Final report

Digital Livestock 4.0
Cibo Labs – Satellite Assisted Forage Budgeting
Romani Pastoral Company

Project code: V.DIG.2022

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Abstract

MLA's Digital Livestock 4.0 pilot project with Romani Pastoral Company was designed to test a range of on-farm solutions as part of MLA's ongoing work in the digital technology space. The project was an extension of a digital project being undertaken by Carwoola Pastoral Company in cooperation with MLA, across Carwoola's four properties in the NSW Southern Tablelands and the ACT.

The Romani Pastoral Company Digital Livestock 4.0 initiative provided an opportunity to demonstrate and leverage Cibo Labs commercial and R&D platforms to provide an over-arching paddock-to-company pasture monitoring platform for RPC, MLA and the other providers.

The project has confirmed that the remote sensing and Machine Learning methods being used by Cibo Labs are capable of high prediction accuracies exceeding R^2 values exceeding 0.9 and median prediction errors of <250kg/ha. Importantly, the imagery products are not a replacement for on-ground knowledge and assessment, but rather a compliment to save time, leverage on-ground knowledge, manage risk and make more confident decisions.

The Cibo-Agriwebb integration is a world-first, but the RPC demonstration also identified some limitations that need to be addressed. Several enhancements have been suggested by RPC. These include:

- Improved cloud detection and image quality flagging; ongoing improvement in biomass predictions across pasture growth stages; measures of pasture quality; and enhancements to the feed budgeting tools across the Cibo Labs and Agriwebb integration.
- Providing both 5-day and 15-day paddock biomass estimates during periods of peak pasture growth.
- Providing a more synoptic property-level carrying capacity analysis functionality would assist with identifying seasonal feed gaps and longer-term planning.

The Digital Livestock 4.0 Demonstrator has provided significant opportunities to improve the quality and benefits derived from the Cibo Labs PastureKey service now operating across 50 million hectares of Australia's grazing industry. It has also provided significant opportunities for business-to-business collaboration which is driving system integration and increased simplicity and value to producers.

Executive summary

Background

MLA's Digital Livestock 4.0 pilot project with Romani Pastoral Company was designed to test a range of on-farm solutions as part of MLA's ongoing work in the digital technology space. The project was an extension of a digital project being undertaken by Carwoola Pastoral Company in cooperation with MLA, across Carwoola's four properties in the NSW Southern Tablelands and the ACT.

The Romani Pastoral Company Digital Livestock 4.0 initiative provided an opportunity to demonstrate and leverage Cibo Labs commercial and R&D platforms to provide an over-arching paddock-to-company pasture monitoring platform for RPC, MLA and the other providers.

Objectives

The overarching objectives of the demonstrator were to provide Romani Pastoral Company (RPC) and other participating solution providers with a "near real-time" operational satellite image-based pasture monitoring service for the entire property aggregation with a specific focus on providing weekly estimates of pasture biomass to support forage budgeting and stocking decisions. The project involved undertaking field calibration and validation of pasture biomass estimates and implementation of the Cibo-Agriwebb API level integration with Agriwebb's Feed on Offer (FOO) calculator. Cibo Labs also provided web service endpoints for other companies involved in the RPC/MLA demonstrator. Most importantly the project provided the opportunity to work with Romani staff to discuss specific requirements and to seek and receive feedback on the utility of the solutions.

Methodology

Cibo Labs operates a fully automated high-performance cloud data processing platform hosted on Amazon Web Services (AWS). A range of proprietary software is used to undertake full atmospheric and radiometric corrections, cloud masking and image mosaicking at a property level on a 5-day interval. Data is generally processed and delivered within 24 hours of a satellite overpass.

A TensorFlow open-source machine learning platform and proprietary software is used to develop pasture biomass prediction models based on field data collection and the full spectral and spatial resolution of the Sentinel-2 satellite imagery.

Cibo Labs provided Romani Pastoral Company (RPC) and participating solution providers with the following:

- a 5-day, 10m resolution satellite image-based monitoring service for the entire northern and southern property aggregations totalling over 40,000ha.
- direct and online access to the Cibo Labs Data Analytics Platform;
- fractional ground cover, NDVI and pasture biomass products;
- 5-day paddock level summaries of total standing dry matter (TSDM) in kg/ha.
- on-ground data collection devices and apps, along with undertaking field calibration work in Feb and April 2020, and April 2021.
- a data repository and direct web service feeds through industry standard web-service endpoints.
- Direct API data feed into the Agriwebb Feed on Offer calculator.

Results/key findings

The project has confirmed that the remote sensing and Machine Learning methods being used by Cibo Labs are capable of high prediction accuracies exceeding R^2 values exceeding 0.9 and median prediction errors of <250kg/ha. Importantly, the imagery products are not a replacement for on-ground knowledge and assessment, but rather a compliment to save time, leverage on-ground knowledge, manage risk and make more confident decisions.

Following a very positive start to the demonstration through the 2020 growing season, in early 2021 RPC started to report significant inconsistencies in the predictions which undermined trust in the biomass estimates flowing into the Agriwebb forage budgeting tools. This was found to be caused by the intense weather patterns and clouds impacting heavily on the accuracy of biomass predictions despite industry best practice cloud detection methods being employed. We also found that our calibration data was also not adequately describing the very high seasonal growth rates, highly variable pasture types and growth stages, and the black soils with heavy stubble loads.

Fieldwork in was conducted April 2021 to capture data across the major summer growing pastures. 2 days fieldwork and model development dramatically improved the reliability of biomass predictions up to around 8,000kg/ha total standing dry matter (TSDM) after which some saturation occurs up to around 12,000kg/ha. This is well within the general “grazing envelops” in this highly productive system. Moreover, while further validation is required, the model is providing very plausible predictions of stubble density which could contribute to future work on soil carbon sequestration potential in cropping systems.

The project has demonstrated the value of investing on tools to enable easy on-ground data collection. Field data collection is typically seen as an onerous and resource intensive commitment. This does not have to be the case. Using the Cibo Labs Biomass Collector App and taking 15 mins per week when you are already in the paddock will not only ensure the model is continuously calibrated across a very complex landscape but increase trust in the numbers.

The Cibo-Agriwebb integration is a world-first, but the RPC demonstration also identified some limitations that need to be addressed. Several enhancements have been suggested by RPC. These include:

- Improved cloud detection and image quality flagging; ongoing improvement in biomass predictions across pasture growth stages; measures of pasture quality; and enhancements to the feed budgeting tools across the Cibo Labs and Agriwebb integration.
- Providing both 5-day and 15-day paddock biomass estimates during periods of peak pasture growth.
- Providing a more synoptic property-level carrying capacity analysis functionality would assist with identifying seasonal feed gaps and longer-term planning.

Benefits to industry

The Windy Station demonstrator has also provided the impetus for Cibo Labs to invest further in automation of our Machine Learning Platform which relies on high quality field data. Currently field data are processed on a seasonal basis to improve the model, with over 4000 sites going into the model to be released in late June. By the end of 2021 we are aiming to have systems in place that process and tune the model (in near-real-time) based on data submitted through our Biomass Collector App continuously, providing input into the next image acquisition the following week.

The Digital Livestock 4.0 Demonstrator has provided significant opportunities to improve the quality and benefits derived from the Cibo Labs PastureKey service now operating across 50 million hectares of Australia's grazing industry. It has also provided significant opportunities for business-to-business collaboration which is driving system integration and increased simplicity and value to producers.

The development of the Cibo Labs PastureKey service and collaboration across businesses over the last 4 years is providing opportunities for a step-change in sustainable grazing management across the industry. With continuous improvements in data science, remote sensing, and engaging producers in rapid data collection we will soon be providing pasture biomass estimates for every farm in Australia on a weekly to monthly basis.

Future research and recommendations

- Improved methods for image cloud detection and data fusion across sensors
- Development of pasture quality measures derived from rapid pasture assessment methods and remote sensing.
- Development of agricultural data standards to facilitate integration across technology platforms and businesses. National adoption of the MyFarmKey application will facilitate this through the creation of an authenticated digital farm record. The development of a national farm mapping platform would remove the single largest barrier to agtech adoption.
- Greater engagement of Producer Demonstration Sites in technology demonstrations coordinated through the MLA Digital Agriculture Team. Potentially this could also be coordinatedthrough Agricultural Innovation Australia.

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1. Background

MLA's Digital Livestock 4.0 pilot project with Romani Pastoral Company was designed to test a range of on-farm solutions as part of MLA's ongoing work in the digital technology space. The project is an extension of a digital project being undertaken by Carwoola Pastoral Company in cooperation with MLA, across Carwoola's four properties in the NSW Southern Tablelands and the ACT.

Cibo Labs has been successfully providing weekly (5-day) satellite-derived information on pasture biomass and ground cover to Carwoola Pastoral Company since October 2018. In addition to providing direct access to the information products and data via an online service, Cibo Labs have also provided open API access to other providers wishing to "plug in" to the data streams including a direct data feed into the Agriwebb pasture budgeting calculator.

The Romani Pastoral Company Digital Livestock 4.0 initiative provided an opportunity to demonstrate and leverage Cibo Labs commercial and R&D platforms to provide an over-arching paddock-to-company pasture monitoring platform for RPC, MLA and the other providers. Cibo Labs has provided MLA, Romani Pastoral Company (RPC) and participating solution providers with:

- with a 5-day, 10m resolution satellite image-based monitoring service for the entire northern and southern property aggregations totalling over 40,000ha.
- direct and online access to the Cibo Labs Data Analytics Platform;
- fractional ground cover, NDVI and pasture biomass products;
- 5-day paddock level summaries of total standing dry matter (TSDM) in kg/ha.
- on-ground data collection devices and apps.
- a data repository and direct web service feeds through industry standard web-service endpoints
- Direct integration with the Agriwebb Feed On Offer calculators for forage budgeting.

Figure 1. Romani Pastoral Company (RPC) property aggregations totally over 40,000ha

2. Project objectives

The overarching objectives of the demonstrator were to provide Romani Pastoral Company (RPC) and participating solution providers with a "near real-time" operational satellite image-based pasture monitoring service for the entire property aggregation with a specific focus on providing weekly estimates of pasture biomass to support forage budgeting and stocking decisions. The project involved undertaking field calibration and validation of pasture biomass estimates and implementation of the Cibo-Agriwebb API level integration with Agriwebb's Feed on Offer (FOO) calculator. Cibo Labs also provided web service endpoints for other companies involved in the RPC/MLA demonstrator. Most importantly the project provided the opportunity to work with

Romani staff to discuss specific requirements and to seek and receive feedback on the utility of the solutions.

3. Methodology

Cibo Labs operates a fully automated high-performance cloud data processing platform hosted on Amazon Web Services (AWS). A range of proprietary software is used to undertake full atmospheric and radiometric corrections, cloud masking and image mosaicking at a property level on a 5-day interval. Data is generally processed and delivered within 24 hours of a satellite overpass.

A TensorFlow open source machine learning platform and proprietary software is used to develop pasture biomass prediction models based on field data collection and the full spectral and spatial resolution of the Sentinel-2 satellite imagery. Cibo Labs is currently compiling field data in every state to continuously calibrate and validate the models across seasons. A simple mobile application is provided to pastoral managers to collect field data in addition to data collected by Cibo Labs. In complex perennial pasture systems, we generally expect that a couple of full seasons are required to characterise the local pasture types and management systems as part of a staged calibration and validation process. Our "crowdsourcing" approach allows us to pool data from individual properties across regions and derive reliable models very rapidly. Figure 2 below provides and overview of the major components of the platform.

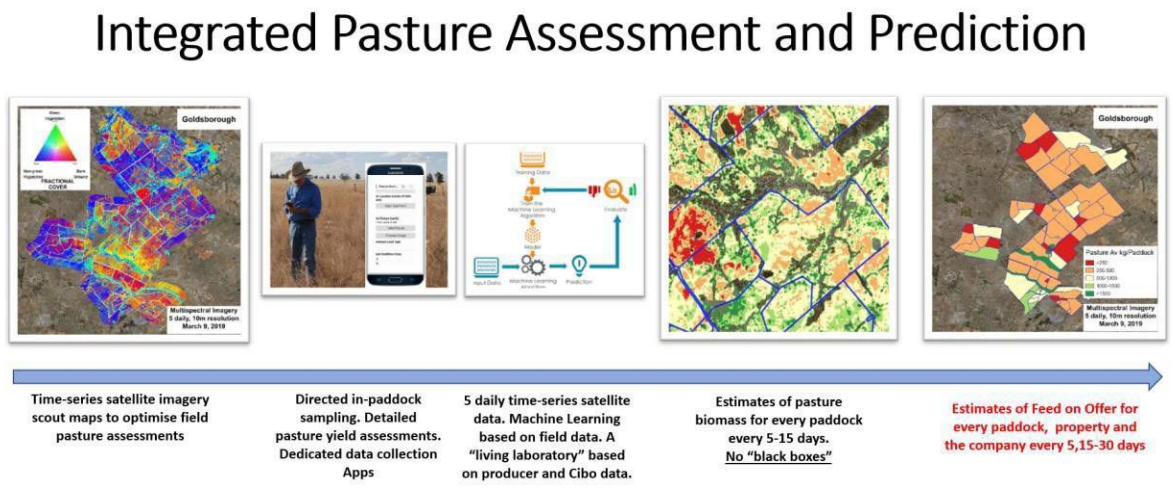


Figure 2. Cibo Labs integrated pasture assessment and prediction process.

In the case of RPCs northern aggregation, no calibration data was collected prior to implementing our "regional calibrations" based on data previously collected by Cibo Labs and other clients across northern Australia. Prior to the project there were no ground truth sites on the Liverpool Plains, with the nearest relevant data on tropical pasture species in southern QLD. RPCs southern aggregation used Cibo Labs Southern regional model calibrations based on data collected across southern NSW slopes and tablelands regions.

Cibo Labs provided Romani Pastoral Company (RPC) and participating solution providers with the following:

- a 5-day, 10m resolution satellite image-based monitoring service for the entire northern and southern property aggregations totalling over 40,000ha.
- direct and online access to the Cibo Labs Data Analytics Platform;

- fractional ground cover, NDVI and pasture biomass products;
- 5-day paddock level summaries of total standing dry matter (TSDM) in kg/ha.
- on-ground data collection devices and apps, along with undertaking field calibration work in Feb and April 2020, and April 2021.
- a data repository and direct web service feeds through industry standard web-service endpoints.
- Direct API data feed into the Agriwebb Feed on Offer calculator.

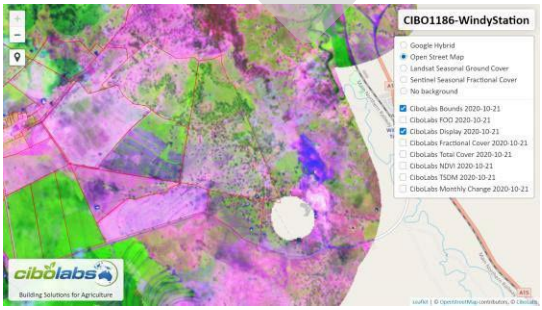
Cibo Labs conducted initial fieldwork on Feb 28 2020 on Warrah and Windy Stations when 8 field sites were completed. Unfortunately, due to COVID-19 restrictions we were unable to return as planned. A mobile App was provided to RPC staff to assist in data collection activities given the COVID-19 restrictions to collect data through April 2020. Cibo Labs then conducted additional field work during April 2021.

4. Results

The figures 4 and 5 below provide examples of the imagery products provided through the Cibo Labs web mapping platform for a portion of Windy-Warrah Station in the north and Garangula in the south which are updated on a 5-day basis across all properties. The imagery clearly shows distinct within and between paddock variability and large individual tree canopies. The products include:

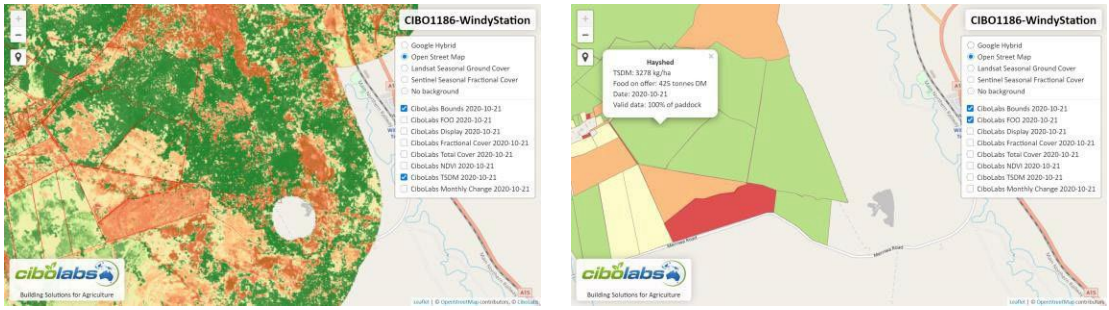
a) 3 band pseudo colour composite Sentinel image. The image uses Sentinel bands 11,8,4 (b1,b2,b3).
b) Fractional Cover (red=bare ground; green = photosynthetically active vegetation (PV); blue = Non-photosynthetically Active (NPV) vegetation.
c) Total Standing Dry Matter (TSDM) in kg/ha
d) Paddock-Level TSDM in kg/ha and total Feed on Offer (kg/paddock). Provided as geoTIFF, CSV and geoJson format. Also a direct API data feed into Agriwebb FOO calculator.

Figure 6 provides an example of the paddock level estimates of TSDM in kg/ha and total Feed on Offer (kg/paddock). In addition to providing this information on the web interface, it is also provided in CSV and geoJson format and as a direct API data feed into Agriwebb Feed on Offer (FOO) calculator which provides the ability to estimate the number of grazing days available based on the mob size, animal class and the Cibo Labs biomass estimates.



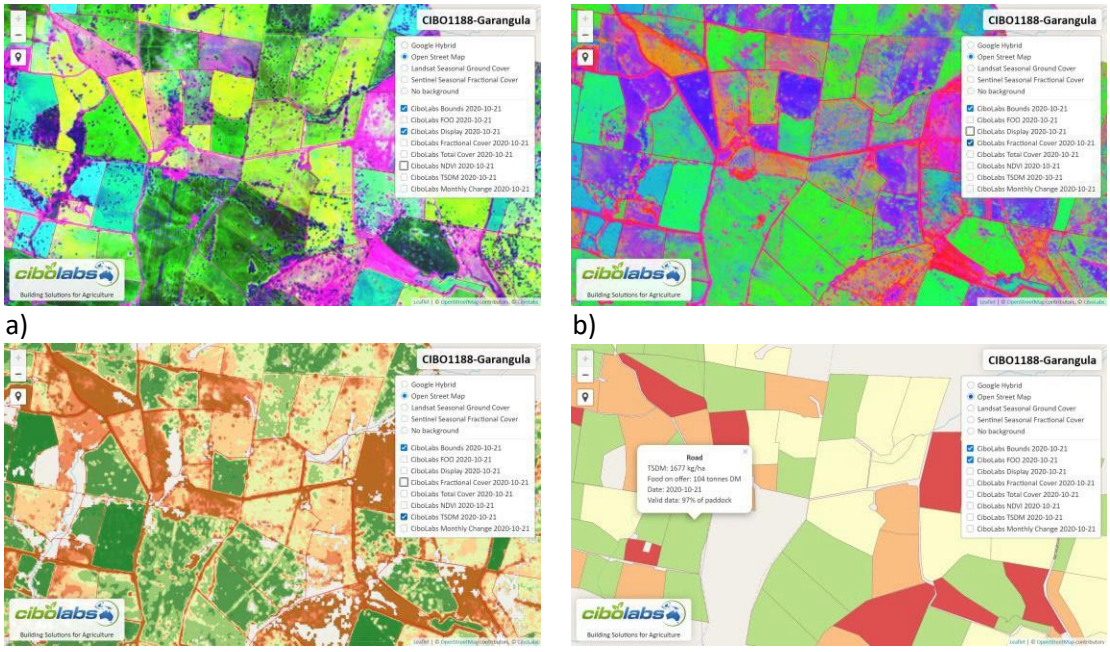
a)

b)



c) d)

Figure 3. Zoomed in view of Windy-Warrah Station. a) 3 band pseudo colour composite Sentinel image. The image uses Sentinel bands 11,8,4 (b1,b2,b3). b) Fractional Cover (red=bare ground; green = photosynthetically active vegetation (PV); blue = Non-photosynthetically Active (NPV) vegetation. c) Total Standing Dry Matter (TSDM) in kg/ha. d) Paddock-Level TSDM in kg/ha and total Feed on Offer (kg/paddock).



a) b)

c) d)

Figure 5. Zoomed in view of Garangula. a) 3 band pseudo colour composite Sentinel image. The image uses Sentinel bands 11,8,4 (b1,b2,b3). b) Fractional Cover (red=bare ground; green = photosynthetically active vegetation (PV); blue = Non-photosynthetically Active (NPV) vegetation. c) Total Standing Dry Matter (TSDM) in kg/ha. d) Paddock-Level TSDM in kg/ha and total Feed on Offer (kg/paddock).

farmId	id	title	cibo_ha	cibo_notreeha	cibo_pid	cibo_property	cibo_foo15_20201016	cibo_foo15_20201021	cibo_tsdm15_20201021	cibo_validArea15_20201021
8f25b198-	e8379264-	Number One	583.92	287.43	1186	CIBO118	2362628	2013729	3449	100
8f25b198-	e8374440-	13	521.18	521.11	1165	CIBO118	1426340	1417191	2719	100
8f25b198-	e837b975	Sth Bull	453.09	319.4	1195	CIBO118	1541684	1534274	3386	100
8f25b198-	e82542e5-	Duddys Hill	344.96	266.46	1061	CIBO118	1277207	1094473	3173	100
8f25b198-	e82569f6-	Emu Creek	335.32	333.88	1070	CIBO118	593731	549940	1640	100
8f25b198-	e8359692-	21	327.26	327.26	1124	CIBO118	911370	906003	2768	100
8f25b198-	e825b811	38	321.58	321.39	1080	CIBO118	859909	888688	2764	100
8f25b198-	e835bda3	Fifth Scrub	318.66	0.95	1129	CIBO118	354865	351294	1102	100
8f25b198-	e835bda1	Nth Bull	300.11	242.34	1127	CIBO118	783057	723026	2409	100
8f25b198-	e8262d44	37	296.93	296.93	1108	CIBO118	750895	780705	2629	100
8f25b198-	e824f4c0-	28	292.25	292.25	1039	CIBO118	81951	93498	320	100

Figure 6. Example of paddock level estimates of TSDM updated on a 5-day basis and provided as estimates of average TSDM per paddock and total kg/paddock. Provided as GIS geojson, CSV and direct API data feed into Agriwebb.

Figure 7. below provides an example of the outputs from the mobile biomass collection app provided to RPC managers. It includes the locations of sites collected, site and quadrat images, and the results of initial validations based on sites collected in April, 2020. Importantly the regression relationship is based on independent validation data that was not used in the model calibration. It shows an r-square of 0.95 and effectively a near one-to-one relationship, with biomass levels exceeding 6000kg/ha.

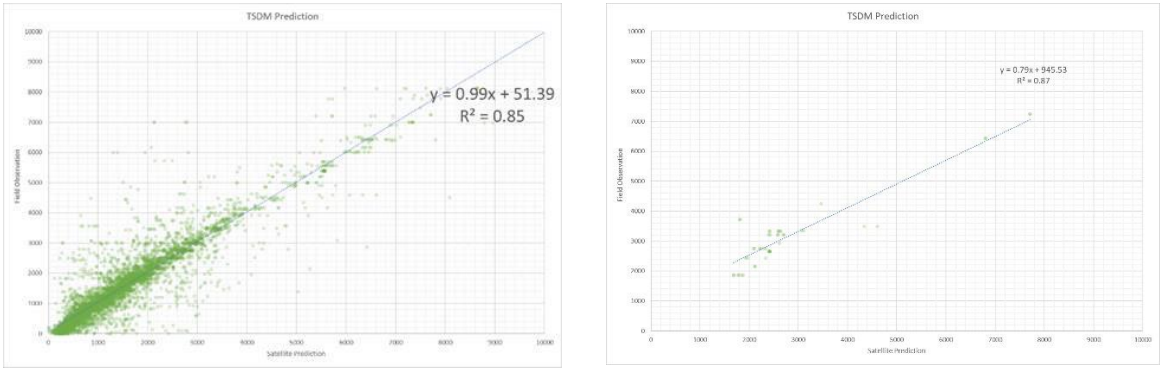
	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AF	AG	AH
1	Endtime	Valid	Prop	Paddock	SiteInfo	SiteInfoL	SiteInf	SiteInf	SiteImage	PastureImage	quadrat1	quadrat2	quadrat3	quadrat4	quadrat5	TSDM	SiteInf	SiteInfo
2	04/07/2020 01:1	Yes	Warı	End of Lane	-31.642	150.674	405.56	5	https://cibolabs.a	https://cibolabs.a	5972	1048	2430	3931	5321	3341	-31.64	150.674
3	04/07/2020 02:1	Yes	Warı	Mailboy	-31.639	150.689	539.85	5	https://cibolabs.a	https://cibolabs.a	8320	7244	6864	7044	6720	7238	-31.63	150.689
4	04/07/2020 02:4	Yes	Warı	Mailboy	-31.632	150.688	462.02	5	https://cibolabs.a	https://cibolabs.a	3315	2731	5605	3424	4547	3489	-31.63	150.688
5	04/07/2020 04:2	Yes	Warı	Patersons	-31.617	150.692	421.07	5	https://cibolabs.a	https://cibolabs.a	1980	2070	2664	1620	2430	2152	-31.61	150.692
6	04/07/2020 04:4	Yes	Warı	Sudax	-31.613	150.676	420.37	5	https://cibolabs.a	https://cibolabs.a	3889	1352	3307	2683	3411	2928	-31.61	150.676
7	04/07/2020 05:1	Yes	Warı	Treeless	-31.611	150.668	432.95	5	https://cibolabs.a	https://cibolabs.a	5584	4472	3099	2496	5636	4257	-31.61	150.668
8	04/08/2020 00:2	Yes	Winc	Sth Gangat	-31.658	150.369	377.80	5	https://cibolabs.a	https://cibolabs.a	6200	7100	6500	6940	5410	6430	-31.65	150.369
9	04/08/2020 01:0	Yes	Winc	Sth Windy Ridge	-31.645	150.371	364.43	5	https://cibolabs.a	https://cibolabs.a	4698	4428	1253	3985	4212	3715	-31.64	150.371
10	04/16/2020 01:3	Yes	Warı	Middle Heifer Nth	-31.600	150.698	386.38	5	https://cibolabs.a	https://cibolabs.a	2490	2310	2850	2670	1980	2435	-31.60	150.698
11	04/16/2020 05:3	Yes	Warı	Ryegrass	-31.663	150.678	383.82	5	https://cibolabs.a	https://cibolabs.a	2892	3912	4500	3564	2088	3336	-31.66	150.678

Figure 7. An subset from the Cibo Labs mobile app showing the site data, site and quadrat images, site locations and the results of initial validation analyses in April 2020.

Feedback from RPC in June suggested that the model was significantly under-predicting higher biomass levels as the pasture senesced. There were also areas of black soils that were over-predicting. With COVID-19 restrictions Cibo Labs continued collecting and sourcing data where possible across QLD from other clients. In August-September approximately 200 additional pasture assessments were undertaken across QLD and some NT properties to assist with late season model calibrations to address identified limitations in the model.

Figure 8 below summarises the overall model prediction accuracy following the compilation of late-season sites exceeding ~1800 pasture assessments collected across northern Australia in the last 2

years, and the subset of data collected on Windy Station. Empirically the model accuracy is strong with r-squares exceeding 0.85. More importantly however, is the stability of the model both in terms of spatial variability and predictions throughout the season across multiple northern pasture types. The median error of current model predictions across all sites is <250kg/ha. As expected, there are always anomalies in complex model predictions. Cibo Labs has been working through many of these with pastoral managers across northern Australia to understand the causes of the anomalies. Typically, anomalies might include sampling error of field estimates; GPS errors on mobile phone devices; sampling on the edges of changes in biomass; tree density, regrowth and tree death causing significant litterfall; soil colour and shrub components.



a) b)

Figure 8. Cibo Labs northern pasture model prediction results. a) prediction results based on machine learning model calibration against ~1800 pasture assessment sites. b) the results of model for the subset of data collected on Windy Station during April 2020.

Feedback from RPC in late winter and early spring suggested the model was generally performing well and providing realistic biomass estimates through the Agriwebb Feed on Offer Calculator. However as the 2020-2021 summer progressed some inconsistency in the predictions were identified.

During the February-April 2021 growing period, feedback from RPC suggested that the model was providing inconsistent results with paddock level predictions changing significantly over short periods. While the general model trends were reasonable, in many high yielding paddocks consisting of tropical pastures such Rhodes Grass, Premier Digitaria and Bambatsi Panic Grass model predictions were significantly lower than field observations.

Several factors were found to be causing these errors:

1. The significantly higher rainfall during the 2021 summer resulted in long periods of cloud. The Cibo Labs processing generally detects and removes more than 90 percent of the cloud from imagery using the industry best practice modified FMASK algorithms (Franz etal, 2018). However, during this period there were many occasions when clouds were not adequately detected and removed from the imagery. Atmospheric aerosols were also likely to be affecting the quality of spectral reflectance data.
2. The Cibo Labs PastureKey default service provides both 5-day estimates and a rolling 15-day “median” of TSDM, which also require a minimum of 3 cloud-free pixels to minimise the effects of clouds. During the higher-than-average rainfall period these processing rules often led to no data being available for individual paddocks from the 15-day median imagery. It also resulted in the 15-day estimates often being behind the rapid pasture growth. To increase the number of predictions we changed the processing rules to only require 1 cloud-free data value to increase the number of predictions, which then also resulted in greater variability in predictions due to the cloud affects.

3. Limited field data collection due to COVID restrictions had not allowed us to adequately characterise the diversity of pasture species, soil types (colour) and vegetation and land types that occurred across Windy Station, particularly the very high yielding tropical pastures.

To address the calibration issues Cibo Labs conducted 2 days of intensive fieldwork across Windy Station, targeting the specific issues and areas identified by the RPC managers. 40 field sites were collected on April 19-20, 2021. At each site 5 quadrat (0.25m^2) photos and pasture cuts were collected at 10m intervals along 50m transects using our Biomass Collector App which provides GPS coordinates. Wet quadrat cuts were weighed, and sub-samples were also oven-dried for the group of cuts at each transect to accurately estimate Dry Matter %, the adjust the wet weights to Total Standing Dry Matter (TSDM) estimates.

Figure 5 below shows the location of sample sites that were chosen specifically to represent high biomass tropical pastures, winter cereal crops (oats) and a range of stubble densities on the black soils. In this image the very bright green areas are typically sown winter crops, the mid-green area tropical pastures and the brown-purple areas are paddocks in fallow with varying levels of stubble retention.

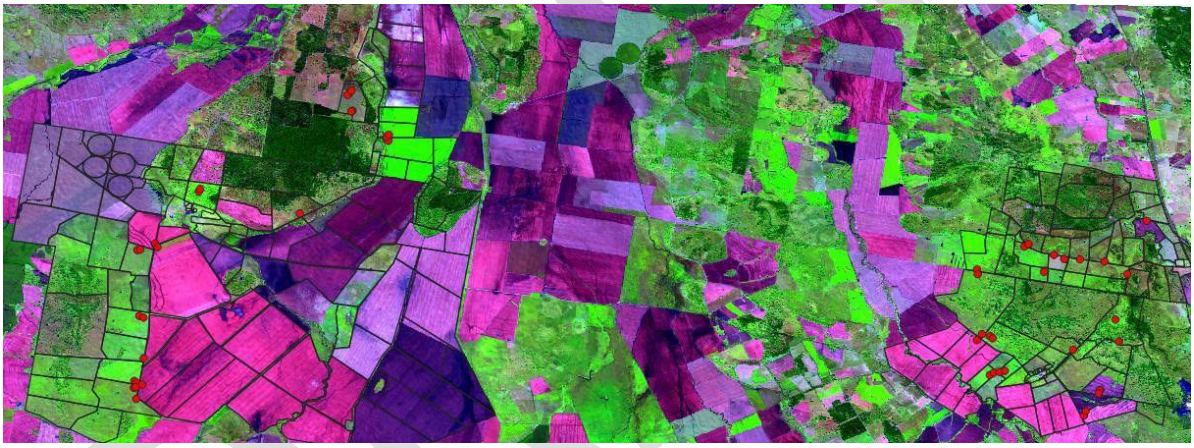


Figure 4. Sentinel imagery (bands 9,8,4) acquired April 19, 2021 and the location of pasture sites collected on April 19-20, 2021.

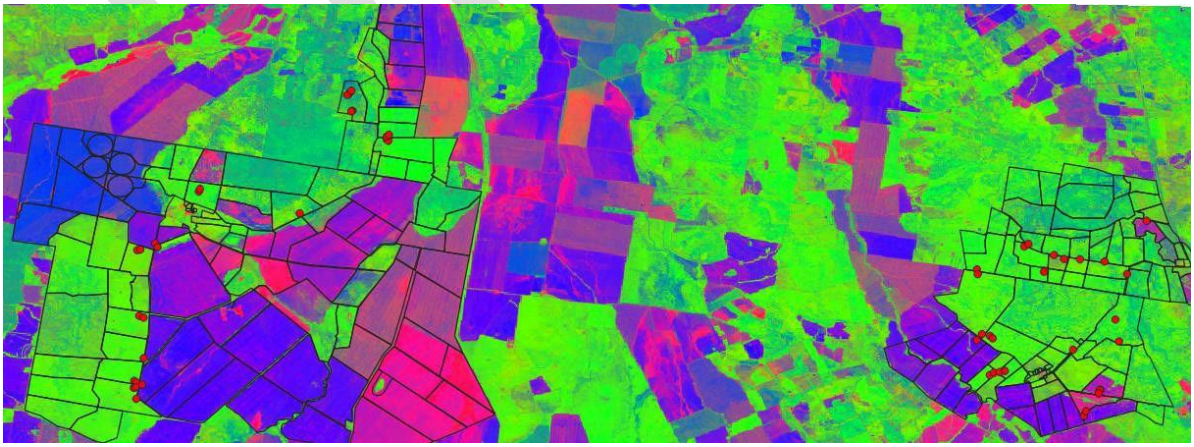


Figure 5. Sentinel Fractional Cover predictions of Bare Ground (BG), Photosynthetically Active Vegetation (PAV); Non-photosynthetic Vegetation (NPV). Displayed as Red, Green, Blue respectively. Acquired April 19, 2021.

Figure 6 above shows predicted fractional cover of in terms of Photosynthetically Active Vegetation (PAV); Non-photosynthetic Vegetation (NPV) and bare ground (BG). Displayed as Red,

Green, Blue, respectively. Of particular interest in this image is the significant NPV showing as blue in the fallow paddocks.

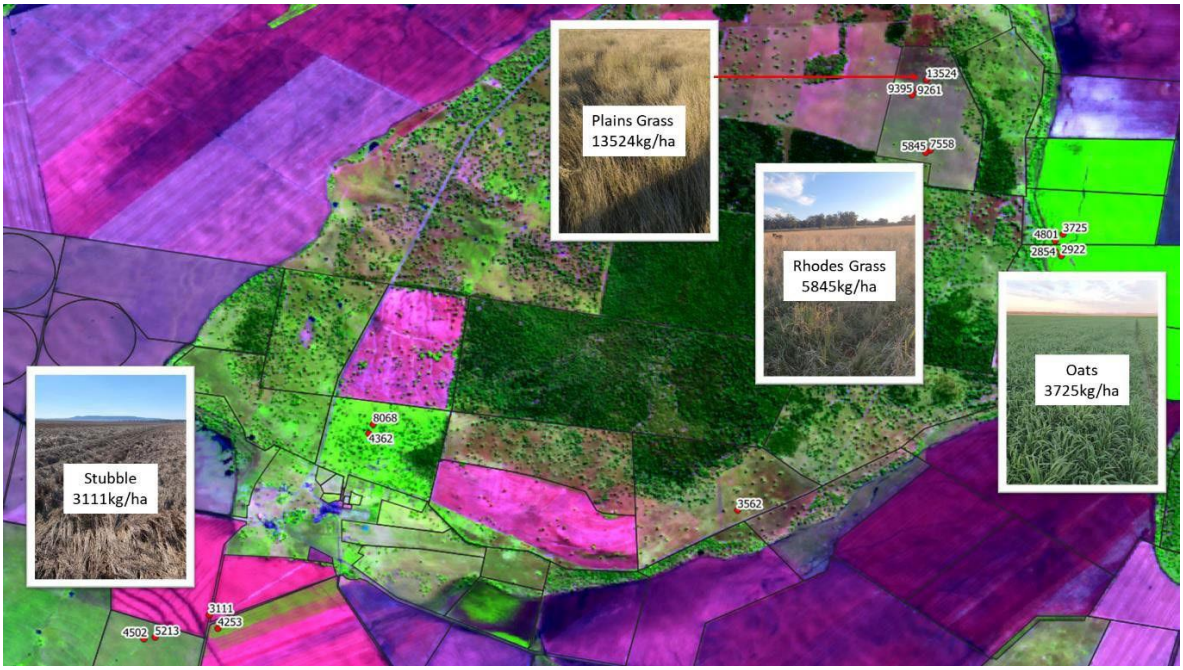


Figure 6. Sentinel imagery (bands 9,8,4) acquired April 19, 2021 and the location of pasture sites collected on April 19-20, 2021. A sample of pasture transect photos.

Figure 7 provides examples of the significant variability in pasture and cover types across Windy and Warrah Stations. Interestingly, the highest biomass pasture on the property, yielding over 13000kg/ha was highly unpalatable plains grass that was seeing very little utilisation given most of the "Big Red" paddock was sown to a mixture of tropical grasses.

The 40 pasture assessment sites collected in April 2021 were incorporated into our new national biomass model which includes some 4000 sites across both northern and southern pasture types. The ML model only uses 80% of the data for training and leaves 20% for validation.

The figure below demonstrates the ability to rapidly tune the model to local conditions using targeted sampling. Importantly, the model is performing well across multiple cover types ranging from stubble with high TSDM (though largely unpalatable) through to highly palatable tropical grasses, winter cereals and relatively high biomass native grasses. Moreover, the model is performing very well within the typical grazing and rest envelope of 1000-8000kg/ha within this mixed northern and southern pasture system.

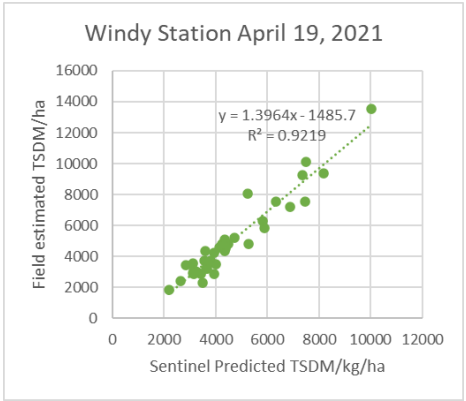


Figure 7. TSDM predictions for Windy and Warrah Station sites. The plot includes both calibration and validation sites.

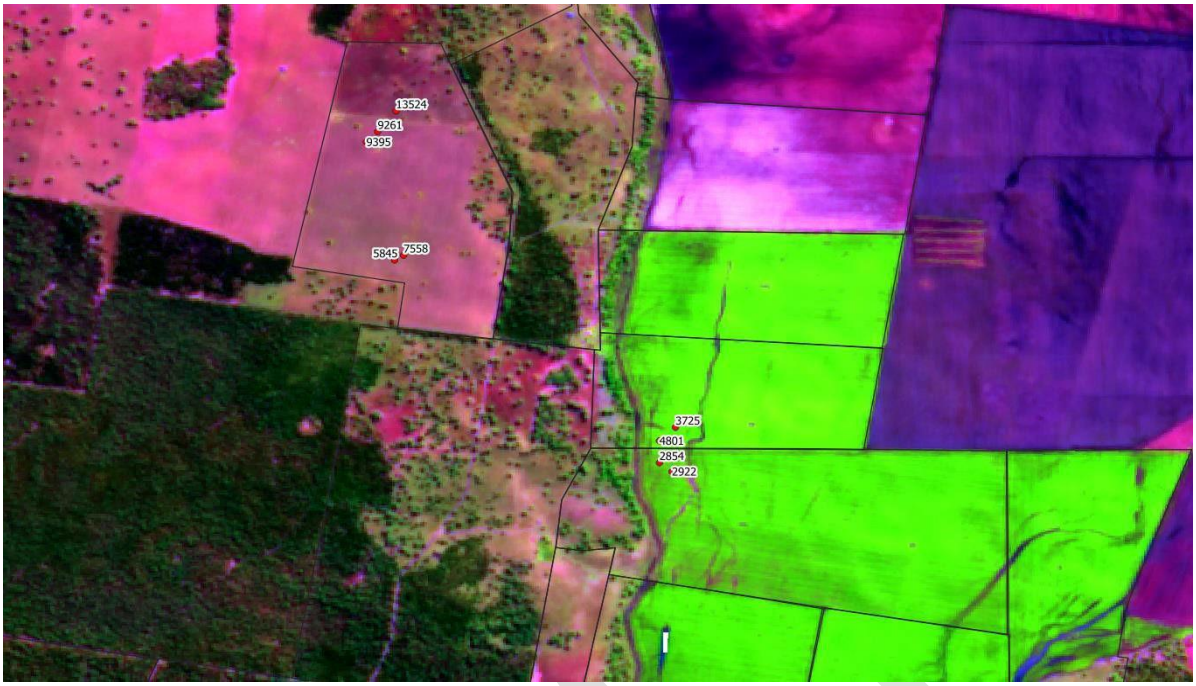


Figure 8. Zoomed in on the "Big Red" paddock to the north west and oats crop with sites to the east. Sentinel imagery (bands 9,8,4) acquired April 19, 2021 and the location of pasture sites collected on April 19-20, 2021.

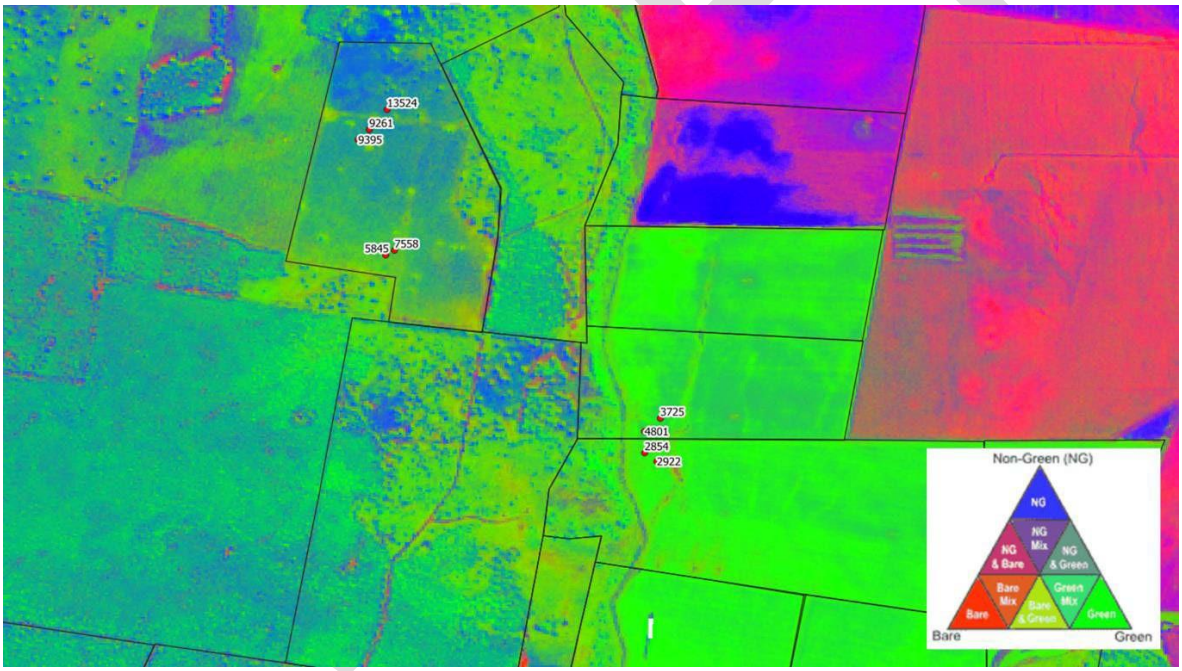


Figure 9. Zoomed in on the "Big Red" paddock to the north-west and oats crop with sites to the east. Sentinel Fractional Cover predictions of Bare Ground (BG), Photosynthetically Active Vegetation (PAV); Non-photosynthetic Vegetation (NPV). Displayed as Red, Green, Blue respectively. Acquired April 19, 2021.

Figures 9 and 10 highlight the enormous variations in pasture and cover types between paddocks and the high levels of variability within paddocks. They also highlight the different information content between just 3 of the Sentinel satellites 10 bands used in our analyses and the fractional cover which provides additional biophysical information on plant senescence and photosynthetic cover. Note the variability in stubble density highlighted in the blue area to the north of the bright green oats, and in the non-photosynthetic cover within the Rhodes Grass paddock in the “Big Red” paddock depicted in the fractional cover with green and blue tones.

Figures 11 and 12 show the TSDM predictions of within paddock variability and across the entire Windy-Warrah Stations.

The oats crop has >2000kg/ha of within paddock variation. The model is also predicting significant variability in stubble biomass which would likely relate to the crop yield.

The “Big Red” paddock in the north-west had cattle grazing on the day of field sampling. It was very evident on the day that the bottom half of the paddock was being preferentially grazed, which is also shown in the TSDM predictions. Interestingly, the less grazed area has a higher proportion of senescent (non-photosynthetic) cover which also coincides with a rise in topography.

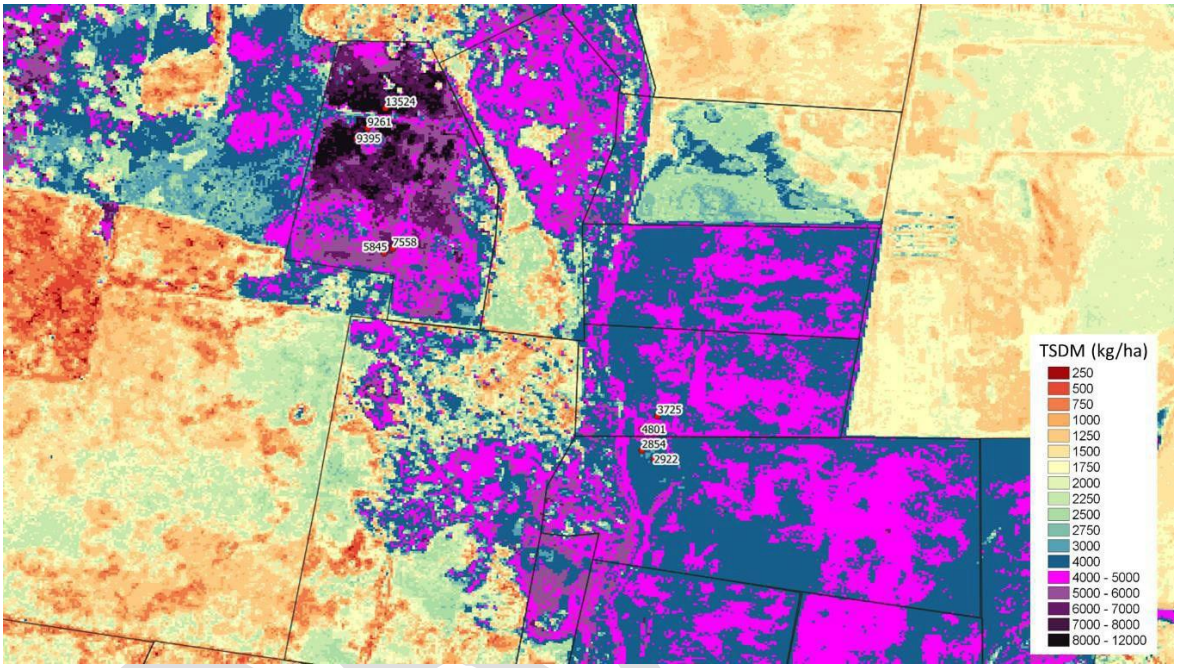


Figure 10. Zoomed in on the "Big Red" paddock to the north-west and oats crop with sites to the east. Sentinel imagery acquired April 19, 2021. Predicted Total Standing Dry Matter (TSDM).

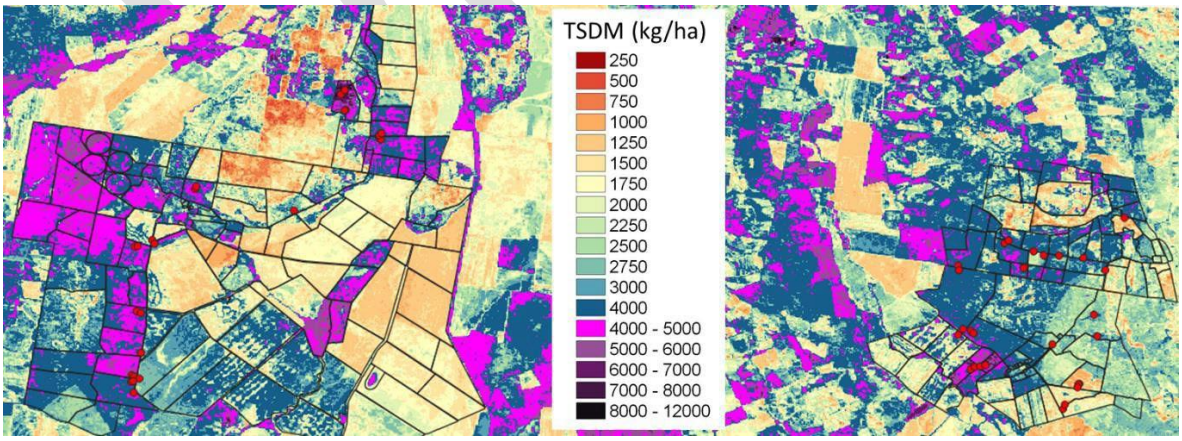


Figure 11. Predicted Total Standing Dry Matter. April 19, 2021 across Windy and Warrah Stations.

Figure 13 below provides a snapshot of an individual paddock (Hayshed) on October 21st 2020 on the Cibo Labs mobile map which are automatically passes the paddock average TSDM through to the Agriwebb Feed on Offer calculator. This is achieved through API integration across the Cibo and Agriwebb platforms. Biomass levels in this paddock at this time varied from around

2000kg/ha to over 4500kg/ha in north-east corner with a paddock average of around 3200kg/ha. This highlights the significant variability across most paddocks and the need to managers to interpret and act on the reasons for the variability in both pasture growth and utilisation.

The Cibo-Agriwebb integration is a world-first, but the RPC demonstration also identified some limitations that need to be addressed:

- The Cibo Labs estimates currently automatically populate the Agriwebb FOO calculator and over-write values that may have been entered by the producer. This caused some frustration with the RPC Pastoral Manager. A solution has been identified through API developments and soon we will store both Cibo predictions and estimates entered by the producer and use them to support local calibrations.
- The current API integration only supports the 15-day median TSDM estimates. When using the 5-day estimates during very cloud periods the predictions may be lower accuracy. The 15-day estimates are also behind in periods of rapid growth. Currently Cibo maintains quality flags against each paddock estimate. This can be resolved by providing both 5 and 15-day estimates and quality flags through the API to Agriwebb.
- While paddock average TSDM is a logical single number for forage budgeting, paddocks with high levels of variability in pasture production, quality or utilisation may need further interpretation. It is therefore important to look at both the Cibo Labs PastureKey viewer and the Agriwebb FOO calculator. Providing additional interactive information when a user clicks on a paddock is also being scoped including a smoothed time-series TSDM graph, and a histogram showing the proportion of the paddock achieving specific TSDM levels.
- Opportunities have also been identified to improve the FOO calculator to include pasture quality, utilisation in relation to distance from water and land types and pasture types within a paddock.

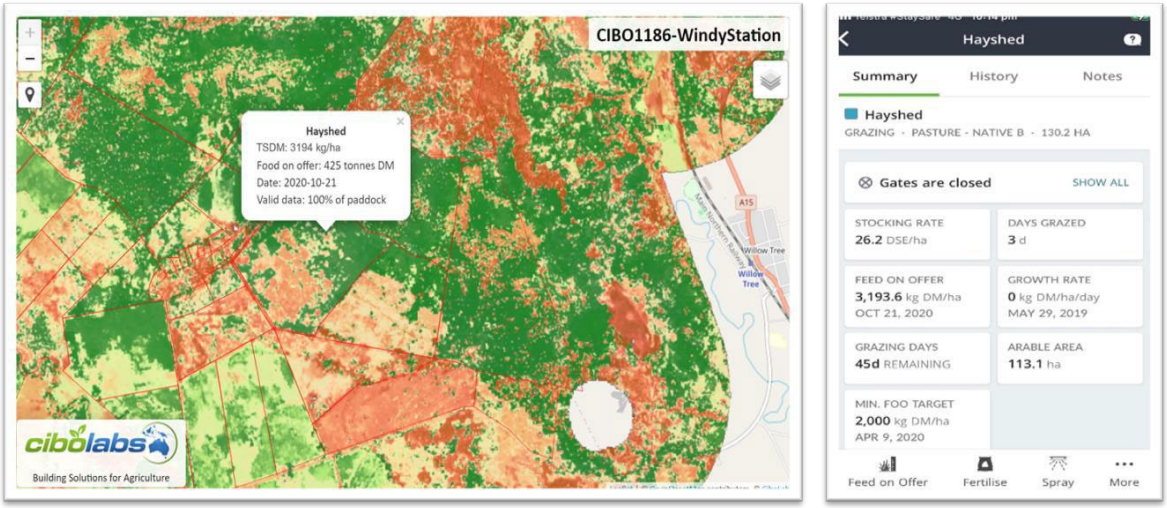


Figure 12. Biomass estimates for Hayshed paddock for the 15 days to October 21, 2020 on the Cibo Labs mobile maps automatically passed through to the Agriwebb Feed on Offer calculator. This is achieved through API integration across the Cibo and Agriwebb platforms.

5. Key findings

Windy Station is in one of the most productive agricultural landscapes in Australia and includes:

- Deep heavy textured soils derived from volcanic material including black vertosols often known as cracking clays and black earths and light textured soils on the ridge tops.
- While rainfall is summer dominant, particularly in February, monthly rainfall and temperature provides conditions for growth through the year.
- The highly productive conditions provide the opportunity to produce a broad range of summer and winter dominant pasture and crop species and livestock enterprises.

From a satellite remote sensing, pasture monitoring and forage budgeting perspective Windy Station provides significant challenges:

- Cloud and atmospheric conditions require sophisticated processing systems to detect clouds and minimum atmospheric effects on imagery.
- A large variation in summer and winter (native and improved) pasture, crop and vegetation types with multiple growing seasons requires investment in field calibration data to adequately describe these interactions.
- The high levels of pasture and crop growth which often generate Total Standing Dry Matter (TSDM) exceeding 8,000kg/ha. This level of biomass is typically well above the saturation level of typical Normalised Difference Vegetation Index (NDVI) remote sensing methods, and one of the reasons the PastureKey service uses a multispectral approach.
- Given the seasonal heterogeneity, any given paddock can have multiple pasture species at different growth stages through the year.
- The relatively intensive rotational grazing system employed on Windy Station therefore requires all the above complexity to be taken into account when providing input into continuous forage budgeting at paddock and property levels.

The RPC-MLA demonstrator has provided the opportunity to evaluate the PastureKey service within a highly complex landscape, environment, and agricultural enterprise. It has both confirmed the capabilities of the PastureKey service and identified areas that require improvement to maximise the potential benefits to a complex enterprise like Windy Station.

- The remote sensing and Machine Learning methods being used by Cibo Labs are achieving high prediction accuracies. Field data collection in April 2020 and April 2021 achieved R^2 values greater than 0.9. i.e. predictions are explaining more than 90 percent of the variation in the data. Importantly there are always anomalies in the last 10 percent that can be improved over time.
- The analysis methods being used by Cibo Labs can reliably predict TSDM up to around 8,000kg/ha after which some saturation occurs up to around 12,000kg/ha. This is well within the general “grazing envelops” in this highly productive system. Moreover, while further validation is required, the model is providing very plausible predictions of stubble density which could contribute to future work on soil carbon sequestration potential in cropping systems.
- The model’s ability to accurately predict biomass levels across multiple species, growing seasons and growth stages throughout the year has improved significantly, but in any region

is dependent on collecting field calibration that adequately describes the phenology of the pasture species. We would suggest a small number of additional calibration sites in winter and spring to confirm the stability of the model and ensure users can trust the estimates throughout the year in this type of environment.

- Field data collection is typically seen as an onerous and resource intensive commitment. This does not have to be the case. Using the Cibo Labs Biomass Collector App this does not have to be the case. In less than 5 minutes a user can complete a 50m transect using the App and photo reference guides. More time is spent driving to a representative site than collecting data. We would therefore suggest that rapid pasture assessments can simply occur as part of daily observations in the paddock rather than seen as a major task which requires days to be set aside. Taking 15 mins per week when you are already in the paddock will not only ensure the model is continuously calibrated across a very complex landscape but increase trust in the numbers.
- The Windy Station demonstrator has also provided the impetus for Cibo Labs to invest further in automation of our Machine Learning Platform which relies on high quality field data. Currently field data are processed on a seasonal basis to improve the model, with over 4000 sites going into the model to be released in late June. By the end of 2021 we are aiming to have systems in place that process and tune the model based on data submitted through our Biomass Collector App continuously, providing input into the next image acquisition the following week.
- Cloud affected imagery significantly eroded trust in the model predictions in early 2021. Cibo Labs have been investigating methods for improving cloud detection that will be implemented as soon as possible. Ultimately however, clouds are a constraint on the use of multispectral satellite imagery. While quality flags are already generated it is crucial that we make this easier to interpret and better manage expectations and understanding of the limitations in the methods.
- The Cibo-Agriwebb integration is a world-first, but the RPC demonstration also identified some limitations that need to be addressed:
    - A solution has been identified through API developments and soon we will store both Cibo predictions and estimates entered by the producer and use them to support local calibrations.
    - The current API integration only supports the 15-day median TSDM estimates. When using the 5-day estimates during very cloud periods the predictions may be lower accuracy. The 15-day estimates are also behind in periods of rapid growth. Currently Cibo maintains quality flags against each paddock estimate. This can be resolved by providing both 5 and 15-day estimates and quality flags through the API to Agriwebb.
    - While paddock average TSDM is a logical single number for forage budgeting, paddocks with high levels of variability in pasture production, quality or utilisation may need further interpretation. It is therefore important to look at both the Cibo Labs PastureKey viewer and the Agriwebb FOO calculator. Providing additional interactive information when a user clicks on a paddock is also being scoped including a smoothed time-series TSDM graph, and a histogram showing the proportion of the paddock achieving specific TSDM levels.
    - Providing both 5-day and 15-day paddock biomass estimates during periods of peak pasture growth and a more synoptic property-level carrying capacity analysis

functionality would assist with identifying seasonal feed gaps and longer-term planning.

- The COVID19 lockdown certainly impacted on our ability to adequately engage with the RPC team and undertake time-critical work. Improving communication, engagement and timeliness of feedback will undoubtably improve our ability to understand the challenges, develop solutions, manage expectations, and deliver benefits going forward.
- The Digital Livestock 4.0 Demonstrator has provided significant opportunities to improve the quality and benefits derived from the Cibo Labs PastureKey service now operating across 50 million hectares of Australia's grazing industry.

6. Conclusions/recommendations

The Cibo Labs PastureKey service has been running continuously since early November 2019 across the entire RPC enterprise of more than 40,000ha comprising 4 property aggregations, providing 5-day, 10m resolution imagery, and estimates of pasture biomass and fractional cover.

Fieldwork conducted in April 2020 and April 2021 confirmed that the remote sensing and Machine Learning methods being used by Cibo Labs are capable of high prediction accuracies exceeding R^2 values exceeding 0.9 and median prediction errors of <250kg/ha. However, given the highly complex summer and winter pasture types and seasonality in the region, it is crucial to calibrate and validate the model over winter and the coming growing season to ensure that the model adequately represents the wide range of pasture types and growing conditions.

Romani Pastoral Company managers provided very positive and constructive feedback through mid-2020. They were gaining trust in the biomass estimates, saving significant time not having to drive across the property, and supporting decisions on timing of mob movements in what is a relatively intensive operation with large mobs and short rotations.

In early 2021, RPC started to report significant inconsistencies in the predictions which undermined trust in the data flowing into the Agriwebb forage budgeting tools. This was found to be caused by the intense weather patterns and clouds impacting heavily on the accuracy of biomass predictions despite industry best practice cloud detection methods being employed. When the clouds cleared, we also found that our calibration data was also not adequately describing the very high seasonal growth rates, highly variable pasture types and growth stages, and the black soils with heavy stubble loads.

Following fieldwork in April 2021, the prediction accuracy across the major summer growing pastures has been dramatically improved with reliable TSDM predictions up to around 8,000kg/ha after which some saturation occurs up to around 12,000kg/ha. This is well within the general "grazing envelops" in this highly productive system. The model's ability to accurately predict biomass levels across multiple species, growing seasons and growth stages throughout the year has improved significantly, but in any region is dependent on collecting field calibration that adequately describes the phenology of the pasture species. We would suggest a small number of additional calibration sites in winter and spring to confirm the stability of the model and ensure users can trust the estimates throughout the year in this type of environment.

Field data collection is typically seen as an onerous and resource intensive commitment. This does not have to be the case. Using the Cibo Labs Biomass Collector App and taking 15 mins per week when you are already in the paddock will not only ensure the model is continuously calibrated across a very complex landscape but increase trust in the numbers. The Windy Station demonstrator has

also provided the impetus for Cibo Labs to invest further in automation of our Machine Learning Platform which relies on high quality field data. Currently field data are processed on a seasonal basis to improve the model, with over 4000 sites going into the model to be released in late June. By the end of 2021 we are aiming to have systems in place that process and tune the model (in near-real-time) based on data submitted through our Biomass Collector App continuously, providing input into the next image acquisition the following week.

Methods for dealing with the impacts cloud cover during peak growing periods are ongoing. This can easily be overcome through making it easier for users to interpret quality flags already provided and ensuring users understand the limitations of the technology. Importantly, the imagery is not a replacement for on-ground knowledge and assessment, but rather a compliment to save time, leverage on-ground knowledge, manage risk and make confident decisions.

The Cibo-Agriwebb integration is a world-first, but the RPC demonstration also identified some limitations that need to be addressed. Several enhancements have been suggested by RPC. These include:

- Improved cloud detection and image quality flagging; ongoing improvement in biomass predictions across pasture growth stages; measures of pasture quality; and enhancements to the feed budgeting tools across the Cibo Labs and Agriwebb integration.
- Providing both 5-day and 15-day paddock biomass estimates during periods of peak pasture growth.
- Providing a more synoptic property-level carrying capacity analysis functionality would assist with identifying seasonal feed gaps and longer-term planning.

An opportunity also exists to use the Sentinel-2 time-series (back to late 2017) to analyse paddock level biomass production. This would enable ranking of within and between paddock performance (carrying capacity) and assess opportunities for pasture or infrastructure improvement. Time-series analysis tools to look back after mob movements to assess utilisation and land condition in terms both biomass and ground cover levels would also assist strategic decision making.

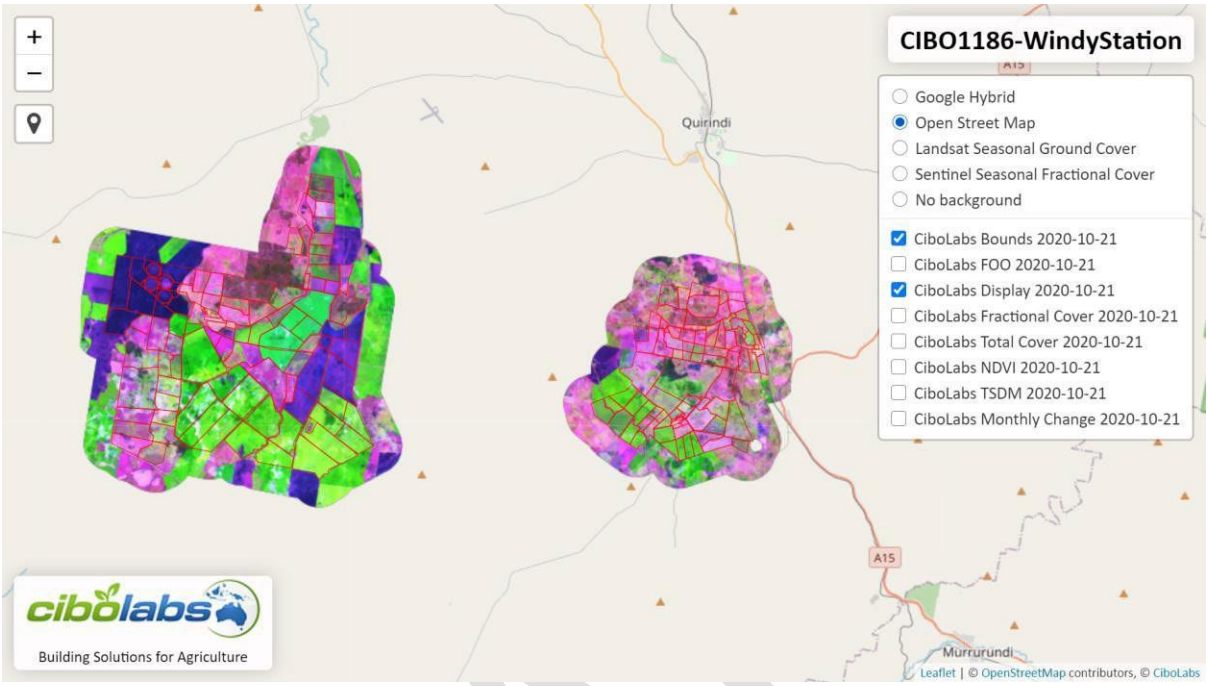
Romani Pastoral Company managers have provided very constructive feedback throughout the project and collected field data to refine the biomass predictions and gain trust and confidence in the biomass predictions which will further guide MLA's future plans in this space. The demonstration has also provided the opportunity to better understand the benefits and limitations of the technology and the processes and investment involved in developing operational capabilities. It has also highlighted the opportunity to improve reliability and utility over time through targeted data collection, just like all other parts of a grazing business.

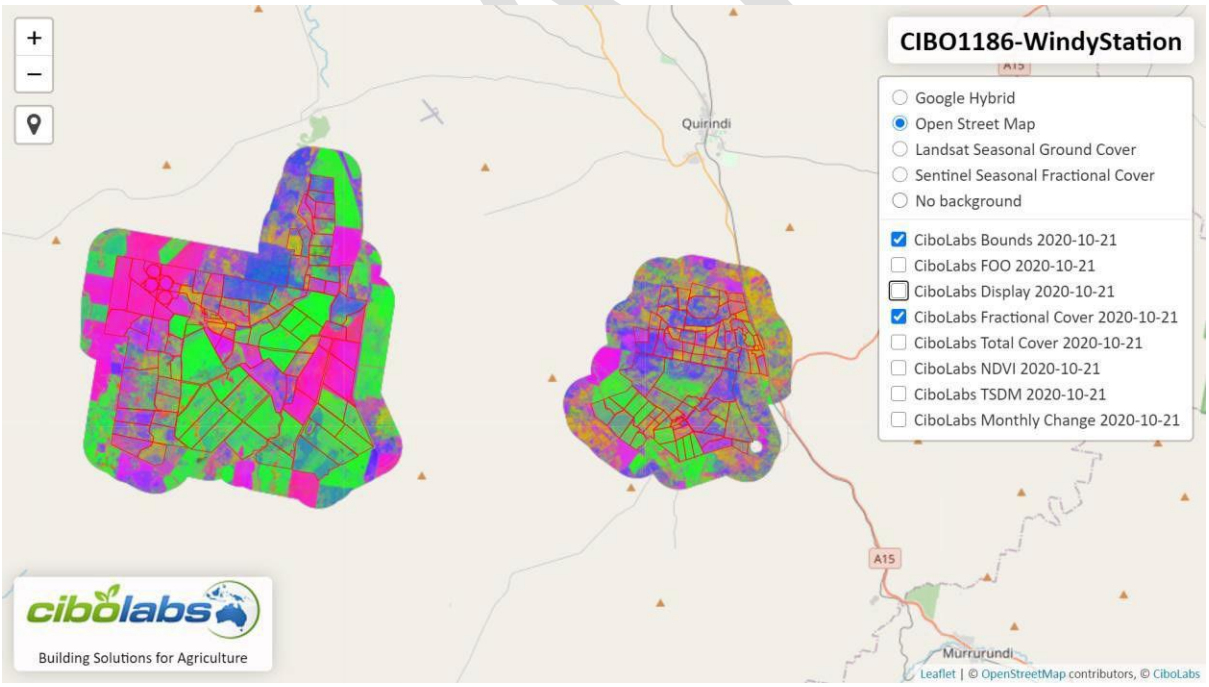
The COVID19 lockdown certainly impacted on our ability to adequately engage with the RPC team and undertake time-critical work. Improving communication, engagement and timeliness of feedback will undoubtably improve our ability to understand the challenges, develop solutions, manage expectations, and deliver benefits going forward.

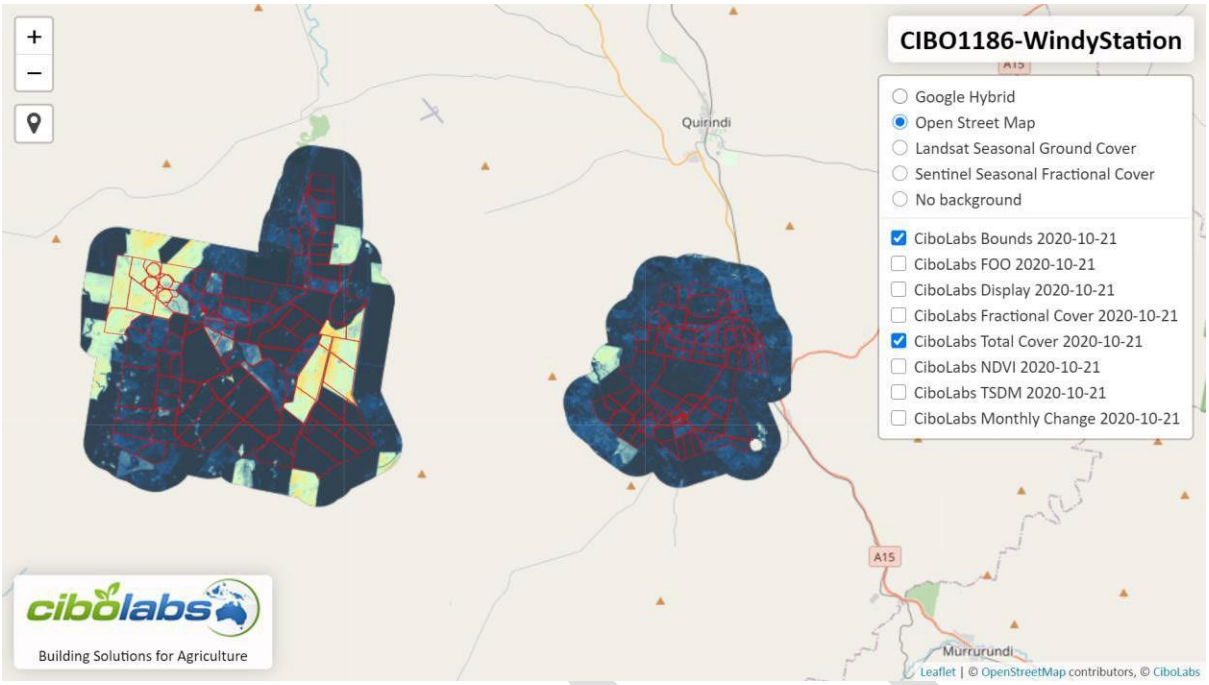
The Digital Livestock 4.0 Demonstrator has provided significant opportunities to improve the quality and benefits derived from the Cibo Labs PastureKey service now operating across 50 million hectares of Australia's grazing industry.

7. Appendix

Windy Station Web Maps



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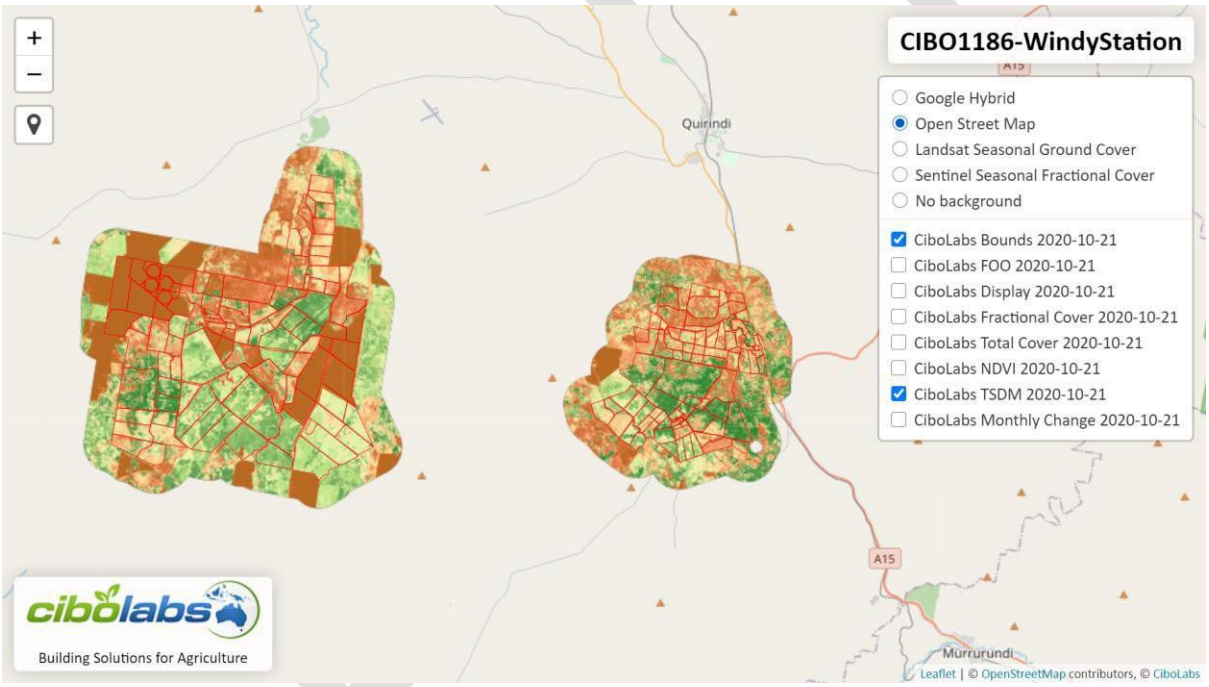
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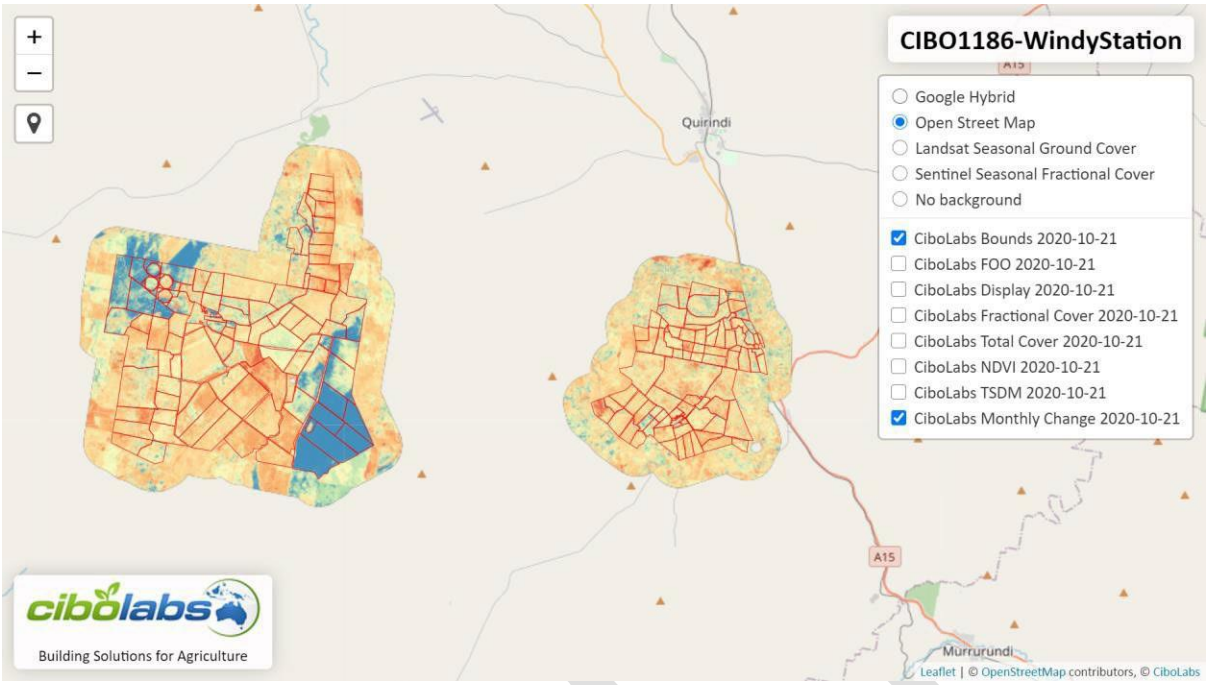
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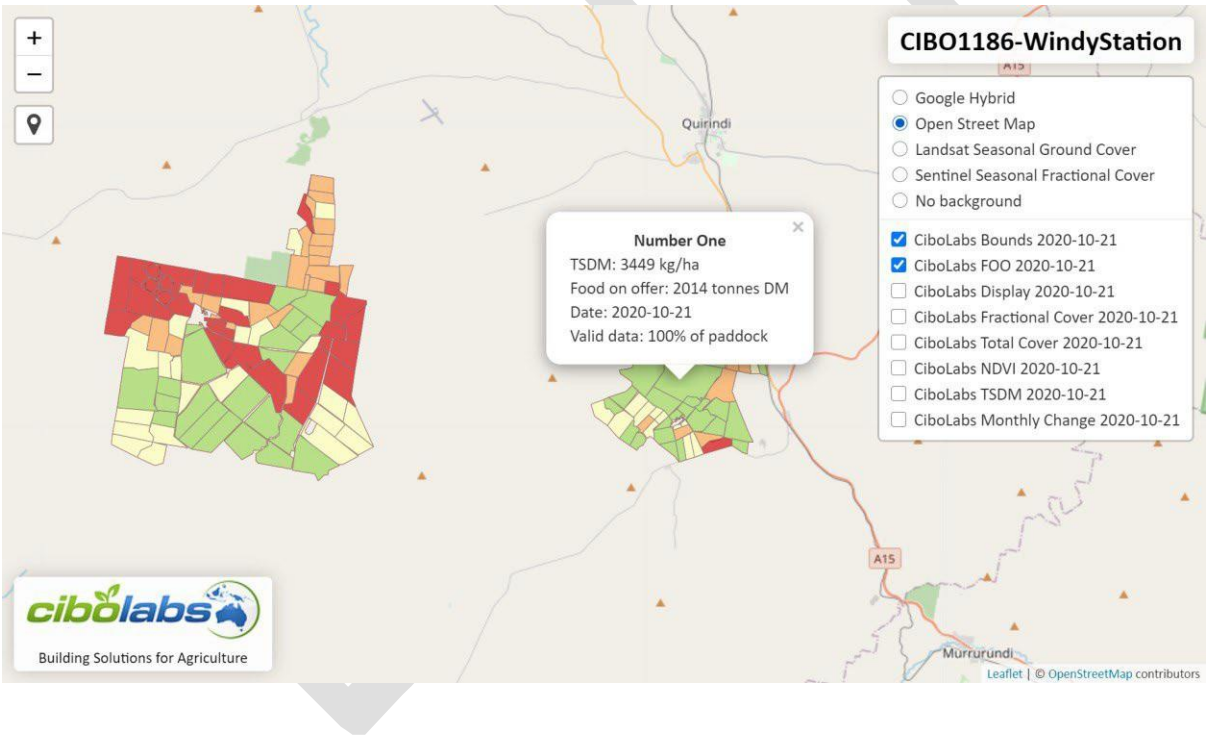
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CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
CiboLabs Monthly Change 2020-10-21
Number One
TSDM: 3449 kg/ha
Food on offer: 2014 tonnes DM
Date: 2020-10-21
Valid data: 100% of paddock
Quirindi
A15
Murrurundi
cibolabs
Building Solutions for Agriculture
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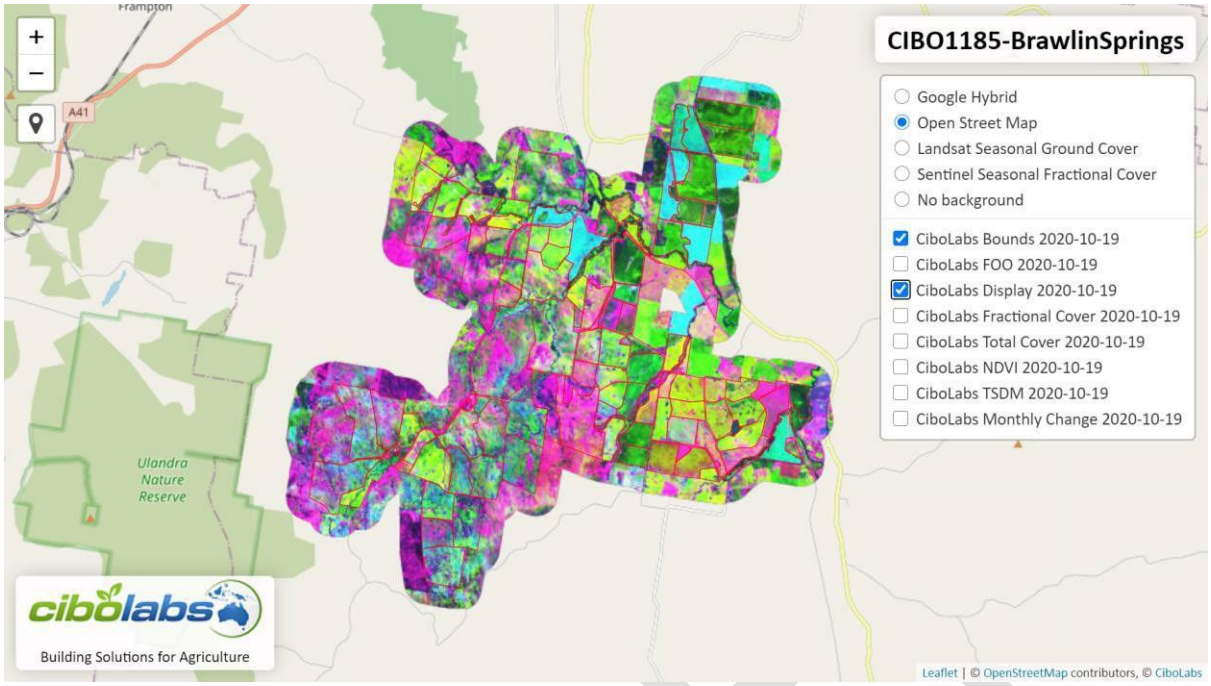
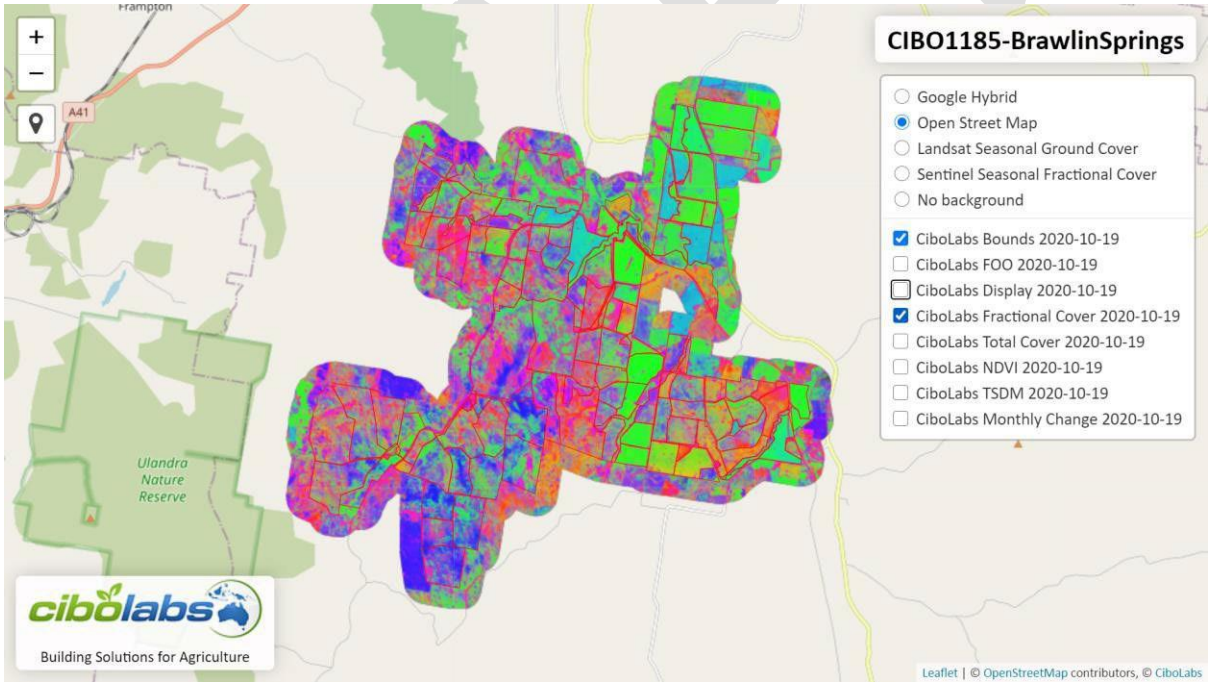
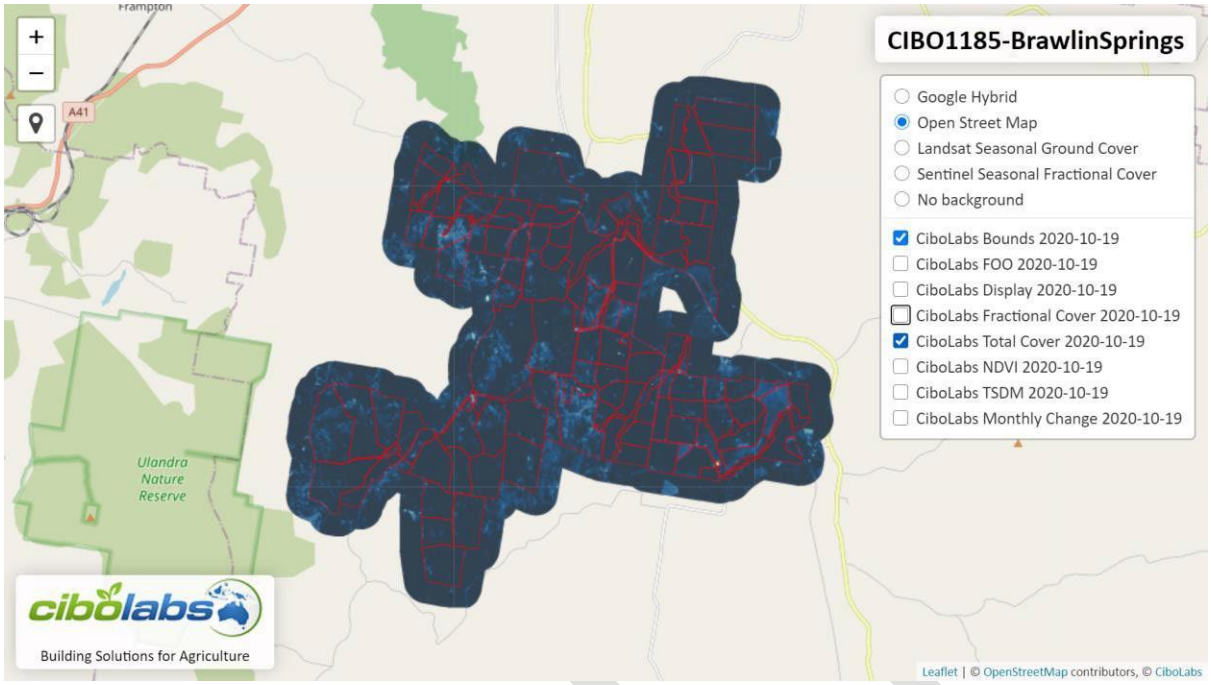
Brawlin Springs Web Maps



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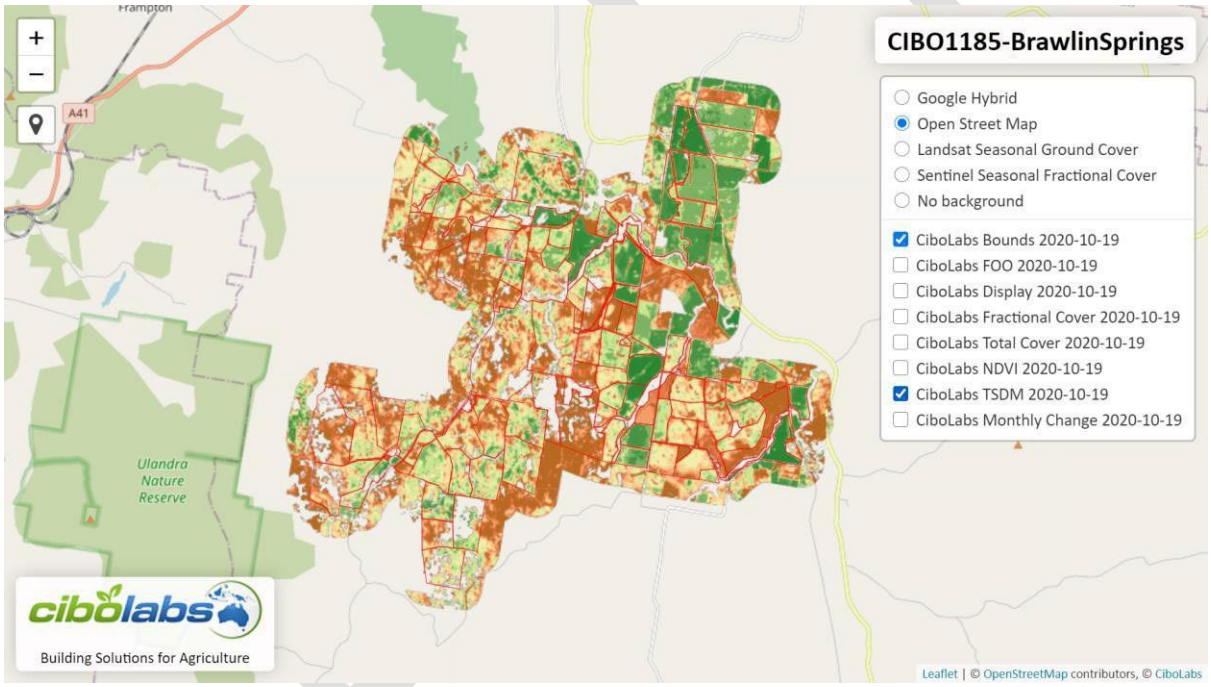
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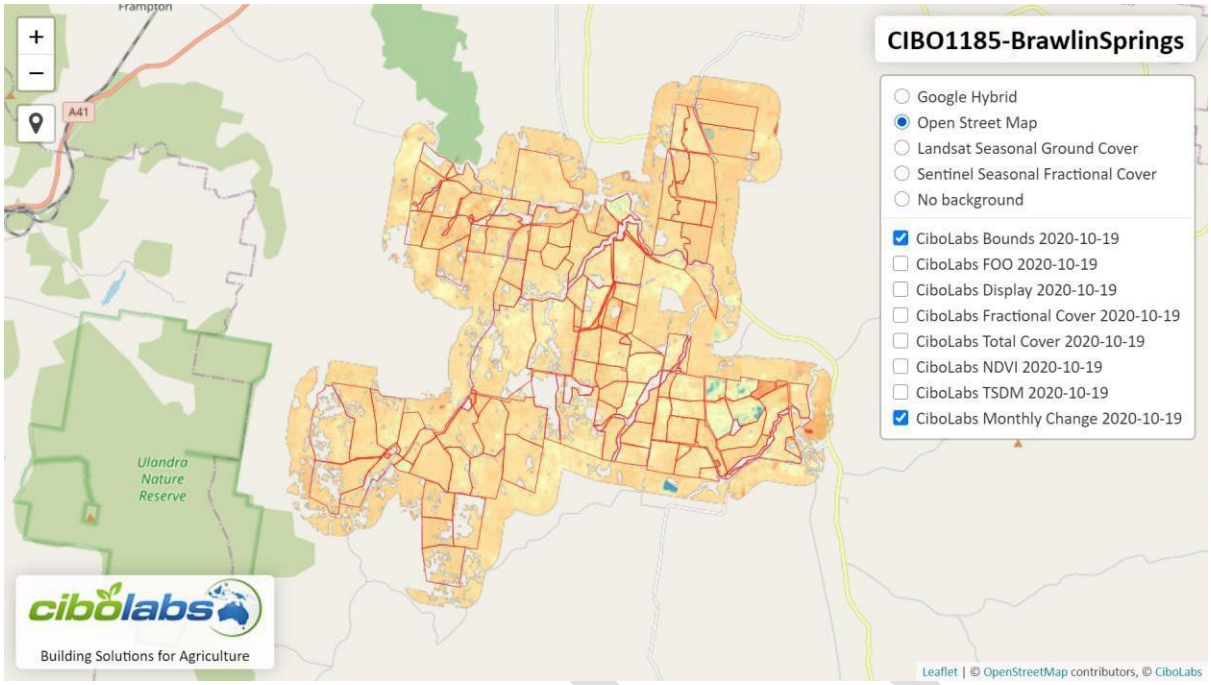
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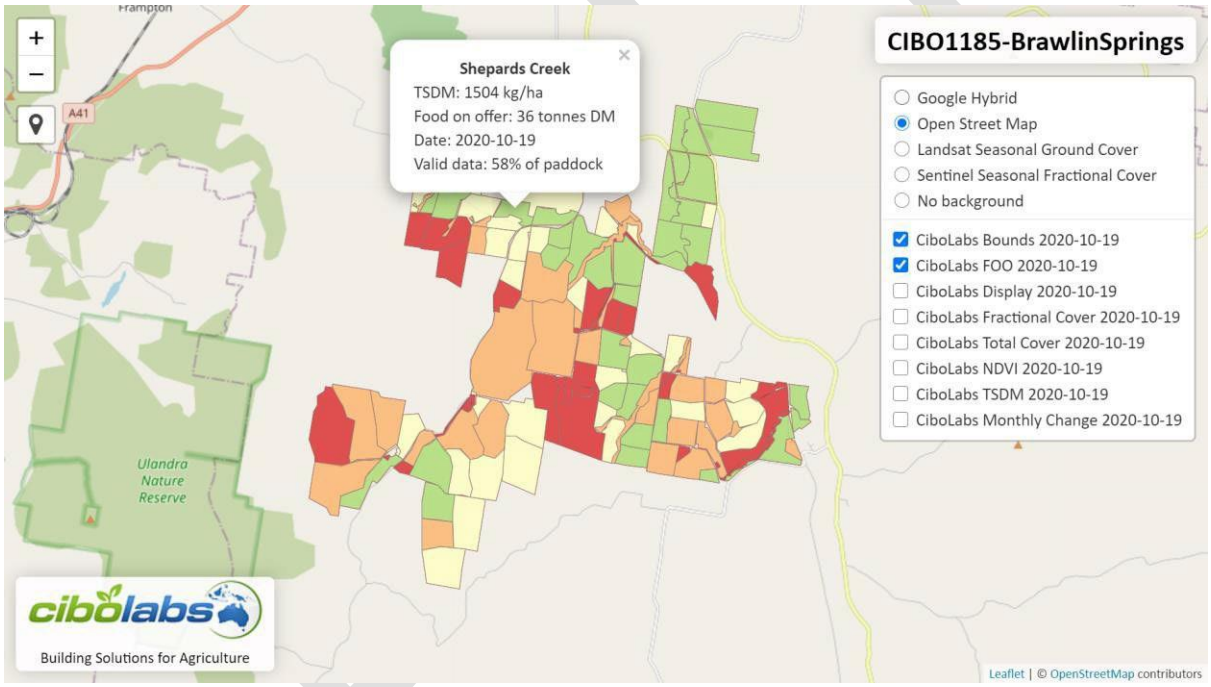
Frampton
A41
Shepards Creek
TSDM: 1504 kg/ha
Food on offer: 36 tonnes DM
Date: 2020-10-19
Valid data: 58% of paddock
Ulandra Nature Reserve
CIBO1185-BrawlinSprings
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
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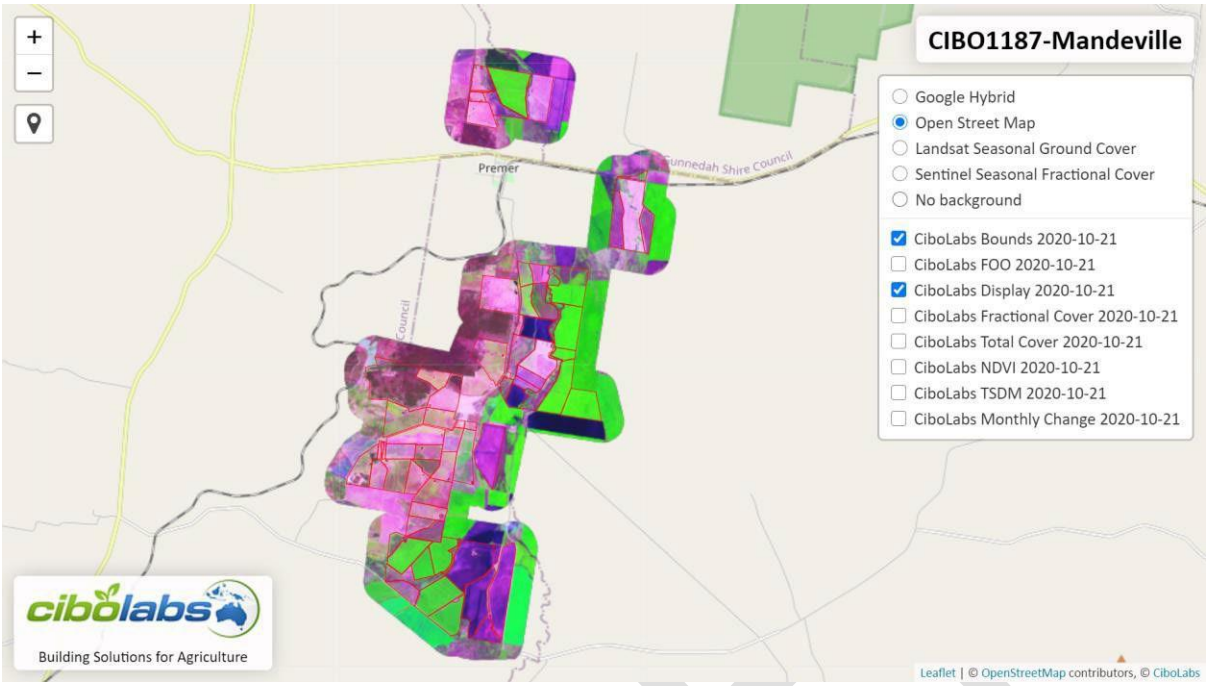
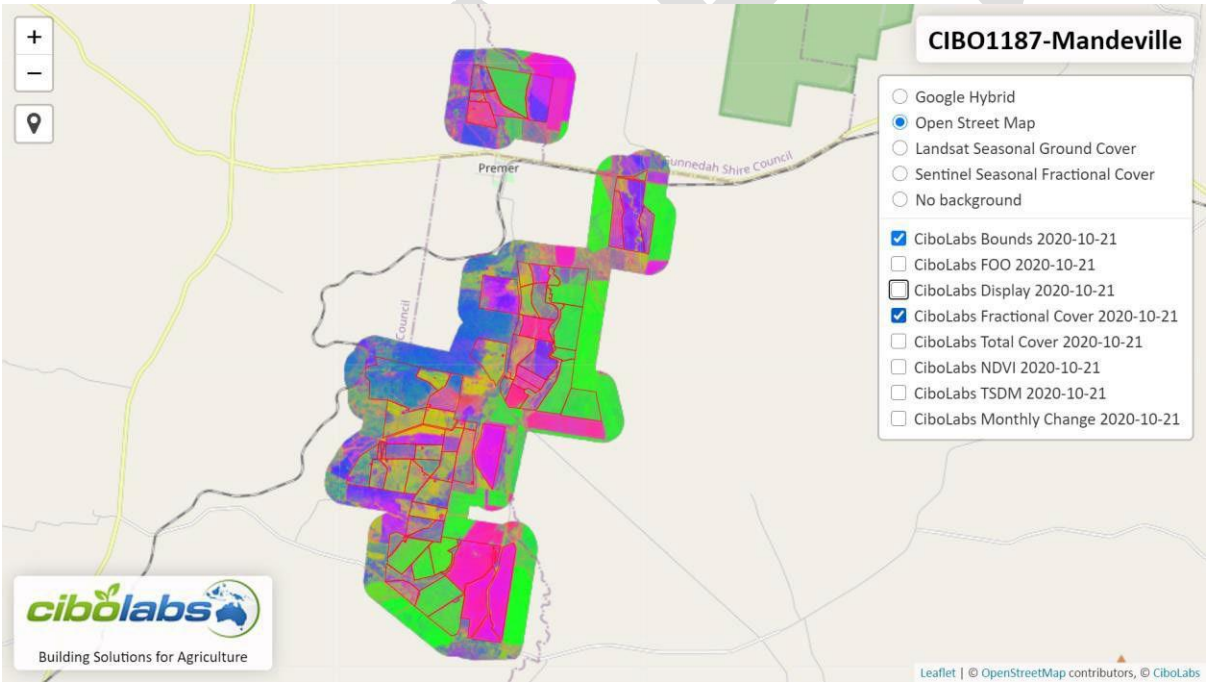
Mandeville Springs Web Maps






CIBO1187-Mandeville
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
No background
CiboLabs Bounds 2020-10-21
CiboLabs FOO 2020-10-21
CiboLabs Display 2020-10-21
CiboLabs Fractional Cover 2020-10-21
CiboLabs Total Cover 2020-10-21
CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
CiboLabs Monthly Change 2020-10-21
Premer
Gunnedah Shire Council
cibolabs
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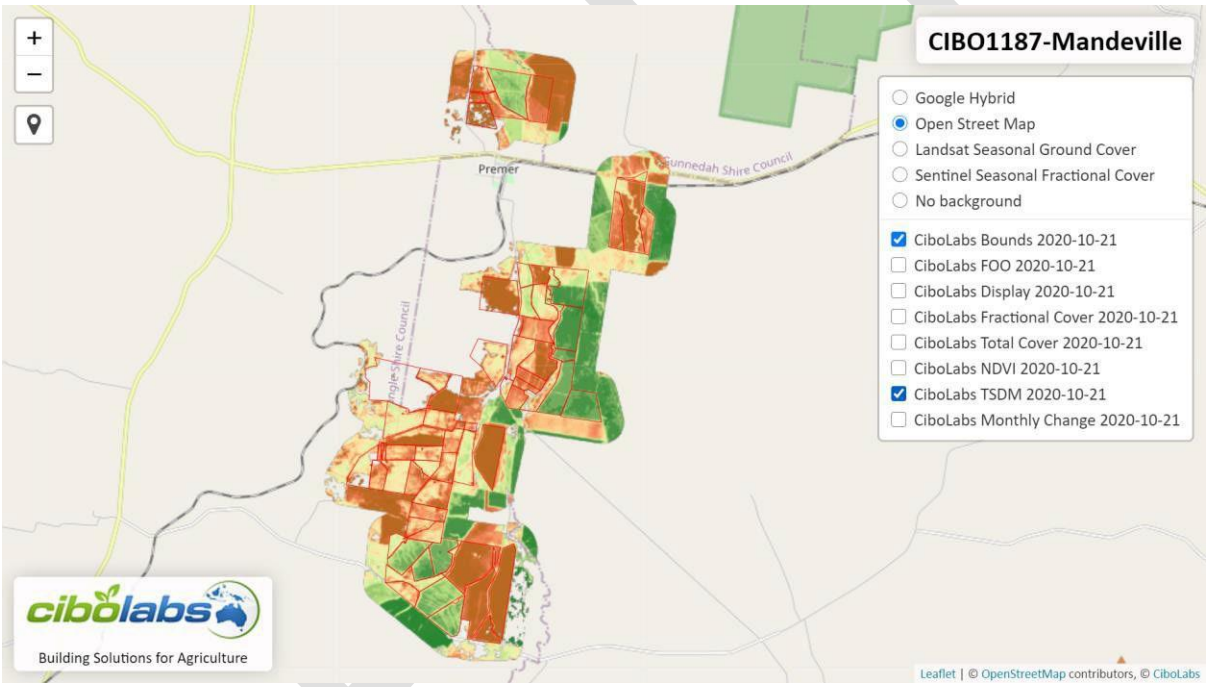
CIBO1187-Mandeville
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
No background
CiboLabs Bounds 2020-10-21
CiboLabs FOO 2020-10-21
CiboLabs Display 2020-10-21
CiboLabs Fractional Cover 2020-10-21
CiboLabs Total Cover 2020-10-21
CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
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Gunnedah Shire Council
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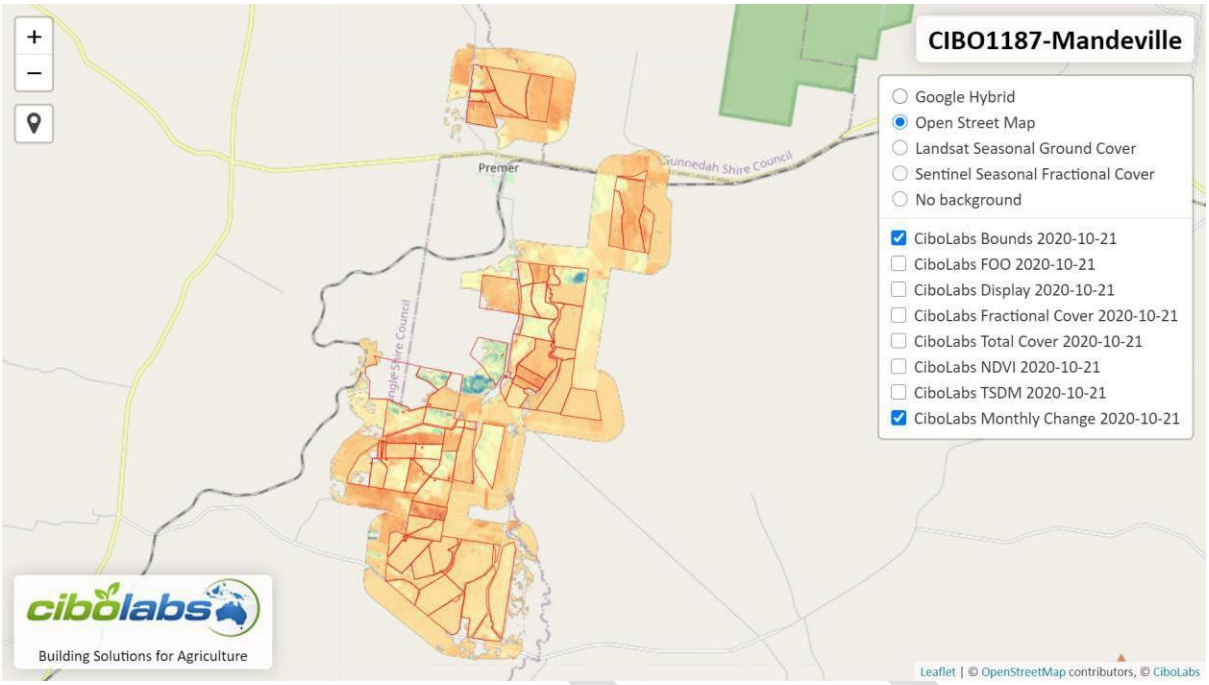
CIBO1187-Mandeville
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
No background
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CiboLabs Display 2020-10-21
CiboLabs Fractional Cover 2020-10-21
CiboLabs Total Cover 2020-10-21
CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
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Premer
Gunnedah Shire Council
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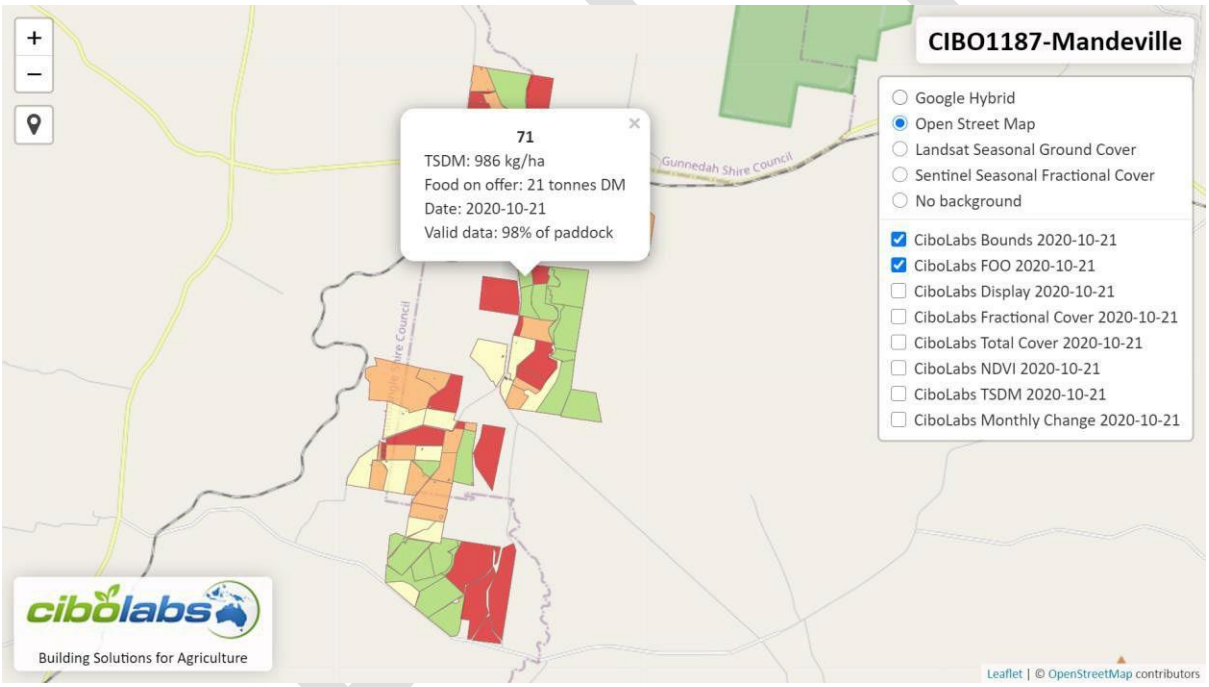
CIBO1187-Mandeville
71
TSDM: 986 kg/ha
Food on offer: 21 tonnes DM
Date: 2020-10-21
Valid data: 98% of paddock
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
No background
CiboLabs Bounds 2020-10-21
CiboLabs FOO 2020-10-21
CiboLabs Display 2020-10-21
CiboLabs Fractional Cover 2020-10-21
CiboLabs Total Cover 2020-10-21
CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
CiboLabs Monthly Change 2020-10-21
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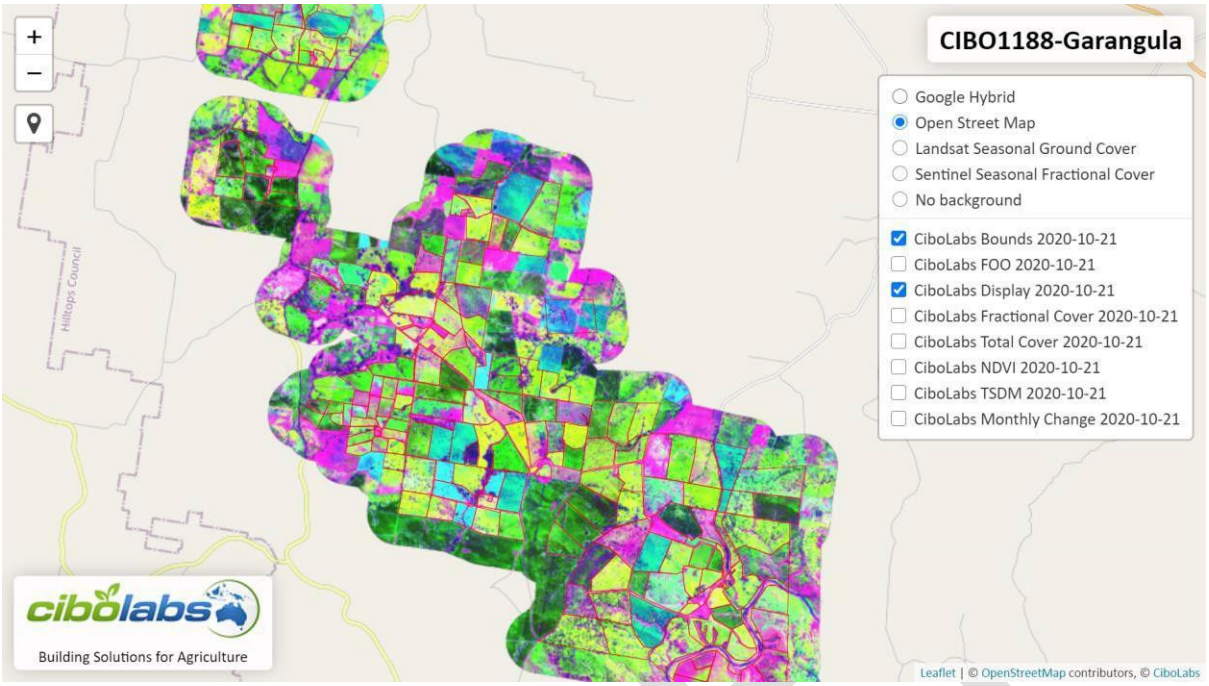
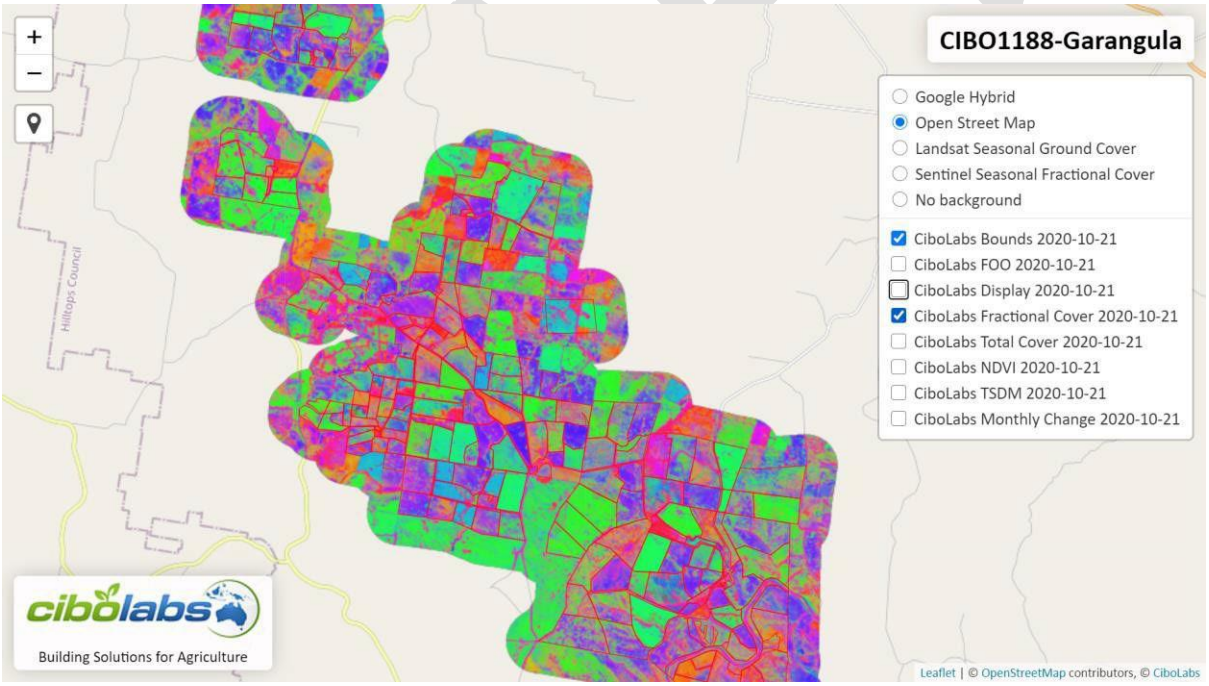
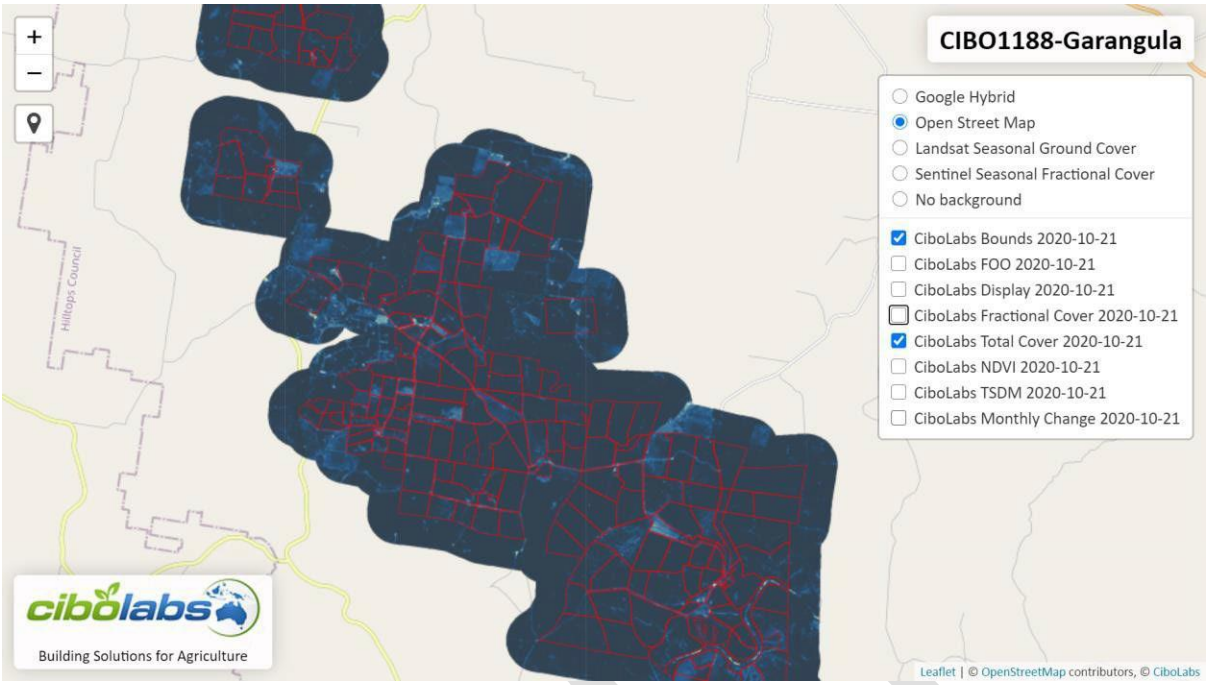
Garangula Springs Web Maps






CIBO1188-Garangula
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
No background
CiboLabs Bounds 2020-10-21
CiboLabs FOO 2020-10-21
CiboLabs Display 2020-10-21
CiboLabs Fractional Cover 2020-10-21
CiboLabs Total Cover 2020-10-21
CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
CiboLabs Monthly Change 2020-10-21
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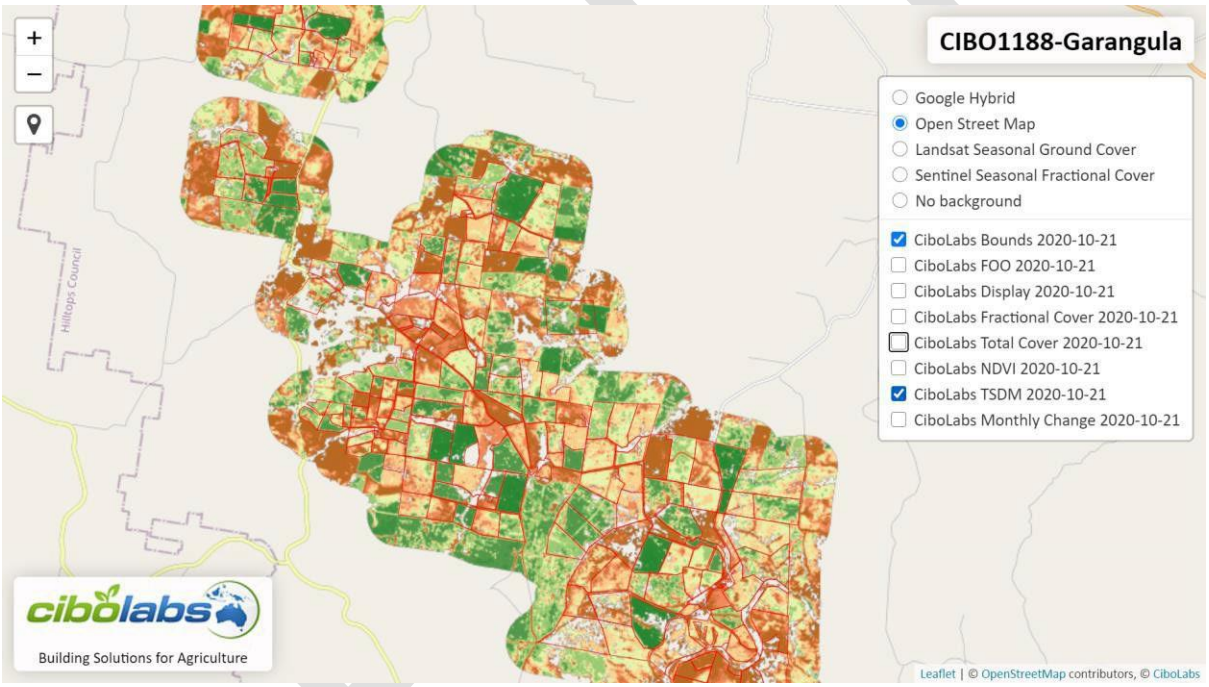
CIBO1188-Garangula
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
No background
CiboLabs Bounds 2020-10-21
CiboLabs FOO 2020-10-21
CiboLabs Display 2020-10-21
CiboLabs Fractional Cover 2020-10-21
CiboLabs Total Cover 2020-10-21
CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
CiboLabs Monthly Change 2020-10-21
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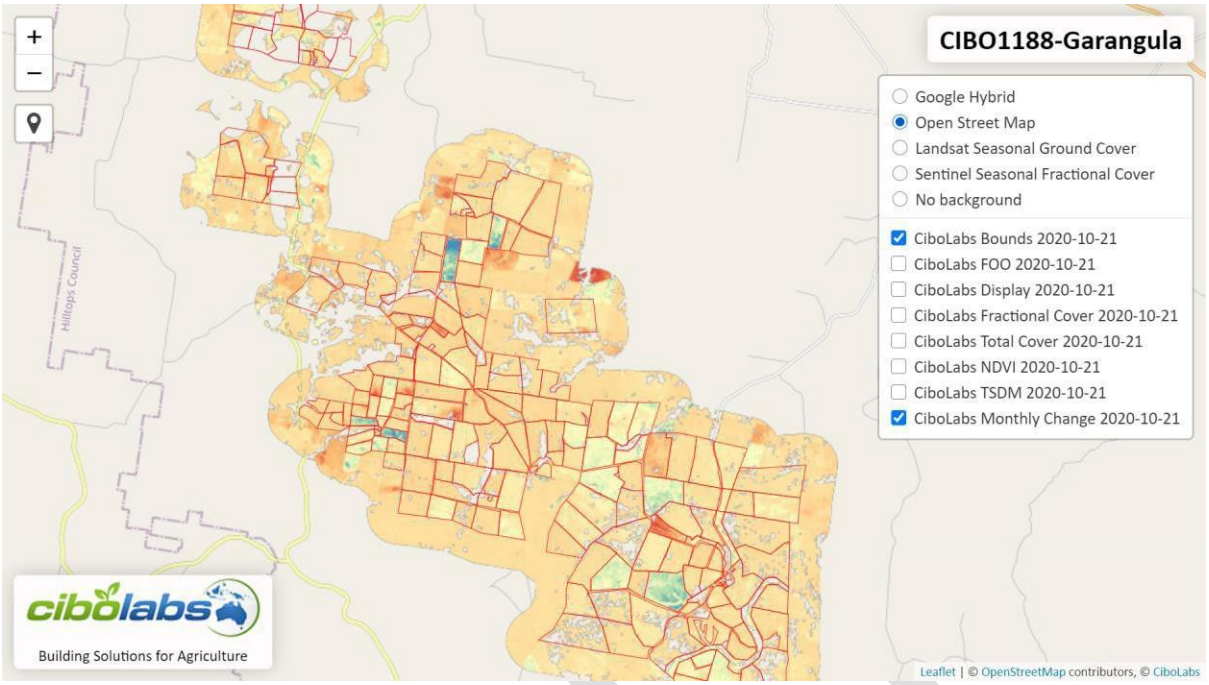
CIBO1188-Garangula
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
No background
CiboLabs Bounds 2020-10-21
CiboLabs FOO 2020-10-21
CiboLabs Display 2020-10-21
CiboLabs Fractional Cover 2020-10-21
CiboLabs Total Cover 2020-10-21
CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
CiboLabs Monthly Change 2020-10-21
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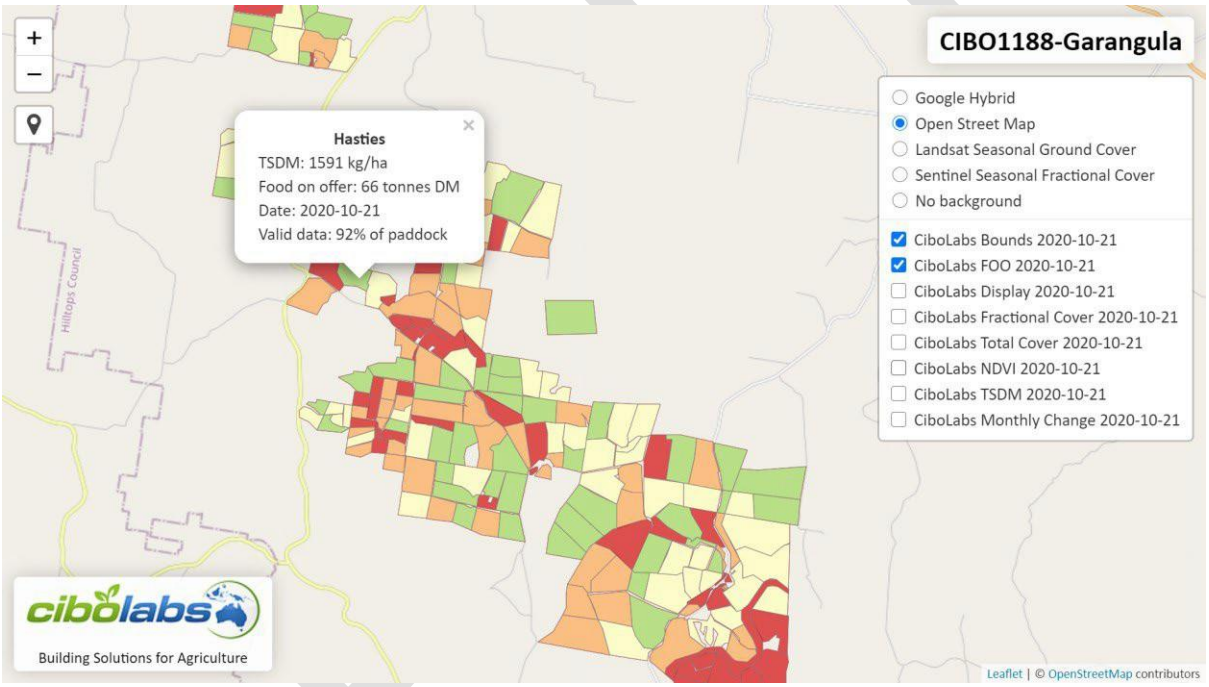
CIBO1188-Garangula
Hasties
TSDM: 1591 kg/ha
Food on offer: 66 tonnes DM
Date: 2020-10-21
Valid data: 92% of paddock
Google Hybrid
Open Street Map
Landsat Seasonal Ground Cover
Sentinel Seasonal Fractional Cover
No background
CiboLabs Bounds 2020-10-21
CiboLabs FOO 2020-10-21
CiboLabs Display 2020-10-21
CiboLabs Fractional Cover 2020-10-21
CiboLabs Total Cover 2020-10-21
CiboLabs NDVI 2020-10-21
CiboLabs TSDM 2020-10-21
CiboLabs Monthly Change 2020-10-21
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