Winona: The Ecological Journey

Author: Matt Bolton

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Case Study

SoilsForLife

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Abstract

Soils for Life returned to *Winona* in July 2020 to document the status and changes to the social and ecological systems on *Winona* since our previous visit in 2012. This report documents the changes to the *Winona* agroecosystem from the further development and implementation of pasture cropping, including the introduction of multi-species crops.

Information has been compiled by interviewing the land manager, Colin Seis, in order to document the ecological response to ten criteria on *Winona*. Transect data, the results of soil tests and fractional ground cover data have been referred to where available to the assessors. Data collected by the land manager and visiting scientists are also cited. The literature relevant to pasture cropping in the Wellington/Gulgong region is discussed to provide context, however implementations outside of this region are mostly beyond the scope of this report.

The functioning of the agroecosystem at *Winona* has continued to improve since Soils For Life first profiled the property in 2012, with pasture cropping and time-controlled grazing now well established as regenerative practices. The incorporation of multiple species into the pasture crops has provided improved forage and continued the accumulation of soil carbon. Farmer observations and soil carbon data were insufficient to conclude that multi-species cropping is more beneficial than single-species pasture cropping. However, abundant ground cover across the majority of the property has increased soil resilience by minimising the risk of soil loss, salinity and degradation.

Regenerative practices have greatly decreased the reliance on fertilisers, herbicides and pesticides. There have been modest improvements in vegetation biodiversity due to the planting of windbreaks and paddock trees in parallel with the pasture cropping developments. Pasture status has improved from a low base to continuous cover and high biomass of desirable species and functional types.

These findings indicate *Winona* is more resilient to drought, fire and flood as a result of Colin Seis's willingness to consider and implement less conventional, more regenerative land management practices.

Introduction

In 2012, Soils For Life (SFL) visited *Winona* and reported on the regenerative land practices of Colin Seis (SFL, 2016). That report documents the conditions on *Winona* that motivated Colin to develop and implement the practice of pasture-cropping (where winter crops are sown into an existing pasture of summer-growing grasses) and describes the rotational system Colin operated. The reports also documents the benefits of implementing less conventional, more regenerative land management practices, including year-round ground cover and increases in soil organic matter and therefore soil carbon.

This report, *Winona: The Ecological Journey* (2020), is one of several products developed from a more recent visit to *Winona* in July 2020. It documents the ecological (and other) benefits of pasture cropping after nearly two decades of implementation and considers the benefits of other innovative practices, including multi-species cropping, implemented since our first visit in 2012.

In particular, this report assesses the ecological status of, and changes to, the *Winona* agroecosystem according to a set of ecological criteria (Thackway and Gardner 2019). The ecological criteria are used to assess the outcomes of land management, including the cumulative effects of implementing multiple practices, with a focus on regenerative practices. An overview of the regenerative capacity of the *Winona* agroecosystem is presented, as is the history of farm practice change and subsequent influences on the ecological criteria (the "journey").

Winona in ecological context

Winona is situated North of Gulgong in the headwaters of the Macquarie River catchment. The landforms comprise flat plains and gentle slopes rising to hilltops and ridges variously comprising granites, basalts, sandstones and shales. There are no incised streams on *Winona*, with the ephemeral drainage variously uncoordinated or flowing to tributaries of the Macquarie River (Talbragar River to the North and Cudgegong River to the South).

Winona comprises 840 ha and supports a self-replacing merino flock of about 4000 sheep. The property is subdivided into 76 conventionally-fenced paddocks, each approximately 11 hectares in area, with a system of laneways for the efficient moving of stock (Figure 1). There are numerous small farm dams supplying the stock with water.

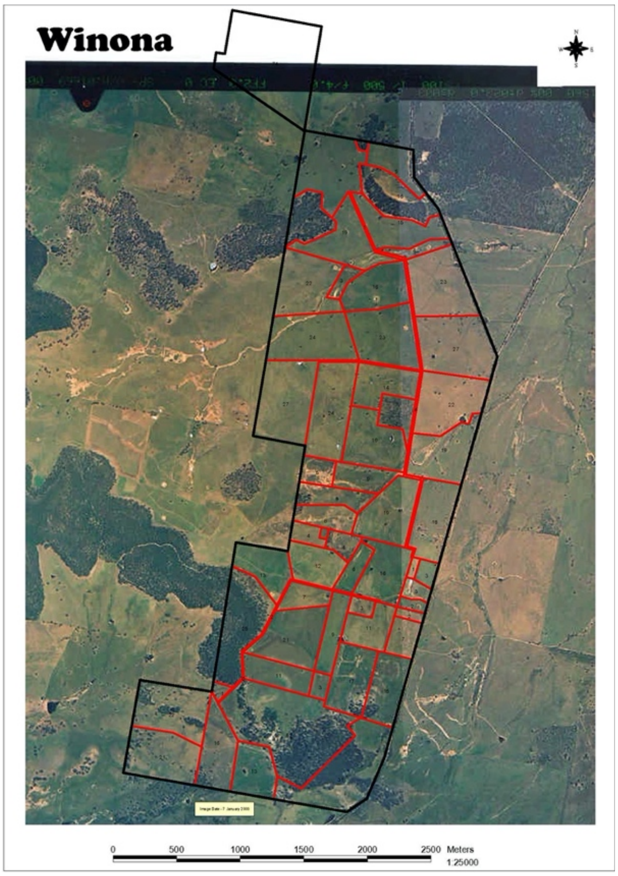

Figure 1. Main paddocks in Winona (courtesy of R. Thackway).

Climate

Rainfall on *Winona* is approximately 650 mm per annum and, other than peaking during Summer, it is typically distributed across the year. The mean monthly rainfall for Gulgong, 20 km to the South of *Winona*, is shown in Figure 2.

During his interview with SFL, Colin said he had noticed an increase in the summer rainfall bias in the past few years. Rainfall in 2016 and 2020 (to 30 June 2020), was above average, but rainfall for 2017, 2018 and 2019, was below average – in 2019 it was markedly so (Table 1).

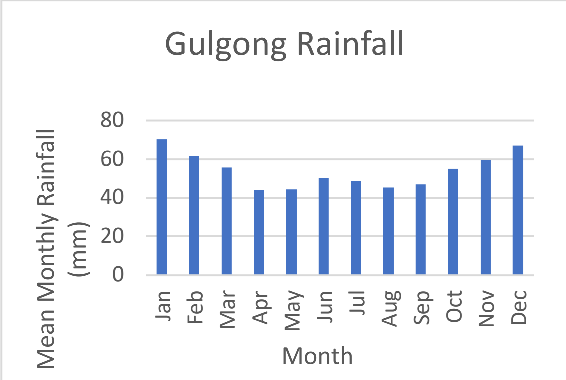

Figure 2. Mean monthly rainfall for Gulgong[1].

Table 1. Recent annual rainfall: totals for Gulgong, NSW.

Year	Annual Rainfall (mm)
2015	651.6
2016	848.4
2017	530.7
2018	461.4
2019	274.9
2020 (till 30 June only)	481.4

Soils

The soils in the region of Winona are described as being low in fertility, fragile, and susceptible to degradation (Murphy and Lawrie 1998) such as erosion. Based on the inherent characteristics of the soils, maintaining ground cover will reduce the risk of erosion and the legacy of scarring left after the early decades of conventional agricultural practices. These soils are mainly suitable for grazing with some of the low-lying land areas also suitable for cropping (Murphy and Lawrie 1998). For more information about the *Winona* soils, see the companion document *The Winona Soil: A Profile* (SFL, 2020).

Vegetation

The reference state (unmodified) native vegetation is sparse woodland with characteristic tree species including rough-barked apple (*Angophora floribunda*), with upland areas covered in forests of Slaty Gum (*Eucalyptus dawsoni*[2]) or Ironbarks (especially *E. sideroxylon*), depending on the underlying geology. Ground cover comprises summer-growing (C4) grasses, such as Red Grass (*Bothriochloa macra*), Spreading Panic Grass (*Paspalidium distans*), temperate (C3) grasses such as Wallaby Grass (*Austrodanthonia* spp.) and Speargrass (*Austrostipa* spp.), and native forbs. In addition to the native perennial grasses, the pre-clearing pasture probably had a large proportion of Kangaroo Grass (*Themeda triandra*) and *Aristida* spp.

From the remnant rough-barked Apple (*Angophora floribunda)* trees on the flattest parts of *Winona*, it is likely that prior to European settlement there were areas of another vegetation type not listed in Table 2. As per Thackway and Freudenberger (2016), we believe this to be the following NSW

[1] http://www.bom.gov.au/climate/averages/tables/cw_062013.shtml
[2] A species endemic to the Upper Hunter region and nearby areas.

Plant Community Type: *281*[3]*: Rough-Barked Apple - red gum - Yellow Box woodland on alluvial clay to loam soils on valley flats in the northern NSW South Western Slopes Bioregion and Brigalow Belt South Bioregion*.

Table 2. Vegetation types on Winona listed in approximately decreasing area[5]*.*

Formation (Keith, 2006)	Class (Keith (2006)	Plant Community Type (PCT)
Grasslands	Western Slopes Grasslands	Derived grassland of the NSW South Western Slopes
Non Native	Non Native	Non Native[4]
Dry Sclerophyll Forests (Shrubby sub-formation)	Western Slopes Dry Sclerophyll Forests	Red Ironbark - Black Cypress Pine - stringybark +/- Narrow-leaved Wattle shrubby open forest on sandstone in the Gulgong - Mendooran region
Dry Sclerophyll Forests (Shrubby sub-formation)	Western Slopes Dry Sclerophyll Forests	Narrow-leaved Wattle low open forest / very tall shrubland on ridges in northern NSW South Western Slopes Bioregion and southern Brigalow Belt South Bioregion
Dry Sclerophyll Forests (Shrubby sub-formation)	Western Slopes Dry Sclerophyll Forests	Mugga Ironbark - Red Box - White Box - Black Cypress Pine tall woodland on rises and hills in the northern NSW South Western Slopes Bioregion
Grassy Woodlands	Western Slopes Grassy Woodlands	Blakeley's Red Gum[5] - Yellow Box grassy tall woodland of the NSW South Western Slopes Bioregion
Grassy Woodlands	Western Slopes Grassy Woodlands	Tumbledown Gum woodland on hills in the northern NSW South Western Slopes Bioregion and southern Brigalow Belt South Bioregion

Pasture cropping

Pasture cropping involves combining a commercial crop (grains or other) with one or more pasture species. This practice was developed by Colin and Darryl Cluff in 1993. At the time, the pair reasoned that killing the summer-growing, perennial (C4) grasses[6] before planting a winter cereal crop was unnecessary. Since these grasses became dormant each autumn, they wouldn't compete with a newly planted crop.

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3 https://www.environment.nsw.gov.au/NSWVCA20PRapp/DataEntry/PlantCommunity.aspx?M=E&PID=281 (requires an account to view)

4 The vegetation mappers may have allocated cropping patterns on remote imagery to this type, despite the prevalence of perennial native grasses.

5 Likely Slaty Gum (*E. dawsonii*) on Winona.

6 https://www.dpi.nsw.gov.au/agriculture/pastures-and-rangelands/native-pastures/what-are-c3-and-c4-native-grass

They experimented with the idea, beginning with sowing winter-active cereal crops into pastures using a no-till drill and initially achieved moderate success. However, after a couple of years, the introduction of grazing animals at strategic times of the rotation was the key to greater success.

Prior to planting the crop, the grazing animals crash graze[7] the native perennials to reduce bulk and increase mulch. The animal excrement adds natural fertiliser. If the weeds (mainly C3 species) remaining after grazing look likely to be a problem, a knockdown herbicide (diquat) is sometimes applied prior to planting the crop via a single pass of a heavy, spiked roller with seed spread behind the roller.

Colin and Darryl's pasture cropping practices have generated much interest from other farmers and scientists both across Australia (e.g. Tunney and Ferris 2010) and the world[8]. Advantages of pasture cropping practiced in this way (Seis 2015; SFL 2016) include:

- Near 100% ground cover year round;
- Superior quality and quantity of stock feed;
- Improvements to soil health and nutrient cycling;
- Crop yields (e.g. oats or barley) approaching those from conventional crop methods
- Building carbon in the soil;
- Dramatically reduced chemical inputs to the farming system; and
- Weed and pest insect control.

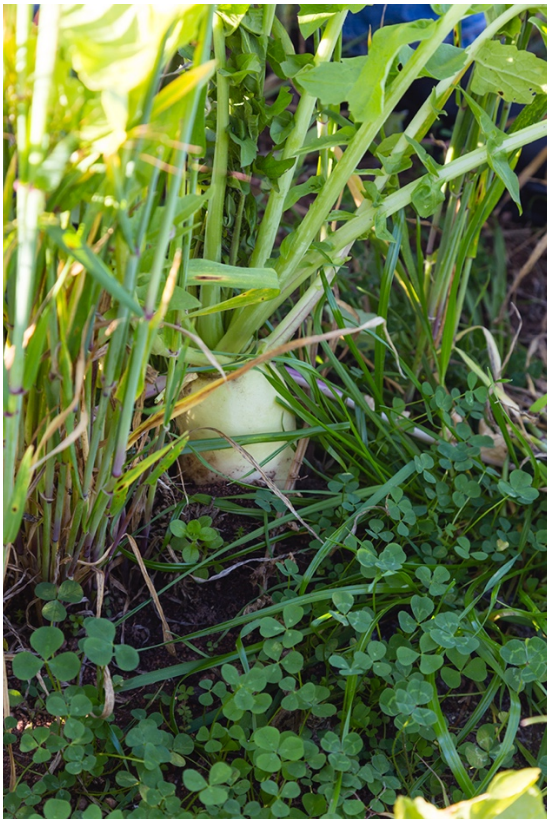

Figure 3. Close up of a multispecies pasture crop, with Barley (Hordeum vulgare) and Tillage Radish (Raphanus sativus var. longipinnatus) with Sub Clover (Trifolium subterraneum) already established on the paddock.

Colin Seis continues to innovate. Conversations with farmers in the USA have led him to progress to multi-species pasture cropping (planting multi-species crops into pasture). Multi-species pasture

[7] Some other implementations of pasture cropping omit this important step.
[8] https://projects.sare.org/project-reports/lnc06-273/

crops have all of the benefits of pasture crops, but are also intended to accelerate the natural processes, increase soil organic matter, fix nitrogen with legumes, and improve biological activity and soil structure. In addition, some of the multi-species "scavenge" plant nutrients in the soil (Seis, 2015), referring to the capture of N, P and other nutrients. These scavenging plants effectively managing element and nutrient excesses and may also retain them for future seasons/crops.

In July 2020, the time of SFL's visit, the following species had been planted as part of a multi-species pasture cropping mix (Figure 3):

- Barley[9]
- Forage brassica
- Field pea
- Faba bean
- Turnip
- Tillage Radish

Based on his experience, Colin Seis's advice is that land management practice changes need to be implemented in the correct order. When planting perennials into degraded pasture and soil was unsuccessful, his priority was to condition the soils. With fertiliser too expensive, this was achieved by retaining maximum ground cover – even if that consisted of mainly annuals, including weeds. After conditioning the soil this way for several years, the combination of pasture cropping with time-controlled grazing kicked off the system dramatically; the existing perennial grasses persisted and seedlings of other beneficial species established (Soils For Life, 2016).

Methods

Phases of agricultural practice

A chronology of ecologically significant[10] land management practices and natural events on the property was used to interpret phases of agricultural practice. These phases are based on the conceptual model outlined by Thackway and Gardiner (2019). The majority of the chronology was already compiled by Thackway and Freudenberger (2016) from interviews with the land manager, Colin Seis, and historic records. Following further conversations with Colin, this report extends the interpretation to the present day and clarifies historic events.

The chronology of land use (ecologically significant practices and events) on *Winona* was compiled from a range of sources and is documented in Appendix A. Using these data, five phases of land management were identified (). With the chronology in place, these five phases were then interpreted according to the following guidelines:

- Phase 0 - Indigenous peoples' production systems and pre-European ecosystems. Phase 0 is not the focus of the Soils For Life case studies.
- Phase 1 – Conventional agriculture production systems[11]
- Phase 2 – Initial trialling of regenerative management regimes production systems
- Phase 3 – Upscaling of regenerative management production systems
- Phase 4 – Whole farm regenerative management production systems

[9] Oat seed was too expensive and barley seed was "at hand"; it turned out to be an early maturing variety.
[10] Those practices and events likely to alter ecological functions and hence change the status of the resource base.
[11] Across Australia, these practices usually led to diminished or degraded function, structure and composition of the landscape.

Assessing responses to land management regimes according to ecological criteria

The responses of ten ecological criteria (Thackway and Gardner 2019) corresponding to ecosystem function, composition and structure in the various phases of land management were identified and documented through a process of expert elicitation (Hemming et al. 2018; Thackway and Gardner 2019). This process involves the SFL ecologist working with the land manager to apply a standardized and systematic approach to elicit the land manager's knowledge to generate two products 1) a systematic chronology of land management regimes and 2) a graphic response to ten ecological assessment criteria illustrating their interpretation of status, change and trend of the dominant soil-landscapes that has occurred ecologically on the property during their management. The rationale behind the ten ecological criteria is presented in Appendix B. The ten ecological criteria are:

A. Resilience of landscape to natural disturbances
B. Status of soil nutrients – including soil carbon
C. Status of soil hydrology
D. Biological activity in the soil
E. The physical properties of the soil
F. Changes and trends in the reproductive potential of plants
G. The extent of tree cover
H. Status of ground cover
I. The diversity of tree and shrub species
J. The diversity of grass species

The SFL ecologist synthesises these two knowledges 1) systematic chronology and 2) the 10 ecological response curves to write an ecological report that summarises the ecological outcomes for the property.

The focus was mainly on the productive areas of *Winona* during the period 1991 to 2020. These productive areas consisted of several, closely related landscape-soil associations on mid to lower slopes and flats, thus being a modest superset of the VAST-2 assessment. Upland outcrop and ridge areas were not assessed; many of these are covered by natural or near-natural native vegetation. The VAST-2 assessment used a pre-European benchmark for scoring and this was retained for continuity with this assessment.

Responses for nine of the ten criteria (B to J) were constructed for the period 1991 to 2020. The first step of the assessment was to average the VAST-2 data underpinning the criteria for 1991 to 2015 (Thackway and Freudenberger, 2016) for a particular soil-landscape association on *Winona*. The VAST-2 criteria are presented in Appendix C).

The second step of the assessment was to create time-series graphs for each criterion. The time-series graphs are based on Colin's observations, experiences and memory and his judgement of the likely effects of his management practices. The time-series for each criterion was drawn on graphs for the period from 1991 to 2015.

Colin was asked to validate the summary of the VAST-2 assessment, and to extend the time-series for each criterion from 2016 to 2020. Colin drew the time-series graphs in the presence of the SFL ecologists, who asked clarifying questions as required. For criterion A, Colin was asked to draw the graph for the period 1991 to 2020.

Empirical data and reports for *Winona* have been referred to, where available, to further build the evidence base. In general, this was obtained from Colin directly or via material collated by Richard Thackway from multiple sources[12] for his 2016 assessment. This included peer-reviewed papers, conference papers, published reports, theses, extension and magazine articles, draft papers and some data (with no metadata).

Findings

Five management phases

The pre-European phase lasted until about 1870, when the first pastoral settlers came to the district. Conventional management (phase one) occurred from 1870 until 1979. Coin Seis calculated that during a particularly intensive period from 1930 to 1979, much of the property had been traversed by machinery 130 times (Seis and Thackway u.d. 2016) leading to degradation of soil structure. A total of five tractor passes per crop year consisted of ploughing (twice), scarification and cultivation (twice); the harvester was an additional pass.

After a disastrous bushfire in 1979, phase two commenced in 1980 as a very low- to no-input regime as a practical response to loss of all plant and equipment and lack of cash flow. The practices in this phase were otherwise “conventional” for the time, such as the use of direct drilling and herbicides for planting.

Regenerative experiments began with time-controlled paddock grazing in 1989, pasture cropping in 1993 and their combination in 1995. Phase three has been assumed to have started in 1993. Since then, there has been only one tractor pass per crop, with the harvesting stage being either by sheep or a mechanical harvester.

Pasture cropping is rotated around paddocks on the farm; at any one time, approximately a quarter of the farm is under pasture cropping. Time-controlled paddock grazing is also practised over the whole farm. Grazing of the pasture crop is managed to suit the agronomic stages of the crop.

Phase four began in approximately 2009, when pasture cropping was well established and experiments with multi-species cropping commenced.

Table 3. The five management phases on Winona.

Phase	Production Regimes	General Observations
Prior to European settlement, the land was managed by the Wiradjuri people.		
Phase one: 1870s–1979	Conventional management practices were undertaken throughout this phase.	• Rabbits were a major problem 1904–1950. • Cropping in 50% of the years: 1930– 1979.
Phase two: 1980–1992	During this phase the land manager experimented with low input practices to restore the farming enterprise following a disastrous bushfire	Management practices were mainly: • grazing of pastures and stubble • conventional cropping in 6 of 13 years • time-controlled grazing of sheep began in 1989.
Phase three: 1993–2008	The manager implemented certain regenerative and sustainability practices.	The land manager • began pasture cropping and refined practices, including the use of stock in the crop rotation in 1995

[12] Including Colin Seis

		• sowed forage and/or cash crops as part of the pasture cropping cycle • began harvesting native grass seeds as an additional productive enterprise.
Phase four: 2009–2020	Further implementation of regenerative practices	The land manager • began planting "mixed species" crops to provide a varied diet for sheep and soil microorganisms. • is investigating the use of native seeds for flour.

Assessment of response criteria

Historic Context

Figure 4 is a visual representation of soil and vegetation criteria for 1800 to 2015 using the VAST-2 system. This provides historic context for this assessment. Note the decline in the summarized criteria until the early 1990s, a period of no change and then improvement in the 2000s. Management phases have not been overlain on the graph for simplicity, but are referred to in the text.

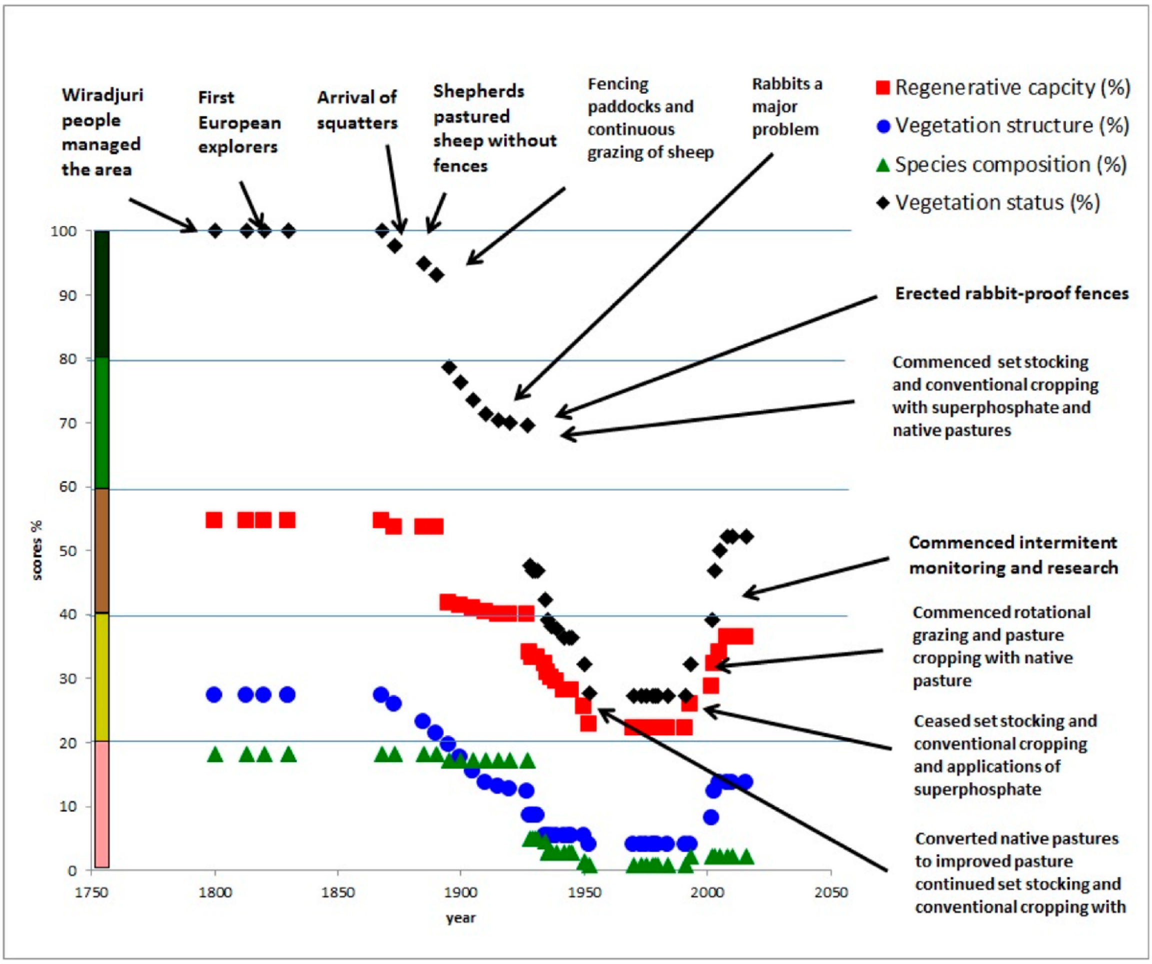

Figure 4. VAST-2 assessment of Winona by Thackway and Freudenberger (2016)

A. Resilience of landscape to natural disturbances

The assessment in Figure 5 is mainly in relation to drought, however an assessment in relation to fire and flood would have a similar trajectory.

In phase one, the land manager practised conventional agriculture. This included a fifty-year period (1930-1979) of cropping where the land manager[13] was an early adopter of leading edge practices. As above, management practices in the period from 1930 to 1979 led to widespread degradation of soil structure over much of the property. Soil erosion was a recurrent theme; weeds and salinity were on the increase. All of these, plus the high cost inputs, led to poor resilience to drought.

In phase two, after the bushfire of 1979, the land manager (Colin Seis's father, also called Colin Seis) practised conventional agriculture with a focus on zero to minimal inputs, because of the need to constrain costs. There was also a focus on retaining ground cover via increased incidence of pasture phases in the rotation, until time-controlled paddock rotational grazing commenced in 1989.

Once the land manager began and refined the practice of "pasture cropping" (phase three beginning in 1993; see figure 5), he noticed a gradual improvement in the resilience of the enterprise to drought, especially when pasture cropping was combined with time-controlled grazing (commenced in 1995).

In relation to fire resilience, the dominant, C4 (summer-growing) grasses "hay off" (become dormant and are unresponsive to showers) in the winter when the risk of wildfire is low. They are green in summer and respond well to summer showers, thus reducing fire risk when the weather can be most hazardous. In drought years, the fuel load is naturally low, but grazing is used as a management tool to reduce it where necessary.

This approach contrasts with much of southern Australia, which relies on C3 (winter/spring growing) grasses that hay off in summer/autumn. The increased productivity of introduced grasses often adds to the fuel load and hence fire risk in those agroecosystems.

The property experienced a flash flood in February 2020. Some fences were knocked over and remained so until our site visit in July 2020. However, grazing operations have been minimally inconvenienced.

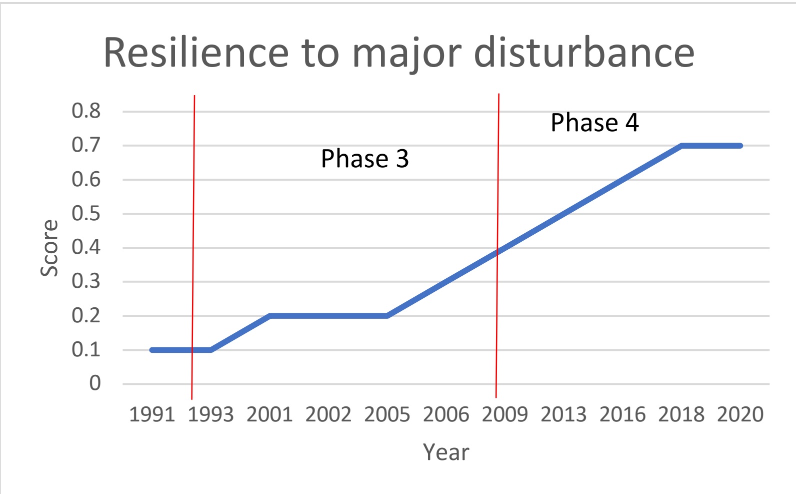

Figure 5 Resilience to major disturbance – e.g. drought, fire, flood, etc.

[13] Colin's father then Colin Seis, in this context.

B. Status of soil nutrients – including soil carbon

Figure 6 shows graphs for soil nutrient status (Criterion B), as well as status of soil hydrology (Criterion C), soil biology (Criterion D) and soil physical properties (Criterion E) for the productive soils on *Winona*. It represents the observed and inferred changes in status with changes in land management practices.

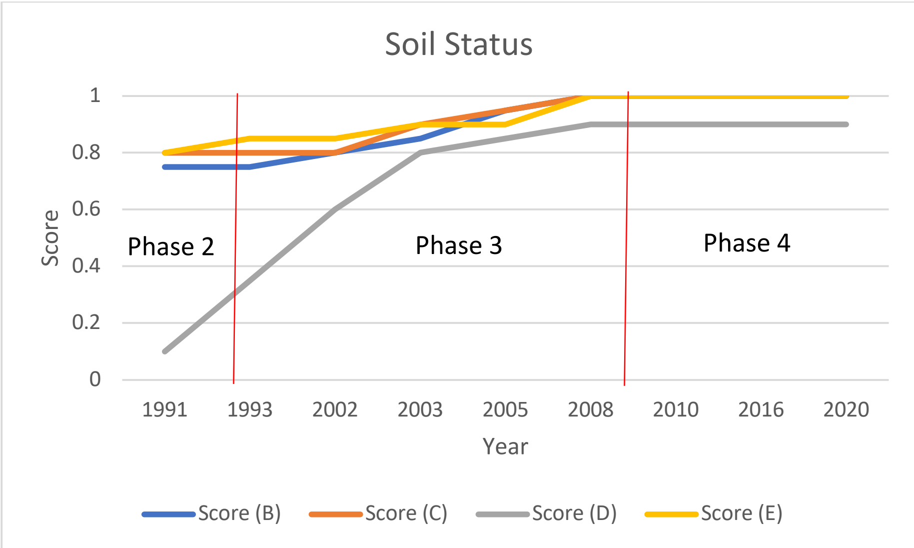

Figure 6 Soil status criteria:.(B) soil nutrients, (C) soil hydrology. (D) soil biology and (E) soil physical properties.

In phase one, the inferred soil nutrient status gradually declined over many years (Thackway and Freudenberger 2016). In phase two, the graph shows a good status of soil nutrients[14] – possibly because of the application of superphosphate on the inherently low fertility soil in phase one. Also, the land manager was always careful not to disturb the potentially dispersive subsoil below the plough line, thus (to an extent) preventing the exposure of the subsoil on the soil surface.

In phase three, pasture cropping plus time-controlled grazing was observed and inferred to have built soil organic matter and thus increased soil carbon. Colin recognised an improvement in soil nutrient status on and after 2003, perhaps because of the good rainfall in 2003. During this phase, the routine application of 80-100 kg/ha of monoammonium phosphate (MAP) and diammonium phosphate (DAP) on crops was gradually reduced[15]. The level of acidity in the soil declined, whilst the areas of salinity on the property also declined in this phase.

Landscape Function Analysis (LFA) (Tongway and Hindley 2004) undertaken in May 2010 indicated significantly higher levels of a nutrient cycling index compared with a comparison site (Ampt and Doornbos 2010). In September 2010, an analysis of soil carbon on Winona using SCaRP protocols (Sanderman et al. 2011) showed more soil carbon than on the neighbour's conventionally managed property to a depth of 60 cm (Figure 7). A longitudinal study from 2010 to 2016, using SCaRP protocols (Sanderman et al. 2011) showed a general accretion of soil carbon at all depths, except in the topsoil[16] (Figure 8).

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[14] Inferred from the health of the crops

[15] The fertiliser was reduced gradually from 1998 at about 10 kg at a time. Another reduction in 2002, another 10 kg reduction in 2004, etc.

[16] The paddock was under holistic grazing with 3 months recovery: pasture cropped in 2009 (oats), 2011 (oats) and 2015 (mullti-species) at 32 10' 35" S – 149 33' 39" E, slightly downslope from the SFL soil sampling site. Bulk density data and proportions of particles >2 mm are not reported here.

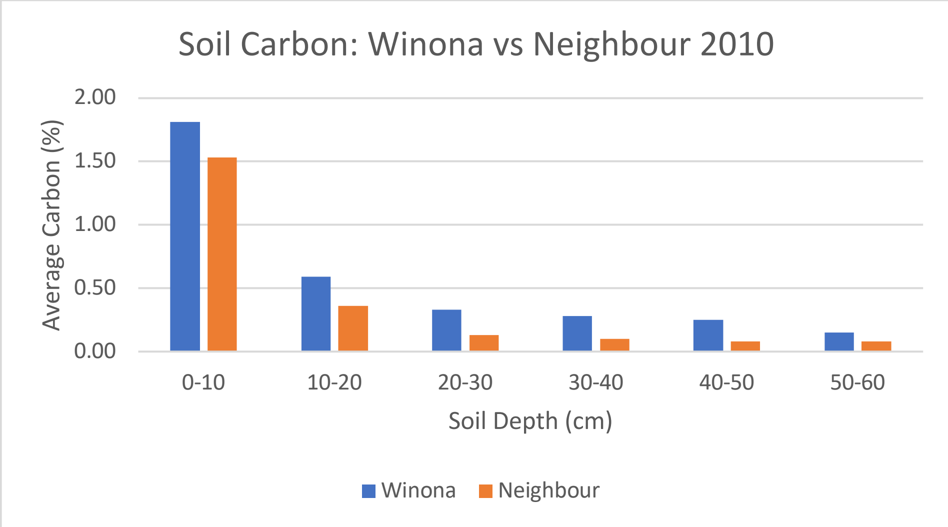


Figure 7 Comparison of carbon on Winona versus neighbour in 2010 (Source, C. Seis, unpubl. Data, 2020)

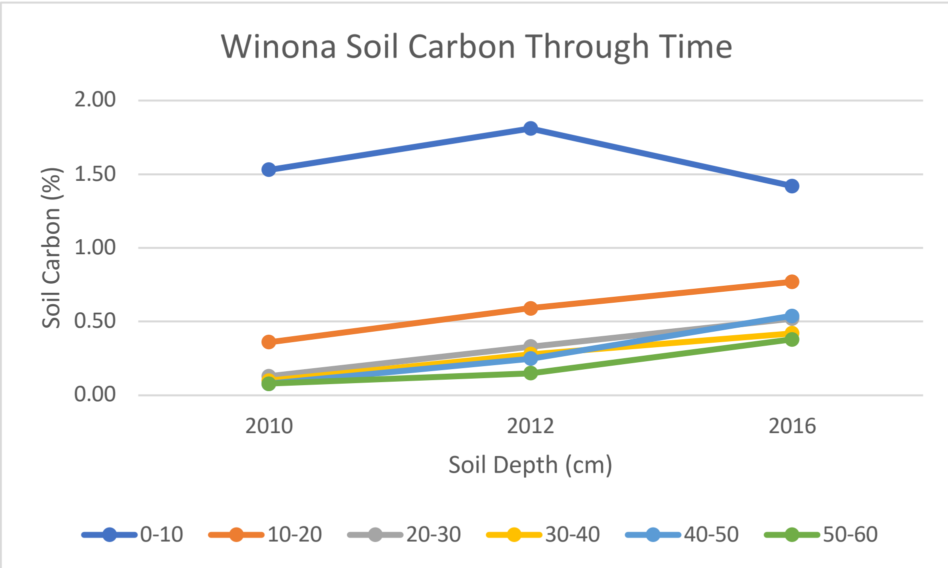


Figure 8 Soil carbon at depth through time for 30 Acre Paddock (Source, C. Seis, unpubl. data, 2020)

In phase four, fertiliser use on crops reaches 40 kg/ha, which is approximately 7 kg of N and 7 of P. Colin Seis considers soil nutrients to have reached pre-European levels for the soil type.

C. Status of soil hydrology

As mapped in Figure 6, the soil hydrological status gradually declined over many years (Thackway and Freudenberger 2016) during phase one. In phase two, the graph shows a good status of soil hydrology arising from the careful application of conventional agricultural practices. Pastures became more common in the cropping cycle and the emphasis was on maximising ground cover, thus slowing the passage of water across the landscape and encouraging infiltration.

In phase three, the period when pasture cropping began, soil carbon and infiltration increased and soil salinity was observed to decline.

LFA (Tongway and Hindley 2004) indicated significantly higher levels of an infiltration index compared with a comparison site (Ampt and Doornbos 2010). The deep-rooted pastures utilise excess soil moisture, thus reducing waterlogging and salinity problems (Bruce and Seis, 2005).

In phase four, the land manager considers soil hydrological properties to have reached pre-European levels for the soil type[17].

D. Biological activity in the soil

The very low status of soil biology in phase two (see Figure 6) is a result of the overworked soils and toxicities from acidity and sodium (Thackway and Seis u.d. 2016). By phase three, during pasture cropping, soil biology had improved in line with increases in soil organic carbon in comparison with land managed conventionally on the same soil type (Ampt and Doornbos 2010).

In phase four, the land manager considered soil biology to be at a "maximum" or ideal level for the soil type. However, he also said that further improvement may be possible due to the quantity and variety of root exudates from the multispecies crops.

E. The physical properties of the soil

Figure 6 demonstrates good status of soil physical properties during phase two, arising from the careful application of conventional agricultural practices. Pastures became a more common inclusion in the cropping cycle and the emphasis was on maximising ground cover, thus minimising soil erosion.

In phase three, the pasture cropping improved the soil physical properties, such as soil aeration[18]. The near-continuous ground cover across all seasons has markedly reduced soil erosion. Increased soil organic matter in the soil profile has generally improved soil "tilth" as a medium for plant growth.

In phase four, soil physical properties are considered by Colin to be near ideal for this type of country. In 2010, LFA (Tongway and Hindley 2004) indicated significantly higher levels of overall stability index compared with a comparison site (Ampt and Doornbos 2010).

After several decades of regenerative management (minimal traffic, minimal cultivation, maximum ground cover), the scarring from erosion on *Winona* is much reduced (Figure 9).

[17] Sodosols typically have impermeable or low permeability subsoils.
[18] Inferred from the improved control of waterlogging and from the bulk density results of Warden (2009).

Figure 9. Aerial photo of Winona and surrounds from May 1964 (left) and 2020 (right).

F. Changes and trends in the reproductive potential of plants

In phases two and three, the landholder inferred a very low status of plant reproductive potential on the productive soils of *Winona* (Figure 10). This is because of a very low coverage of trees and shrubs on the productive soils. In phase four, the planting of windbreaks, biodiversity corridors and paddock trees have progressively improved the plant reproductive potential. The land manager expects to continue such plantings in the future.

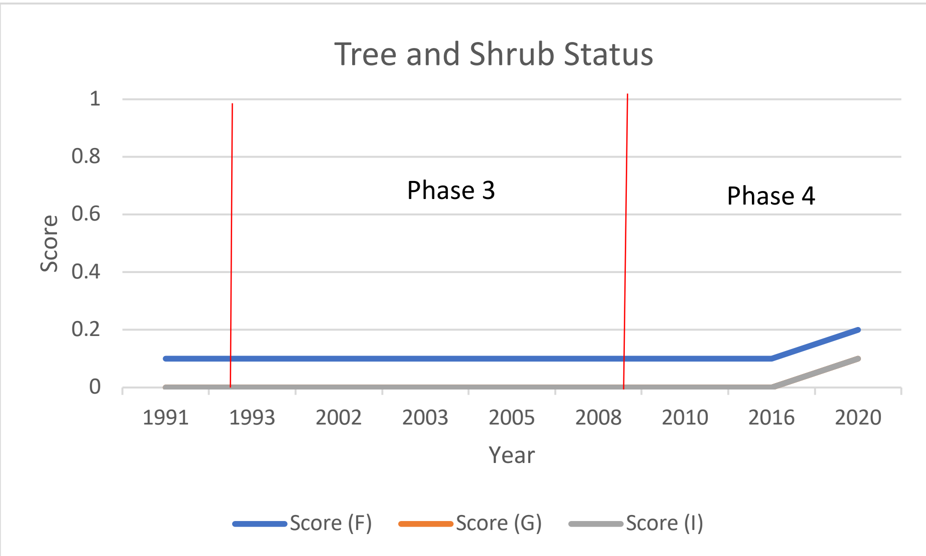


Figure 10. Tree and shrub status criteria: (F) reproductive potential of plant species and plant community, (G) tree and shrub structure (line underneath trace for criterion I) and (I) tree and shrub species richness and functional traits.

G. The extent of tree cover

There are few trees and shrubs on the productive soils of *Winona* (Figure 10). The small uptick in phase four is related to tree plantings discussed in criterion F (above). The “unproductive” areas of forest and woodland on *Winona* were not assessed, but remain a valuable asset for biodiversity and landscape functions.

H. Status of ground cover

Figure 11 shows a low status of grass and herb structure on the productive soils of *Winona* in phase two. This is because of the poor native pasture regeneration and high annual weed cover on the overworked soils under conventional tillage and pasture management (Seis pers. comm. 2020). In phase three, pasture cropping has demonstrably increased the cover and biomass (Bruce and Seis 2005) of native perennial grasses, especially the native, summer-growing (C4) grasses – see Figures 12 and 13.

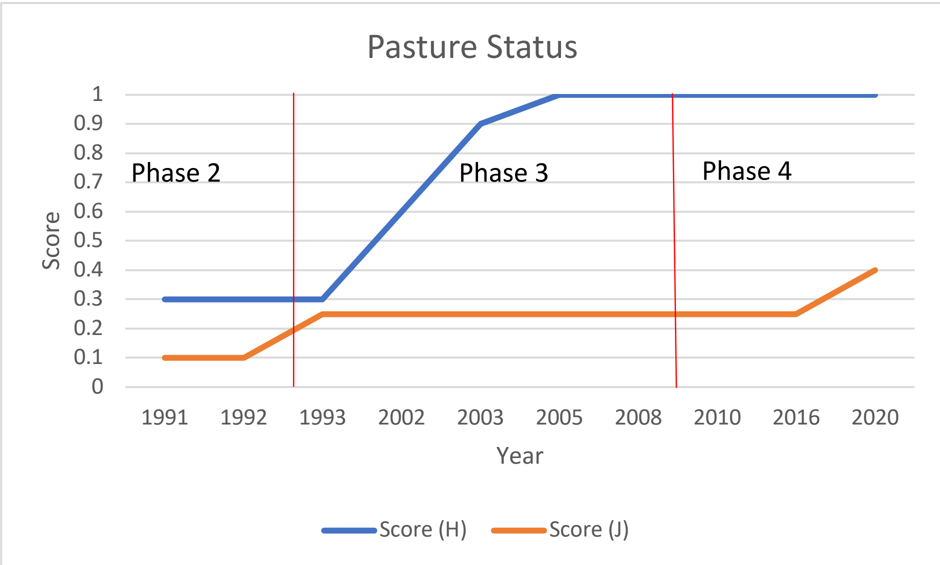


Figure 11. Pasture criteria: (H) ground cover structure and (J) ground layer species richness and functional traits.

In phase 4, the high cover of desirable species has been maintained, as per transect measurements by the land manager[19] in Autumn 2020 (Figs 12 and 13). The low levels of bare ground and increasing proportion of desirable native grasses shows drought resilience despite the worst rainfall year ever recorded (2019) and three extreme drought years in a row 2017, 2018 and 2019 (Table 1).

[19] Summarised data provided by Colin Seis, September,2020.

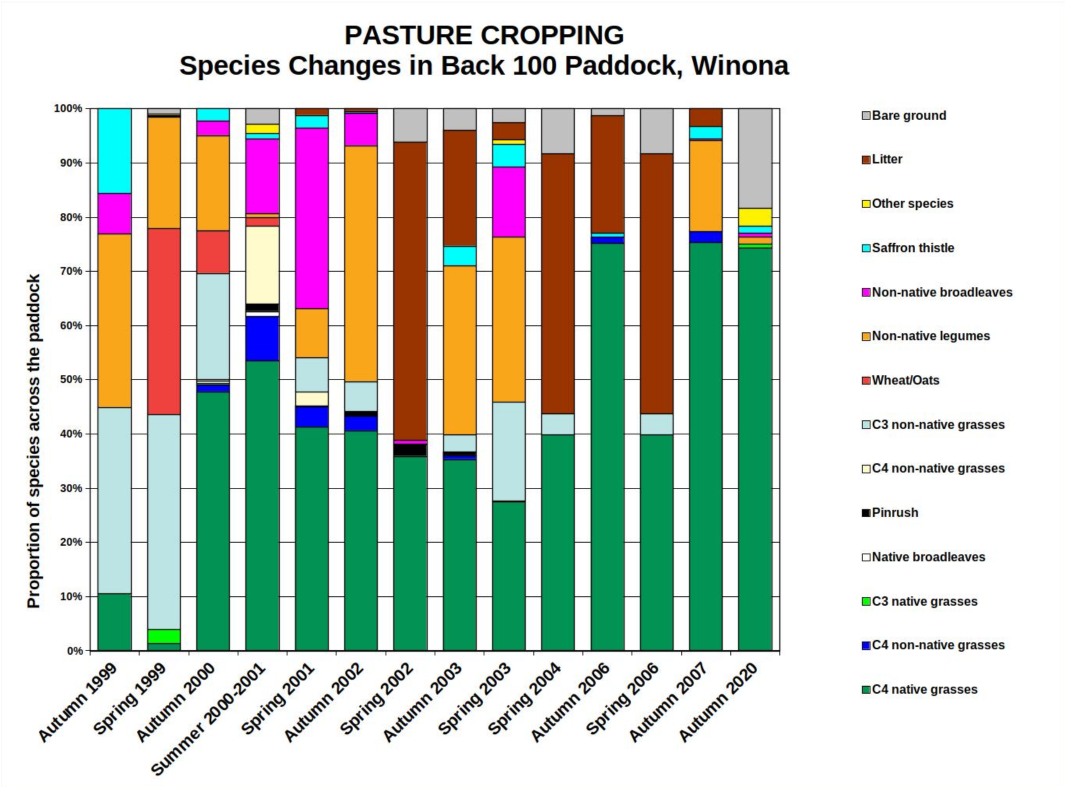


Figure 12: Species cover changes over time in the Back 100 Paddock on Winona.

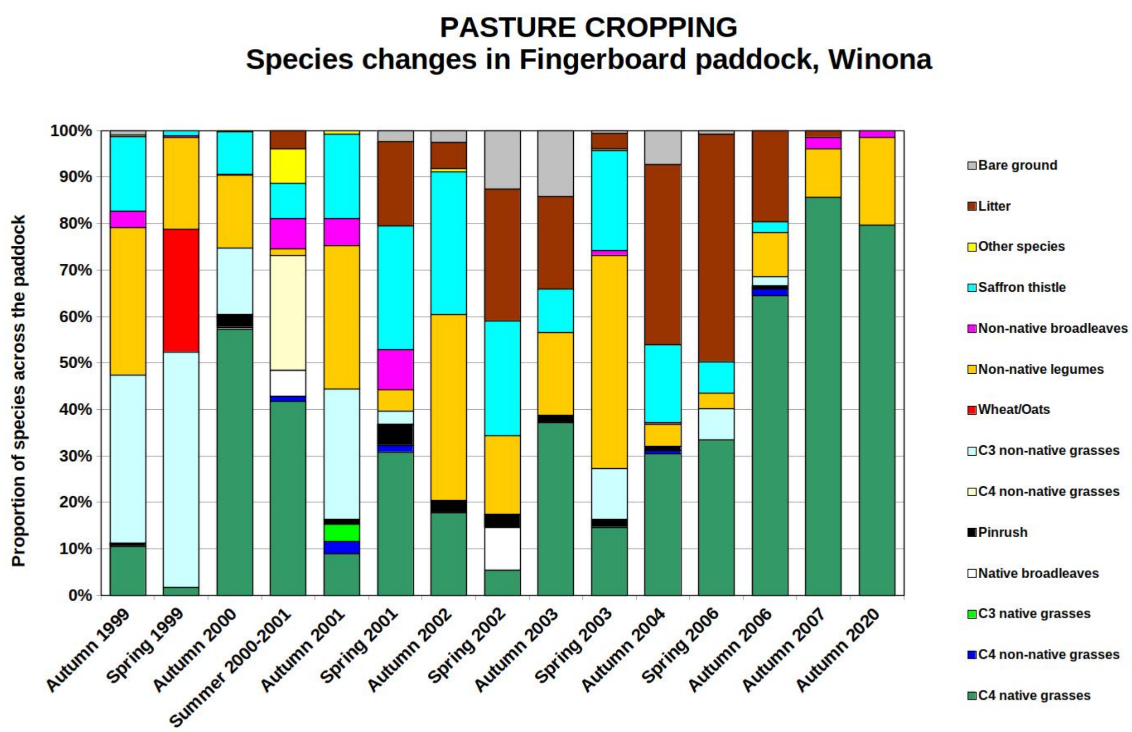


Figure 13: Species cover changes over time in the Fingerboard Paddockon Winona.

I. The diversity of tree and shrub species and functional traits

As previously noted, trees are relatively rare on the productive soils of *Winona*, whilst shrubs are generally not present. In phase four, the planting of windbreaks, biodiversity corridors and paddock trees have progressively improved the plant species richness and diversity of functional traits (Figure 10). The land manager expects to continue such plantings in the future. As mentioned in criterion G, the "unproductive" areas of forest and woodland on *Winona* were not assessed, but remain a valuable asset for biodiversity and landscape functions.

J. The diversity of grass species and functional traits

Figure 11 shows a low status of grass and herb species richness on the productive soils on *Winona* during phase two. In phase three, pasture cropping improved the ground layer species richness relative to conventional farming in phase two. More-desirable, palatable and productive native species such as *Paspalidium*, Austrodanthonia, *Microlaena* and *Elymus* (Seis 2001), have established under the regenerative regime; in turn, the diversity of weeds and annual grasses has decreased (Colin Seis pers. comm. 2020). In phase four, the multi-species plantings of improved pastures have diversified the agroecosystem above and below ground.

LFA (Tongway and Hindley 2004) indicated significantly decreased levels of plant species diversity compared with a comparison site (Ampt and Doornbos 2010). This may be due to the density of the perennial grasses on *Winona* successfully competing with annuals, while the "open" nature of the comparison site enabled germination and establishment of annuals, including weeds. The discrepancy with the graphical results (Figure 8) can be explained by the land manager valuing desirable species over weeds.

Discussion

This assessment shows that all functional criteria are considered by the author to have improved with increased implementation of regenerative practices since the major bushfire in 1979, and certainly since commencement of pasture cropping in 1993.

The phases of agricultural practices identified on *Winona* have somewhat arbitrary thresholds to assist in the interpretation of multiple changes. It's difficult to make definitive thresholds when the land manager is continuously innovating whilst maintaining a viable, diversified enterprise. For example, phase 3 should perhaps start in 1995, when the combination of pasture cropping and time-controlled grazing was the key to ultimate success. An alternative interpretation of changes to land management practices would be the Gleissman (2015) Levels of Conversion.

Winona phase two is clearly similar to Level 1 where conventional inputs are much reduced and parts of Level 2, where industrial agriculture inputs and practices were substituted with less-damaging practices. Phase 3 on *Winona* is clearly a redesigned agroecosystem and thus conforms to Gleissman Level 3, while phase four has elements of Levels 3, 4 and 5 with Colin Sies's sale of native grass seed and world-wide promotion of pasture cropping.

Resilience

In relation to the resilience of *Winona* to drought, fire and flood, the turn-around from the catastrophic wildfire in 1979 is remarkable. Colin Sies has observed and thought about the life cycles and other characteristics of his pasture resource, thus underpinning his innovative practices and their contribution to resilience. A year-round supply of fodder for his stock fills the regular winter and late summer "feed gaps" experienced by conventional farmers in this region.

Colin Seis is not immune to the need to sell stock during drought, but in the 2016-2019 drought, Colin was able to minimise keep stock sales further into the drought because his pasture and/or crops responded well to light showers of rain. Recovery from drought was quicker too – Figures 12 and 13 show excellent ground cover of desirable species soon after the drought broke in February 2020. This compares with bare paddocks on some other properties that require so-called "drought breaking" rains to facilitate germination and establishment.

Colin Seis's observations and practices regarding fire ecology contribute to the resilience of *Winona* to fire. They may provide lessons for temperate regions where native C4 grasses have been replaced by C3 grasses, which now provide dry fuel at the times of highest fire risk. Colin regards the flood and soil erosion control earthworks of the 1950s to now be unnecessary, due to the consistently high ground cover over his property protecting the soil.

Soils

According to Colin Seis, three of the four criteria showed steady improvement in phase 3, while soil biology showed dramatic improvement. SFL regard the maximum scores for three criteria in phase 4, coinciding with multi-species cropping, to be an artifact of the scoring system. Further improvement may be possible via the quantity and variety of root exudates from the multi-species crops and from targeted tree planting.

As well as building soil organic matter and therefore increasing soil carbon, pasture cropping plus time-controlled paddock grazing is likely to have enhanced nutrient cycling. Colin Seis has also confirmed that, based on observations of plant health, the extent of soil acidity has been reduced. The decline in areas of salinity on the property could be partly attributed to the greater usage of water by deep-rooted perennial grasses[20] (Millar and Badgery 2009; Pierret et al. 2016; Southwell et al. 2005; Zhongnan Nie 2011), now well established on *Winona*. Soil properties and characteristics are discussed further in SFL's report *The Winona Soil: A Profile* (Soils For Life 2020).

The carbon data for *Winona* referred to in Figure 7, above, indicated good accumulation at all depths (0 – 60 cm) compared with a conventionally managed paddock with the same soil type. However, we would need to know the sampling plan of the study[21] (and additional data) to draw firmer conclusions; the data points arise from multiple samples per layer, but it is unclear whether the samples have been bulked or individual measurements have been omitted.

A similar caveat relates to the time-series of carbon data for a site on *Winona* (Figure 8). However, all layers seem to be gradually accreting carbon except the topsoil. Whether this is due to local spatial variation, short term temporal variation or a depletion of carbon from the multi-species cropping would require more investigation (Sanderman et al., 2010) - well beyond the scope of this project.

Controlled experiments on pasture cropping at nearby Wellington warned of a possible long-term decline in nitrogen in such management systems (Millar and Badgery 2009). Bruce and Seis (2005) recorded lower levels of nitrogen under pasture cropping, but this may serve to reduce soil acidification and denitrification problems. From crop yields on *Winona*, there is no evidence of such

[20] https://www.mla.com.au/research-and-development/Environment-sustainability/Sustainable-grazing-a-producer-resource/climate-variability-using-water-wisely/maximise-plant-water-use/
[21] How (Sanderman et al., 2011) was implemented on this site.

a decline in nitrogen under current practices (Seis, pers. comm., 2020), which include low rates of fertiliser application (see Results: Criterion B).

Based on Colin's observations, soil physical and hydrological properties showed a similar trajectory to soil nutrients. Colin has noticed a gradual improvement in infiltration, aeration and drainage properties most likely from the increase in soil organic matter in the profile and continuous ground cover. The decline in salinity and protection from soil erosion have been dramatic, thus endorsing Colin Seis's regenerative practices in those important areas.

Vegetation

Trees and shrubs have not featured greatly in the productive areas of *Winona*. However, with the planting of shelter belts and reintroduction of native pastures, Colin Seis has noticed a gradual increase in native birds compared with the common exotics (SFL, 2016). This may have improved pest control along with the rotational paddock grazing which helps to break parasite life cycles[22]. Colin Seis's next step is to plant isolated trees to recreate the pre-European grassy open woodlands on *Winona*. The amenity value of these trees would include shelter for stock, improved nutrient cycling and improved deep drainage to further control waterlogging and salinity.

Ground cover

The high ground cover and biomass over the whole of *Winona*, except for laneways, is remarkable; many photographs taken during the site visit validate this, including the *Soil Surface Condition* image taken as part of the site and soil observation and description (The *Winona* Soil: A Profile, SFL 2020). The low values for pasture species diversity (Ampt and Doornbos 2010) may appear counterintuitive, however, this reflects the high cover of desirable functional types (especially perennial grasses) suppressing weeds (Figures 11, 12 and 13). Field experiments near Wellington NSW by Thapa *et al.* (2011) found that seedlings of Red Grass (*Bothriochloa macra*) germinated more successfully under pasture cropping than the ungrazed control and grazed treatment. This matches Colin Seis's observations and suggests that episodic breakdown of the grassy thatch under rotational paddock grazing delivers favourable germination sites for perennial native grasses.

Pasture cropping

Regarding crop yields from pasture cropping, in experiments near Wellington, NSW, Millar and Badgery (2009) found crop yields were 65% of yields from conventional cropping. Colin Seis was achieving oat yields of 4.3 tonnes/ha (at least equalling district average yields using full ground disturbance cropping) on some areas of *Winona*, and average yields of 3.4 tonnes/ha – i.e. 80% of conventional methods (Dunn, 2012). In any case, the lost grain production is compensated by the increased duration and biomass of the grazing resource (Bruce *et al*., 2005; Bruce and Seis, 2005). It is not the intention here to make yield comparisons, but Colin Seis is very happy with the productivity and flexibility of his farming system. The typical rotation cycle has been documented already (Soils For Life 2016).

Our assessment shows that since 2012, pasture cropping has continued to show the ecological benefits previously documented on *Winona.* Controlled experiments on pasture cropping at nearby Wellington have validated many of these benefits (Millar and Badgery, 2009). In addition, we believe that this assessment demonstrates improved resilience to drought, fire and flood from the regenerative practices on *Winona*. It is difficult to quantify these benefits without suitably replicated, "before and after" measurements under each of our assessment criteria, but the anecdotal and available hard evidence would seem to confirm these findings.

[22] https://archive.dpi.nsw.gov.au/__data/assets/pdf_file/0007/518191/Managing-internal-parasites-in-organic-livestock-production-systems.pdf

The successful reestablishment of native grass pasture – essentially a permanent, deep-rooted pasture stage of the rotation - has underpinned the stability of the resource base on *Winona*. This stability in turn has enabled Colin Seis to experiment with innovative practices, such as pasture cropping, on a “no regrets” basis and obviously contributes to the resilience discussed above. This compares with older conventional practices, such as bare fallows, which were vulnerable to episodic events such as severe thunderstorms.

The addition of multi-species crops into the rotation has undoubtedly provided more improvements, but the extent of this improvement has not been quantified – again via the absence of “before and after” or “place for time” (comparative) experiments on *Winona* or nearby. The carbon data are an exception to this, but even then, the results are equivocal. In a sense, we were attempting to demonstrate a gradual increase relative to a large, fluctuating resource.

Controlling all of the variables involved in regenerative agriculture challenges the capacity of most scientific agencies - for example, Sanderman et al. (2010) for carbon. However, the expected benefits of multi-species cropping appear sound. A diversity of physical (e.g. aeration pathways from tillage radish) and chemical inputs (e.g. nitrogen from legumes) into the soil from multiple species would take up plant nutrients in various forms and promote a diverse and flourishing microflora compared with single species crops, even with the native pasture always there. Stock eating the crop would get a varied diet.

In a modelled risk assessment, Howden *et al.* (2005) found that pasture cropping was more variable than pasture only and conventional cropping; pasture cropping was most suited to regions relying on in-crop rainfall (as with *Winona*) rather than stored soil moisture (as in districts with heavier soils). Despite these predictions, the resilience of *Winona* to drought and other disturbances has continued to improve with the introduction of multi-species pasture cropping. Profitability is actually <u>less</u> variable with the rotations, reduced inputs and diversification of enterprises on *Winona* (*Winona*; The Economic Report, Soils For Life 2020). We note that that pasture cropping is also successful on the light soils near Dongarra, Western Australia (Tunney and Ferris 2010); summer rainfall (benefitting the C4 grasses) is higher there than in inland parts of the WA wheat belt. Farmers need to evaluate their own resources and circumstances before attempting pasture cropping (Leach, 2020).

Independent Scientific Assessment

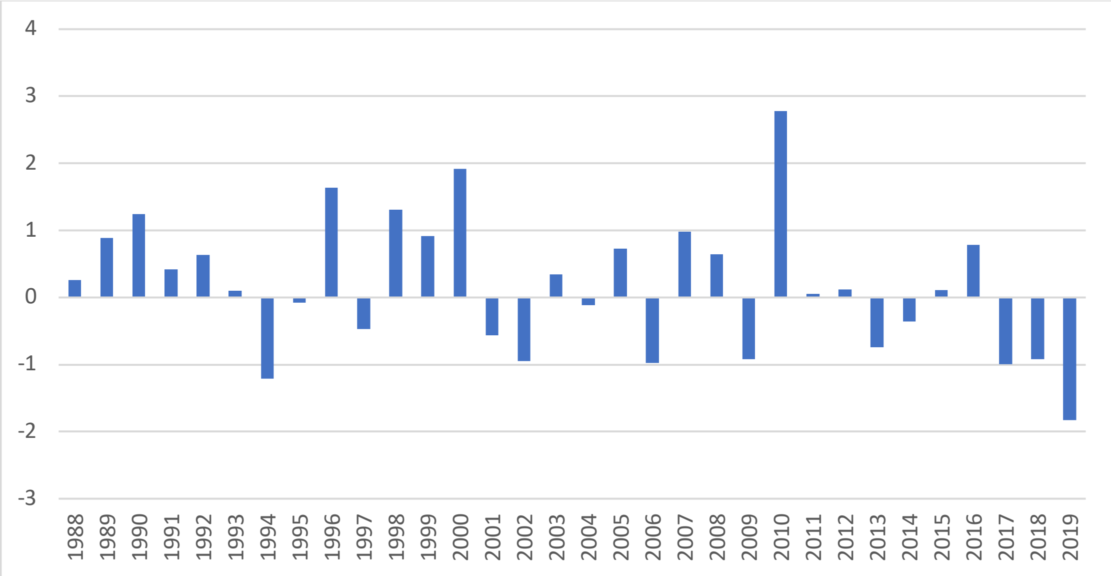
An independent assessment was used to validate the land manager’s self-assessment of the graphical ecological responses derived using the structured expert elicitation approach. This involved using almost 30 years of Landsat satellite derived land cover metrics to analyse pattern and trend over this period within the property compared to the surrounding district (Appendix D).

Ground cover

It is widely accepted that changes and trends in per cent ground cover is a response to rainfall patterns as well as land management regimes (Thackway et al. 2013). The annual rainfall anomaly for Winona is shown in Figure 14. This figure shows below average rainfall occurred in the following years: 1994, 1997, 2001-02, 2006, 2009, 2013-14 and 2017-19.

Ground cover within Winona was compared to the surrounding properties for the years 1988-2019. Over this period ground cover on Winona remained predominantly above 50% (Figure 15). This is particularly interesting when we look at the three years 2017-19, which were particularly severe, with much of the central west of NSW declared as drought affected.

While Figure 15 shows there was an obvious reduction in ground cover (%) on Winona between 2014-19 compared to 2011-13, Figure 15 shows that ground cover on Winona did not fall below 50% even in the severe rainfall deficit year 2017-19 (Figure 14).



Source: BOM modelled monthly rainfall 1900-2019

Figure 14. Annual rainfall anomaly for Winona. This figure shows the standard difference anomaly for annual rainfall about the mean.

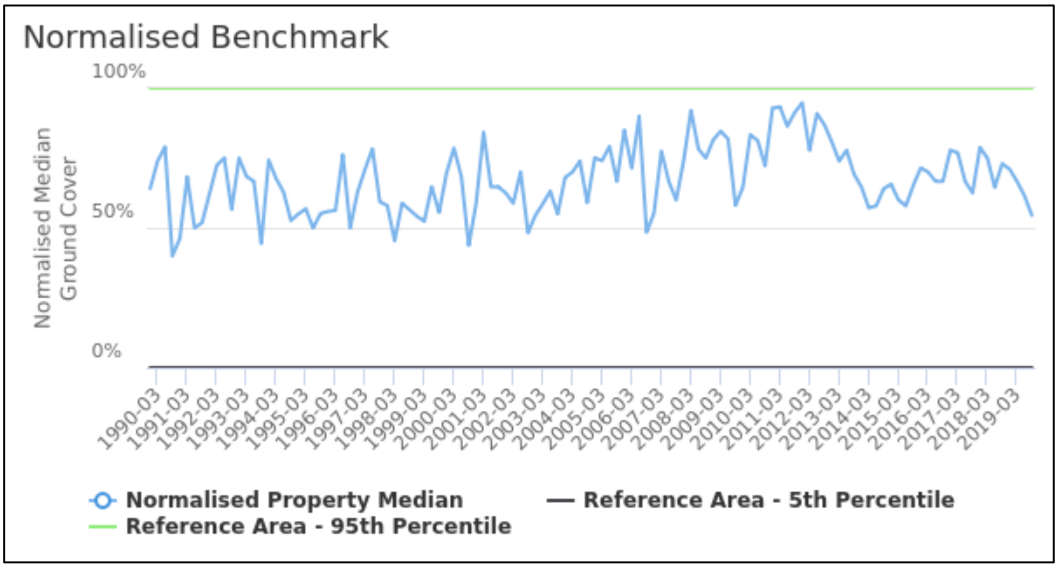


Figure 15: Winona's median ground cover relative to reference area's 5th and 95th percentile which are represented at 0% and 100% respectively. For example, a normalised median ground cover of 50% is hallway between the 5th and 95th percentile.

This analysis confirms that the 'Status of ground cover (Figure 11)' supplied by the land manager is regeneratively managed. It is also worth noting that the amount of ground cover and its persistence over time affects the performance of several other functional ecological criteria. This includes the first five criteria discussed above:

- Resilience of landscape to natural disturbances (Figure 5)
- Status of soil nutrients – including soil carbon (Figure 6)
- Status of soil hydrology
- Biological activity in the soil
- The physical properties of the soil (Figure 9)

Woody plant cover

An independent assessment of the extent of woody plant cover on Winnona was assessed relative to 1990. The area of woody vegetation has been slowly increasing since 1991. Starting in 1991 with 70.6ha (8.4%), the area of woody vegetation on Winona in 2019 was 116.8 ha, an increase of 60% (Figure 16).

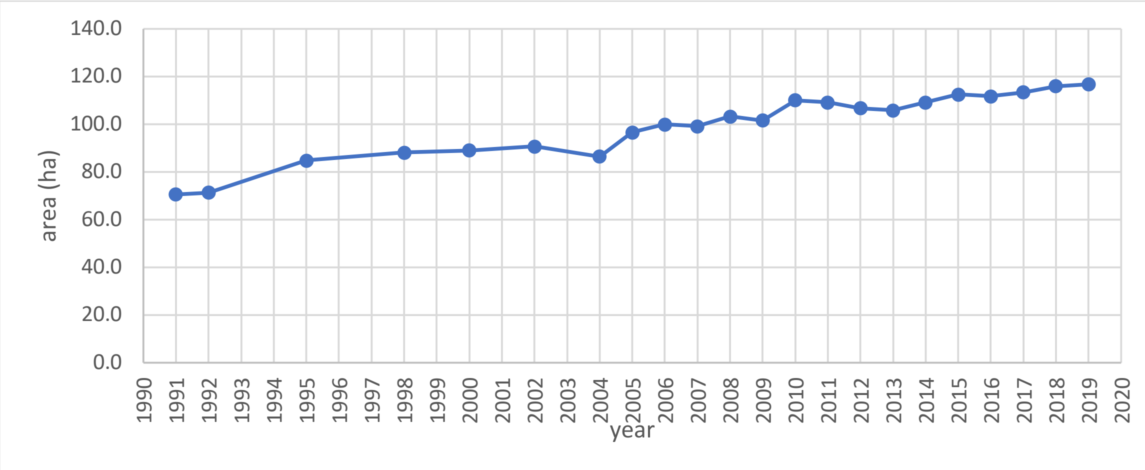


Figure 16. Area of woody vegetation recorded on Winona using Landsat imagery and Montreal definition of a forest.

This analysis confirms the land manager's assessment of 'The extent of tree cover' and 'Changes and trends in the reproductive potential of plants' (Figure 10) that tree cover on Winona is gradually increasing. The increase in total woody vegetation is made up from a natural process of thickening and infilling i.e. the conversion of extant native woodland to open forest. In addition, this increase outside natural woodland and forest, is made up from new plantings including windbreaks, biodiversity corridors and paddock trees across the productive agricultural areas.

Conclusions

Colin Seis's practice shows that good soil carbon outcomes are possible on very fragile soils. Pasture cropping appears to be most relevant to subtropical and warm temperate grasslands on lighter soils with a strong component of C4 (summer-growing) grasses. We are unable to draw conclusions about the relevance of pasture cropping to the management of other temperate grasslands previously containing C4 grasses.

Colin Seis's journey on Winona shows that regenerating soils and landscapes is a continuous learning process where engaging with other innovators is key. Taking on regenerative practices like pasture cropping does not necessarily require cash or good resourcing – Colin Seis changed his practices precisely because he could not afford inputs. However, it is a long-term undertaking that requires persistence and continuous innovation over a number of years.

The independent ecological assessment highlights the importance of a local land manager understanding, planning for, and implementing well-informed land management regimes that aim to achieve sustainable ecological outcomes. This assessment supports the conclusion that Winona is an outstanding example of regenerative landscape management in an agricultural setting.

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Appendix A

The chronology of land use describes the land management regimes and production systems on *Winona* and was compiled in partnership with Colin Seis for each of the phases 1-4, and from Soils For Life (2016), Thackway and Freudenberger (2016[24]), Seis (2015) and other unpublished sources.

Chronology of land use: *Winona*, NSW	
1868	Seis family selected the first allotment; raised merino sheep and grew wheat to feed the family
1870s	Dry years (grassland with scattered trees)
1880s	Wet years (recruitment of trees)
Late 1890s - 1902	Federation drought
1906	Stringybark saplings recorded in title deeds
1904 – 1950	Rabbits
1920s	Erosion caused primarily by rabbits Tree ringbarking
Late 1920s	Col's father began farming
1930	Changed from horse teams to tractors Began "industrial agriculture" Grew wheat on the same 300 acres for 20 years straight
1930s to 1979	Crops planted every 3–5 years; yields 3 tonnes per hectare Increasing acidity, aluminium toxicity and saline areas and decreased carbon in soil
1940s	Major erosion caused by cropping practices, especially long summer fallows. Most damage done (3 m deep gullies) in a storm in January 1946 Stopped long fallows and reverted to pasture in rotation with crops
1950s	Rehabilitation of gully erosion[25] by land manager
1950s to 1970s	Industrial agriculture very profitable initially Superphosphate applied annually to correct nutrient deficiencies Regular re-sowing of introduced pastures Ploughing and pesticide use for crops Set stock (continuous) grazing

[24] Also, Thackway, unpubl. data from his 2016 visit to Winona
[25] A requirement in the catchment of the (then) new Burrendong Dam, near Wellington.

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1970s	Increased degradation of resource base; declines in soil structure and infiltration with increased soil acidity and salinity Gradually going broke; increased costs of fertiliser and improved pastures
1975	Major salinity outbreak; 40 ha grew no grass
1979	Lead-up years were very wet Disastrous wildfire destroyed everything on property including house, sheds, fences and 3000 sheep
1980s	Rebuilding enterprise as a very low input system Agronomic advice ignored; it was inappropriate scientifically and financially Superphosphate too expensive; the land manager observed that native grasses evolved without fertiliser, so shouldn't need fertiliser. Promoted ground covers and mulch; few native grasses to start (10% cover from 9 species) with 60% cover of weeds Still cropping wheat
1985-86	Soils becoming acid
Late 1980s	Tried zero tilling and direct drilling; results not optimal Learned about Alan Savory's ideas
1989	Commenced time-controlled grazing
1990s	Dryland salinity project to rehabilitate saline sites; Grassed waterways and contour banks to take away excess water.
1993	Commenced pasture cropping
1995	Combined pasture cropping with time-controlled grazing
Early 2010s	First experiments with multi-species pasture cropping
2012	Soils For Life visit to *Winona* (Soils For Life, 2016)
2014	Multi-species plantings well established as part of pasture cropping
2016	VAST-2 assessment of *Winona* (Thackway and Freudenberger, 2016)
2020	Soils For Life visit to *Winona* Normally 4000 sheep; currently 2000, after three drought years

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Appendix B

Ten ecological criteria for assessing landscapes against management regimes (Soils For Life, 2020)		
	Criteria	**Rationale**
A	Resilience to major natural disturbances	Resilience to major disturbances includes the following factors depending on the agro-climatic region (wildfire, drought, cyclone, dust storm, flood, frost). A major natural disaster or natural disturbance event can occur at any time. Some disturbances give a warning, such as a windstorm or electrical storm preceding a wildfire or a flood. Once a disaster happens, the time to prepare is gone. Lack of preparation can have enormous consequences on farm life including social, ecological, economics and production. Drought is the most frequent natural disturbance affecting this property.
B	Status of soil nutrients including soil carbon	Soil organic matter (SOM) plays a vital role in influencing available soil nutrients. Generally, for every tonne of carbon in SOM 15 kg of phosphorus, 15 kg of sulphur and about 100 kilograms (kg) of nitrogen become available to plants as the organic matter is broken down. It is vital to know how much carbon we have in soil so that we can roughly estimate the potential supply of nutrients. SOM releases nutrients for plant growth, promotes the structure, biological and physical health of soil, and is a buffer against harmful substances.
C	Status of soil hydrology	Soil texture and structure greatly influence water infiltration, permeability and water-holding capacity. Of the water entering a soil profile, some will be stored within the root zone for plant use, some will evaporate, and some will drain away. In agro-ecological settings, by increasing water infiltration, permeability and water-holding capacity this will usually act as a stimulus to improve ecological function. Management regimes that promote the capture and utilisation of rainfall where it falls generally enhances ecological function.

D	Biological activity in the soil	Soil biology affects plant and animal production by modifying the soil physical, chemical and biological environment within which plants grow and persist. The ratio of fungi to bacteria is important for land managers to understand – too many bacteria can indicate an unhealthy and unproductive soil. In healthy soils, there is a good balance between fungi and bacteria; invertebrates including arthropods and worms are usually present. Collectively these form a vital part of a plant nutrient supply web.
E	The physical properties of the soil	Soil is a medium for plant growth, given the right environmental conditions. In some agroclimatic regions, the naturally occurring surface layers (A horizon) have historically been adversely impacted by inappropriate land management regimes. Major and moderate loss of the A horizon either through water or wind erosion may have diminished the ecological function of the soil as a medium for optimal plant growth.
F	Changes and trends in the reproductive potential of plants	Grazing production systems rely on an ecosystem's inherent capacity to bounce back after grazing and natural climate events (e.g. wildfire and drought). Where regenerative land management regimes have been implemented to build or rebuild the reproductive potential of plants and pastures, we look at the observed outcomes on plant/pasture reproduction, germination, establishment, development and maintenance.
G	The extent of tree cover	Tree cover in agricultural landscapes provides important ecosystem benefits, including mitigation of soil erosion; shelter for pastures and crops; improved animal welfare; enabling added revenue from stacked (multiple) enterprises; habitat and breeding sites for pollinators and predatory insects birds and animals; improved salinity management; improved interception of rainfall; and improved aquifer recharge.

H	Status of ground cover	Ground cover in agricultural landscapes provides important ecosystem benefits. The quality of ground cover provides essential protection to keep the soil cool against direct, searing summer heat by reducing evaporation and protecting bare soil against raindrop splash and wind erosion. A dense, matted ground layer of pasture grasses slows overland flows during the intense rainfall events and assists with infiltration of rainfall, thus mitigating soil erosion and replenishing soil moisture. Ground cover also provides essential habitat and breeding sites for pollinators and insects and birds and other biodiversity. Land management regimes that promote higher levels of ground cover and biomass in critical growing seasons generally enhances ecological function.
I	Diversity of tree and shrub species	Intensively managed agricultural landscapes typically adopt management regimes that simplify the diversity and number of species of trees and shrubs for pasture and crop production. Where regenerative land management regimes have been implemented there has been an observed increase in the number of tree and shrub species.
J	The diversity of grass species	In many grazing production systems, the implementation of regenerative land management regimes can improve the variety of pasture plants (annuals and perennials). In turn this can improve pasture production, animal nutrition, protect natural resources (soil and water) and build the capacity of farming systems to adapt to future production and environmental challenges. The intensity of the grazing management system will determine the health and vitality of pastures and their longevity. The management and selection of the perennial pasture species for a grazing production system should be based on considerations of climate, soil conditions and performance of pasture species under different management regimes.

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Appendix C

The ten ecological criteria used in this assessment and the VAST-2 criteria used to populate the criteria for the period 1989-2016 by averaging two or three criteria into one.

SFL Criterion	VAST-2 Criteria26	Comments
A. Resilience of landscape to natural disturbances	-	SFL criteria populated by SFL expert elicitation for 1989-2020.
B. Status of soil nutrients – including soil carbon	• Nutrient stress: rundown (deficiency) relative to reference soil fertility (RC_soil_nutrient_rundown) • Nutrient stress: excess (toxicity) relative to reference soil fertility (RC_soil_nutrient_excess)	
C. Status of soil hydrology	• Rainfall infiltration and soil water holding capacity (RC_soil_hyd_gnd_water) • Surface and subsurface flows (RC_soil_hyd_surf_water)	
D. Biological activity in the soil	• Organisms responsible for maintaining soil porosity and nutrient recycling (RC_soil_biol_invert_recyc) • Surface organic matter, soil crusts (RC_soil_biol_organ_matt)	
E. The physical properties of the soil	• Effective rooting depth of the soil profile (RC_soil_phys_dpth_a) • Bulk density of the soil through changes to soil structure or soil removal (RC_soil_phys_struct)	
F. Changes and trends in the reproductive potential of plants	• Reproductive potential of overstorey structuring species (RC_reprod_potent_OS) • Reproductive potential of understorey structuring species (RC_reprod_potent_US)	
G. The extent of tree cover	• Overstorey top height (mean) of the plant community (VS_OS_height) • Overstorey foliage projective cover (mean) of the plant community (VS_OS_fpc) • Overstorey structural diversity (i.e., a diversity of age classes) of the stand (VS_OS_div_age_class)	Shrubs are included in this criterion in both assessment systems.
H. Status of ground cover	• Understorey top height (mean) of the plant community (VS_US_height) • Understorey ground cover (mean) of the plant community (VS_US_gnd_cov) • Understorey structural diversity (i.e., a diversity of age classes) of the plant (VS_US_div_age_class)	

[26] In the attribute codes, RC = Regenerative Capacity; VS = Vegetation Structure and SC = Species Composition. These were plotted in Figure 4.

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I. The diversity of tree and shrub species	• Densities of overstorey species functional groups (SC_OS_fnl_groups) • Richness: the number of indigenous overstorey species relative to the number of exotic species (SC_OS_richness)	
J. The diversity of grass species	• Densities of understorey species functional groups (SC_US_fnl_groups) • Richness: the number of indigenous understorey species relative to the number of exotic species (SC_US_richness)	
-	• Area/size of disturbance events: foot prints (e.g., major storm cells, floods, wildfire, cyclones, droughts, ice) (RC_fire_burnt_area) • Interval between disturbance events (RC_fire_starts)	These criteria partially relate to SFL Criterion A, but were not used in this project.

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Appendix D

SFL used an online subscription-based service developed Cibolabs Pty (Myfarmkey) to assess the land manager's self-assessment of the response s of the ecological criteria discussed above. This method is presented below.

Myfarmkey is a toolkit for rapidly characterizing and benchmarking the performance of a property or land parcel/s. The Myfarmkey online toolkit integrates several national geospatial datasets including current high resolution visual satellite imagery, national land parcel cadastre, cartographic map, time-series ground cover and woody plant cover, property names, land types, bioregional coverages (sub-IBRA regions).

The Myfarmkey online toolkit utilises ground cover and woody plant cover data and information products derived from time-series Landsat satellite data 1990 to the present time using widely accepted standardized and calibrated land cover metrics. These time-series products are regularly updated for the whole of Australia. These information products include ground cover (e.g. pastures and crops) and woody plant cover (woodlands and forest). The resolution of these information products is 30mx30m. The time-series commences in 1990 and represents the baseline and extends to the current year. The information products use national standardized definitions for ground cover (Stewart et al. 2011; Thackway et al. 2013) and forest (Montreal Process Implementation Group for Australia and National Forest Inventory Steering Committee 2018).

It should be noted that young shrubs and trees cannot be detected using Landsat imagery until these growth forms reach around 10 years old, i.e. when the projective foliage cover is greater than the understorey ground cover.

The geographic footprint of the property was saved within the Myfarmkey online toolkit. The property footprint was then benchmarked against selected land parcels in the neighbourhood and district. In the case of Winona we used a fixed buffer surrounding the property (10 km). Where land parcels did not share the same broad land cover classes i.e. pasture and cropping these land parcels were deleted from this fixed width buffer.

The Winona property footprint and the reference land parcels was saved within the Myfarmkey online toolkit and a report was generated. The report includes GIS coverages of the land parcels within the property footprint and the reference land parcels, ground cover and forest cover response curves for the property, response curves for ground cover showing the property compared to the reference land parcels and the performance of the property compared to the responses of all land parcels within the sub-IBRA region. QGIS is used to import the GIS coverages and prepare figures for use in reports.

Separately, long-term standardised rainfall information for the property were generated from a Bureau of Meteorology (BOM) rainfall database http://www.bom.gov.au/climate/history/ . Information about Winona includes monthly, seasonal and annual rainfall patterns and anomalies. The BOM data are modelled monthly rainfall for each 5kmx5km grid cell across Australia.