic Wine Regions**
1908	ITA	Sicily	Messina	10.3	6

1904	BG	Blagoevgrad	Strumyani	10	2
1909	FR	Provence-Alpes	Lambesc/Bouches-du-Rhone	10	2
1931	NZL	Hawke's Bay	Hastings	10	2
1968	ITA	Sicily	Agrigento	9.8	4
1906	USA	California	Sonoma	9.4	5
1976	IT	Friuli-Venezia Giulia	Udine	9.2	2
1906	CL	Valparaiso		9	2
1907	TJK	Tadzhikistan Territories	Hissor	9	1
1913	BG	Veliko Tarnovo	Gorna Orhyahovitsa	9	1
1914	GR	Ionioi Nisoi	Levkas	9	1
1921	RS	Skopje	Cair	9	1
1923	JP	Yamanashi	Koshu	9	1
1939	CL	Maule	Cauquenes	9	2
1940	RO	Galati		9	2
1948	TM	Ahal		9	1
1952	JPN	Hokkaido	Ikeda	9	1
1977	ARG	San Juan	Caucete	9	2
1995	JP	Hyogo	Kobe	9	1
1928	CHL	Maule	Talca	8.9	5
1971	CHL	Coquimbo	Choapa	8.9	2
1971	USA	California	Los Angeles	8.8	1
1976	CN	Tianjin	Tianjin	8.732	1
1976	ITA	Friuli-Venezia Giulia	Udine	8.7	2
1969	ZAF	Western Cape	Ceres	8.6	1
1905	ITA	Calabria	Vibo Valentia	8.6	3
1977	AR	San Juan	Caucete	8.6	3
1910	DZ	Bouira	Ain-Bessem	8.5	1
1965	CHL	Valparaiso		8.5	1
1907	ITA	Calabria	Reggio Di Calabria	8.4	1
1994	US	California	Los Angeles	8.4	1
1918	USA	California	Riverside	8.2	2
1944	ARG	San Juan	Capital	8.2	2
1981	GR	Boeotia	Boeotia	8.2	1
1983	GR	Ionioi Nisoi	Kefallinia	8.2	1
1985	ARG	Mendoza	Junin	8.2	1
2010	CL	Libertador General Bernardo O'Higgins	Cardenal Caro	8.2	1
1963	MKD	Skopje	Cair	8.2	1
1906	ET	Oromia	East Shewa	8	1
1909	TW	Taipei	Taipei City	8	1
1911	KZ	Almaty	Talgarskiy	8	1
1912	MM	Shan	Taunggye	8	1
1912	TUR	Tekirdag	Merkez	8	1
1914	TUR	Isparta	Merkez	8	1
1915	ITA	Abruzzo	L'Aquila	8	1
1928	TUR	Izmir	Torbali	8	1
1929	NZL	Nelson	Nelson	8	1
1931	ARM	Syunik		8	1
1935	TUR	Balikesir	Marmara	8	1

1938	GR	Boeotia	Boeotia	8	1
1941	GR	Thessalia	Larisa	8	1
1942	EC	Guayas	Daule	8	1
1942	NZL	Wellington	Masterton	8	1
1957	GR	Thessalia	Magnesia	8	1
1957	US	Notio Aigaio	Dodecanese	8	1
1960	PER	Arequipa	Arequipa	8	1
1965	GRC	Dytiki Ellada	Ilia	8	1
1967	COL	Santander		8	1
1971	CHL	Valparaiso	Quillota	8	1
1977	RO	Bucharest		8	1
1979	RS	Ulcinj		8	1
1988	AM	Shirak		8	1
2003	JP	Hokkaido	Ikeda	8	1
2007	PE	Ica	Pisco	8	1