# VegMachine.net. online land cover analysis for the Australian rangelands

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**Abstract.** This paper documents the development and use of the VegMachine.net land cover monitoring tool. From 2002 to 2015, VegMachine® software was used by government agencies, natural resource management (NRM) groups and individual pastoralists in northern Australia to assess and benchmark vegetation cover levels. In 2016 the VegMachine.net website was launched to build a wider user base and assure service continuity. Users can now graph historical (1990–) cover on one or more user defined areas of interest (AOI), produce comprehensive paddock-by-paddock property monitoring reports, and view a range of land cover raster images through the website map panel. In its first 32 months of operation 913 users logged 1604 sessions on the website and more than 1000 of the website's most comprehensive monitoring reports were distributed to users. Levels of use varied; 26% of users ($n = 237$) have used the website more than once, and within this group a smaller set of regular users ($n = 36$) have used the site more than five times, in many cases to provide analyses to multiple clients. We outline four case studies that document the significant impact VegMachine.net has had on users including graziers, government agencies, NRM groups and researchers. We also discuss some possible paths forward that could widen the user base and improve retention of first time users.

**Additional keywords:** environmental change, grazing pressure, land management, rangeland health, rangeland management, remote sensing.

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## Introduction

Remote sensing assists rangeland monitoring at many scales, and the range and volume of available datasets derived from remote sensing has increased rapidly over recent decades. Correspondingly, as rangeland stakeholders have recognised the value of remotely sensed data to inform management and demonstrate stewardship, demand for these data has also increased (Reeves *et al*. 2015). In the rangelands, remotely sensed datasets have quantified and mapped topography, productivity, fire and ecological degradation (Reeves and Baggett 2014, Lawley *et al*. 2016; Ramoelo *et al*. 2018), but the most frequent focus has been on land cover. This may be because total cover is easier to define and remotely quantify than more complex attributes like erosion and degradation, and also because cover is a component/correlate some more complex attributes, which has encouraged its use as a proxy for them.

Australian agencies have invested heavily in remote assessment of vegetation cover, and particularly ground cover (Caccetta *et al*. 2007; Guerschman *et al*. 2009; Scarth *et al*. 2010; Trevithick *et al*. 2014; Guerschman *et al*. 2015; Scarth *et al*. 2015; Barnetson *et al*. 2017). Today, there are comprehensive multi-decadal ground cover time series derived from both MODIS and Landsat sensors that cover the entire country (Clancy *et al*. 2013; Stewart *et al*. 2014). These data can be used to monitor ground cover levels, and perhaps more interestingly, longer term patterns that correlate with other landscape attributes like land condition (e.g. Wallace *et al*. 2004; Karfs *et al*. 2009). Consequently, the ground cover archives are incorporated in a wide range of national, state and regional monitoring and evaluation processes (e.g. Bastin 2008; Leys *et al*. 2016; Queensland Government 2018; Zhang and Carter 2018).

At the farm scale, there is clear potential for these data to support better management. On-ground, site scale knowledge improves the interpretation of remote sensing (Lawley *et al*. 2016; Eddy *et al*. 2017), and most managers have detailed knowledge of their land and management history. This gives them unique capacity to interpret ground cover changes in the context of their paddock layouts, stocking rates and other local variables. In turn, they can better quantify the effects of their management on the grazed landscape, and so inform more sustainable management. Despite this potential though, the size of ground cover archives and the cost and complexity of interrogating them have hampered land manager access. This has left ground cover data out of the reach of most rangeland managers.

VegMachine® software was developed as a simple tool for interrogating large raster time series. It was built to bridge the gap

between emerging cover datasets and land managers wanting to use them (Beutel *et al.* 2004; Karfs *et al.* 2004). From 2002 to 2015 it pioneered land cover analysis for land managers and natural resource management (NRM) groups in the Australian rangelands (Thornes 2007; Beutel *et al.* 2015), allowing non-technical users to better understand the effects of management on landscape, and particularly on vegetation cover dynamics. Work began in 2015 to move VegMachine services to an online delivery mode, and in 2016 the VegMachine.net website was launched as a national land cover monitoring tool. The web service is not the only web-based tool providing ground cover analysis in the Australian rangelands (e.g. Zhang and Carter 2018, FarmMap4D 2018); however, it is the only nationwide web service that allows any user to monitor ground cover (1990–) at any location in Australia. Consequently, it significantly advances the way rangeland stakeholders measure landscape change, and their ability to understand the relationships between rangeland change and rangeland management.

In this paper we describe the VegMachine.net web service and how it is used. We then outline its history including that of the preceding VegMachine software. We detail the website's layout, underlying datasets and major functions. We then focus on user demographics and activity including four case studies that show how the tool is currently used. We conclude with some learnings from the website's development and a discussion regarding future developments on the website.

## Development history

In 2002, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) developed the VegMachine software for Microsoft Windows personal computers (PC). It allowed simple interrogation of large image time series. In particular, it could compare cover history on a user defined area of interest (AOI) with simultaneous cover levels on similar land types in the surrounding region (Karfs *et al.* 2004). The rationale for this comparison was that if the AOI and region shared both rainfall history and land type, any differences were likely management driven. This gave users insights into the impacts of past management decisions on the landscape. As part of the same multi-agency project, extension staff supported software users on 31 pastoral properties across northern Australia, providing software, training and annually updated property datasets (Peel *et al.* 2006). From 2005 to 2008 the same support was extended to an additional 16 properties western Queensland, and a final survey of software users showed that 75% agreed that the software was easy to use, and 53% agreed that having VegMachine influenced their land management (Beutel and Silcock 2008). However, two significant challenges were evident by 2008; the cost of face-to-face support for geographically dispersed users, and the difficulty of keeping users proficient on software they used irregularly.

The VegMachine software was updated in 2009 and a training package was developed in 2010 (Beutel *et al.* 2015). In Queensland, a new approach to delivery was also trialled to overcome the cost and proficiency issues identified above. Extension providers in the grazing industry were assisted to operate the software on behalf of grazier clients, freeing graziers from operating the software, deferring some support costs to

operators, and giving operators a useful client engagement tool. Between 2010 and 2015, more than 60 Queensland government, NRM and agricultural consultancy personnel were trained on the upgraded software, and provided with regional datasets. The software was embedded in the corporate activities of several agencies and NRM groups. The Department of Agriculture and Fisheries (DAF) used VegMachine in one-on-one extension activities, mostly in discussions about management practices. VegMachine was also used to evaluate potential investments on more than 300 grazing sites by the Fitzroy Basin Association (FBA) and North Queensland Dry Tropics (NQDT) NRM groups (Beutel *et al.* 2015). By the end of 2015 though, the software was due for either another update or transfer online to assure its continuity. Online delivery was viewed as a better option to reach more users, and work began in 2015 on the web service.

## The VegMachine.net website

The VegMachine.net website launched on 28th of July 2016. The site can be accessed for free via a web browser, with no user registration and no geographic restrictions on user queries. It was designed for a broad user group including land managers, agency staff and researchers, so website design focussed on maintaining a small number of simple layouts and workflows. This was intended to ensure most users could operate the website without significant support.

The main elements of the VegMachine.net homepage are a menu bar, graph panel and map panel. AOIs are defined by polygons in the map panel, which has tools for drawing, deleting, naming, importing and saving these polygons. The map panel can display a base map as well as images from seven cover time series. Users can search for locations within Queensland using land parcel identifiers, and nationally using street address or geographic coordinates. The website has several help facilities including a manual, help popups, and links to a YouTube channel with instructional help videos. The site offers three groups of tools; interactive analyses which are shown in the website graph panel (Table 1), delivered reports that users request on the website and receive by email (Table 1), and visual image displays that allow users to progressively view raster time series in the map panel (Table 2). These are each discussed below.

### Interactive analyses

Interactive analyses use code called an application programming interface (API) to interrogate cover data stored in the cloud, and deliver results to the website graph panel. These analyses can use either of two possible fractional cover time series – ground cover or fractional cover (Table 1) – both of which include an image for each season since summer 1990. The user defines their AOI in the map panel and then the AOI is passed to the VegMachine.net API. The API samples up to 4068 pixels of each seasonal image within the AOI. The sampled values statistically summarised, and the API returns the summary for display in the graph panel. Graphed data can also be exported as a spreadsheet or an image of the graph panel. VegMachine.net delivers three interactive analyses; single polygon analysis, polygon comparison, and PEPER analysis (paddock erosion predictor using RUSLE) (Table 1).

**Table 1.   VegMachine.net interactive analyses and reports**

Superscripts indicate the cover time series used in these products

| Product | Description |
|---|---|
| *Interactive analyses* | |
| Single polygon[A,B] | Seasonal time series analysis (1990–) of four cover fractions in a single area of interest (AOI). Includes monthly rainfall (1990–). Displayed in graph panel and exportable as image or spreadsheet file. |
| Polygon comparison[A,B] | Seasonal time series analysis (1990–) comparing average total cover (green + non-green fractions) and its percentiles from two separate AOIs. Includes monthly rainfall (1990–). Displayed in graph panel and exportable as image or spreadsheet file. |
| PEPER analysis[B] | Modelled estimate of average annual soil erosion from a single AOI under three separate historical cover scenarios. Displayed in graph panel and exportable as image or spreadsheet file. This report is only available for Queensland locations. |
| *Reports* | |
| Regional comparison[A] | Detailed analysis of seasonal cover across multiple AOIs (1990–). AOI cover is benchmarked against cover in similar land types in the surrounding region. PDF report including maps, time series graphs and summary table. This report is only available for Queensland locations. |
| Foliage projected cover[C] | Summary of recent woody vegetation cover[C] for single AOI. PDF report including map of woody cover levels in AOI plus tabular data summary. This report is only available for Queensland locations. |
| Ground cover[A] | Summary of cover[A] primarily for a single season in a single AOI. PDF report including map of ground cover in requested season plus tabular data summaries and graph of long-term cover fractions on AOI. This report is only available for Queensland locations. |

[A]Seasonal total ground cover (TERN AusCover 2017*a*).
[B]Seasonal fractional cover (TERN AusCover 2017*b*).
[C]Foliage projected cover (TERN AusCover 2017*c*).

**Table 2.   Raster time series displayed in VegMachine.net map panel**

| Product | Description |
|---|---|
| Ground cover | Medium resolution (30 m pixel) seasonal images (1990–) of three ground cover fractions (green, non-green, bare ground) (TERN AusCover 2017*a*) |
| Total ground cover | Medium resolution (30 m pixel) seasonal images (1990–) of combined green and non-green ground cover fractions (TERN AusCover 2017*a*). |
| Fractional cover | Medium resolution (30 m pixel) seasonal images (1990–) of three vegetation cover fractions (green, non-green, bare ground) cover. (TERN AusCover 2017*b*). |
| Sentinel fractional cover | High resolution (10 m pixel) seasonal images (2015–) of three vegetation cover fractions (green, non-green, bare ground) (TERN AusCover 2019). |
| Cover deciles green | Medium resolution (30 m pixel) seasonal images (1990–) of green cover fraction ranked against same season green fraction values at same pixel in all years of time series (TERN AusCover 2018). |
| Cover deciles total | Medium resolution (30 m pixel) seasonal images (1990–) of total cover fraction (green + non-green) ranked against same season total fraction values at same pixel in all years of time series (TERN AusCover 2018). |
| Persistent green | Medium resolution (30 m pixel) seasonal images (1990–) of estimated woody vegetation cover (TERN AusCover 2017*d*). |

The single polygon analysis returns a graph of average cover inside one AOI for each season (1990–). This is the simplest VegMachine.net analysis, and is useful where AOI cover histories are required. It also graphs monthly rainfall in the AOI to assist interpretation of results. The polygon comparison is a potentially powerful ground cover benchmarking tool. It contrasts cover in two AOIs, graphing the median and range of total cover on each site in each season along with monthly rainfall. In these analyses, cover on a well known site can benchmark cover on another site with similar land type and rainfall history. Since any significant difference in cover history is probably attributable to management differences (and not rainfall or land type), this analysis highlights the effects of management on cover. For sites outside Queensland, this is an accessible alternative to the more detailed regional comparison report (discussed below) which is only available for Queensland sites. Fig. 1 shows an example polygon comparison where cover on a site with consistently higher levels of cover benchmarks cover on a nearby site. Finally, the PEPER report estimates sediment loss from one AOI under three historical cover scenarios using the revised universal soil loss equation (Renard *et al*. 1997). PEPER is used by FBA, which co-funded VegMachine.net, for evaluations of potential NRM investment sites.

*Delivered reports*

VegMachine.net can deliver three reports – ground cover, foliage projected cover and regional comparison – to the user's email (Table 1). These reports are requested via AOIs in the map panel, and generated on cloud facilities shared with FORAGE (Zhang and Carter 2018), an online service creating and delivering climate and landscape reports for Queensland cadastral parcels. These PDF reports are delivered within ~20 min. The ground cover report includes a map, graphic and table summaries of total ground cover history for a single AOI. The foliage projected cover report provides a map and table summary of woody vegetation cover in an AOI. Both of these reports are identical to those served through the FORAGE service (Zhang and Carter 2018).
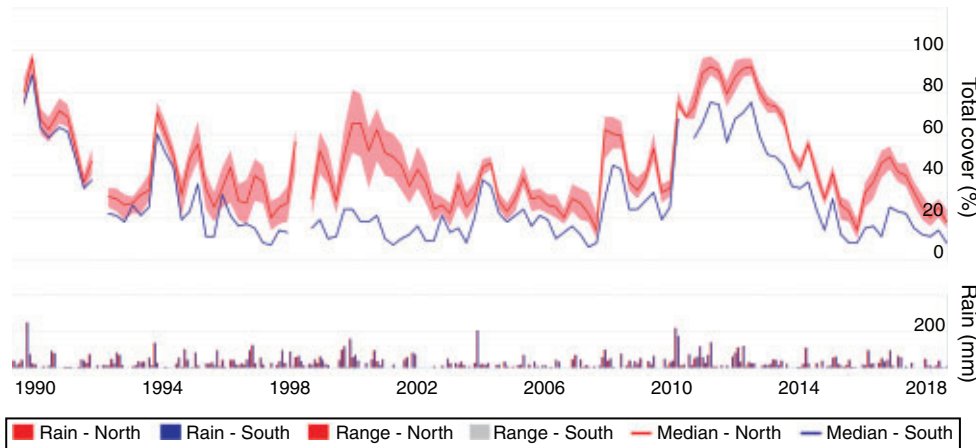
**Fig. 1.**   Partial screenshot from VegMachine.net polygon comparison of two adjacent sites that are separated by a fence. The two sites have been known to the authors since 2003, and the North site has had consistently more ground cover and better land condition than the South site over that period. Red and blue lines respectively show the median seasonal ground cover at each site, and the red band shows the 'Range' (actually 20th to 80th percentile) of ground cover values on the North site. The analysis reflects known conditions at the sites since 2003, and also suggests the observed difference extends back to the early 1990s. Since the two sites are in the same land type with a common rainfall history, management is the most likely cause of the observed differences. This analysis is available to all users, and is a potential alternative to the regional comparison, which is only available within Queensland. Labels have been enhanced to aid readability.
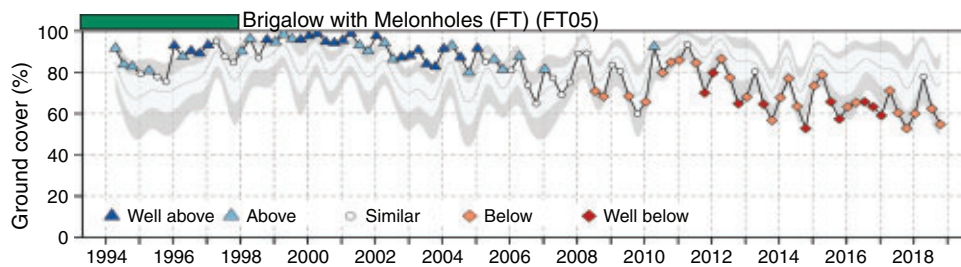


**Fig. 2.**   Extract from a regional comparison report showing total ground cover in part of a paddock that has been very heavily grazed from 2005. The pale grey bands show the percentiles of ground cover in the FT05 land type of the surrounding region (5th–20th: lower grey band, 50th: central grey line, 80th–95th: upper grey band). The overlayed time trace shows median ground cover in the same land type within the paddock. The symbols along the time trace classify cover in the paddock relative to the regional cover percentiles (Well below: <5th, Below: 5th–20th, Similar: 20th–80th, Above: 80th–95th, Well above >95th). This analysis shows cover in the paddock has declined dramatically since 2005, corresponding to the increased grazing pressure over this period. This trend is evident despite the presence of rainfall driven fluctuations in regional cover (higher in 2010–2012 and lower in 2004–2007 and 2013–2014). This analysis is available only in Queensland, but see the polygon comparison (Fig. 1) for an alternative approach outside Queensland.

The most important report delivered by VegMachine.net is the regional comparison report. This summarises ground cover in multiple AOIs, so can provide comprehensive ground cover monitoring for each paddock of a grazing property in a single document (a similar FORAGE document reports at land parcel scale). The report is particularly efficient if users already have existing paddock mapping, since they can upload their paddock vector files (SHP or KML) and immediately request the report. The regional comparison report includes a single page for each paddock (AOI), graphing ground cover history in up to three land types per paddock. Each graph also shows ground cover in the same land type in the surrounding region (Fig. 2), and thus effectively benchmarks cover in each paddock/land type combination against relevant region values. Grazing enterprises commonly own suitable digital mapping of their paddocks, making this information rich report very accessible for many grazing enterprises in Queensland. The regional comparison report has been critical in making VegMachine.net products more accessible to pastoralists, and we have actively encouraged extension/technical specialists working with graziers to produce this report for their clients. This arrangement has several advantages; it frees graziers from operating the website, provides the operator with a high value client engagement tool, and provides VegMachine.net with face-to-face third party client support.

*Image time series displays*

Users can also view seven separate raster time series in the map panel. These time series each depict different seasonal derivatives of cover datasets (Table 2). Any of these continent scale, seasonal images can be overlaid on a base map along with a legend to assist interpretation of the overlaid cover image. When time series imagery is displayed in the map panel users can toggle between image dates, adjust their transparency, or run the temporal series of images in a movie style format.

## User activity

Since July 2016, 1010 regional comparison reports have been requested and emailed to 145 VegMachine.net user emails addresses. Sixteen addresses account for 74% of delivered reports, and these addresses mostly belong to DAF and NRM extension staff working in the Queensland grazing industry. The presence of these high volume users shows that a third party support network has begun to form, and the case studies below indicate where many of the reports are ultimately directed.

Table 3 shows Google analytics data summarising the numbers of user sessions completed on the website up to 28 February 2019. A user session is a period of time in which a user (from Australia only) interacts with the website beyond opening the home page. 1604 VegMachine.net sessions lasting an average of 11.8 min ran in this period. The higher level of use by Queensland users (66% of all sessions) reflects the better functionality and greater promotion provided in Queensland, though more than 50 sessions were completed in all Australian states and territories except Tasmania.

VegMachine.net has had 913 users up to February 2019 (Table 4). The number of sessions per user is highly skewed with 676 users (74%) completing one session and 36 users (4%) completing more than five sessions. These numbers show a clear

**Table 3.  Google analytics data for VegMachine.net website (1 July 2016–28 February 2019)**

Columns show total number and average duration (minutes) of all sessions in each Australian jurisdiction

| Jurisdiction | Sessions | Minutes |
|---|---|---|
| Australia Capital Territory | 100 | 11.8 |
| New South Wales | 183 | 15.6 |
| Northern territory | 58 | 12.4 |
| Queensland | 1054 | 12.0 |
| South Australia | 80 | 6.4 |
| Tasmania | 9 | 10.3 |
| Victoria | 57 | 7.4 |
| Western Australia | 63 | 9.0 |
| Australia | 1604 | 11.8 |

**Table 4.  Google analytics data showing the number of VegMachine.net users completing a given number of sessions on the website (1 July 2016–28 February 2019)**

| Sessions | 1 | 2 | 3–5 | 6–10 | 11–20 |
|---|---|---|---|---|---|
| Users | 676 | 110 | 91 | 26 | 10 |

demand for the service, with many users trialling it and one-quarter returning to use it again. It is worth note that repeat-use is underestimated in these data. Google identifies users by a unique combination of their device and browser. If a user operates VegMachine.net on two device/browser combinations or clears browser cookies between sessions on the same device/browser, Google counts them as two users. Consequently, one-time users and total users (Table 4) are very likely overestimated, though it is unclear by what amount. Even allowing that single-use is overestimated though, a large group of users still must not have returned after their first visit. There are several possible reasons for this, but the two most likely are that some users struggle to operate the website independently so don't return, or some see insufficient benefit in repeat use after a first viewing. At this point in time we have no data to clarify the situation, but reducing one-time use is an obvious avenue for improving the service, and is discussed later.

VegMachine.net has clear potential to assist rangeland users in a variety of activities that require cover data and analysis (Cowley 2018; Russell-Smith and Sangha 2018; Chen *et al.* 2019), and its impact has been substantial given its recency. This is demonstrated in four case studies below, where it has been applied by users for a range of purposes.

- VegMachine.net products are used directly in the grazing community to assist in property scale management decisions. Beef producers Dan and Emma-Jane Burnham from Stonehaven near Thangool in Queensland are one example. They use regional comparison reports to benchmark ground cover and for 'identifying paddocks in need of more attention' (Brinsmead 2017; QRIScloud 2018).
- VegMachine.net is part of the extension practices of Grazing Best Management Practice (BMP) (Willis *et al.* 2017), a partnership between FBA, the grazing industry and the Queensland government to improve practices and sustainability in the Queensland grazing industry. Over 200 regional comparison reports have been provided to grazing enterprises participating in Grazing BMP audits and related extension activities. Enterprise managers use these reports to demonstrate their stewardship during audit, to document and interpret changes in their grazing landscape, and to communicate with family and other stakeholders in their business.
- Several NRMs regularly use VegMachine.net analyses to engage clients and evaluate potential NRM investments. FBA has generated more than 100 PEPER reports to evaluate potential investment sites, including 20 properties where $468 000 of Reef Trust 2 funding has been invested to reduce sediment runoff. Similarly, the Mary River Catchment Coordinating Committee have used PEPER analyses on 13 investment sites where $129 000 of Reef Trust 3 funds will be invested. NQDT has used ground cover analyses and regional comparison reports on more than 50 potential investment sites for planning and client engagement.
- VegMachine.net has provided data for several peer reviewed studies (Elledge and Thornton 2017; Saiz *et al.* 2018; Bird *et al.* 2019; Chen *et al.* 2019). These studies have extracted cover data from the site for both descriptive and analytical purposes, using the numeric and graphic outputs of the site.

## Discussion

The rationale for developing VegMachine.net was to reach more users and provide continuity for the ageing VegMachine software. The results of that development show that is possible to deliver land cover monitoring in an accessible online format. More importantly though, the user statistics and case studies show a demand for the service and a user community with a wide range of uses for the tool. VegMachine.net has exceeded the capacity of its PC forerunner, and provided a significant advance in the ability of users to remotely monitor land cover and understand landscape change. Consequently, it has widened the scope for more sustainable management decisions, better stewardship, better NRM investment and better science in the rangelands.

Online delivery has had several advantages. As expected, a larger and more diverse user group has accessed and interrogated the ground cover archive online. Online delivery also ensures that the site interface and data are equally current for all users. Finally, although we have not compared the relative costs under PC and online delivery, ongoing support per user is certainly less time consuming and very likely less costly when delivered online.

However, lower support costs also reflect lower capacity for face-to-face user assistance. One risk of this is that users will depart the website if they cannot find adequate online support to operate the site. Whether this happened to our users is unclear, since we don't have user survey data. It is possible that all our single visit users exited because site content was not what they wanted or were simply misclassified repeat visitors using a novel device/browser combination. However, given the large proportion of one-time users (74%) we think it is very possible that at least some users departed because they had difficulties and could not find sufficient help online. Anecdotally, users at our training events (where personal help is available) regularly request assistance, which indicates some users don't immediately master site operation without personal help. This shows the challenge of building a single tool for a diverse user group (e.g. graziers, technicians, extension providers, scientists). Obviously, users can be better supported through more face-to-face assistance, but online delivery cannot rely heavily on personal support. Factors like website design, better connecting particular users to particular workflows, and further development of the third party support network seem likely paths for future development if one-time use is to be reduced.

Historically, graziers have had little access to the type of data VegMachine.net provides, and improved access for this group is particularly advantageous. This is because most graziers know the layout and management history of their land, and can interpret ground cover changes through that prism. Multiple studies show local knowledge assists the interpretation of remotely sensed data (e.g. Karfs *et al.* 2009; Lawley *et al.* 2016; Eddy *et al.* 2017). The on-ground knowledge of graziers is no exception to this finding, and grazier access through VegMachine.net creates many positive outcomes. These include informing more sustainable management decisions, improved tools for communication with stakeholders, and better ability to demonstrate stewardship to markets and regulators.

One way to increase public use of large datasets like the ground cover archive is to provide users with multiple access points. VegMachine.net is currently one of several web services

that access land cover time series data (Leys *et al.* 2017; Russell-Smith and Sangha 2018). The costs, products and complexity of these services vary widely, but we should view the presence of multiple services as advantageous. For example, the VegMachine.net regional comparison report provides high return for effort if users have existing property mapping, since mapping can be uploaded and a report for all paddocks delivered promptly. By comparison, users without mapping must plot their paddocks in VegMachine.net before requesting the same report. This can be time consuming, and these users might prefer a less detailed land parcel report through the FORAGE website (Zhang and Carter 2018). The availability of multiple access points is beneficial for end users, and particularly less experienced users, but it also requires clear messaging to users about how services differ and whom they best suit (Whish 2016). This should be considered in future programs that promote the use of ground cover data and services.

Ground cover is one aspect of grazing land ecology, and it has some limitations that affect how it is viewed in VegMachine.net. At present the cover imagery in VegMachine.net is seasonal, so the most recent imagery is often at least three months old. This limits how well it can support short-term decisions, and consequently, the service largely focuses on longer term trends and assists longer-term decisions. Cover is often also interpreted as a surrogate for land condition. Over the longer term this relationship is reasonably reliable, particularly where consistently low levels of cover indicate poor land condition. At higher cover levels though, the cover–condition relationship is less robust, for example where increaser species are abundant. This is why cover analysis is enhanced by knowledge about species composition and other local features. There is clearly a place for additional products besides cover data. Good examples are pasture biomass and land condition, though these have proven harder to monitor remotely (Karfs *et al.* 2009; Kumar *et al.* 2015; Punalekar *et al.* 2018). If and when they are developed, VegMachine.net is well suited to deliver them to users. Until then it will remain important for users to consider analyses of ground cover in light of the local context at the AOI.

A core engagement strategy has been encouraging third party extension providers to operate the website for their grazier clients. As previously noted, this has benefits for both the provider and the grazier client. The large number of regional comparison reports generated by a relatively small number of users suggests both that this is happening and that the support network has room to grow. Since VegMachine.net can deliver to land managers in multiple jurisdictions with different funding and policy environments, it is unlikely any single group would have either the scope or resources to support all pastoralist users. A more segmented support network is needed, and for this reason, developing third party support networks will remain an important engagement strategy into the future.

A second strategy for future development is better connecting users to the workflows they need. This could take several forms. Improved website design can make it easier for users to extract the data and analyses they need, and so increase repeat user numbers. There is also scope to provide more and different time series data. Work is underway to deliver monthly rather than seasonal cover data, making VegMachine.net more relevant for short-term decision support, and there is also demand for other

datasets like land condition and pasture biomass data. A third approach could be the development of more bespoke tools for specific user groups. The PEPER tool is one example, but there are many potential tools and analyses that would suit smaller groups of users better than those currently provided.

In the Australian rangelands VegMachine.net provides a unique capacity for public, private and institutional users to measure and understand landscape change on a range of scales. Since its inception in 2016, it has had a significant impact on how rangeland users operate. It has provided large numbers of users with a simple means of accessing a vast archive of historical landscape measurements. It has allowed users to quantify the impact of their management on their landscape, to demonstrate stewardship, to assess the potential of NRM investment at specific locations, and to extract data for scientific analysis. Despite these successes, there is still a great deal of scope to expand the size and geographic spread of the user population, and to enhance user experience. We are considering several strategies to achieve these goals.

## Conflicts of interest

The authors declare no conflicts of interest.

## Acknowledgements

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