Potential indicators for the co-benefits of carbon farming

Evaluation of potential indicators for the co-benefits of carbon farming in NSW

Department of Primary Industries

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Progress Brief #3 to the NSW Department of Primary Industries for the project 'A Decision Support Tool to Enhance Carbon Farming Opportunities'

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Executive summary

This report is designed to fulfil the purposes of Progress Brief #3 for the project 'A Decision Support Tool to Enhance Carbon Farming Opportunities', reporting to NSW Department of Primary Industries on the following activities:

- Convene a meeting to develop criteria to assess co-benefit indicators in conjunction with NSW DPI project team.
- Undertake an evaluation and assessment of the utility value of potential metrics or indicators to quantify impacts of land-use management and to access environmental markets

An expert workshop was held on 30 July 2019 at UNSW Sydney where a range of potential metrics and indicators that could be used to quantify co-benefits (and dis-benefits) of carbon farming in NSW were discussed, along with a range of different purposes and criteria that underpin the selection of appropriate indicators. A table of potential indicators was circulated prior to the workshop and subsequently revised based on the workshop outcomes.

Key recommendations emerging from the workshop that have been incorporated into the revised table of potential indicators include:

- A range of key **purposes** should be considered in indicator selection and development (e.g. providing landholders with information, enabling payments, harmonising policy objectives) along with key **criteria** such as cost, availability of data, lag time, directness of relationship, scalability and applicability to different contexts (e.g. rangelands and higher-rainfall zones).
- A **nested approach** is required for indicator development, including state-scale and property-scale indicators.
- **Biodiversity and soil health** represent top priorities for indicator development, but provisioning and cultural services should also be considered.
- Indicators should consider **differences between rangelands and higher-rainfall zones** in terms of vegetation extent, connectivity and condition.
- **Outcome-based indicators** should be used to measure the actual impacts of carbon farming where possible, particularly relating to:
  - **For biodiversity**: woody vegetation (extent, vertical complexity, refugia value, perennial weed cover) and ground cover heterogeneity (patchiness)
  - **For soil health**: ground cover (bare ground, persistent green, patchiness), soil carbon (modelled SOC) and woody vegetation (extent, carbon stock).
- **Activity-based indicators** (e.g. area of rehabilitation, perennial grass utilisation, strategic destocking) should be used to complement outcome-based indicators and improve understanding of the links between actions and outcomes.

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Background to expert workshop:

The NSW Department of Primary Industries, in collaboration with UNSW and UTS, hosted an expert workshop on 30 July 2019 on indicators relating to the potential co-benefits of carbon farming (CF), these were benefits other than climate regulation.

The workshop aimed to discuss the following:

1. The **various purposes** for which co-benefit indicators could be used
2. **Key criteria** for selecting indicators of carbon farming co-benefits
3. **Prioritising potential co-benefits** of carbon farming for indicator development
4. **Possible co-benefit indicators** that could be applied to carbon farming

Background information on each of the above points was provided (Appendix 3), including a sample table of potential indicators and associated co-benefits that was used as a starting point for discussion.

Workshop structure

Session 1: Project outline & introductions (expertise)

Cathy Waters welcomed the participants and introduced the project and purpose of workshop, followed by introductions from each participant (appendix 3).

Cathy reflected on:

- The story of Rana and John as farmers involved in carbon farming and how the economic benefits of this activity has enabled them to do fencing, land rehabilitation and fast track implementation of changes in the property. Carbon farming also provided well-being co-benefits (e.g. can sleep at night, and can keep young people working at the property).
- Map of carbon farming projects which showed the emphasis to date on vegetation methods such as human-induced regeneration (HIR) and avoided deforestation (AD) in the rangelands of NSW, QLD and WA, as well as savanna burning in northern Australia. While there are also several other methods for 'carbon farming' (e.g. environmental plantings, plantation forestry, grazing herd management), there has been little uptake of these to date.

Cathy identified key issues that remain:

- Strategies to integrate with pastoral land use (including maintaining fire breaks, pest and weed control)
- Lack of accurate, comprehensive, independent advice
- Lack of developed markets for environmental services e.g. biodiversity

The session concluded with an overview of current research at Cathy's DPI Division, identifying interlinkages amongst different projects; and key issues that need addressing around practical implementation of indicators to measure benefits of carbon farming beyond climate regulation:

- Tools to assess additional value
- Should we aggregate metrics into a single indicator?
- Field testing applicability of indicators across different carbon farming methods
- Satellite, drone, ground based data – what role can each of these play in developing indicators?
- Productivity benefits, environmental co-benefits
- Review of literature, proof of concept, stakeholder analysis, expert opinion workshop, on-site validation

Session 2: Purposes and criteria for indicators

Summary of review work

The session began with Alex Baumber providing a synthesis of the report and journal paper the team has prepared, which focused on reviewing the existing literature on co-benefits of carbon farming in Australia and reviewing existing market-based schemes that cover biodiversity, soils, water quality and other ecosystem services. Alex clarified that Indigenous and other cultural benefits would be not discussed in detail at this workshop due to relevance to NSW and lack of expertise in the room.

The co-benefits review conducted by Baumber et al. (2019)[1] showed that many co-benefit studies have largely focused on permanent plantings, not HIR or AD methods which have dominated carbon farming (CF) adoptions to date in Australia. The review showed most research to data has been speculative, with few potential tools and metrics identified, and very few studies available that directly measured actual co-benefits. A list of tools and metrics discussed in the literature includes indices, indicators, spatial modelling, other modelling (economics, biomass growth, bio value, fire regimes), and stakeholder perceptions/surveys. A gap exists around the development of indices/indicators of co-benefits of carbon farming. Cathy mentioned that multifunctional indicators (not composite) will help identify spatial optimisation of land-use to support the integration of carbon farming with primary production.

The literature review also looked at tools and metrics used in current or former payment for ecosystem services (PES) schemes that may have relevance for measuring CF co-benefits: Examples of indicators can be found in biodiversity auctions and offset schemes (e.g. Victoria's habitat hectares metric, the Macquarie salinity credits trial in NSW, the NSW ground cover incentive scheme, the Hunter River salinity trading scheme, and voluntary carbon certification schemes such as SocialCarbon. Indices may combine multiple benefits (e.g. biodiversity, soil, water) and may be used

[1] Baumber et al. (2019).Ecosystems Services 39: https://doi.org/10.1016/j.ecoser.2019.100982

to compare different projects (i.e. scores) when awarding a tender or auction-based payments. Indicators may be linked to benchmarks that must be achieved to release a payment (e.g. ground cover benchmarks used under NSW ground cover incentive trial). Benchmarks are used in voluntary carbon schemes but are not specific to Australia and are not linked to payment or certification (landholders must have a monitoring regime but are not required to achieve any specific results). Models include biodiversity forecasting tool, BAM calculator (NSW), offset/impact calculator, regrowth benefits tool (QLD).

An important point from the review of other PES schemes was that most indicators being used are activity-based rather than outcome-based (i.e. payment linked to an activity like changing grazing regimes rather than an outcome like an increase in bird density).

Purposes

A draft list of potential purposes that indicators might serve was circulated prior to the workshop. This list was added to and amended during Session 2 and sorted into the two categories shown in Table 1: ultimate purposes (i.e. longer-term or larger-scale objectives) and intermediate purposes (i.e. tools or actions that help contribute to the ultimate goals). The intermediate purposes have been placed next to relevant ultimate purposes below, but in reality some intermediate purposes may contribute to more than one ultimate purpose. Participants were then given the opportunity to vote for the purposes they felt were most important (Appendix 1), with each participant asked to vote for 3 of the most important purposes.

Table 1: Purposes for which co-benefit indicators could potentially be used

Intermediate purposes	No. votes	Ultimate purposes	No. votes
Scientific and practice-based evidence around relationships between co-benefits and land management actions	9	Provide landholders with information so they know how to maximise co-benefits and minimise trade-offs (to production, water, wildlife etc.) as well as informing management change	6
Prioritise locations where carbon farming should be *established and where it shouldn't to risks* of dis-benefits)	6	Harmonising multiple goals around land use (ie: multi-functional landscapes)	6
		Verify policy effectiveness (of carbon farming, emissions abatement and related policy)	4
Accounting of natural capital and environmental social governance	5	Enable payment of landholders who provide co-benefits	3
		Market advantage/market share for products from land managed for co-benefits	2
Enable certification for co-benefits	2	Informing policy; prioritising resources of government	1
		Protecting against risks of disbenefits	1
Enable us to weigh up co-benefits on a common scale (e.g. to encourage actions that optimise co-benefits)	0	Managing risks to carbon farming projects (e.g. to assist management and convince banks)	1

The voting exercise largely confirmed that the list of purposes generated by the participants were relevant, except for a few outliers. Most notably, weighing up different co-benefits on a single scale (e.g. developing a multifunctional index) was not a top priority for the group, despite the fact that several incentive schemes for land restoration or protection have taken this approach (e.g. Victoria's BushTender, ESS NSW, US CRP). Also, protecting against risks of disbenefits and risks to carbon farming projects scored poorly, as did prioritising resources of government (although participants noted the overlap between this and harmonising goals which ranked highly and could potentially be combined).

It was also observed by some participants that the rankings were heavily influenced by the types of stakeholders present (largely government and academic) and would likely differ if the exercise was repeated with other stakeholders (e.g. landholders may rate income opportunities higher and carbon aggregators or investors may be more concerned about project risks). Nonetheless, this list of purposes was useful for referring back to in later sessions to assess whether proposed indicators would be able to fulfil the range of purposes for which they may be required.

A list was also complied of key criteria against which indicators could be evaluated. Table 2 presents some criteria that were suggested as desirable at the workshop.

Table 2: Desirable criteria to evaluate indicators

1	Low cost
2	Available data sources to draw on
3	Short lag time between on-ground action and measurable outcome
4	Direct relationship between indicator and the desired co-benefit
5	Scalable
6	Applicable to the different contexts in which carbon farming may occur in NSW (e.g. AD and HIR in rangelands as well as environmental plantings further east)
7	Amenable to independent verification
8	Ability to be linked to multiple sources of evidence (i.e. able to form part of a coherent and compatible dataset that helps us to understand co-benefits)

Below are some other criteria that were raised as important considerations, but cannot be expressed as a single attribute that would be desirable in all cases:

- Outcome-based vs activity-based: Both types of indicators are likely to be required in order to meet the range of purposes for which indicators could be used
- Proximity: Both remotely-sensed and on-ground measurements may be needed to feed into indicators.
- Single benefit vs multiple benefits: Some measurements may support indicators for multiple co-benefits in some contexts (e.g. biodiversity value and soil health), but in other contexts a separate indicator may be needed for each co-benefit. The extent to which multi-functional indicators could be used is subject to much uncertainty at this point in time.

Comments made in the discussion of criteria included:

- Scientific and practice based-evidence of co-benefits is needed for enhanced understanding and documenting of ecosystem services. In other words, evidence-based for understanding relationship between land management and co-benefits.
- Activity vs outcome-based indicators – activity-based could be problematic, example, incentivising farmers to move to no-till under the assumption that it increases soil carbon when in fact it doesn't. We need to enhance our ability to predict outcomes based on actions.

- Provisioning benefits, i.e. production benefits less-commonly mentioned in literature than, for example, biodiversity or soil benefits.
- The rate of change and direction of change relative to a 'tipping-point" is difficult to determine, but it is important to determine to avoid further degradation;
- Should we develop an 'avoiding losses' blueprint or is it better to keep environmental issues unpacked, for example, with a focus on salinity or biodiversity? If packed into a blueprint, it would get too complex. Everyone wants a good outcome across the landscape, but no matter how you weight different aspects of landscape health, some indicators will come out on top.
- Indicators need to provide information on trends, be reliable and be repeatable; use sources including local site sources of information and be evidence-based.
- The dashboard concept leaves the final decision to the policy maker and indicators can have more or less weight depending on their interpretation. Composite indicators are dangerous especially for policy makers not understanding the meaning of the final 'figure'; what is actually represented in the landscape.
- Help landholders target activities to maximise co-benefits and minimise trade-offs.
- Broader objectives of having indicators: achieving resilience, carbon abatement, net zero target for NSW that are beyond carbon farming methodologies – informing climate policy beyond carbon farming policy, for example, land degradation policy. Harmonising with other activities and illustrating how they all come together to produce multiple benefits from land management.
- Indicators can be useful for prioritisation of resources/incentives – for helping Rural Development Corporations and government identify where carbon farming should be established
- Indicators and issue of scale also need to be discussed – what do indicators look like at the farm or property scale versus the regional scale. Indicators of biodiversity look at broader scale assessment; connectivity/representation of different ecosystems, and more of the latter equates to a bigger benefit. Indicators of regrowth are useful for restoring degraded ecosystems.
- Indicators could be developed to avoid loss of existing value, for example, where there are currently high levels of soil carbon existent in the landscape, or where carbon farming shouldn't be established because there is already current value (and no need for additionality). However, disbenefits are present with co-benefits and balancing out the former may be needed to achieve neutrality. This won't be known unless a suite of actions can be tested at the same time. Hence the importance of information to help policy makers design carbon farming policies to maximise co-benefits, and to enable landholders to get paid for carbon farming co-benefits.
- Co-benefit indicators can help to secure market share and market advantage via premiums for social licence (environmental stewardship) for producing products. These indicators could help identify and manage risks and instigate practice change, for example, in grazing regimes. Of note is the concept of natural capital; banks are more interested in valuing it and in improving or maintaining the

resource base that supports the productivity of farms. Work is underway on natural capital accounting which may be of relevance to indicators of co-benefits of carbon farming.

- Development of co-benefit indicators may have broad applicability across agricultural systems and do not need to be confined to carbon farming.

Session 3: Proposing and evaluating possible indicators

After purposes and criteria were defined in Session 2, the discussion focused on possible indicators, with a table of possible indicators circulated prior to the workshop used as a starting point (Appendix 2). Given the expertise of the workshop participants, it was agreed to focus primarily on biophysical indicators, leaving social/cultural indicators for further discussion after the workshop.

Hereafter follows a summary of main points discussed by participants, sharing knowledge and past experiences on metrics and data/information that is available, as well as limitations for their application in the context of the current project: **Indicators of agroecological system quality vs system management**: current quality of agroecological systems can be measured by woody cover, floristic diversity/bird counts; indicators of management: grazing pressure, though total grazing pressure (TPG) is hard to capture at a broad scale

Data availability for indicators and associated metrics[2]:

- **Ground cover and biomass** are important to capture; fractional ground cover is currently available at a spatial resolution of 10 m in QLD using remote sensing data, and it was reported that Geoscience Australia is developing this as a product for other States. If it is done in Qld it can be adopted in NSW. At a landscape scale, Landsat-based products are available that focus on fractional cover (not ground cover) [3]
- Indicators based on satellite remote sensing can provide information on **trends and dynamics of vegetation** since the 1980s (Landsat images). This is of importance to understand and separate human-induced changes (because of management) versus climatic pressures (drought, extreme climatic events). To separate climatic from management-induced changes on the land we need the temporal component that remote sensing can offer through time series analysis. The Landsat family of satellites has provided so far the most continuous data set, and groups like Joint Remote Sensing Centre in UQ are calibrating Landsat with Sentinel imagery, to facilitate access and use of these satellites in time

[2] Most of the remote sensing datasets are already in the inventory table of Brief #1, Baumber et al.
[3] This is summarized in the Table of Brief 1 (Baumber et al, 2019).

series analysis. Examples of calibration between these two satellites for rangelands and drylands exist in Queensland and the USA[4].

- OEH NSW (now DPIE) has a 90 m spatial resolution product on **Habitat condition**. Such data can be used to show connectivity – primary use vs secondary use.
- Information is available on **biodiversity**: condition plus pre-clearing distribution of ecosystems equals to conservation benefit of each pixel; and it could be used to prioritise areas to conserve and restore (for all NSW at 90 m spatial resolution). At this spatial resolution, and in geographies like the Western division minor changes will not be detected over time, just major changes.
- Jeff Horn reminded that two reference maps (2009 and 2013) are available on **biomass change, above ground biomass**; these are derived from the ALOS SAR and IceSAT[5], and can provide information at regional/landscape level (30 m spatial resolution). They are reference maps of Australian forest and woodland structure (height and cover). Horn's team is working on data fusion of Sentinel-1 (SAR) and Sentinel-2 (optical/Infrared) to derive information on native vegetation re-growth, structure, and height. Should be available in 2020[6].

Limitations of data:

- Limitations of change detection based on remote sensing information include lag time between change in management and visible outcome; i.e. need a big step for it to be visible via remote sensing.
- Further limitations relate to the availability of ground plots for calibration and validation of products. Products like the fractional cover (bare, photosynthetic, non-photosynthetic) have been validated through TERN and funding and time was committed to generating ground data for validation (which is open access). Sentinel-1 and Sentinel-2 data fusion in NSW, derived for gathering information on vegetation structure and height, is being validated in the ground (December 2018 campaign). This adds to current work of Stoner's team on forest biomass products derived from remote sensing, and field observations.

A discussion followed on **assumptions related to land condition and what an indicator (and associated metric) can express**. For instance:

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[4] Spatiotemporal Analysis of Landsat-8 and Sentinel-2 Data to Support Monitoring of Dryland Ecosystems. Pastick, N., Wylie, B., & Wu, Z. (2018). Spatiotemporal analysis of Landsat-8 and Sentinel-2 data to support monitoring of dryland ecosystems. Remote Sensing, 10(5), 791.

[5] Listed in the Table of Brief #1, and more information at http://data.auscover.org.au/xwiki/bin/view/Product+pages/ICESat+Vegetation+Structure and A Structural Classification of Australian Vegetation Using ICESat/GLAS, ALOS PALSAR, and Landsat Sensor Data, at https://www.mdpi.com/2072-4292/11/2/147/htm

[6] Work being undertaken by Dr Anthea Mitchell UNSW.

a) Greater ecosystem structural integrity-> greater biodiversity[7] -> the use of AGB as indicator.
b) Density of shrubs and trees has low structural complexity (few habitat features); high density shrubs may result in low C stocks and negative impacts on biodiversity[8].
c) Differing interpretation of Invasive Native Species (INS): different perceptions and interpretations depending on stakeholder/application (e.g. production versus conservation or recreation). For example, INS has traditionally been considered an indicator of land degradation in productivity-related activities; other stakeholders see INS as native vegetation that aid responses addressing land degradation, protecting landscape from erosion and storing carbon[7]. Whereas INS are a disbenefit for agriculture, in the context of carbon farming they represent a benefit for carbon sequestration, and landholders can still graze areas (i.e. fine tuning grazing).
d) Expected changes in carbon storage during forest regrowth: Brad Law[9] led a project which examined a chrono-sequence of forest thinning in the Pillia Forest regrowth. It is comprehensive study which examined biodiversity impacts and can be used to indicate expected changes in carbon areas during regrowth (HIR) and AD (further discussion in Brief #2 of Baumber et al., 2019); various suites of biodiversity benefited overtime. We can expect that as regrowth occurs, there will be benefit for different species as time goes on. Exclusion fencing may lead to greater bird diversity if predators are controlled (little evidence to date).
e) It was discussed that at present maybe 40% of all carbon farming areas in NSW had total grazing pressure (TGP fencing). AD beneficiaries don't need to fence to earn carbon credits, but some are using the money they earn from carbon credits for fencing other areas (to control TGP).
f) Post millennial drought saw livestock largely removed (destocking); goat numbers remained high over this period, but have recently dropped (perhaps due to over harvesting with high goat prices). Areas under INS grazing pressure removed some stock in 2009; following drought breaking rains some regrowth occurred with some areas of obvious increase in perennial ground

[7] Biological diversity is defined for a certain reference area, and landscape structure is a key element for the understanding of species diversity. Spatial heterogeneity, as an expression of landscape structure, indicates the variability of the system's properties in spatial terms. http://lrlr.landscapeonline.de/Articles/lrlr-2011-3/articlese4.html#x7-40004

[8] Waters CM, Cowie A, Orgill SE, Garland F, Simpson M, Chappell A, Paul K, Cockfield G and Grant R (2017). Assessing the impacts and opportunities from carbon farming in western NSW. Proceedings of the 19th Australian Rangeland Biennial Conference, Port Augusta 25-38 September 2017

[9] Gonsalves L, Law B, Blakey R (2018) Experimental evaluation of the initial effects of large-scale thinning on structure and biodiversity of river red gum (Eucalyptus camaldulensis) forests. Wildlife Research 45, 397-410

cover. In a soon to commence NSW DPI/MLA funded project a tool will be developed which provides early warning of when an imbalance between feed supply and demand is occurring. This represents a potential opportunity to co-locate sites for the MLA project with sites for validation of co-benefit indicators of carbon farming.

Exploring metrics and approaches for potential indicators:

Indicators of woody cover: it is not enough to just measure the extent of woody cover; more information is needed on increase in habitat they provide (i.e. composition). INS are important for soil carbon and biodiversity and represent a benefit to biodiversity, though it varies over timescales. Biodiversity value does not occur at site if all INS are the same, though benefits may be more evident at regional scale given a combination of different patches of different ages/sizes in a landscape. Hence an indicator on woody cover should contain metrics quantify ground cover plus habitat.

Discussion followed on the potential of undertaking drone-based measurements. Drones are being used by landholders, and there may be an opportunity for adding more sensors on this platform, or to combine data from this platform with other data sets (e.g. satellite imagery, or ground information) to be used for supporting management decisions. Validation of indicators can be undertaken using paired paddock contrasts (inside and outside carbon areas, potentially managed for TGP).

Regarding data/information on **higher conservation value areas,** a general discussion identified ideas around using existing TERN dataset. Such areas could be used as priority locations for carbon farming practices that are known to protect or enhance habitat value. These could be integrated into PES schemes to create incentives to establish carbon farming in such areas.

Peter Scarth described a pilot study based on a nested-approach of multi-scale remote sensing and field transects. The study uses patchiness of the landscape as indicator of biodiversity value. His team used Planet Labs[10] images (3 meter spatial resolution), combined with transects over 100m (Wombeyan). Scaling of patchiness, looking for relationship between grazing intensiveness and patchiness – scaled it up to .5m, then checked with Sentinel-2 and Landsat imagery (20-30 meters). Change in patchiness cannot be observed at the resolution of Planet Lab (3 meters), but it was identified on Sentinel imagery (20 meters pixel size). Scarth's team used this indicator in a model of patchiness for predicting impact on reef catchments. This is a promising indicator, and Peter will look at how this indicator changes in response to climate change.

[10] https://www.planet.com/products/monitoring/

Figure 1: Example of PlanetLab data set at 3 m resolution. Area: Brazil. Source: https://www.planet.com/gallery/

Discussion followed on **paired paddock contrast** (Cathy) to try and verify indicators, could patch structure be one of these indicators? Peter indicated a possibility to re-examine how we look at the long-term green signal (see an example in Figure 2), but focusing on the cycle of land clearing, then regrowth, then re-clearing and the error around grey points; to map **cycles of disturbance and recovery**. Work is underway in relation to disturbance and recovery in forest areas of NSW (Stone group), looking at seasonality vs long-term trends. The idea is to detect severity by looking at the depth of the changes in trend then it can identify what is deviating from normal oscillations. Other ideas were discussed around using normal averages within IBRA regions, analysing areas that are above or below the 'norm'[11]. It was noted for such approaches a suitable reference site for grazing benchmarking is needed, as well as information on land type; and mention was made of 'dynamic benchmarks".

[11] Past work of P Scarth in areas of Qld using vegetation cover fraction.

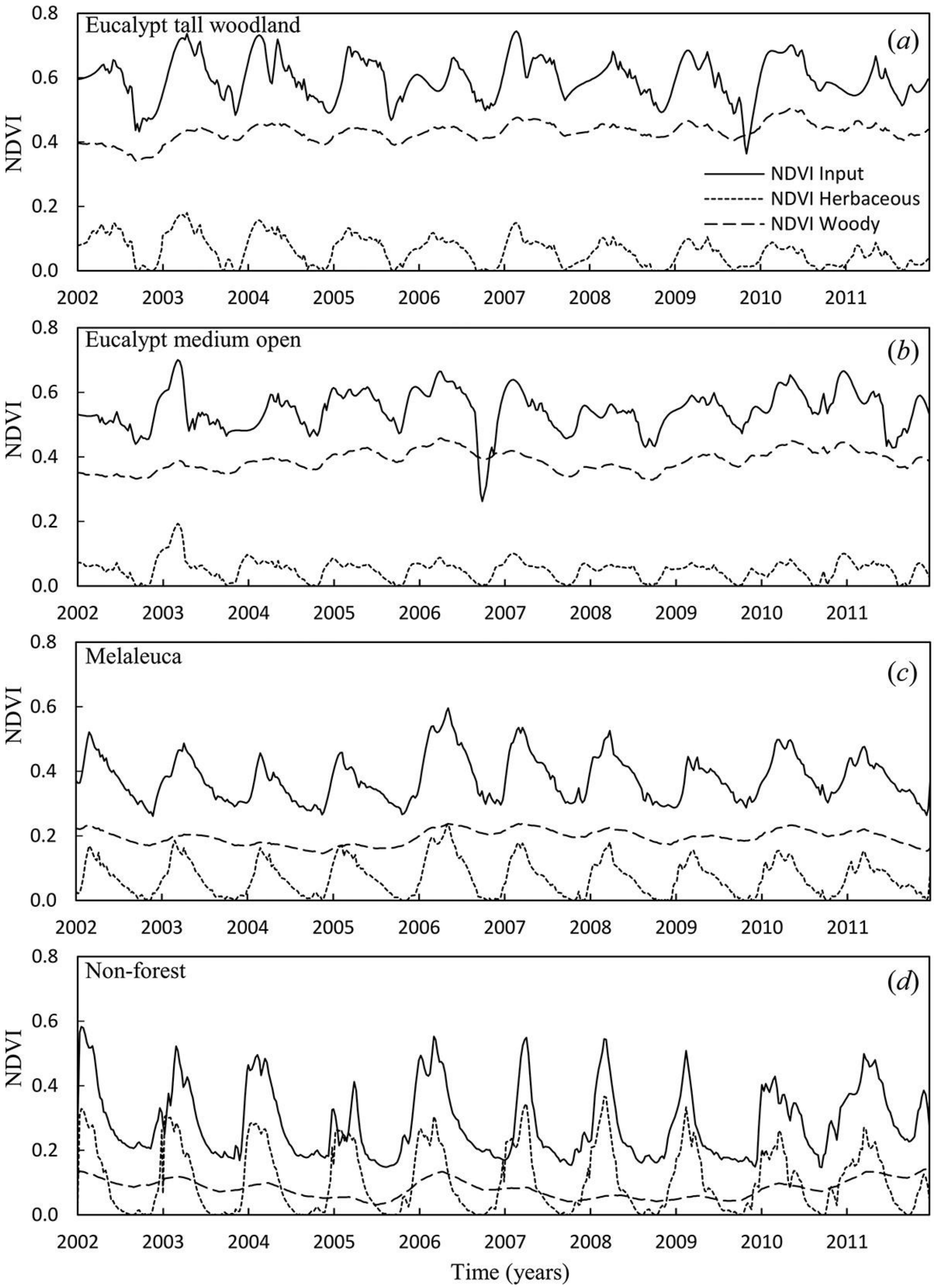

Figure 2: Example of analysing long-term green signal of vegetation. From: Retrieving understorey dynamics in the Australian tropical savannah from times series decomposition and linear unmixing of MODIS data. Zhou et al (2016). https://doi.org/10.1080/01431161.2016.1154224

Other innovative approaches were discussed such as **the use of phenocams** (Figure 3) for monitoring forest recovery rate, though not grasslands[12]. Could a combination of phenocams and Sentinel-based fractional cover be used for monitoring woody regrowth? to obtain information of the understorey and ground layers where response to land interventions are more evident? A point was made on location of phenocams to be representative of the 'paddock/property', and it was noted landholders know very well which areas on their property are sensitive to change – most productive, or where kangaroos are more frequently found, etc.

Figure 3: Sentinal Phenocam or TERN's network of environmental monitoring cameras. https://www.tern.org.au/Newsletter-2017-Mar-Sentinal-Phenocam-pg31941.html

Phenocams could be linked with satellite data and used as data for calibration[13], to derive some consistency in information that is relevant to metrics of carbon farming and co-benefits[14]. An ideal setting would be phenocams that can send back green

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[12] Under TERN the Australian Phenocam Networks has been developed; from the website it appears trials include semi-arid rangelands. Led by Tim Brown. Other researchers using phenocams for satellite phenology validation are Alfredo Huete, K Davies (UTS). TERN produced the protocol for phenology Validation, led by Mariela Soto-Berelov. http://data.auscover.org.au/xwiki/bin/view/Good+Practice+Handbook/PhenologyValidation https://phenocam.org.au/

13 An example that uses Landsat-8, Sentinel-2 and phenocams. at Zhou, Q., Rover, J., Brown, J., Worstell, B., Howard, D., Wu, Z., Gallant, A.L., Rundquist, B. and Burke, M., 2019. Monitoring Landscape Dynamics in Central US Grasslands with Harmonized Landsat-8 and Sentinel-2 Time Series Data. Remote Sensing, 11(3), p.328.

14 May be worth checking on the work of Alfredo Huete (UTS). He has developed phenology information from MODIS, too coarse for farm-scale applications. However there is recent research: Brown, T. B., Hultine, K. R., Steltzer, H., Denny, E. G., Denslow, M. W., Granados, J., ... & Sánchez-Azofeifa, A. (2016). Using phenocams to monitor our changing Earth: toward a global phenocam network. Frontiers in Ecology and the Environment, 14(2), 84-93.
Browning, Dawn, Jason Karl, David Morin, Andrew Richardson, and Craig Tweedie. "Phenocams bridge the gap between field and satellite observations in an arid grassland ecosystem." Remote Sensing 9, no. 10 (2017): 1071. Richardson, A. D., Hufkens, K., Milliman, T., Aubrecht, D. M., Chen, M., Gray, J. M., ... & Melaas, E. K. (2018). Tracking vegetation phenology across diverse North American biomes using PhenoCam imagery. Scientific data, 5, 180028.
Watson, C. J. (2017). Exploring the seasonal dynamics of Australian temperate grasslands through phenocam imagery, remote sensing and field data (Doctoral dissertation from UTS). And Watson CJ, Restrepo-Coupe N and Huete AR (2019) Multi-Scale

signal daily to assess how different vegetation types respond to rain, etc. More novel ideas were discussed for gathering information on what could be indicators of biodiversity as a co-benefit of carbon farming: audio recordings as well (bird calls?)[15]. Limitations of on-ground sensors like phenocams include measure movements, being stolen, prey of animals (goats).

Of note is that soil types and preceding rainfall should be part **of a monitoring system** (Sue Orgill). A monitoring system could be developed in the future that provides a suite of measures: phenology (Phenocams), woody cover, fractional ground cover, perennial weed cover derived from satellite imagery from Sentinel and/or Landsat imagery[16].

The concept of **nested-approach** for developing metrics for carbon farming and co-benefits was discussed next. GreenCollar described a **multi-stage approach using satellite remote sensing they use to work with indicators at property level** (i.e. remote sensing to get a first cut at indicator; at property use points to validate and if false positive, then adjust), noting that the values of indicators are context specific. Green collar is working on dynamic benchmarking based on vegetation type, with consideration of dynamics due to climatic variability (e.g. drought, etc). Put simply, they try to consider variations through time and space.

Other discussions around nested approaches included: Habitat condition and ecosystem persistence using indicators of soil surface condition and vegetation patchiness. Patch scale and the use of standard deviation of the bare ground in a paddock to estimate patchiness using Sentinel satellite data) (P Scarth team). The approach that Peter Scarth and colleagues experimented for the MLA beef sustainability framework for indicators which uses data on primary woodland, seasonal products of TERN, rainfall, soil landscape, cadastral, IBRAs, and census data.

Discussion points followed around:

a) dynamics of ground cover, the main issues associated with developing a pilot to inform sampling design (Cathy); changes in 'detectability' of vegetation patches depending on satellite sensor spatial resolution[17];
b) the needs for metrics to capture changing carbon stocks rather than woody extent;

Phenology of Temperate Grasslands: Improving Monitoring and Management With Near-Surface Phenocams. Front. Environ. Sci. 7:14. doi: 10.3389/fenvs.2019.00014

15 work led by Tim Brown of ANU was mentioned.

16 The Joint Research Programme is working on the harmonization of Landsat and Sentinel data sets for deriving fractional cover. These products should be also available for NSW.

[17] Peter Scarth summarised the changes in statistics related to increased extent of woody cover in Queensland, which in fact are related to the transition from Landsat-based detection (30m spatial resolution, to Sentinel-2 based detection (20 m spatial resolution). The Joint Research Program (Qld and NSW) are trying to show and explain why land clearing statistics are changing dramatically in change from Landsat to Sentinel. QLD next round of land clearing statistics is to be Sentinel-2-based, and the increased spatial resolution means that more little trees can now be detected, and hence better accounting of loses of woody cover from isolated patches, which Landsat-based detection could not 'see' at 30 m spatial resolution.

c) the complexity associated with handling and processing data – hence focus on existing products; the cost of updating **sophisticated models of recruitment and mortality rates.** An example of the latter was provided by Stone's team, stating that those produced by the forestry corporation are 20yrs old, and their updating is cost prohibitive.
d) the use of the **green accumulation index (GAI)**[18] for identifying wet refugia[19], and how that could be used as a criteria for **prioritisation of future carbon farming areas**;
e) the identification of areas for land restoration using satellite-based products (Scarth's team using difference between max biomass in a landscape/land type, and current biomass, and use that as criteria for prioritisation).

The potential of using wet refugia as a first cut was suggested, to then overlay it with Carbon Farming initiatives, and assess its impact. Horn reflected that using the GAI as a blunt instrument is not a great outcome due to local nuances; Cathy argued that it is an important layer to consider, providing evidence to support management recommendations in CF areas; plus it could show additionality – retaining vs improving vs degrading. A topic deserving more thinking and research is whether time series of GAI may show change due to climatic variability or land management practices.

Sue Orgill argued that some indicators are more useful in dry than wet years, hence a line of thinking could be around a temporal prioritisation of indicators. For example, wet refugia areas change in dry/wet seasons and information from this index could be used to identify drainage areas, and then measure changes. It was noted, though, that these are the areas that get hammered by goats and kangaroos (more green cover available). If information on TPG is available, they would respond in dry years and could be identified in a tool box of indicators.

Michael reflected **on spatial resilience** based on climate futures and how populations adapt to climate change, describing the OEH approach to look at future temporal change: connectivity changes between like for like; how does the landscape connect up in different locations/climate scenarios; and the mapping of hotspots for climate change adaptation. Protecting areas that allow biodiversity to move, not where biodiversity is at present.

A point was made about **existing carbon farming areas** and the use of indicators that accommodate for 'lag time'; longer-term, outcome-based evidence of positive impacts

[18] Described in the data table of Brief #1 (Baumber et al 2019)

[19] Interpretation of the green accumulation index for Wet refugia (Jeff): if an area went green and stayed green for longer= more likely to be a refuge – lower points in landscape stay greener. Tony Gill and Jeff used time series and calculated area under green curve. Data has distinct patterns – drainage lines etc. LLS were then going to overlay GIS data to prioritise areas. Water count as well, how close to nearest tree or wet area? They were looking at 'epochs' of dry and wet; using time series, identify 3 'dry periods' and 3 'wet periods' -> where to invest in the future? It is a wet / dry comparison, can be done at regional level. That can provide a guidance for future areas, where to invest.

of management takes a few years to show in the landscape/property using approaches based on remote sensing. Using ground-based approaches to derive metrics enable to capture improvements over shorter-lag times. Examples were cited of dog fences[20], and reflection on cluster fences (Qld versus NSW; the latter is 20 properties, given that cattle and sheep producers have different priorities such as targeting dogs/kangaroos). A final note was on the 'baseline' of carbon farming: it begun in 2012 (a wet year), and that could be also criteria to consider in the proposition of indicators (outcome-based). The **percentage of perennial grass utilisation** was discussed as a metric to measure activity related to carbon farming that leads to set goals. Important for rangelands is annual pasture utilisation plus biomass.

Session 4: Prioritising and developing indicators

The final session of the workshop began with an attempt to prioritise indicators by thinking about which are the **absolute must-have indicators** for the key potential co-benefits of carbon farming (biodiversity and soil health).

In order to prioritise indicators that have high potential for application to measure co-benefits of carbon farming in NSW, the workshop sought to compile a list of the most promising indicators (Table 3). This was further subdivided into state-scale and property-scale indicators, and into indicators that are close to being deployable and those requiring greater amount of work for their development. Also see Appendix 2 for more detailed notes.

Table 2: Promising data sources for indicators development (from workshop)

State-scale data sources close to deployment	Property-scale indicators
Indicators from the NSW Biodiversity Indicator Program[21]: Habitat Condition (3.1) (sub-indicators 3.1a Ecological condition of terrestrial vegetation; 3.1b Ecological connectivity of terrestrial vegetation; 3.1c Ecological carrying capacity of terrestrial vegetation) and Ecosystem Persistence (2.2c), which are relevant for biodiversity, are almost ready for release, at 90m resolution, processing	Soil organic carbon Pasture biomass (could act as an indicator of trade-offs between services e.g. carbon/biodiversity vs provisioning) Pasture utilisation (to give an indication of grazing

[20] Dog fence in SA = better green accumulation than WD. Bring back bilbies with TPG = better green accumulation. Exclude feral animals, does it equate to an outcome that is an expression of co-benefit?

[21] https://www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Animals-and-plants/Biodiversity/measuring-biodiversity-and-ecological-integrity-in-nsw-method-190132.pdf

and analysis to convert raw data into indicators already done.	pressure/intensity to act as an activity-based indicator)
State-scale data sources requiring further work to develop indicators TERN Fractional Cover - relevant for soil health, 30m resolution, would need further work to convert raw data into useable indicators but includes layers on:- bare ground, - green veg; - non-green veg, and is available for the State of NSW. Standard deviation of bare ground (Sentinel data, would need further work to take it from a metric to an indicator) Adrian Chapel's dataset (not readily available) Luke's work with GreenCollar - ongoing work combining remote sensing with ground-truthing, focusing on: Vegetation Height and Perennial weed Cover Maps of ERF projects in NSW by method type (e.g. HIR, AD etc.) – These could be combined with rainfall zone, land type etc. and used as activity-based indicators of which activities are occurring where.	Ground-truthing of veg height and perennial weed cover (as per Luke's work with GreenCover) Trials for collecting metrics for property scale indicators could include the use of drones (sensor to go on board of the drone needs to be specified Recent research also points to the potential of phenocams, though conclusions on their effectiveness for drylands are mixed.

In relation to **biodiversity**, it was suggested that the Habitat Condition and Connectivity (indicator 3.1) and Ecosystem Persistence (indicator 2.2c) products that are almost ready for release by the NSW Government (at a spatial resolution of 90m) could replace several of the biodiversity-related indicators (e.g. carbon stock, woody extent) that appeared in the initial table circulated prior to the workshop (Table 3). However, upon further exploration after the workshop, this data source appears to be focused on vegetation extent and connectivity. This may be suitable for higher-rainfall areas, but in rangeland environments there is often 100% native vegetation cover and the more significant issues are the structural complexity of that vegetation, the patchiness of vegetation (heterogeneity) and the presence of perennial weeds.

The value of using change in woody extent (measured on an area basis) as an indicator was questioned, as it may be more valuable to measure change in biomass and/or structure at specific sites, rather than change in area of woody vegetation.

Synthetic Aperture Radar (SAR)-based measurements of change in woody biomass are now available (although this may be redundant if above-mentioned products are available (Habitat Condition and Connectivity 3.1 and Ecosystem Persistence 2.2c).

For biodiversity purposes, it is important to measure both change in woody biomass and the structure of that biomass (but above-mentioned products may incorporate both factors).

Direct measures of biodiversity such as mammal counts, bird counts and floristic diversity are desirable, but past experience has shown them to be expensive, time-consuming and to have produced little by way of usable results (although phenocams could be an option).

Perennial weed cover is an important variable to measure in conjunction with overall woody biomass and overall cover (as not all cover or biomass is equally valuable for soils or biodiversity).

In relation to **soil health**, ground cover was highlighted as a key factor. The TERN Fractional Cover product measures bare ground, green veg and non-green veg at 30m spatial resolution, but would need to be developed further from a metric into an indicator (e.g. consideration of key thresholds, benchmarks etc). Noteworthy is that in rangelands soil health is heavily related to biodiversity.

It was indicated that Green Collar estimates ground cover once a year, during the driest time of the year when the signal is strongest, to avoid seasonality effects. Dry season fractional cover is derived using woody cover, ground cover, veg height (structure) and the 2009 remote-sensing derived vegetation height product, then ground truthing for information on perennial weed cover (composition). Height changes are slower, green fraction and ground cover change annually.

It was concluded that for **indicators of co-benefits of carbon farming, a nested approach** to account for scale/different methods will be needed, particularly at **property scale**. Discussion included on soil properties that could serve as metrics of co-benefits.

Teasing out seasonal from management effects is a difficulty identified. The costs of ground observations is very high, so some ideas were discussed about multi-scale remote sensing and access to Planet Lab (3m or 5m) data, which is available for some areas of NSW. Furthermore, the benefits and limitations on how to incentivise property owners to go out and measure to a certain quality were weighed.

Promising is the approach of the Sustainability Framework indicators (P Scarth), that considers multiple metrics: Primary and secondary forest woodland; Seasonal products on TERN; Rainfall; Soils and landscapes; Cadastre; Postcodes; NRM regions; and Census data (with these social indicators potentially able to measure some of the social/cultural benefits of carbon farming).

The idea of a resource list, then an indicator list as done by A Chappell for water erosion was discussed. Such list could include:

1) Activities – ERF method x Land/rainfall vs non-carbon farming; fencing; TGP; de-stocking.
2) For HIR – some indication of pasture biomass and utilisation, could be used as a tool to remove livestock from carbon areas = trigger points. Coincide with seasonal conditions.
3) Grazing pressure
4) Forage report in QLD = ground cover, over time;
5) Pasture biomass – trade-off between carbon and grazing.

Post-workshop recommendations and revision of indicators

Following the workshop, the table of potential indicators was revised to take into account information presented at the workshop and the views of the participants.

Recommendations emerging from the workshop for the evaluation and development of potential indicators include:

- **Key purposes should be considered** when selecting and designing indicators, including both *ultimate* and *intermediate* purposes. A range of stakeholder perspectives should be considered, including those who were not present at the workshop (e.g. landholders)
- **Ultimate purposes of indicators** including:
  - Providing landholders with information to help them manage for co-benefits
  - Harmonising policy objectives around land use
  - Verifying the effectiveness of carbon farming policy in delivering co-benefits
  - Enabling payments to landholders for co-benefits they deliver
  - Providing market advantage for products from land managed for co-benefits
- **Intermediate purposes** that may enable these ultimate purposes to be achieved include:
  - Collecting scientific and practice-based evidence of co-benefits
  - Prioritising locations where carbon farming should be established
  - Accounting for natural capital and environmental social governance
- **Key criteria should be considered** when selecting and designing indicators, including cost, availability of data, lag time between action and measurement, directness of relationship between indicator and desired co-benefit, scalability, applicability to different contexts (e.g. rangelands and higher-rainfall zones), suitability to independent verification and compatibility with other datasets.
- A **nested approach** is required for indicator development, whereby broad-scale State and landscape level indicators (e.g. measured using satellite data, and other

geo-referenced data sets available within GISystems) are complemented with property-scale indicators. Such approach should involve state-wide datasets at broad-scale resolution (e.g. 90m) as well as finer-scale measurements that can be used to develop property-scale indicators (e.g. on-ground measurements, drone surveys or emerging remote sensing products that could provide data at 3m spatial resolution). Phenocams could be an option for on-ground measurements of soil cover, vegetation structure and possible even bird or mammal counts.

- **Biodiversity and soil health** represent top priorities for indicator development[22], but consideration of grazing productivity (i.e. provisioning services) and social impacts (i.e. cultural services) is vital if carbon farming is to gain and maintain a **social licence to operate** amongst graziers and farming communities in NSW.
- Indicators should consider key **differences between rangeland contexts** (where native vegetation extent is often 100% but condition is variable) **and higher-rainfall zones** (where loss of vegetation extent and connectivity are often key concerns for biodiversity).
- **Outcome-based indicators** should be used to measure the actual impacts of carbon farming where possible, with **activity-based indicators** used to complement these and improve our capacity to predict outcomes based on management actions.
- **Synergies between indicators** should be considered, including opportunities for a single indicator to be used to measure multiple ecosystem services/co-benefits of carbon farming.

Suggested indicators are shown in the revised table over the page (Table 3). This table has been revised based on the recommendations above arising from the workshop. It includes the following key features:

- **An ecosystem services approach** is employed, with supporting and regulating services related to **biodiversity** and **soil health** representing the highest priority areas for the development of co-benefit indicators
- **Outcome-based indicators** may allow key elements of biodiversity and soil health to be measured following the introduction of carbon farming. These include:

[22] Co-benefits related to biodiversity and soil health were the two most commonly-cited benefits in the literature review undertaken for Progress Brief #1 for this project, which has been published in: Baumber, A, Metternicht, G, Cross, R, Ruoso, L, Cowie, AL & Waters, C 2019, 'Promoting co-benefits of carbon farming in Oceania: Applying and adapting approaches and metrics from existing market-based schemes', *Ecosystem Services*, vol. 39

- **For biodiversity**: indicators related to woody vegetation (extent, vertical complexity, refugia value, perennial weed cover) and some related to ground cover heterogeneity (patchiness)
- **For soil health**: indicators related to ground cover (bare ground, persistent green, patchiness), soil carbon (modelled SOC) and some related to woody vegetation (extent, carbon stock)

- **A nested approach** has been adopted (Figure 4), with **state-scale and property-scale data** sources suggested for the development of appropriate indicators at each scale.
- **In the rangelands,** it is important to complement indicators of woody vegetation *extent* with indicators of *habitat value* (e.g. structural complexity, refugia value), as many areas have high extent of native vegetation but variable condition (this may be different in higher-rainfall zones where loss of woody vegetation extent and connectivity is widespread)
- **It is not necessary to develop separate indicators for regulating services,** as indicators of the supporting services of soils are also likely to provide an indication of their regulating services (e.g. sequestration, water regulation)
- **Activity-based indicators** may be useful for predicting what changes in biodiversity and soil health are likely to occur due to changes in management (e.g. area of rehabilitation, perennial grass utilisation, strategic destocking)
- **Measuring outcome-based and activity-based metrics simultaneously** may allow relationships between activities and outcomes to be better understood
- Indicators relating to the **provisioning services** of grazing systems are important for helping landholders understand how carbon farming affects grazing enterprises, including: available pasture, perennial grass utilisation, SOC, soil compaction and perennial weed cover
- **Social indicators** relating to the cultural services of carbon farming are not included in the revised table, but it is recognised that these are an important consideration that require further development. The results of the stakeholder needs analysis being undertaken for this project will inform future development of social indicators

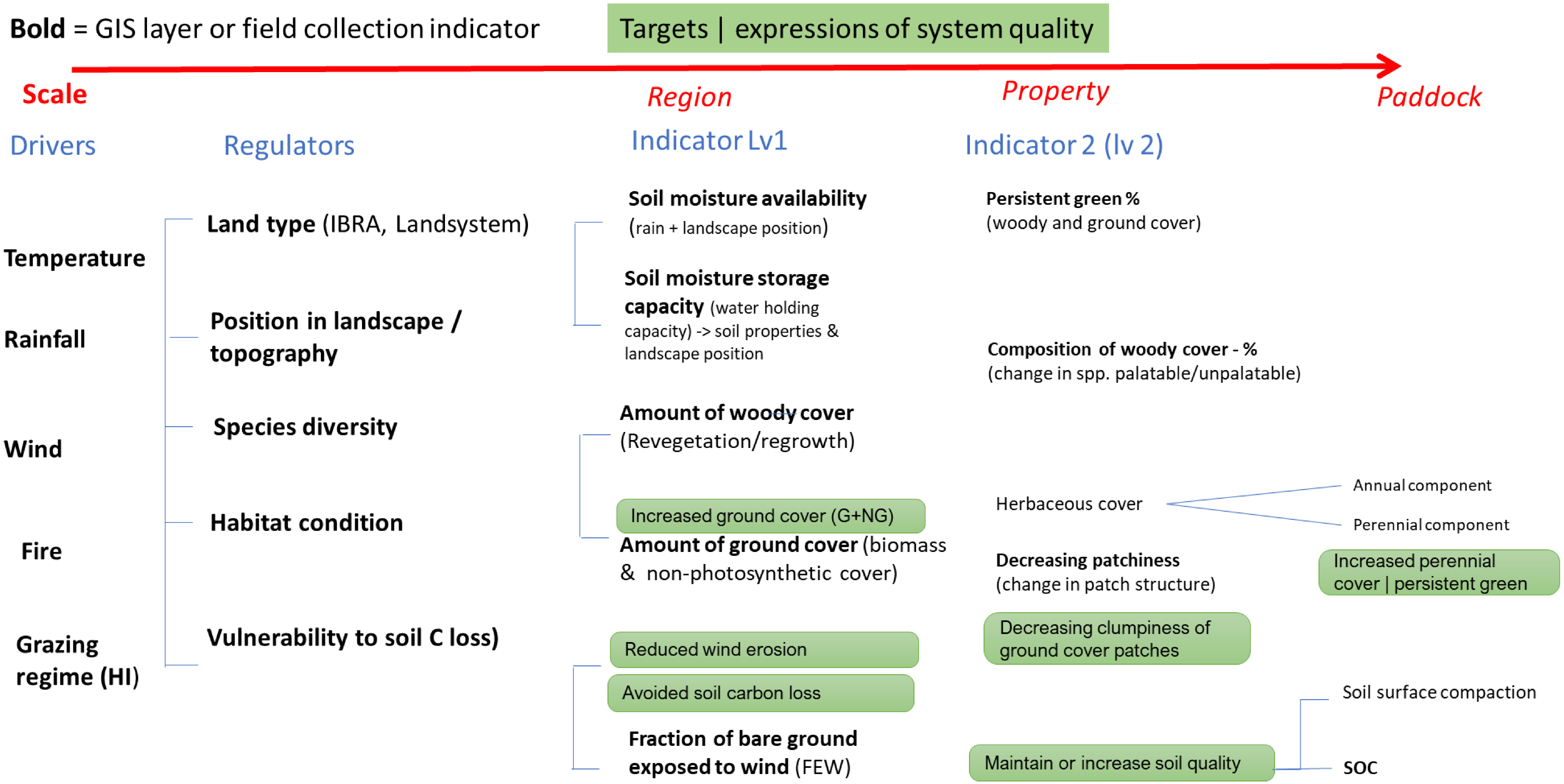


Figure 4: Conceptual design of a 'nested approach' to develop indicators of benefits and co-benefits of carbon farming.

Table 3: Potential indicators for biophysical co-benefits as refined post-workshop

	Descriptor	Indicator	Outcome or activity based	Metric	Trend, value or threshold	Supporting (biodiversity)		Supporting (soil health)		Provision-ing (food and fibre)	Regulating		Potential data sources	
						Protect	*Enhance*	*Land productivity*	*Nutrient cycling*		*Soil carbon sequestr ation*	*Water*	*State-scale*	*Property-scale*
Agroecological system quality	**Amount and type of ground cover**													
	Increase in cover	Ground cover	Outcome	% bare ground	**Threshold**: >50% bare ground			X	X		X	X	TERN Fractional cover bare/green/non-green (30m resolution) https://vegmachine.net/	Drones, Step-pointing transects, Photo points, Phenocams, can be guided by multi-temporal analysis of VegMachine datasets.
	Wind erosion	Fraction of bare ground exposed to wind erosion	Outcome	FEW[1.]	**Threshold:**								Adrian Chapell data?	
	Temporal greenness pattern (NDVI) relative to rainfall	Increased perennial cover	Outcome	Persistent green	**Trend:** Degree of landscape responsiveness to rainfall events			X	X		X	X	NDVI satellite data https://vegmachine.net/	
	Paddock heterogeneity	Patchiness	Outcome	Patch area as a proportion of	**Trend:** increase in patch area or decrease in inter-patch area		X	X	X		X	X	TERN Fractional cover bare/green/non-green (30m resolution)	

	Descriptor	Indicator	Outcome or activity based	Metric	Trend, value or threshold	Supporting (biodiversity)		Supporting (soil health)		Provision-ing (food and fibre)	Regulating		Potential data sources	
						Protect	*Enhance*	*Land productivity*	*Nutrient cycling*		*Soil carbon sequestration*	*Water*	*State-scale*	*Property-scale*
													https://vegmachine.net/	
	Available pasture	Pasture biomass	Outcome*	tDM ha^{-1} pasture biomass	**Value:** Feed demand not exceeding supply			X		X			Aussie Grass: https://www.longpaddock.qld.gov.au/aussiegrass/ (5kmx5km resolution)	Field based measurements combined with data on NPP (derived from satellite measures[23]) or the method of Smart Farms (UNE)
	Soil quality													
	Modelled SOC	SOC stock	Outcome	△ SOC t/ha to 30cm	**Trend:** increase SOC relative to map SOC			X	X	X	X	X		
	Soil compaction	SOILpak[2] score	Outcome	△ SOILpak score	**Value:** 0.0- severely compacted 2.0- Not compacted					X	X	X		
	Amount and type of woody cover													

[23] See the example of Meat & Livestock Australia for real time measurement of pasture quality. https://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/Real-time-measurement-of-pasture-quantity/3647

Descriptor	Indicator	Outcome or activity based	Metric	Trend, value or threshold	Supporting (biodiversity)		Supporting (soil health)		Provision-ing (food and fibre)	Regulating		Potential data sources	
					Protect	*Enhance*	*Land productivity*	*Nutrient cycling*		*Soil carbon sequestr ation*	*Water*	*State-scale*	*Property-scale*
Increased C stock	AGB/BGB	Outcome	Δ AGB tDM ha^{-1}	**Trend**: Change relative to carbon carrying capacity		X	X	X		X	X		
Increased extent of woody cover	Woody extent	Outcome	Δ Area of woody veg as % total land area	**Trend:** Increasing trend in woody extent	X	X	X	X		X	X	TERN woody vegetation cover or persistent seasonal green (30m resolution)	Work underway to implement in Sentinel-2 data, with a resolution of 20 meters. Suitable for property scale
Habitat value	Increase in area of wet refugia	Outcome	Δ Area of wet refugia as % total land area	**Trend:** Changes in proportion of landscape element	X	X					X	TERN Green Accumulation Index (30m resolution) at 2012	Green Accumulation index at 30m can be sufficient for property scale
Habitat value	Vegetation structure	Outcome	Increased vertical complexity	**Trend:** Increasing	X	X						TERN vegetation height and structure (only for specific dates)	Collect Airborne LiDAR data and model height and structure of plantings.
Increased perennial weed cover		Outcome	Δ Area of woody weed % total land area	**Trend:** Decreasing	X	X	X		X				Green Collar work on properties with carbon farming projects

	Descriptor	Indicator	Outcome or activity based	Metric	Trend, value or threshold	Supporting (biodiversity)		Supporting (soil health)		Provision-ing (food and fibre)	Regulating		Potential data sources	
						Protect	*Enhance*	*Land productivity*	*Nutrient cycling*		*Soil carbon sequestr ation*	*Water*	*State-scale*	*Property-scale*
	Land management													
Agroecological system management	Land condition improvement	Change in extent of land degradat-ion	Activity	Area of rehabilitati on, water ponding/sp reading, TGP fencing, rotational grazing)	**Value**: increased area	X	X	X	X		X	X	JRSRP (Qld) fractional cover data can be used to guide improvement of ground cover and combined with bare ground estimation. JRSRP uses field data estimates to calibrate and validate estimates of persistent green and non-green vegetation in the upper- and mid-stratum to adjust for the amount of cover expected on the ground.[24]	Management actions recorded by landholders, LLS records of funded NRM projects
	Land condition improvement	Change in extent of land	Outcome	Δ Area of bare ground as	**Trend**: Decreasing bare ground	X	X	X	X		X	X	TERN Fractional cover bare/green/non-	Multi-scale approach of Vegetation cover

[24] See https://www.austrangesoc.com.au/data/2015conference/papers/3P._Tindall_et_al.pdf paper at the ARS Conference 2017

	Descriptor	Indicator	Outcome or activity based	Metric	Trend, value or threshold	Supporting (biodiversity)		Supporting (soil health)		Provision-ing (food and fibre)	Regulating		Potential data sources	
						Protect	*Enhance*	*Land productivity*	*Nutrient cycling*		*Soil carbon sequestr ation*	*Water*	*State-scale*	*Property-scale*
		degradat-ion		% total land area									green (30m resolution)	fraction data and field data
	Management of grazing intensity													
	Total grazing pressure management	Perennial grass utilisation	Outcome	% perennial grass biomass grazed	**Threshold**: < 30% perennial grass utilisation	X	X	X	X	X	X	X	Vegmachine generates information derived from remote sensing that can be used at this scale.[25]	See FORAGE initiative, it can provide useful information.
	Total grazing pressure management	Strategic livestock destocking	Activity	Presence/ absence of grazing stock	**Value:** Proportion of livestock remaining	X	X	X	X		X	X		Management actions recorded by landholders, Records maintained under carbon farming contracts

(*) It may also be an activity-indicator (e.g. undertaking a sustainable stock rotation, biomass is kept healthy)

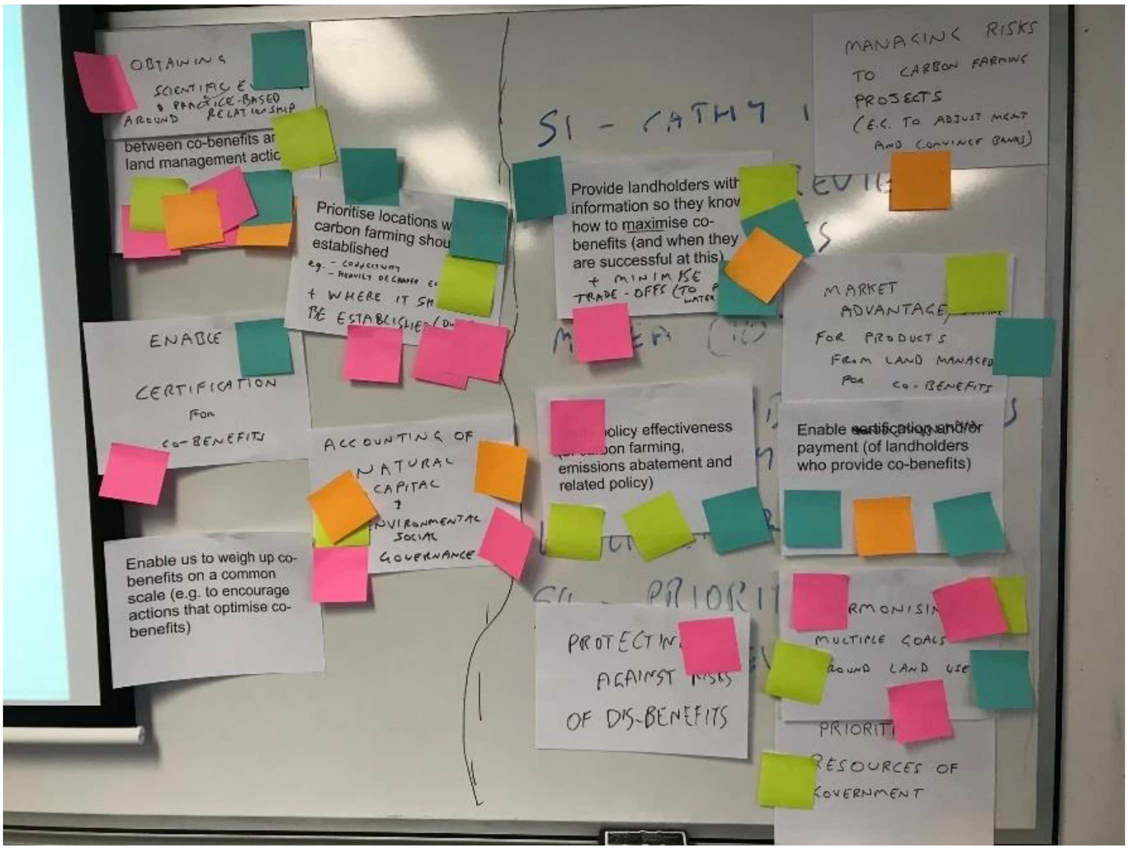
[25] https://www.publish.csiro.au/RJ/fulltext/RJ19013

Other leads from the workshop worth to follow up

- **PhenoCAMS**: TERN Mariela Soto (now at RMIT), Peter Scarth mentioned it, and Tim Brown at ANU), plus some initial work of Alfredo Huete at UTS. Alfredo is an expert in phenology mapping from MODIS. Huete has a joint publication with C Watson (now affiliated at DPIE, on multi-scale phenology of temperate grasslands[26]
- **Sequestration potential:** Peter Scarth mentioned that he had a carbon biomass map – need to see if we can source and how it was developed. (Cath)
- **Remotely sensed ground cover patch structure:** Peter Scarth mentioned a conference paper which used the Wombiana Grazing Trial site to look at remotely sensed ground patch/inter-patch areas. (Cath)
- **FEW:** Fraction of bare ground exposed to wind erosion developed by Adrian Chappel – determine spatial resolution and accessibility. (Suz O)
- **Carbon co-benefits:** Michael Drielsma indicator NSW OEH has done work here in the past (salinity control). (Cath)

[26] Watson CJ, Restrepo-Coupe N and Huete AR (2019) Multi-Scale Phenology of Temperate Grasslands: Improving Monitoring and Management With Near-Surface Phenocams. Front. Environ. Sci. 7:14. doi: 10.3389/fenvs.2019.00014

Appendix 1: Purpose of indicators



Votes on relative importance of various purposes for which indicators could be used

Appendix 2: Summary table from workshop session on prioritising and developing indicators

High-priority Indicators		**Comments**	**Statewide data sources (static, annual)**	**Property-scale data sources (seasonal)**
% Fractional Ground Cover (soil) Soil surface condition – SD bare in paddock (Sentinel-2 derived) = helps with understanding patchiness, changes with wetness – useless when completely dry.	Needs benchmarking; needs development to take it from a variable to an indicator	Primary layer. Across NSW. 30m resolution at present.	Green fraction is similar to NDVI. Area under green and area under bare as well as non-green veg. Bare in high rainfall areas = important. Rangelands you expect bare. More relevant for some CF activities vs others. Proxy for soil health? Erosion etc, bare vs non-green litter over soil.	Soil surface condition Green fraction Ground cover (plus veg height and perennial weed composition) Soil roughness Soil organic carbon Bulk density? Would expect a change Run-off potential?
Habitat Condition/ Connectivity (feeds into ecosystem persistence)	At indicator stage already	Across NSW, not yet publicly available 90m resolutions (Biodiversity fed into condition)	Suitable for broader scale and not property scale? Large scale patchiness	Small scale patchiness – diversity within patches (product for woodiness down to 5m) Pasture biomass and Pasture utilisation (eaten) = grazing intensity
Adrian Chapell – Soil surface roughness, shadowing, wind direction, solar radiation		Not readily available		

Appendix 3: Expert Workshop Participants & Expertise (30 July 2019):

Name	**Expertise**
Cathy Waters (DPI, Climate Research	Grazing systems (rangelands), biodiversity, carbon farming and NRM
Annette Cowie (DPI, Climate Research)	Emission reduction, carbon farming, land degradation and system resilience
Sue Orgill (DPI Soils South, Wagga)	Soil science (incl. rangeland systems)
Sarah MacDonald (DPI Pastures & Rangelands Division)	Pasture systems and biodiversity
Christine Stone (DPI Forest Science, Parramatta)	GIS, forest monitoring project via NRC, setting up permanent plot system, has experience with multicriteria indicators under Montreal process for forest management
Sam Hisslop (DPI Forestry)	GIS, geospatial monitoring, forest systems, formerly at RMIT
Jeff Horn (NSW DEES)	geospatial rangeland monitoring, GIS analysis
Peter Scarf (Joint Remote Sensing Research Program, UQ)	Grazing system monitoring in rangelands (remote sensing, fractional cover, field observations, veg. structure mapping, weed mapping), sustainability framework for grass/tree systems with MLA working group (how grazing industry can be more sustainable – beef supply chain, demonstrate benefits to corporates)
Michael Driesma (NSW DEES)	Biodiversity monitoring and modelling indicator development for new biodiversity conservation act (to prioritise conservation/restoration), 20 years Western Division experience (incl. Fowlers Gap)
Luke Shoo (GreenCollar)	Broker and investor in environmental markets, currently developing co-benefit indicators to capture social and environmental outcomes across GreenCollar's carbon farming portfolio
Rebecca Cross (U Sydney)	Social geographer, carbon farming
Alex Baumber (UTS)	Development of indicators and MBIs
Graciela Metternicht (UNSW)	GIS, integrated environmental assessment

NSW
GOVERNMENT