TREND: Transects for Environmental Monitoring and Decision Making

Premier's Science and Research Fund Final Report

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1 Summary of Program

1.1 Aims and ambition of the TREND program

The TREND program was instigated in 2010 as a collaboration between the University of Adelaide, South Australian Research and Development Institute (SARDI) and then Department of Environment and Natural Resources to address the four major challenges:

- Improved understanding of the trajectory of climate change
- The establishment of coordinated baseline measurements to track future change
- Execution of experiments along environmental gradients to help predict the impacts of future change
- Engage the public in the project and contribute to policy decision making

To ensure that the TREND program was able to inform upon climate change and its likely impacts on South Australia in a useful way, policy officers from the South Australian government and other research users were involved in the development of questions to guide the research undertaken.

Throughout the program, the Policy Translation theme was involved in distilling the salient points of research products and presenting them to a government and NRM audience. In this, TREND differs from other research initiatives in ensuring its relevance and maximising its potential to influence future climate adaptation and mitigation actions.

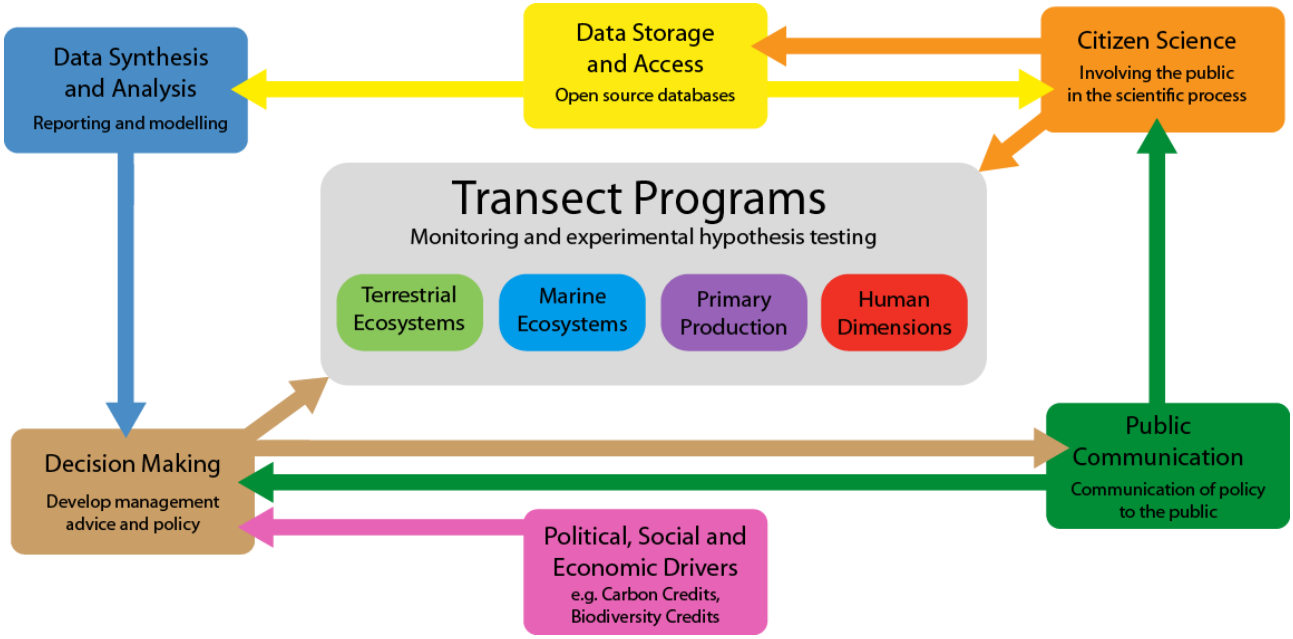

Fig 1: TREND has been designed to ensure that the program supports a feedback loop of science supporting decision making, with feedback loops ensuring that political, social and economic drivers as well as management advice, policy and community interest (through citizen science) help direct the scientific process.

1.2 Overview of impact

The TREND program has been remarkably successful, both as a research program (in terms of traditional metrics such as contribution to primary literature (Figure 2) and number of students supported (Appendix 3), but also as an investment in building South Australia's capacity to understand and adapt to the likely impacts of a changing climate, in the terrestrial, production and marine sectors. TREND has kept strong emphasis on the dissemination of scientific results through workshops and presentations (Figure 3), both as a means of informing government, NRM managers, farmers, and the general community, and as a means through which end-user groups can directly engage with scientists and provide feedback to help shape future research

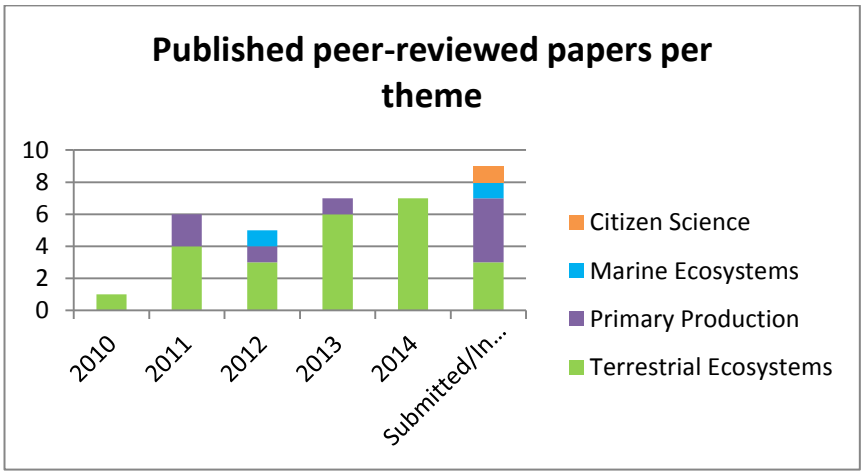

Fig 2: Published papers per theme for to date for the TREND program. Note that 2014 figures are as of 25 April.

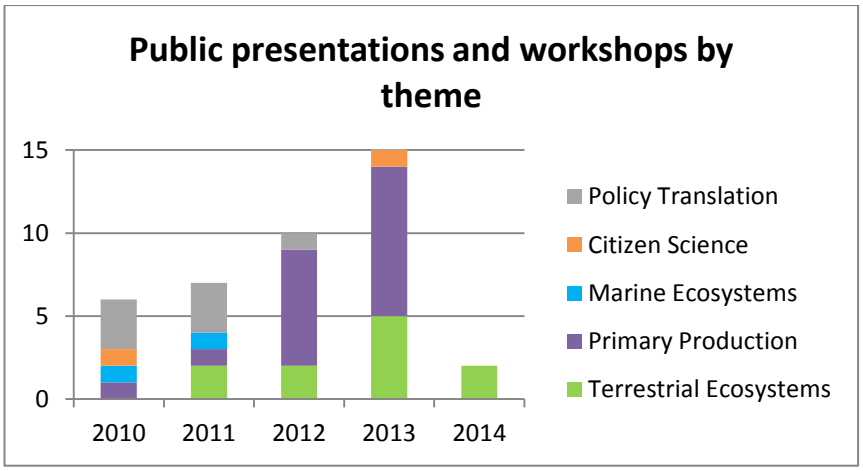

Fig 3: Public presentations and workshops per theme for to date for the TREND program. Note that 2014 figures are as of 25 April.

In addition to the tangible outputs of the TREND program (above), the opportunity to work on this cross-cutting and transdisciplinary project has provided unparalleled development opportunities for scientists, students and end-user groups to engage in the climate change agenda and better understand the motivations, processes and needs of other groups. The **Policy Translation** component of TREND has led to new collaborations and improved understanding which enhance the quality of future ecosystem and agricultural science in South Australia, particularly its utility to policy makers (support for the NatureLinks and Marine Parks programs), NRM managers, farmers and the community sector (ReefWatch). Indeed a new iterative method for working across the science/policy divide to develop and address key questions around

how best to undertake resource management has been developed by the TREND teams.

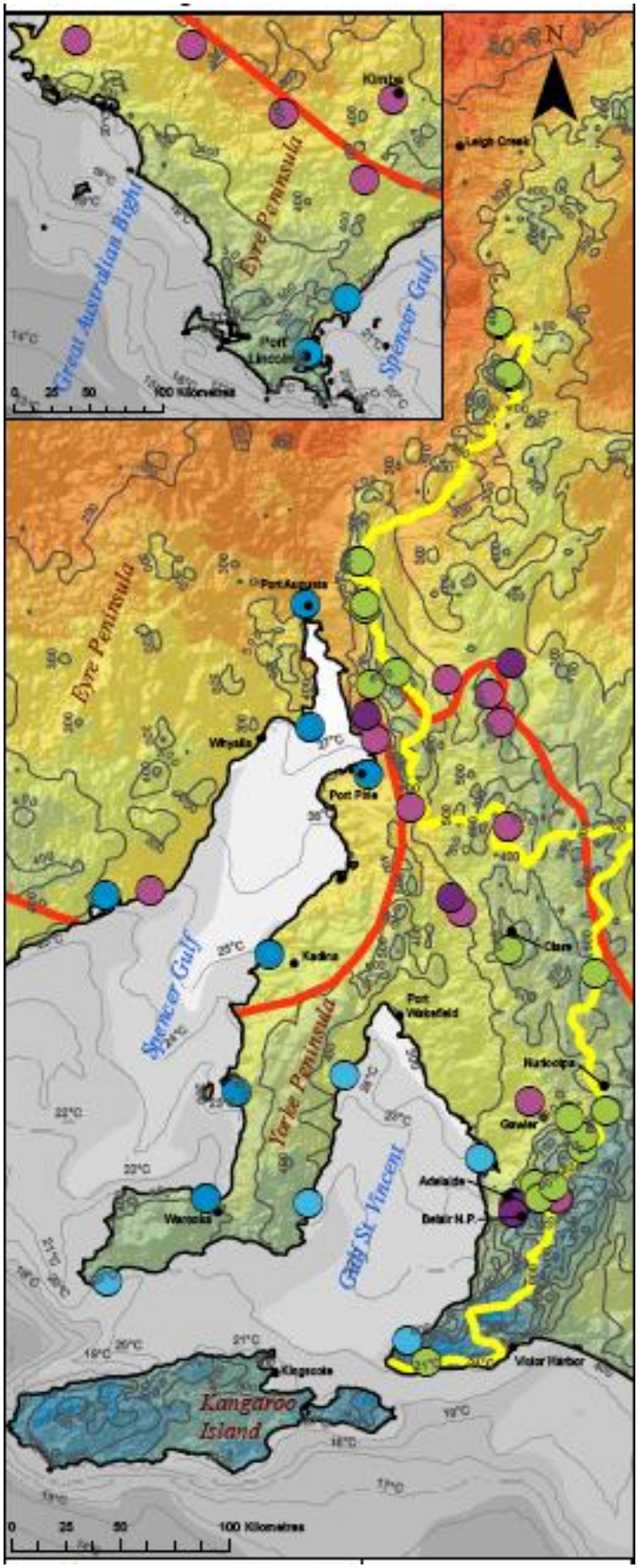

Fig 4: TREND monitoring locations for terrestrial ecosystems (green), primary production (purple) and marine systems (blue) along a temperature and rainfall gradient in South Australia. Heysen's trial (yellow) and Goyder's Line (red) are shown for reference.

A key output from the TREND project has been the establishment of monitoring infrastructure or transects for terrestrial ecosystems, primary production and marine systems. Research from these transects has provided critical information on how systems are changing due to climate change (Figure 4).

For **Terrestrial Ecosystems,** key results have been to identify locations that are likely to be stable during periods of climate change (refugia) and those plant communities that are likely to be more sensitive to the impacts of climate change. Key adaptations (leaf thinning and earlier flowering) have been recorded in plant communities indicating that climate change is already affecting native systems. New genomic methods for rapidly assessing biodiversity and ways to construct climate resilient restoration programs have been developed by the project. These results are being incorporated into NatureLinks and NRM climate adaptation planning. Ongoing support for the terrestrial transects program has been leveraged from TERN (see below)

For **Marine Ecosystems**, new methods for identifying and assessing changing marine invertebrate communities were developed. Across the range of monitoring sites, a significant shift in new marine invertebrate communities was recorded compared to those already present, and is likely influenced by ecological successful and ongoing climate change. Results and ongoing monitoring are being taken up by the Marine Protected Area management group in SA Department for Environment and ReefWatch.

The **Primary Production** component of TREND has worked with the dryland grains

and irrigated wine grape industries. The notion of space as a proxy for time in a changing climate has been a constructive way to discuss the complex issue of climate change. The idea of spatial analogues moves the discussion beyond impacts to the process of adaptation. Specific findings of the field monitoring were temperature-linked phenological changes in grape vines, and changing phenology and disease community composition in wheat crops, Linking the research in the grains industry back to Goyder's Line which drawn in the 1860s has been a fruitful area of research that is ongoing within SARDI (Figure 5).

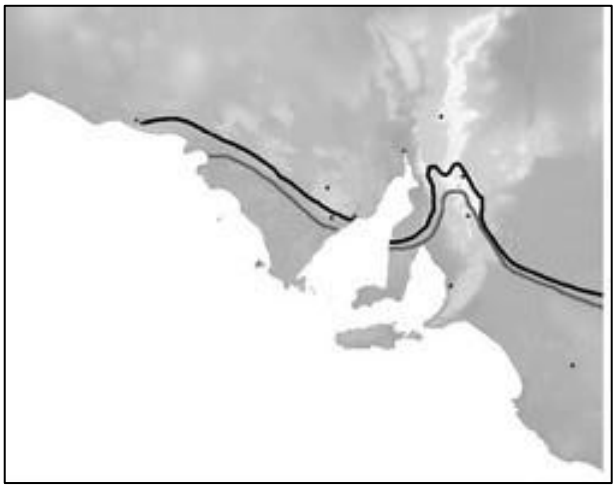

Fig 5: Original delineation of Goyder's line (black) and predicted current extent (grey) based on farmer interviews and climate modelling.

Community engagement has been a strong focus of TREND, and the establishment of a new **Citizen Science** program and development an App (TRENDSA - downloadable free from the Apple App Store or on Android devices Google Marketplace) has seen tremendous interest and uptake from the public both in terms of helping with environmental monitoring and satisfying a thirst for knowledge on the subject of climate change and adaptation. The App gives key information on the findings of the project in terms of how ecosystems are changing and allows the recording of key indicator species which can be viewed on the project website. Monitoring infrastructure has been established at 12 sites located in parks along the Heysen trial which allow photos taken by the App to be used to assist with the long-term assessment of baseline condition and change in plant communities (growth and flowering times). The App has been successfully trialled with Friends of Heysen Trail, Parks Friends groups and local scout groups and schools.

Fig 6: Screenshots of the TRENDSA App that has been one way the project has engaged the public.

The substantial infrastructure (in the form of reference plots and baseline data) developed through the **Terrestrial Ecosystems** theme has formed the basis of a new national facility, the Australian Transect Network (ATN), which is based at the University of Adelaide and has received Commonwealth funding through the Terrestrial Ecosystem Research Network (Table 1 and Figure 7).

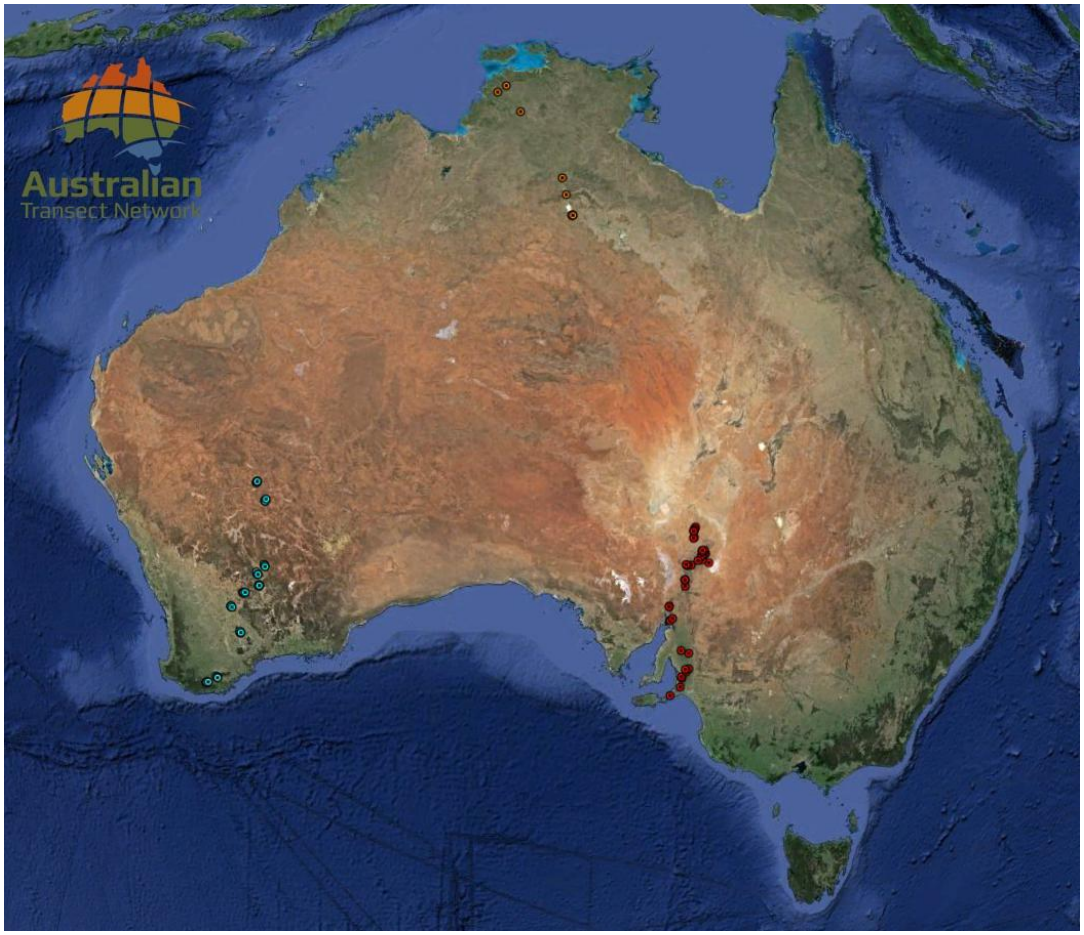

Fig 7: The Australian Transect Network has significantly expanded TREND (red points), with an additional 18 sites being surveyed and data uploaded to AEKOS for public use. The ATN has also funded the creation of analogous transect programs interstate, namely the SWATT (blue points) and NATT (orange points), which are currently being surveyed

The ATN is a facility of the Terrestrial Ecosystem Research Network (TERN), which is charged with developing national environmental infrastructure for researchers around Australia to utilise. The ATN has provided funding to improve the spatial breadth and scientific depth of TREND Terrestrial Ecosystem investigations and has provided an aegis under which this research can continue in to the future. Uptake in to the ATN will ensure that the TREND Terrestrial Ecosystem plots continue to be maintained into the future and their data made publically available. The ATN also involves three other transect programs: the Northern Australian Tropical Transect (NATT) in the Northern Territory, the South West Australian Transitional Transect (SWATT) in Western Australia (Figure 7), and a new transect for which funding was also obtained from the ARC to develop the Biological Adaptation Transect Sydney (BATS) in New South Wales. In addition to TREND, these three new transect programs provide a focus to underpin a new interest in gradient research nationally and internationally. This new capacity and scientific interest has led to a national workshop on

gradient research being scheduled in Adelaide in May 2014. To date, representatives from every state and territory, as well as the Chinese Academy of Sciences, have accepted invitations to attend.

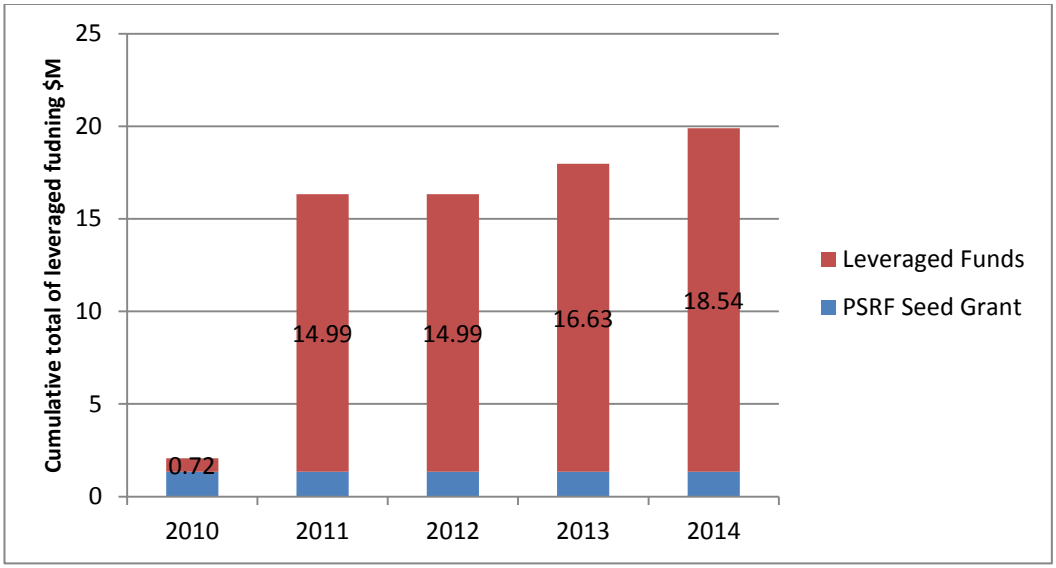

Fig 8: The initial grant provided by the PSRF has been used to leverage a total of $18.535 million in additional funding, primarily from the Commonwealth (ARC, NCRIS, EIF, etc).This represents a return of 13.7x the initial PSRF investment for South Australian science.

Table 1: The initial grant provided by the PSRF has been used to leverage a total of $18.535 million in additional funding (including $720,000 co-contribution by TREND partners to the initial investment), primarily from the Commonwealth (ARC, NCRIS, EIF, etc).This represents a return of 13.7x the initial PSRF investment for South Australian science.

Applicants	**Grant and Funding Source**	**Funding**
Lowe, A. J., Lindenmayer, D., Liddell, M.	Long-term Australian Multi-scale Plot System (LAMPS), incorporating AusPlots, LTERs and Supersites. Terrestrial Ecosystem Research Network (TERN). Environment Investment Fund. Department of Innovation, Industry, Science and Research. 2011	$12M
Lowe, A. J., Rossetto, M., Summerell, B.	Species and gene turnover across environmental gradients – a landscape approach to quantify biodiversity and resilience for climate adaptation. ARC Linkage, LP110100721. 2011	$410k
Lowe, A. J., **Bradshaw, C.**, van den Hengel, A., Brook, B., Cooper, A.	Multi-model predictions of ecosystem flux under climate change based on novel genetic and image analysis methods. ARC Super Science Fellowships, FS1102 00051. 2011	$556k
Breed M., Ottewell K., **Lowe, A. J.**	Developing best practice approaches for restoring River Murray forest ecosystems that are resilient to climate change. Native Vegetation Research Grant. 2013	$45k
Clancy, T., Phinn, S., **Lowe, A. J.**, Saunders, M., **Thurgate, N.**, Walker, C., Sparrow, B., **Caddy-Retalic, S.**	Terrestrial Ecosystem Research Network. National Collaborative Research Infrastructure Strategy. Department of Education. 2013	$1.6M
Clancy, T., Phinn, S., **Lowe, A. J.**, Deed, J.	Terrestrial Ecosystem Research Network. Collaborative Research Infrastructure Scheme. Department of Innovation, Industry, Science, Research and Tertiary Education. 2014	$2.8 M
Lowe, A. J., Brooke, B. W., **Bradshaw, C. J. A.**	Developing best practice approaches for restoring forest ecosystems that are resilient to climate change. ARC Linkage LP110200805. 2014	$404k
Hayman P., et al	Transformative Climate Change Adaptation in Australia's Crop Livestock Farming Systems. Dept Agriculture. 2014	$93k
	Total	**$17.908M**

In addition to the above grants, applications for a further ~$1M of Commonwealth funding are currently being assessed, with several additional grants building upon TREND to be submitted in the coming year.

Flow-on benefits to other South Australian-based projects is also evident as a result of the above investment, with an agreement brokered to see all data collected through the initial TREND program and subsequent

Australian Transect Network investment, deposited in the Australian Ecological Knowledge and Observation System (ÆKOS). ÆKOS (www.aekos.org.au) is an online repository for Australia's rich ecological data based at the University of Adelaide. The facility has partnered with a range of institutional data custodians (including DEWNR) to make ecological data more widely available to researchers. This will enable researchers to work more efficiently with integrated data so that the majority of their time can be devoted to undertaking excellent science and producing novel outcomes that address national environmental challenges. This means that TREND data will be able to be viewed alongside existing South Australian data, such as the Biological Survey of South Australia, and combined to allow researchers to access the full richness of existing data for analyses at a local, state or national scale. To date, data from around half of the ATN-sponsored TREND surveys have been published in ÆKOS and related data visualisation tool, Soils to Satellites (www.soils2satellites.org.au). Due to the time involved in the description and upload of data to the system, the remaining data is expected to be uploaded over the next year.

2 Theme reports

2.1 Terrestrial Ecosystems

2.1.1 Overview

The main hypothesis tested by the Terrestrial Ecosystems theme of TREND was that climate change is driving changes to the species composition of ecosystems, and that space can be used as a proxy for time. To this end, studies in this theme have used a combination of new field plots, new species-specific sampling and collation of existing data to analyse patterns of spatial and temporal changes in plant communities in relation to climate. The aim was to identify climate sensitivities in native ecosystems that could be interpreted to inform the Policy Translation theme.

A core activity of this theme of TREND was to establish an environmental transect from the Fleurieu Peninsula in the south to the Flinders Ranges in the north, covering major ecosystems in the study region (Fig. 1). This broad scale transect has become the context for the establishment of over 100 field plots that sample vegetation and soils, as well as the compilation and analysis of a range of existing and new data. The wider range of data used for TREND include those from several thousand historical vegetation inventory plots established under the Biological Survey of South Australia, as well as measurements taken from historical herbarium specimens. These specific data points have been combined within analyses with map-based data such as interpolated climate layers. In addition to empirical analyses of new and existing data, TREND has contributed to the conceptual understanding of climate change ecology, especially for Mediterranean-climate regions. We begin with an overview of the main findings of the research. Details of some of the main case studies conducted as part of TREND are reported in the section that follows.

In addition to a series of individual research projects forming peer-reviewed journal articles, TREND has established long-term infrastructure for research and ecological monitoring, including datasets, plant and soil samples and field plots. To ensure the standardisation and longevity of core elements of this infrastructure, the TREND transect has become part of the Australian Transect Network within the national program TERN (Terrestrial Ecosystems Research Network).

The studies completed to date have provided corroborative data on the influence of climate on terrestrial ecosystems in the region. We have provided empirical evidence for significant shifts in ecosystem characteristics through space and time correlating with climate. Along the TREND transect, there is a major landscape-scale shift from wet, heathy forest communities in the southern Mount Lofty Ranges to dry shrubland and woodland communities of the northern plains. Our analyses have shown that climate is a key factor driver of dramatic changes in the character of vegetation across the region, and quantified its

influence. Small changes in climate (e.g. 1^{o}C warming) can produce sharp changes in ecosystems and some climate change scenarios forecast for the coming century would be expected to result in complete changes in the species make-up of some ecosystems. We have also been able to quantify the influence of other important contributors to observed vegetation diversity, such as landscape factors and the influence of geographic isolation between habitats.

The rate at which species and communities are affected by change in climate varies between geographical locations and plant species/groups. Elevated regions of the southern Mount Lofty Ranges are less sensitive to moderate shifts in climate relative to the northern Flinders Ranges, but less resilient due to habitat modification. Some species are adaptable and occur across areas with large differences in climate, whereas others have limited capacity to respond to climate change. These results are directly relevant to conservation planning in the region in terms of which areas should be managed for climate change, where changes are expected, and strategies for restoration.

On-going monitoring using the established infrastructure is critical to adaptive management and this function is expected to occur through the activities of TERN.

2.1.2 Theme performance against milestones, deliverables and KPIs

Table 2: Performance of the Terrestrial Ecosystems against project milestones and KPIs

Milestone	KPI	Response
1.1 Collate existing terrestrial biodiversity data to analyse climate variability	Develop a data repository and exchange framework Where possible, the submission of synthesised data to peer reviewed periodicals Findings collated in the first annual report	Existing data in the form of spatial layers and SA Biological Survey data has been compiled through partnership with SA DEWNR. Several syntheses have been produced and published (see Section 3). Findings presented in first and subsequent annual reports.
1.2 Combine the analysis of new and existing production system data	Data entered into database Publication of synthesised data in peer reviewed periodicals Findings collated in the final report	Data has been collected from 120 newly established sites in collaboration with the Australian Transect Network. This has led to the generation of floral, soil, genetic and metagenomic data which has been published in publically available repositories and papers.
2.1 Identify a range of monitoring sites along environmental gradients (transects) in terrestrial biodiversity systems	Transect locations and sites identified and detailed in the first annual report	120 sites established in public and private conservation reserves and listed in first annual report.
2.2 Continue monitoring a range of sites along environmental gradients	Data entered into data base Findings outlined in final report	Ongoing surveys have occurred over the last three years, with additional surveys planned through the Australian Transect Network. Findings detailed below.
3.2 Experimental manipulation of species or strains along	Data entered into data base Findings outlined in final	Experimental provenancing trial conducted and results detailed below and in attached papers.

environmental gradients (transects) in terrestrial systems	report	
4.1 Develop policy questions, issues and first order recommendations from data 4.2 Community consultation and engagement 4.3 Community monitoring developed 4.4 Incorporate feedback from policy makers, the community and industry into the monitoring sites along the gradient	Policy briefs produced from the analysed data Public outreach tools allow for perpetual data collection Data sources from the community and industry included in the final annual report Mechanism established to ensure ongoing monitoring and reporting of data	Terrestrial ecosystems theme contributed to policy meetings and briefs. TREND investigators have had ongoing interaction with DEWNR and NRM boards to ensure they are aware of our results and the impact it can have on their regions and processes. In addition to engagement with DEWNR and NRM groups, ongoing work through the Terrestrial Ecosystem Research Network will ensure that science continues to be communicated in to the future.
Completed/On track	Delayed	Severe impediment to progress

More detail on the following milestones is provided below on the milestone activities that highlights the overall work of the project.

Milestone Activity	**KPI**
1.2 Combine analysis of new and existing terrestrial biodiversity data	Data entered into the database Publication of synthesised data in peer reviewed periodicals Findings collated in this report and its attachments

A number of studies and activities contributed towards this milestone, and the detailed results and outputs of these individual studies are outlined in this report. The analysis of data to test space as a proxy for time has taken advantage of the following new and existing sources of data:

- New data on species occurrences and environmental features within 120 newly established field plots – includes several thousand individual species records as well as temperature, soils and other environmental data.
- New data from hundreds of targeted population collections (individual species) to examine genetics and functional aspects as part of on-going TREND projects.
- New data gathered from historical herbarium specimens to examine spatial and temporal variation in flowering time and leaf shape, as well as population genetic structure – data from hundreds of specimens were used in these analyses (through tissue samples or images taken of herbarium sheets)
- A large set of data on species occurrences within previously established vegetation inventory plots from the Biological Survey of South Australia – over 3,500 plots.
- A range of spatial (mapping) data, such as interpolated climate layers.

All new data have been either published as online datasets with journal articles, or been described and

published in TERN's AEKOS database (for sharing ecological plot data). These analyses have resulted in a number of publications in peer-reviewed journals, and these are listed as outputs in this report.

Milestone Activity	KPI
2.2 Continue monitoring a range of sites along environmental gradients (transects) in terrestrial biodiversity systems	Transect locations continued to be monitored and collected data detailed in this report and its attachments

An ecological monitoring transect was established with 120 plots established over a distance of ~750 km (Figure 7). The transect allowed for spatial analysis of abiotic drivers of community composition, while establishing a monitoring baseline. Most of these sites have been sampled at least twice, as more detailed measurements were made in association with TERN's Australian Transect Network.

The transect samples strong temperature gradients (~5°C in mean, 10°C in mean summer maxima) and rainfall gradients (~700 mm in mean annual rainfall). The region has a Mediterranean climate with a small pocket of relatively high rainfall in the Mount Lofty Ranges, which grades into desert-like conditions. Consequently, the main vegetation over the transect changes from heathy dry sclerophyll eucalypt forest through to Mallee and woodland with an open shrub understorey. The region is rich in biodiversity and has been recognised as a centre of species richness and endemism and is one of Australia's 15 national biodiversity hotspots.

Sampling in the transect was stratified to: (1) compare geographic and climate influences on ecosystem composition by using topographic variation to emulate differences in climate between sites over relatively small distances and, conversely, (2) compare distant sites with similar climate for several climate types across the landscape. At each site, five spatially clustered replicate plots were established and located within similar habitat. This design reduces confounding factors associated with individual sites.

An initial spatial analysis of the plot data in terms of climatic variables and species composition of vegetation has been published (Guerin *et al.* 2014a) and the specific results are reported in more detail above in this report. Details of the new field plots that have been analysed for TREND are shown in Appendix S1 of this paper, which is an attachment to this report.

Milestone Activity	KPI
3.2 Experimental manipulation of species or strains along environmental gradients (transects) natural terrestrial systems	Data entered into the database Findings outlined in this report and its attachments

For this milestone, a 'common garden' experiment was implemented in the field during winter 2012, to test seed provenancing strategies, in partnership with SA Water. Results are presented in Section 3 below.

2.1.3 Project impact and key findings

Knowledge development and capacity building in South Australia and nationally

The TREND Terrestrial Ecosystems theme has had a major impact on our understanding of the impacts climate shifts are likely to have on South Australian vegetation. The work funded by the PSRF has directly supported the work of three Postdoctoral fellows (Dr Greg Guerin, Dr Hugh Cross, Dr Ed Biffin), four PhD candidates (Matthew Christmas, Nicholas Gellie, Martin Breed and Phyllis MacGillivray, the latter two having now graduated), two completed Honours projects (Kimberly McCallum and Taj Arndell) and two international vising students (Haixia Wen, China and Irene Martin Fores, Spain).

The successes of the TREND Terrestrial Ecosystem theme allowed funding to be leveraged from the Commonwealth Government for the creation of the Australian Transect Network (ATN), based at the University of Adelaide. The ATN is one of ten facilities within the Terrestrial Ecosystem Network (TERN), a national program developed under the National Collaborative Research Infrastructure Strategy (NCRIS) and Education Investment Fund (EIF). The establishment of the ATN has led to the establishment of three similar transect programs interstate: the Northern Australian Tropical Transect (NATT) in the Northern Territory; the South West Australian Transitional Transect (SWATT) in Western Australia; and the Biological Adaptation Transect Sydney (BATS), based out of the Royal Botanic Gardens in Sydney.

Key findings:

- The TREND Terrestrial Ecosystems theme has supported three postdoctoral fellows, four PhD students and two Honours projects.
- The success of the TREND program has facilitated the development of analogous programs in New South Wales, the Northern Territory and Western Australia, and directly led to the inception of a new national facility, the Australian Transect Network, funded by the Commonwealth.

Survey of the Terrestrial Ecosystems TREND transect

An ecological monitoring transect was established with 120 plots established over a distance of ~750 km (Keith *et al.* 2014; Guerin *et al*. 2014a). The transect allowed for spatial analysis of abiotic drivers of community composition, while establishing a monitoring baseline (Figures 9 & 10).

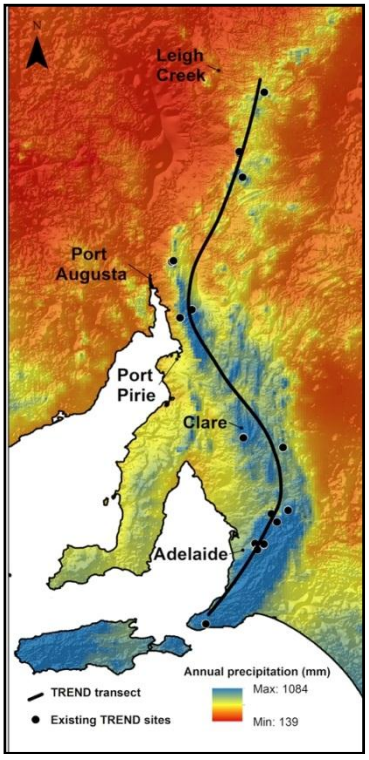

Fig. 9: Location of the TREND terrestrial ecosystems transect and some of the existing TREND

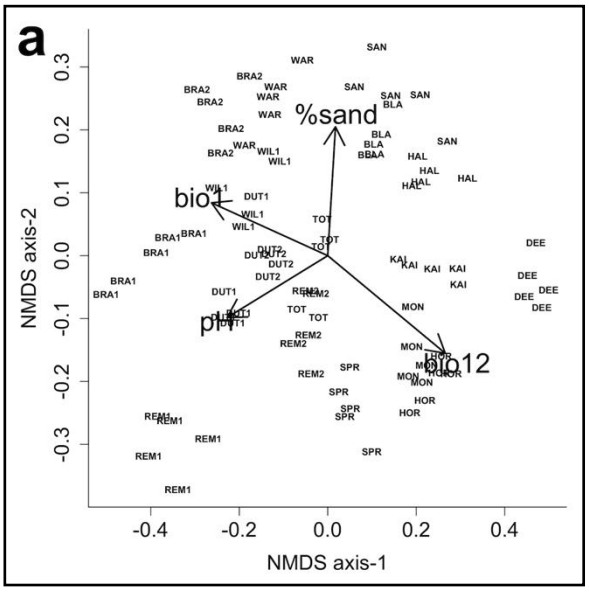

Fig. 10: Analysis of TREND field plots shows how they are separated according to species composition. Arrows indicate climate and landscape factors associated with these changes in ecosystems. The trajectory of ecosystems in this context can be predicted for future climate change and mapped when TREND plots are able to be resampled. Reproduced from Guerin *et al.* (2014a)

The transect targeted vegetation less impacted by other stressors, such as habitat fragmentation and weed invasion. With data from the transect, Guerin *et al*. (2014a) concluded that climate was the most important abiotic driver of species composition that generated large changes in composition. In a trial resampling of historical plots, Guerin and Lowe (2013c) found a shift in species composition between 1986 and 2010 at two sites which is likely due to temporal replication of sampling, fire dynamics, ecological drift and climate change.

Key findings:

- 120 plots were surveyed across a transect extending from the Gammon Ranges to the southern Fleurieu peninsula (~750km).
- Intact vegetation communities were targeted and data analysed to determine that climate was the most important factor in determining the rate of species turnover along the transect.

Conceptual framework

Identification of the influence of climate change on ecosystem composition requires a broader context of factors that lead to species composition. TREND developed a conceptual model of species assembly processes, visualised as a pipeline from processes that operate at coarser (e.g. historical biogeography) to finer (e.g. population demography) spatial and temporal scales (Figure 11; Guerin *et al.* 2014b).

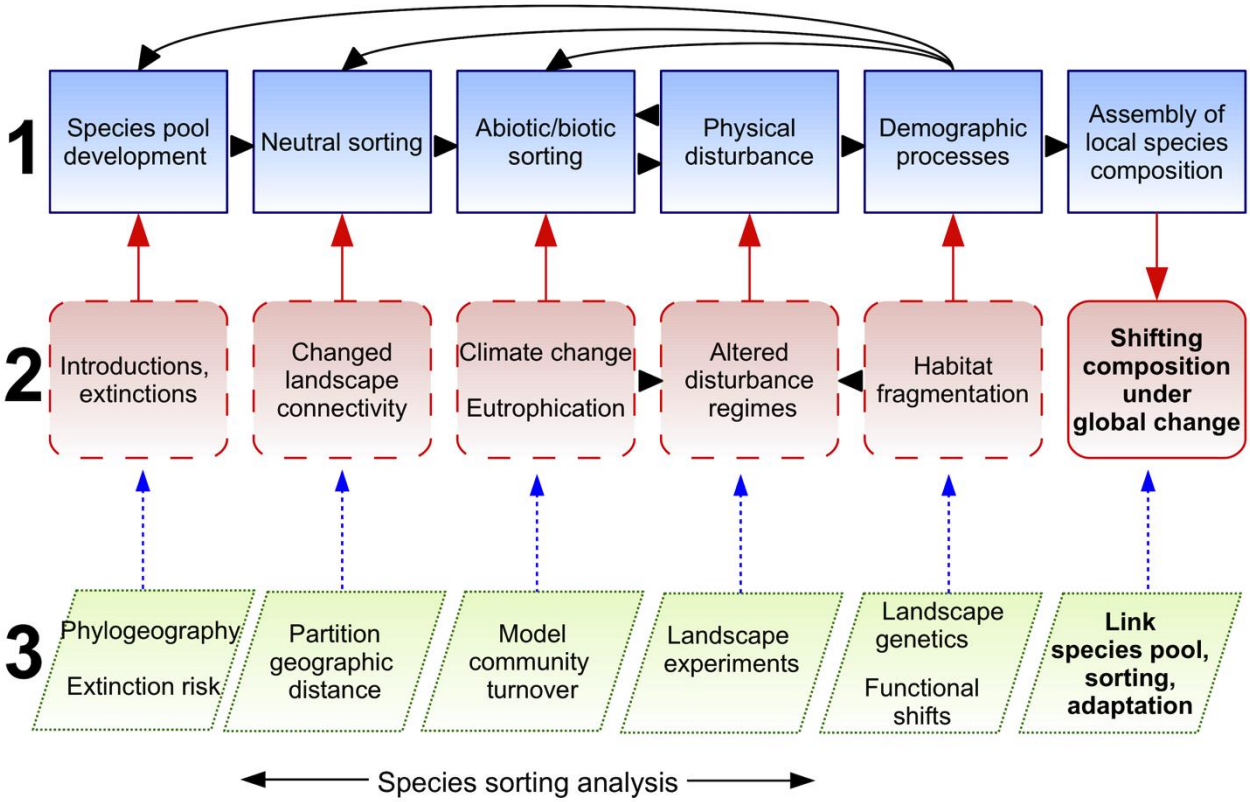

Fig. 11: Community composition under global change: (1) simplified conceptual model of community-assembly. Community composition (patch level) is a complex function of historical and neutral factors, present-day environmental filters, ecological interactions and demographic processes, resulting in communities that bear the signatures of these processes. (2) Examples of how global change is influencing community-assembly processes to divert future composition. (3) Examples of diverse approaches at different spatial and temporal scales that are used by ecologists to analyse the past, present and future impacts of global change on ecosystem composition. Reproduced from Guerin *et al.* (2014b).

Predicting the species composition of plant communities under climate change, based on the responses of individual species, is fraught with complexity. One way to reduce this complexity is to initially consider the higher level community constraints determined by the environmental setting. From this, the likely expression of community level changes at species level under climate change can be determined (Guerin *et al*. 2014b).

Plant communities are characterised by their species composition, but also by functional aspects, such as vegetation structure, biomass or the distribution of 'functional traits', such as leaf attributes that relate to growth and resource investment. Plant communities are constrained by the amount of biomass and the functional traits that particular environments can support. Shifts in these functional constraints on plant communities due to climate change may be expressed by two community responses: 1) changes in the relative abundance, or functional characteristics, of individual species or; 2) species replacement. The relative contribution of these intrinsic (1) versus extrinsic (2) responses determines the resilience of the community, and expected species turnover (replacement of current species with different species).

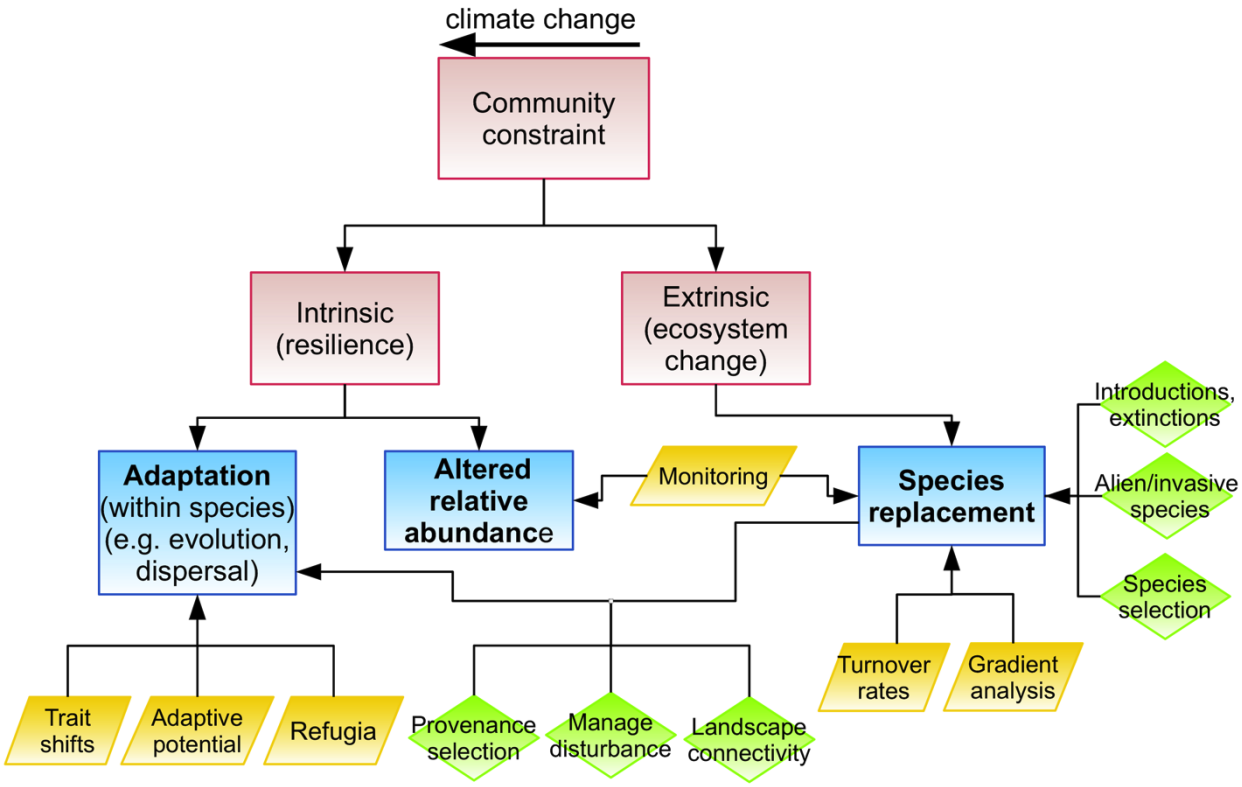

Fig. 12: Conceptual framework for ecosystem adaptation to climate change, informed by research (yellow boxes) and influenced by management actions (greens boxes). A community level functional constraint shifts with climate change (top red box). The community level response can be intrinsic or extrinsic (blue boxes). Intrinsic resilience includes species adaptation (e.g. evolution, plasticity) and changes in relative abundance, to match the new constraint. Resilience levels can be informed by studies identifying refugia and species adaptive potential (e.g. landscape genetics). Resilience can be manipulated in restoration via provenance selection and management of landscapes. Extrinsic responses involve changes in species composition. Gradient analysis can inform rates of species replacement across heterogeneous landscapes. Restoration can pre-empt species replacement via species selection and management of alien species. Managing at community level avoids the complexity of predicting responses among diverse species. However, information on species sensitivity and adaptive capacity is useful for understanding vulnerability. Reproduced from Guerin *et al*. (submitted).

Data on the potential for intrinsic versus extrinsic responses (Figure 12) informs decision making to enhance resilience. For example, intrinsic resilience is dependent upon maintenance of genetic variation within populations – a function of population size, historical factors (e.g. refugia during glacial maxima) and the potential for gene flow between populations. Adaptive potential can be enhanced via landscape planning and appropriate seed selection for restoration (Breed *et al.* 2013).

Multi-species distributions models under climate change

Correlative species distribution models (SDMs) are useful for determining species sensitivity to climate. Guerin and Lowe (2013a) compared SDMs under current and future climate scenarios for 20 contrasting species along the Adelaide Geosyncline. Climatically suitable habitat declined substantially for many species under a scenario of 1.5ºC warming and 8% drying. Suitable habitat was predicted to persist in the Mount Lofty Ranges for most species. Predicted south and upwards shifts of habitat generated species turnover in the Flinders Ranges (Figure 13).

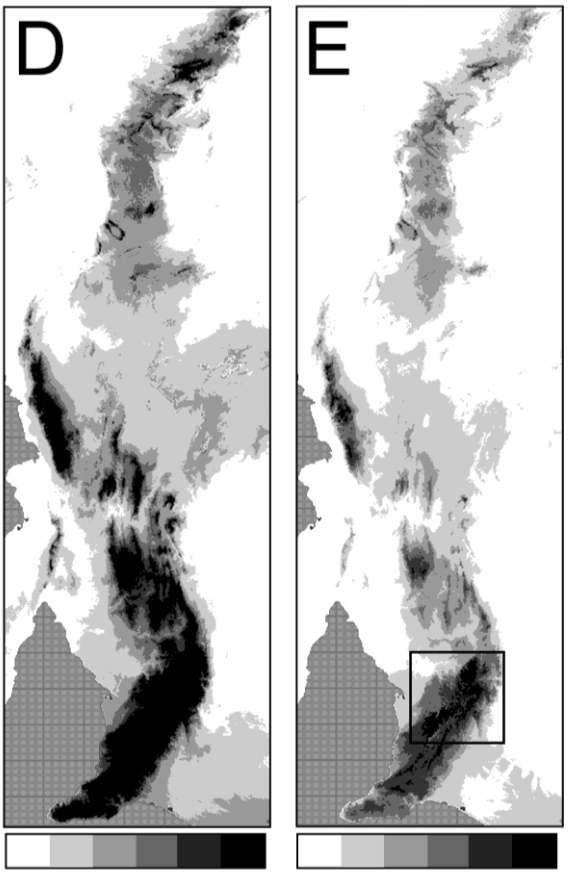

Fig. 13: Climate distribution models for 20 species for current (left) and future 2050 (right) climates suggest loss of suitability but retention of habitat in the Mount Lofty Ranges. This analysis revealed climate sensitivity but also highlights potential refugia and areas for priority habitat restoration. Reproduced from Guerin & Lowe (2013a).

Future species turnover from historical surveys

Guerin *et al.* (2013) predicted plant species turnover under four climate change scenarios, using data from 3,600 historical field plots (Biological Survey of South Australia) and space-for-time substitution. They detected significant but non-uniform sensitivity of plant community composition to changes in climate (Figure 14). Discrete transitional zones were identified that had more rapid species turnover, which were interpreted as a mesic–arid ecotone (ecosystem boundary). More mesic habitats had lower rates of turnover with changing climate, and were interpreted as potential refugia for temperature increases up to two degrees. Species turnover was expressed at family level, so that, with increasing aridity, there was turnover from families characteristic of more mesic, mediterranean ecosystems (e.g. Ericaceae, Myrtaceae, Haloragaceae, Cyperaceae, and Xanthorrhoeaceae) to families characteristic of the arid zone (e.g. Amaranthaceae, Malvaceae, Scrophulariaceae, Sapindaceae, and Solanaceae).

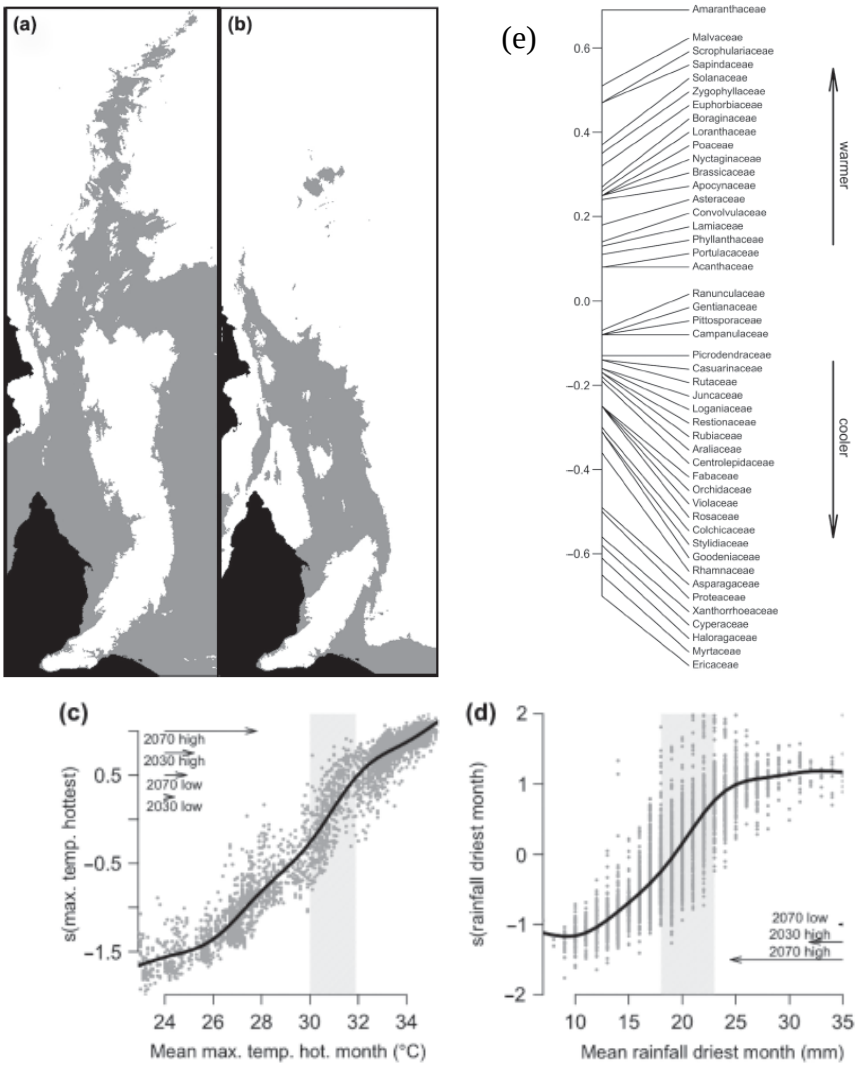

Fig. 14: (Reproduced from Guerin *et al.* (2013) Maps showing spatial areas corresponding to climate gradient ranges with higher species turnover.

(a) Mean temperature;
(b) mean annual rainfall. Grey areas: gradients ranges with higher turnover relative to white areas; black: ocean.
Models of relative species composition as a function of climate gradients:
(c) mean maximum temperature of hottest month;
(d) mean rainfall of driest month. Points: partial residuals; solid lines: model predictions; shaded areas: discrete gradient ranges with higher slope; arrows: magnitude of change predicted under climate change scenarios.
(e) Family-level expression of species compositional turnover with mean temperature. Ranunculaceae: $p<0.05$; Acanthaceae, Pittosporaceae, Campanulaceae: $p<0.01$; Portulacaceae, Gentianaceae: $p<0.001$; all other families shown $p<0.0001$. Arrows indicate orientation of mean temperature gradient to observed turnover.

Key findings

- The distinctive Mediterranean flora of South Australia is sensitive to climatic changes
- Modelling of four future possible climates suggest that South Australian ecosystems will become more like those characteristic of arid Australia
- The degree to which this occurs will depend upon the degree of climate shift.

Functional responses to climate within species

Guerin *et al*. (2012) analysed the leaf morphology of a widespread shrub, Dod*onaea viscosa* subsp*. angustissima*, in the Flinders Ranges in relation to climate. Some aspects of leaf morphology have ecophysiological significance. For example, narrower leaves better tolerate heat in arid climates (Yates *et al.* 2010). Leaves were narrower in populations of *D. viscosa* at northern (warmer/drier) latitudes. Leaves had also become narrower over time across the latitudinal cline, based on herbarium samples spanning a century. The narrowing of leaves is consistent with a physiologically relevant response to climate change (Guerin and Lowe 2013b; Figure 15).

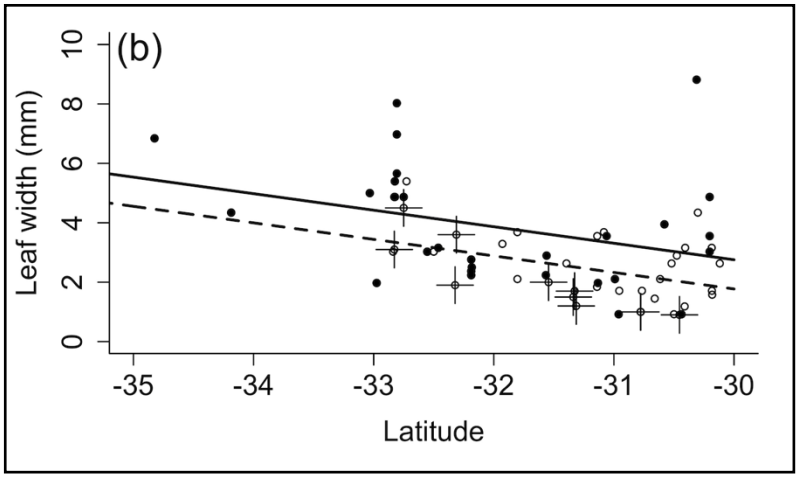

Fig. 15: Leaf width in the study species *Dodonaea viscosa ssp. angustissima* decreases with more northern (hotter, drier) latitudes and shifted significantly between pre-1950 (solid line) and post 1990 (dashed line), matching predictions for response to increasing temperatures over that time. Reproduced from Guerin & Lowe (2013b).

The ability of species to apparently track a rapidly shifting optimum phenotype suggests that species have some intrinsic resilience to climate change that may slow species replacement.

Flowering phenology was studied in detail for orchids of the genus Diuris in the TREND region, based on herbarium records (MacGillivray et al. 2010). Plants of D. orientis have flowered significantly earlier in spring since around 1972, in association with El Niño events and a strong warming trend. While the conservation significance of this phenological change is not yet known, it may impact plant-pollinator interactions and the potential for interspecific hybridisation.

Key findings

- Some native species, such as the shrub *Dodonaea viscosa*, are showing the capacity to adapt their morphology to better cope with a changing climate.
- A trend towards earlier flowering has been detected in the orchid *Diruris orientis.* This may also be a signal of the impact of climatic shifts on plants but its conservation significance is not yet established.

Species-specific climate change vulnerability analysis

Species with restricted ranges may be vulnerable to climate change. The myrtaceous shrub *Callistemon teretifolius* is endemic to the Mount Lofty–Flinders Ranges region, and mostly restricted to ridge tops (McCallum *et al.* 2014). A population genetic assay based on microsatellites and Amplified Fragment Length Polymorphisms (AFLPs), combined with species distribution models, established the species vulnerability to climate change (McCallum *et al.* 2013). Populations of this species are geographically isolated and have low genetic diversity. The southern Flinders Ranges was identified as a key area for conserving the species, due to larger population sizes, greater genetic diversity and predicted persisting suitable habitat (Figure 16).

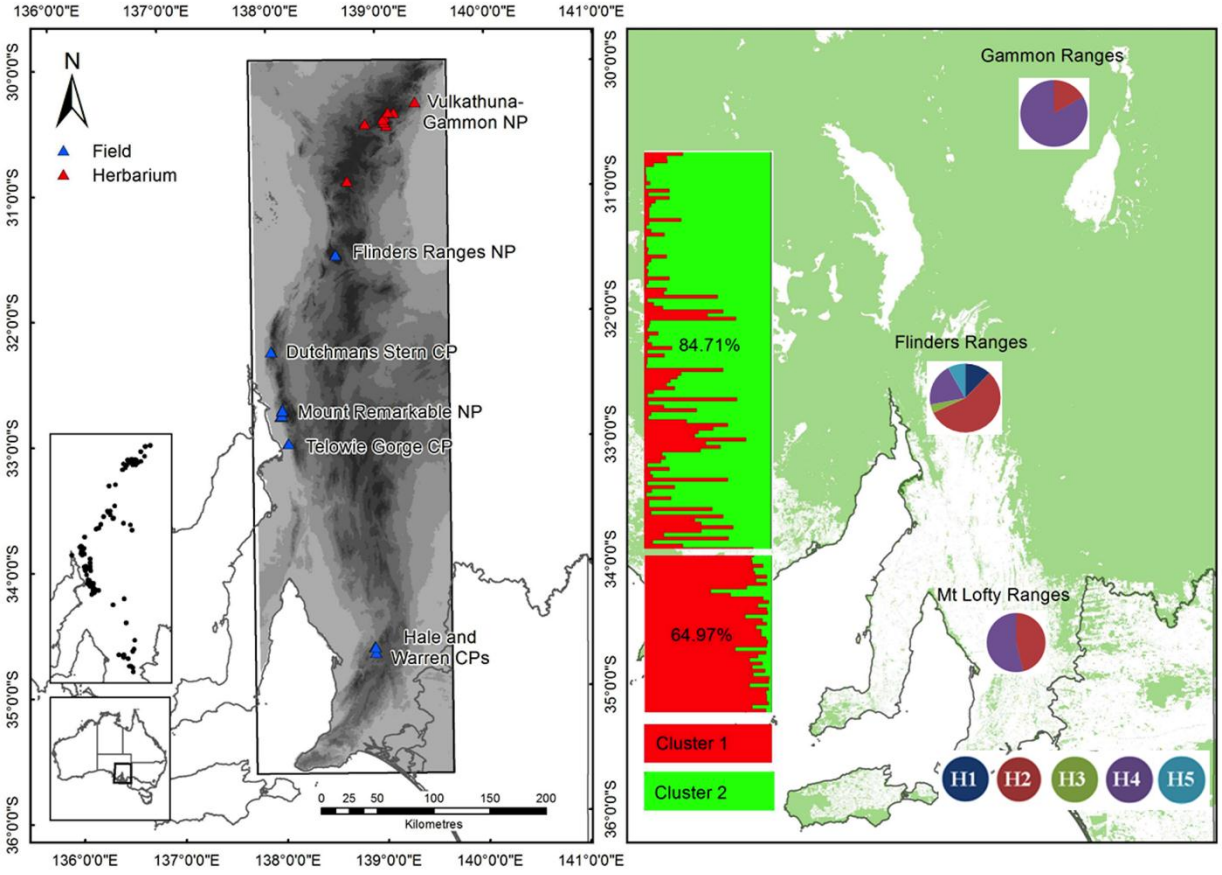

Fig. 16: Sampling locations and genetic diversity of *Callistemon teretifolius* along the Adelaide Geosyncline, Australia. Locations of field (blue triangles) and herbarium (red triangles) collected material is shown on left, inset map shows locality records from the Biological DataBase of South Australia (BDBSA).The modelling extent is shown by the altitude grid, where darker colours represent areas of higher elevation. Distribution of the five chloroplast haplotypes and population composition for the Mount Lofty, Flinders and Gammon Ranges is shown on the right. Each section of the pie chart represents the portion of each genetic cluster made up of each haplotype. Reproduced from McCallum *et al.* (2014).

Key findings

- Species with isolated, fragmented distributions are vulnerable to selection pressures, including climate change. Areas of high genetic diversity and persisting suitable habitat should be prioritised for conservation.

DNA Barcoding and High Throughput Sequencing

DNA barcoding allows species identification of any organism based on sequencing a short reference gene (or barcode region). This technology has developed as an important tool in biodiversity assessment and evolutionary ecology. While standardised approaches exist, TREND researchers have applied new advances in high throughput sequencing to barcoding. This has the potential to enable vastly higher outputs at much lower cost. As part of our research, we have been developing high throughput sequencing approaches for DNA barcoding using the TREND plot terrestrial plant samples. To date, we have developed c. 20 different markers that have been successfully sequenced across the taxonomic range encompassed by the TREND plot plant samples, including successful runs using high throughput sequencing. This suite of markers should provide more confident identification of species. Relative to established methods, we have developed several markers from the nuclear genome that will provide novel insights into hybridisation events and polyploidy evolution. Ongoing development will be focussed on increasing the efficiency of marker recovery from plot samples. In particular, we are developing highly multiplexed assays (i.e. combining markers and samples into a single pool prior to high throughput sequencing) that will enable the very efficient recovery of DNA barcodes. All gene sequences, including DNA barcodes are submitted to online databases to improve reference libraries and allow other researchers to build upon our research.

Using high throughput sequencing, we have developed novel methods for obtaining a broad representation of the genome of non-model plants species, providing large scale data sets suitable for ecological and evolutionary exploration. We have applied this approach to several widely distributed and ecologically important plant species within the TREND region. Initial analyses of *Eucalyptus* species suggests long term persistence in the region and identifies a deep divergence in these species consistent with historical isolation in northern (Flinders Ranges) and southern (Mount Lofty Ranges) refugia. Using these same data, ongoing investigations will seek to identify DNA markers that show signatures of natural selection, which will provide insights into the strength, direction and drivers of local adaptation.

Key findings:

- High Throughput Sequencing has the capacity to vastly improve the efficiency and lower the cost of DNA barcoding. Several species from the TREND transect have been barcoded in this way, demonstrating the efficacy of this technique.
- The generation of large quantities of data through high throughput sequencing techniques has provided a platform on which to base ongoing research on the genetic history of native species, as well as the key factors affecting (and likely trajectory of) these species.

Experimental manipulation across space

A 'common garden' experiment was implemented in the field during winter 2012, to test seed provenancing strategies, in partnership with SA Water. Three ecological keystone and established restoration tree species were selection for this trial: *Eucalyptus leucoxylon*, *E. camaldulensis* and *E. fasciculosa*. Composite provenancing (sourcing seeds for revegetation from a mix of local and more distant locations) has been proposed, to take into account climate change effects on local environmental conditions, thereby accounting

for unsuitability of local seed for local ecological restoration plantings. Indeed, this strategy prescribes the collection of seed from provenances spanning from local to locations with environments that are non-local but are predicted to be local in the near future. The geographic span of provenance collections using this strategy mimics natural gene flow dynamics, but can be weighted towards seed sources that may suit climate change predictions. Seed is then mixed and planted together at one site.

Pilot data after 15 months of growth for *E. leucoxylon* shows a significant effect of provenance on growth, where local provenances performed the worst and distant provenances performed the best (Figure 17). This supports the use of composite provenancing, as these data suggest non-local provenances (collected from environments predicted under climate change) outperform local provenances, potentially indicating maladaptation to local conditions has already taken place. More detailed studies are ongoing to disentangle climate change from other confounding effects, e.g. pollination ecology, pathogen resistance and maternal effects.

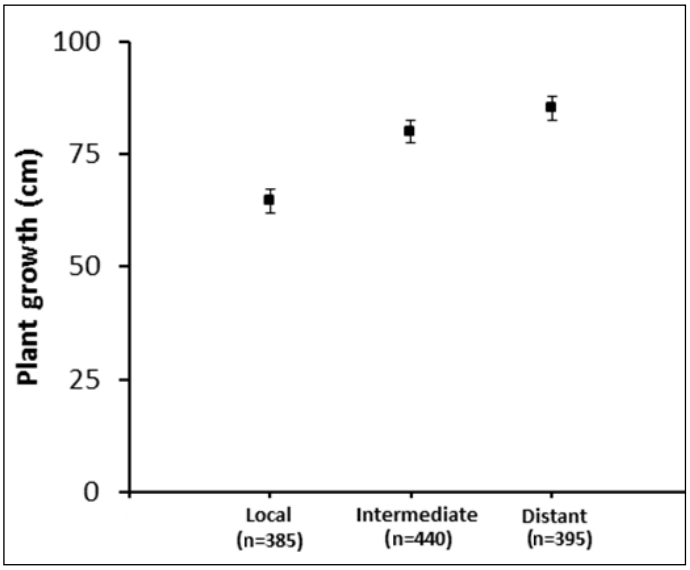

Fig 17: Growth of *E. leucoxylon ssp. leucoxylon* provenances after 15 months at the Clarendon SA Water bio-sequestration and restoration site, SA ($F_{2,1219}$ = 62.680; P< 0.0001), 95% CI. Provenances were collected from remnant stands (local <100, intermediate <100, and distant >100 individuals) and delineated along a north-easterly climatic gradient. (Local; within 10km of the Clarendon site, Intermediate; collected near Macclesfield approximately 20 km from the site, and Distant; collected at Monarto approximately 50 km from the Clarendon site.)

A second common garden experiment has also been established, where seeds of *Dodonaea viscosa ssp. angustissima* from two of the TREND sites (Mount Remarkable and Brachina Gorge) as well as a third population from Brookfield Conservation Park are being grown under glasshouse conditions. The aim of this study is to assess to what extent adaptation to local conditions is a result of genetic differentiation versus phenotypic plasticity. If these populations show high levels of phenotypic differentiation resulting from genetic variation then this has implications for how the species will cope under a changing climate and highlight the importance of connectivity and gene flow between the populations in order to assist the flow of adaptive alleles.

Key findings:

- Experimental manipulation of three *Eucalyptus* species has demonstrated that for at least some plants, current levels of gene flow are not providing optimal adaption to local climate. This may suggest that climate is changing faster than some species are able to adapt.
- The use of composite provenancing (using seed from a variety of sources) rather than only local stock may be beneficial when revegetating areas or planting for long-term carbon storage.

- In combination with genetic screening, ongoing work is attempting to determine the degree to which an example species, *D. visosa*, is able to adapt to changing conditions to understand the degree to which genetic connectivity of populations is important for adaptation. This work is ongoing.

Genetics and transcriptomics

The sticky or narrow-leaved hopbush, *Dodonaea viscosa*, is ubiquitous along the length of the TREND transect and, as such, has been selected as a focal species for phenotypic and genomic studies. In terms of the genomic studies, the overall plan is to gain measures of gene flow, population genetics and signals of selection from populations of *D. viscosa* distributed along the entire length of the TREND transect. To this end, a transcriptome has been assembled for this species following the sequencing of RNA samples collected from seven populations (Figure 18) (Christmas *et al*. *in prep.* "Transcriptome sequencing, annotation and polymorphism detection in the hop bush, *Dodonaea viscosa*"). Through comparing the sequences from each population, a large set of SNP markers has been identified and a multi-population (~20) large-scale screening project is now underway. This will allow for the screening of neutral and putatively adaptive loci in populations traversing the length of the transect, thus enabling us to identify signals of selection along an environmental gradient as well as gain measures of population demography and connectivity along a highly fragmented landscape.

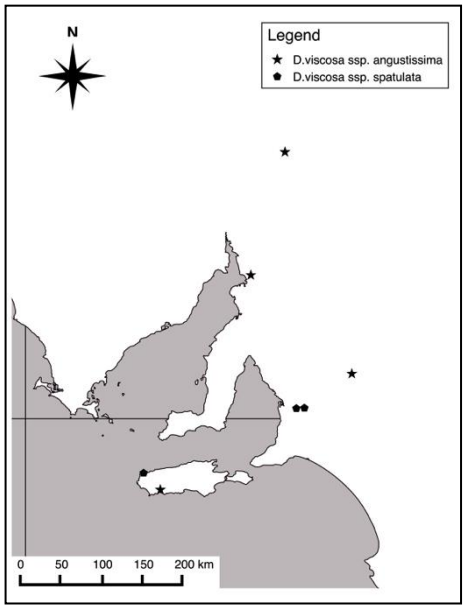

Fig 18: Locations of seven populations of *Dodonaea viscosa* sampled for RNA extraction

Key findings:

- Genetic screening of a common species which spans the entire TREND climate gradient, *Dodonaea viscosa* has identified a suite of markers which will be used to screen for genetic adaptations in this species. This work is ongoing.

Wider application

While case studies focused on the transect, some results may have wider relevance for the southern agricultural regions of South Australia, which is useful because little has been reported on ecosystem sensitivity to climate across the state. Based on TREND research, ecosystems in the transitional zone between mesic and arid biomes are likely to be climate-sensitive, whereas landscapes that are less fragmented, and contain refugia (or heterogenous habitats), such as mountain ranges, are likely to be relatively resilient. Therefore landscape planning must balance increasing adaptive capacity versus predictive provenancing/species selection. In the absence of specific data on climate sensitivity and genetic diversity, it could be assumed that species with small, isolated populations, or with restricted climatic ranges, will be at greater risk than phenotypically variable and widespread species (McCallum *et al.* 2014).

2.2 Primary Production

2.2.1 Overview

The TREND Primary Production theme investigated the concept of space as a proxy for time to better understand the climate change impacts and adaptation options for South Australian agriculture. The project focussed on dryland grains and irrigated viticulture sectors and involved extensive field monitoring and experimentation backed up by simulation modelling using current and projected climate data. Work from the project has contributed to a number of public presentations to the public and industry groups and peer reviewed publications (see Section 3). Three additional papers based on the experimental work and grower surveys are in preparation.

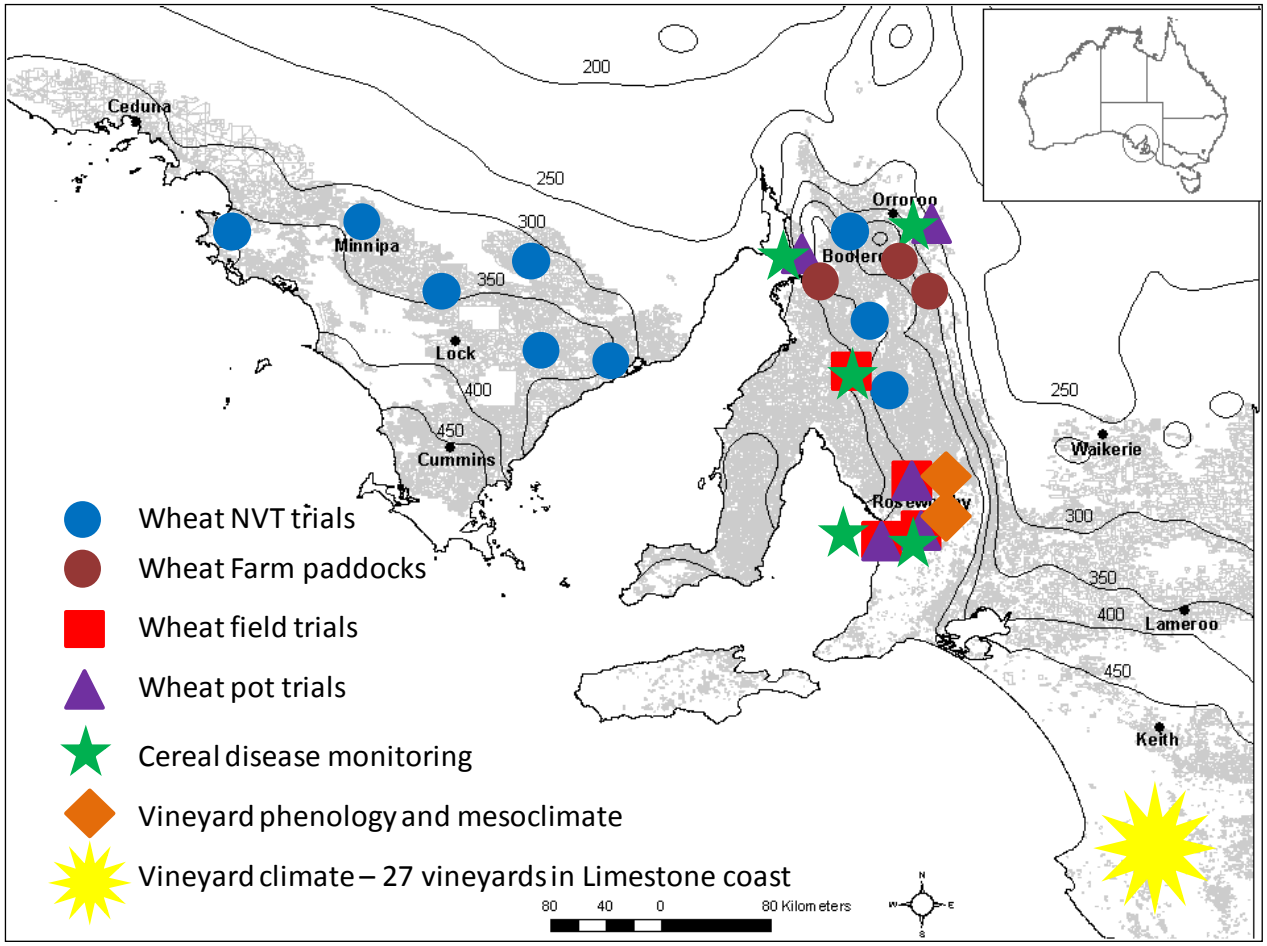

Fig 19: Map showing key experimental and monitoring activities for primary production component of TREND. Isohyets are annual rainfall and grey shows grain farms in 2008 (map data supplied by U. Nidumolu, CSIRO and DEWNR).

2.2.2 Theme performance against milestones, deliverables and KPIs

Table 2: Performance of the Primary Production theme against project milestones and KPIs

Milestone	KPI	Response
1.1 Collate existing terrestrial biodiversity, production and marine data to analyse climate variability	Develop a data repository and exchange framework Where possible, the submission of synthesised data to peer reviewed periodicals Findings collated in the first annual report	Key sources of production data (e.g. ABARES & PIRSA crop reports) have been collected along with climate data in format suitable for simulation modelling. The experimental data developed by the project is linked to climate data recorded on site and the closest Bureau of Meteorology station. Findings are collated in first Annual Report.
1.2 Combine the analysis of new and existing production system data	Data entered into database Publication of synthesised data in peer reviewed periodicals Findings collated in the final report	Data from monitoring and experimental work has been collated and stored in PIRSA's secure database, Objective. Journal papers on wheat and grape monitoring and experimental work are in draft form. Modelling the edge of the grains belt has been published in Climatic Change and a paper has been submitted to the Journal of Agricultural & and Resource Economics.
2.1 Identify a range of monitoring sites along environmental gradients (transects) in terrestrial biodiversity, productive and marine systems	Transect locations and sites identified and detailed in the first annual report	First annual report has details on sites. Map in this Fig. 16 shows sites of activities
2.2 Continue monitoring a range of sites along environmental gradients	Data entered into data base Findings outlined in final report	Data entered into Objective data base and findings outlined in final report
3.1 Develop protocols for the experimental manipulation of species or strains along environmental gradients (transects) in production systems.	Protocols detailed in the first annual report	Annual reports have details on experimental protocol with additional information in appendices on experimental work
3.2 Experimental manipulation of species or strains along environmental gradients (transects) in terrestrial systems	Data entered into data base Findings outlined in final report	Data entered into Objective database and findings outlined in final report
4.1 Develop policy questions, issues and first order recommendations from data 4.2 Community consultation and engagement 4.3 Community monitoring developed 4.4 Incorporate feedback from policy makers, the community and industry into the monitoring sites along the gradient	Policy briefs produced from the analysed data Public outreach tools allow for perpetual data collection Data sources from the community and industry included in the final annual report Mechanism established to ensure ongoing monitoring and reporting of data	Production systems contributed to policy meetings and briefs. As discussed under industry collaboration later in this report effective partnerships have been built with dryland farming system groups and viticulture grower groups. Data from industry is included in grains and viticulture monitoring and experimental work. Brooke Howell, viticulturist from Yalumba to be co-author on publication In addition to engagement with industry groups in viticulture and grains there is ongoing work with NRM including the new Goyder Line Sustainability Hub organised by Northern and Yorke NRM, Regional Development and Local Government.
Completed/On track	Delayed	Severe impediment to progress

An early recommendation from the TREND steering committee was to focus on a series of testable research questions. These research questions were in response to the most effective use of limited resources of time and money within the project and second to highlight the point that the funding from PSRF is for research.

We devised four research questions which relate to the monitoring and experimental part of the project (milestones 1 to 3) and three research questions that fed into the policy milestone. All seven research questions involve biophysical experimentation, monitoring or modelling. The aim is to be policy relevant rather than conducting policy research.

Tables 3 & 4: Definitions of the underpinning research questions of the Primary Production theme

Monitoring and Experimental (Milestones 1, 2 & 3)	
Research question	*Activities to address question*
Do mesoclimates exist within vineyards and can we use them to explore the impact of warmer climates on grape phenology?	Intensive monitoring of temperature, phenology and grape quality in vineyard Adelaide Hills and Eden Valley
Are phenostages of wine grapes in South Australia adequately predicted by simulation models?	Detailed analysis of data from TREND experiment supplemented with industry data
Is wheat crop development across transects in the SA grains belt adequately predicted by the simple vernalisation, photoperiod and thermal time model within the cropping simulation model APSIM?	Extensive monitoring of farmer paddocks and experimental manipulation with pots moved after establishment
How do cereal diseases respond to climate along environmental transects	Spore trapping experiments at key points on the transect

Climate and simulation modelling to feed into policy questions (Milestone 4)	
Research question	*Activities to address question*
To what extent is climate the primary determinant of the location of different primary production land use zones across environmental gradients in South Australia?	These gradients are more apparent to dryland farming than irrigated viticulture. There is a long history of analysing the relationship of the South Australian grains belt with climate dating back to Goyder in the 1860s, Davidson, Prescott and Trumble in the 1930s, Nix in 1970s and French in 1980s. The work with CSIRO as part of this project builds on this work
Is a 10% reduction in growing season rainfall at a given location equivalent to shifting production to a location on a similar soil type that is 10% drier?	Using the crop simulation model APSIM we could not find a significant difference in the probability distribution of yields between a site that is 10% drier and modifying the climate file. This offers support to the notion of using space as a proxy for time
What are the consequences of a trade-off between improvements in water use efficiency due to higher levels of carbon dioxide and reductions in rainfall	A limit to spatial analogues is the point that the future will have different levels of carbon dioxide than the present. The cropping system model APSIM adjusts the radiation and transpiration efficiency for wheat growth based on Free to Air Carbon dioxide Experiments (FACE). We found that an increase to 550ppm offset a 10% rainfall decline in wheat yield.

2.2.3 Project impact and key findings

Developing the concept of space as a proxy for time in SA Agriculture

The use of spatial analogues for climate change is well established in the ecology literature and has been applied to agriculture both internationally and in Australia. Rather than introduce the concept of space as a proxy for time to those involved in agricultural production in South Australia, we have built upon and tested the concept. The concept has an intuitive appeal to farmers and policy makers. Dryland farmers are well aware of the sharp climate gradients which are reflected in land prices and farming systems. Likewise viticulturists are aware of different wine regions, but given the time and expense in selecting a site and establishing and then intensively managing a vineyard, viticulturists are cognisant of climates across the vineyard, otherwise known as meso-climates.

The use of space as a proxy for time is appealing for farmers, as visiting a location where people are doing things differently but still managing with a livelihood makes the concept of adaptation concrete and "doable". It also means that there is a rich source of data for analysis. Also, local knowledge on the impacts of climate change and ways to cope are given a high status rather than the information coming only from climate science and simulation models. Transects encourage a focus on the edges of systems (eg boundaries of crops or varieties) which can provide some sense of thresholds. If for example the same crop is grown in regions much warmer to where a farmer is growing a crop, this suggests a long future for that crop. However, if a nearby region is only slightly warmer (adjacent climo-sequence) has very different crops and farming systems, this suggests that significant changes will be required with relatively small changes in climate.

An obvious limit to the concept of transects is that climate is only one of many factors that change with distance. This is however primarily a limit to an overly simplistic use of transects. Transects can be used to think through how climate interacts with soil, water availability, distance to market etc. A transect that has a climo-sequence can usefully challenge exaggerated claims of the impacts of climate change such as "everything will be unrecognisable with 1.5˚ increase". At the same time, the notion that climate is only a small determinant of land use is also usefully challenged. A transect can be used to think through what aspects change and what are likely to differ.

Key findings:

- Space as a proxy for time and transect methodologies can be usefully applied to explore the current and future patterns present in primary production industries in South Australia
- These approaches are appealing to policy makers and scientists, as well as farmers

Monitoring changes in phenology and temperature across single vineyards

We conducted field experiments at two vineyards; one in Eden Valley (Yalumba), and one in Adelaide Hills (Henschke) to explore the impacts of microclimate on sloping vineyards. We confirmed that position on the slope affected date of budburst, flowering and berry development. Berry quality differed with slope position more at veraison than at harvest. Inexpensive ($100) remote cameras were used to collect daily phenological observations and this has generated considerable interest with the industry and has created new possibilities for cost effective research.

Additional funding was leveraged from Yalumba and the Barossa Grape and Wine Association to conduct further trials to exclude the effects of other factors, such as soil variability. Vines were grown in large pots to be positioned in the vineyard. These showed similar slope effects as the field-grown plants but unfortunately severe frosts affected flowering and meant berry quality data could not be compared. The high level of industry involvement and co-investment is encouraging.

We found distinct temperature mesoclimates in both vineyards that differed for temperature in the day and night. Local topography allowed for cold air drainage and varied due to factors such as wind direction and speed. These mesoclimates, while not necessary by exact surrogates for a projected future warmer climate,

do provide a useful starting point to explore potential impacts. Higher elevation meso-sites were cooler during the day (the analogue for the current climate) than lower elevation meso-sites (the analogue for a future warmer climate), while changes in night minimum temperatures were frequently similar between meso-sites but was also influenced by cold air ponding.

Key findings:

- Position on slope affects key vine characteristics including date of flowering and berry development
- Industry funding was leveraged to conduct additional trials to exclude soil effects
- The use of inexpensive remote cameras were pioneered to study vine phenology, attracting significant industry interest
- Mesoclimates within individual vineyards are not a perfect surrogate for predicting the impacts of future climates, but do provide key insights in to how vines may be affected in the future.

Are grape phenostages adequately predicted by simulation models?

This study compared the phenology predicted by the vineyard performance simulator *VineLogic 2,* to observed phenology from several commercial vineyards (Henschke and Yalumba) and regions (Barossa Valley, Eden Valley, Adelaide Hills, Riverland, Coonawarra and Wrattonbully). The software was able to predict the date budburst, first flower, endset and veraison within 10-12 days, but was less accurate (within 19 days) for harvest. The larger error for predicted harvest date is most likely because cultural considerations (i.e. desired wine style) will influence the decision to harvest. The accuracy was similar for each grape variety and region.

While it is known that a warmer climate will affect grape quality, the risk profile and therefore cost-benefits of management options from severe weather events is less understood. The risk profile will be influenced by the expected weather in a future climate and the age of vines. These findings add to the certainty of the risk profiles developed for future climates, and will contribute to cost-benefit economic analysis of management options.

Key findings:

- Tests of Vineyard performance simulation software showed it was able to predict key dates in vine phenology within 10-12 days, with similar results across varieties and regions. This trial provides a useful performance analysis for vineyards interested in using *VineLogic 2*, a product of the CRC for Viticulture.

Testing and applying affordable, accurate and reliable temperature sensors

SARDI and ScienceMob, a not for profit organization, collaborated to develop affordable accurate and reliable sensors and data loggers to be used in measuring temperature in the field. We successfully designed and field tested a low cost logger and improved the accuracy of a low cost digital thermometer from ±0.5°C to ±0.1°C. We collaborated with the Bureau of Meteorology to establish that the ScienceMob temperature sensor is comparable with the gold standard measurements provided by the Bureau of Meteorology.

SARDI and ScienceMob have continued this collaboration with the Vineyard Microclimate project (http://vmicroc.org/) in which temperature is monitored at seven heights (from 20 cm soil depth to 1.8m above ground in 27 vineyards in the Wrattonbully, Robe and Mount Benson wine growing regions in South Australia. This project, supported by the Limestone Coast Grape and Wine Industry Council through the Grape and Wine Research and Development Corporation (GWRDC) grass roots program, aims to examine the variations in climate across the regions to locate micro climates within a region and see how they affect development of Cabernet Sauvignon across the two regions.

Key findings:

- Small and inexpensive temperature sensors and data loggers were produced with ±0.1°C accuracy.

- Field tests conducted with the BoM showed that these sensors performed comparably with BoM weather station sensors.
- Funding has been leveraged from the Grape and Wine Research and Development Corporation to use these sensors to assess microclimates and their impact on Cabernet Sauvignon development.

Measuring wheat phenology and disease along a climate transect

Wheat breeders provide farmers with a choice of wheat strains, which if sown on the same date will have a range of flowering dates. Farmers match the strain to the environment and the timing of the autumn break. Adjusting maturity type of wheat is one of the main ways that farmers manage current climate risk, including dealing with frost and heat events and is a way that they will react to future climate change. The agricultural simulation software APSIM is commonly used to simulate management impacts and wheat yield, but its accuracy in predicting crop development has not been fully explored in SA conditions.

A transect with temperature monitoring provided a valuable way to compare the effect of mean daily temperature and diurnal temperature range on phenology, and the ability of APSIM to predict phenological development. Phenology was simulated with greater accuracy when temperature data collected closer to the planting location was used, and no bias in simulations was apparent due to mean daily or mean diurnal temperature. This implies that APSIM can continue to be used to simulate phenology in a warmer climate with the same certainty as when used to simulate phenology in the historic climate. This further implies that the weather risks such as frosts or heat at flowering in a warmer climate can also be modeled with some certainty.

Key findings:

- The APSIM simulation software is effective in SA conditions and likely to continue to be effective even under future climatic shifts
- The accuracy of APSIM predictions was improved when local temperature data was collected

Monitoring of spore release from three common diseases of field crops

Field trials commenced in 2011 across five locations to measure the spore release from three common diseases of cereal crops. Spore release patterns were quantified using a molecular assay developed by SARDI's Root Disease Testing Service. Molecular detection methods were validated using existing microscopic techniques and sacrificial trap plant data. Localised climate conditions (e.g. temperature and rainfall) were collected in conjunction with the spore release data. A model of spore release will be developed through correlation of spore release data to climate variables (e.g. temperature and rainfall). This model will provide information on production risks in a current season, and in scenario modelling.

Key findings:

- Molecular techniques were used to detect the spores of common cereal crop diseases
- Molecular techniques were compared with traditional microscopic and sacrificial plant data
- A model which will correlate spore release and abundance with climate is currently under development

The relevance of Goyder's Line in a changing climate

Goyder's Line was drawn in 1860s and came to be understood as the demarcation between safer wheat production to the south and unreliable or risky farming to the north. It is a mainstay of NRM planning and resources from TREND were used to characterise Goyder's Line using current climate records, soil maps, pre European vegetation, land use and simulation modelling. This research highlights the importance of rainfall and evaporation in explaining the inner edge of the cropping belt and how the cropping belt may shift under a changing climate. Of particular interest is the observation that these same climate variables also explained the extent of cropping in the rest of the southern and western Australian grains belt. This work has been published (Nidumolu *et al*. 2012 – see Section 3.2) and has been the subject of many speaking requests. TREND investigators have delivered talks to the SA Royal Geographic Society, the National

Climate Change Adaptation Research Facility Conference (Melbourne), the National Friends of the Botanic Gardens the Upper North Farming System Field Day. A second paper examining grower perceptions and adaptation options is currently being drafted.

Key findings:

- The historical Goyder's line (254 mm of average annual rainfall) was examined with a range of contemporary and historical data to test its current and future ability to demarcate safe and marginal (or risky) cropping lands.
- This work has resonated and been the subject of several public lectures and scientific presentations (see Section 3.2)

2.2.4 Industry links and collaborations

Agriculture is a human activity system and most of the NRM decisions are made by individual landholders rather than through government policy. In this case the terrestrial production theme of TREND differs from the terrestrial biodiversity and marine themes. Rather than citizen science the link is through individual farmers and farming systems groups and wine grape growers associations. The main collaboration continues to be with individual farmers and viticulturists. These included:

- Mr Barry Mudge (Farmer), Pt Germain
- Mr Tony Moten (Farmer), Pekina
- Mr Gary Byerlee (Farmer), Tarcowie
- Mr John Cozens (Farmer), Orroroo
- Mr Craig Markby (Viticulturalist), Henschke Wines
- Ms Brooke Howell (Viticulturalist), Yalumba Wines

We also worked closely with the Upper North Farming Systems Group funded by the Grains Research Development Corporation (GRDC), who provided financial support to conduct the disease monitoring trials. We presented a number of public lectures at Jamestown and Morchard due to the interest in the region.

Yalumba and Henschke Wines were valuable industry partners for vine mesoclimate analysis. The Barossa Grape and Wine association organised a field day and successfully applied for funding as part of the Barossa and Clare regions local grants from the wine grape industry through the Grape and Wine Research and Development Association. We also collaborated with ScienceMob and the Limestone Coast Grape and Wine Industry Council to fund and install temperature monitors at seven heights in 27 vineyards in that region.

In addition to the links to the grains and wine grape industry research and development corporations the work from TREND overlapped with the Commonwealth Department of Agriculture (previously DAFF) project on Resilient Crop Livestock Project which was led by CSIRO through its Climate Adaptation Flagship and included Qld, NSW, Victoria, Tasmania and WA. The SA component was managed by SARDI and combined APSIM and climate change projections for a number of sites including the TREND production transect.

The TREND production transect was also used as a study site for an NCCARF project led by economists from the University of Sydney on the use of the economic framework 'Real Options' that used crop and sheep production in a transect from Clare to Orroroo and then Hawker to model farmer decision making under uncertainty associated with climate change and at what point of drying and warming a farmer is likely to shift from cropping to grazing.

Simulation modelling across transects to better understand the risk of wind erosion was used in a project with the SA Department of Environment and Natural Resources. Using spatial soil data and APSIM simulation modelling of wheat growth indicated that erosion risk increases in poorer seasons and increases in frequency with a drying climate. Those parts of the state that are already dry are more vulnerable to wind erosion risk if rainfall declines due to low biomass production. The lowest biomass production came from

soils with a higher percentage of clay in the surface compared to soils with a sandier surface. This was due to the ability of crops on sandy soils to utilise small rain events. Erosion risk is complicated by the need for more coverage on sandy soils than clay soils. A drier future would impose dual consequences to farming of reduced yields and increased risk of soil erosion which would further reduce soil fertility and farm and landscape sustainability.

The notion of space as a proxy for time and the association with Goyder's Line has been the basis for interaction with state government and NRM bodies. In March 2014 the Northern and Yorke NRM board, the Central Northern Local Government Association and Regional Development Australia Yorke and Mid North launched the Goyder's Line Sustainability Hub. Both the Environment Institute of the University of Adelaide and SARDI are partners, as is the Ag Excellence Alliance which is an association of farmer groups.

2.3 Citizen Science

2.3.1 Overview

Together with Policy Translation, Citizen Science theme has sought to provide a link between the primary research conducted by research themes and the communication and use of this information by non-scientists. The Citizen Science theme also provides an opportunity for members of the community to become involved in the collection of useful primary data. This empowers members of the community to better understand the science that is being conducted and improves their ability to digest and make decisions based on information presented to them. The use of appealing mobile data collection apps also mobilises members of the public to collect data, vastly increasing the amount of data able to be generated and thus the power of subsequent analyses of trends.

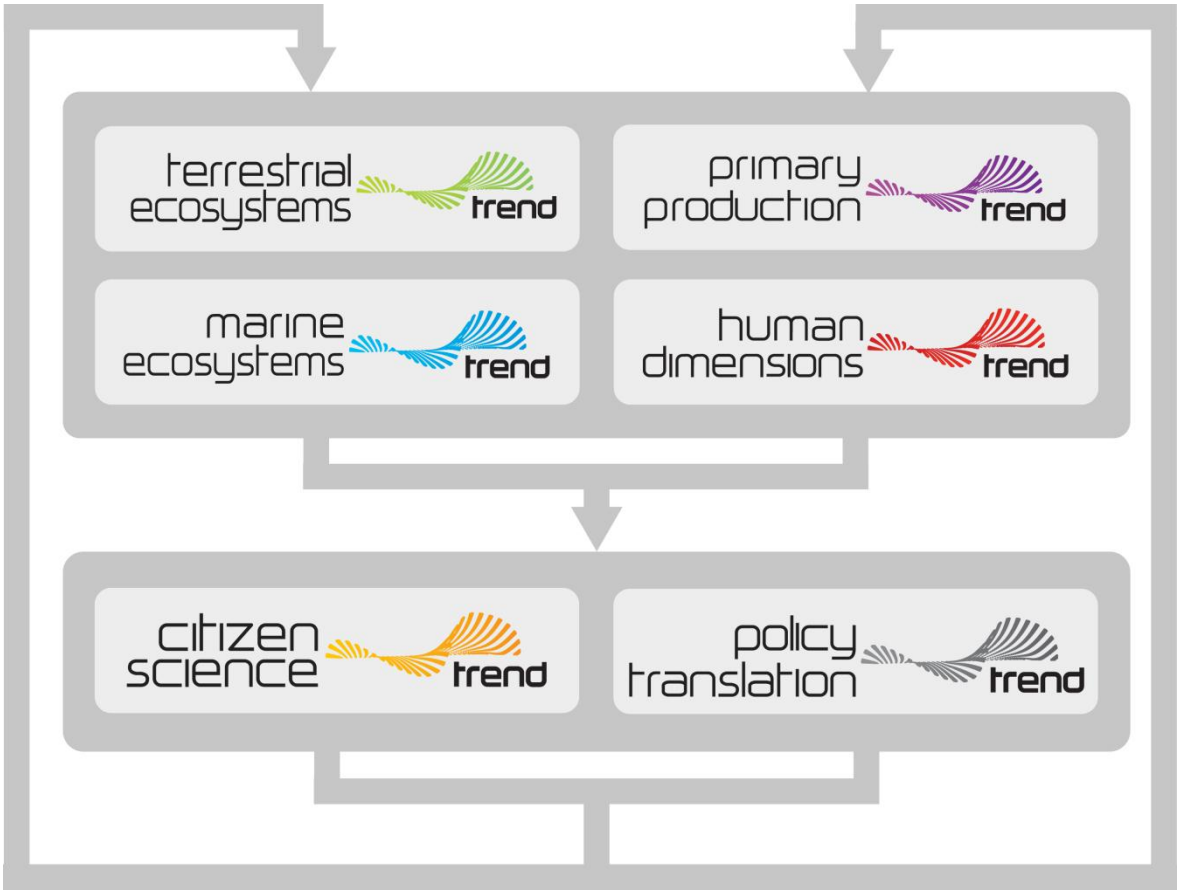

Fig. 20: Together with the Policy Translation theme, Citizen Science provides a feedback link between primary research and its uptake to influence decision making. This subsequently feeds back to the primary research, providing opportunity to the community and policy makers to influence the work conducted by scientists as well as shape its presentation and communication.

2.3.2 Project impact and key findings

The Terrestrial Ecosystems transect is roughly coincidental with the Heysen Trail (Figure 21), one of the most heavily walked trails in South Australia. The Heysen Trail attracts strong community interest from community groups including Friends groups, Conservation NGOs, Scouts, walkers, etc. Consistent 3G mobile coverage and the presence of several species of plants and animals that are both conspicuous to

walkers and sensitive to environmental change provides an ideal opportunity to use a mobile app for the collection of citizen science data.

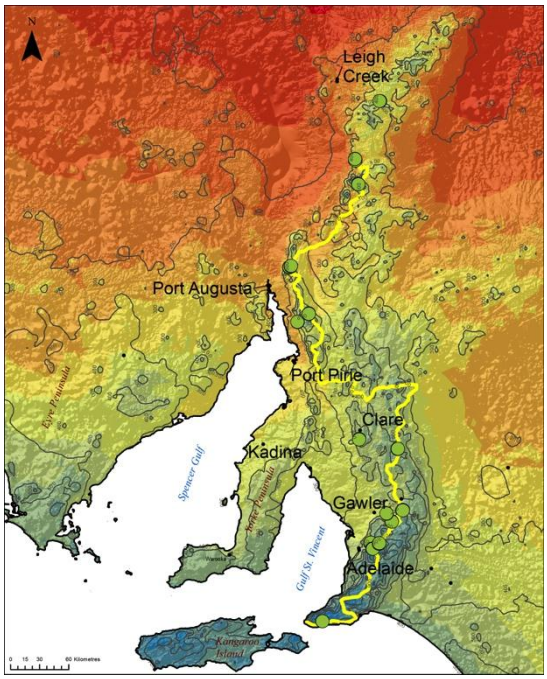

Fig. 21: The Heysen Trail is one of the most heavily trafficked walks in South Australia. Reasonably consistent mobile 3G coverage along the trail has facilitated the development of a mobile app to engage citizen scientists to collect useful ecological data.

To exploit this opportunity, TREND has developed a mobile phone app which is available on both Android and Apple iOS devices. The app has two broad functions: the collection of species presence data to complement the Terrestrial Ecosystems theme, and the collection of landscape data to model change in specific communities over time.

Species presence data

The collection of species presence data is a well-established technique for successful citizen science programs, with high profile projects such as eBird and Project Noah based on this concept. To embed this concept within the TREND program, we selected a suite of species which are sensitive to change, reliably photographable, identifiable by members of the public, and, of interest to both managers and scientists. Citizen Science has also consulted widely regarding appropriate species to include in its production version of the apps. Experts from DEWNR as well as the environmental consultancy Ecoknowledge, have provided their recommendations on appropriate species based on ecological relevance, visibility, abundance, community interest and perceived threat status with respect to future environmental change.

Table 5 The mix of native and introduced species allows analyses of both change in distribution of indigenous species, as well as the spread of invasives, including Weeds of National Significance (marked with an asterisk). This allows the distribution data to be used not only for ecological analysis, but also management activities such as weed spraying, controlled burns or feral pest baiting/shooting.

Flora	**Fauna**
Brushtailed possum	Banksia
Butterflies and moths	Black Anther Flax-Lily
Cockatoos	Boneseed*
Red Fox	Bottlebrushes
Feral Deer	Bridal Creeper*
Koala	Broom*
Miner Birds	Castor Oil Plant
Orb-weaver spiders	Mistletoe
Rabbits and hares	Orchids
Raptors	Salvation Jane
Short-beaked echidna	

Fig. 22: Users are able to record sightings of species, which are submitted to the TREND online database complete with location, date and time of the sighting. If participants choose to register a user name, their sightings contribute to an individual ranking. Users can also join teams, who are similarly ranked.

To add a sense of competition to the process, users are able to register a handle and create or join a team, which is then ranked in a dynamic leader board. As of 21 April 2014, the user topping the Individual leader board is “eCologist”, who has contributed 98 individual sightings. The top team is “The Planeteers”. Public interest in downloading the TREND app and contributing species sightings has been high, with several hundred sightings recorded across the length of the Terrestrial Ecosystems transect (see Figure 23).

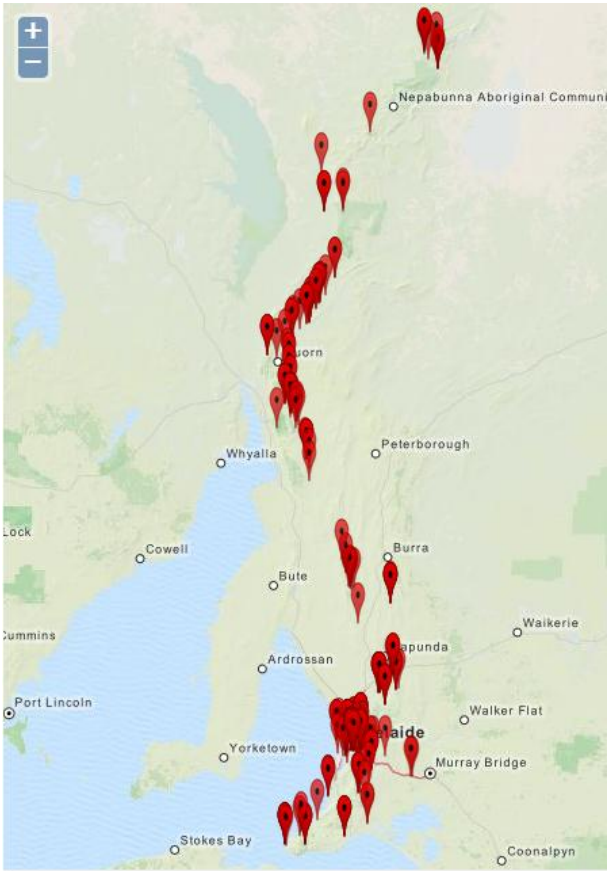

Fig. 23: The 100 most recent species sightings along the TREND transect.

All species sightings are available online through the TREND Citizen Science species sightings page. A search feature has been added which allows members of the public to query the database based on species or time period (Figure 24). It is therefore possible for a researcher to identify all sightings of raptors for a given time period to allow ordination analysis to be undertaken. Similarly, a DEWNR park ranger wanting to direct weed control operations in his or her park could identify reports of Boneseed and Broom (both Weeds of National Significance and therefore of high management importance) for priority action. Because all sightings include a photograph, data miners can be confident of the accuracy of contributed data. Data can also been downloaded for offline analysis.

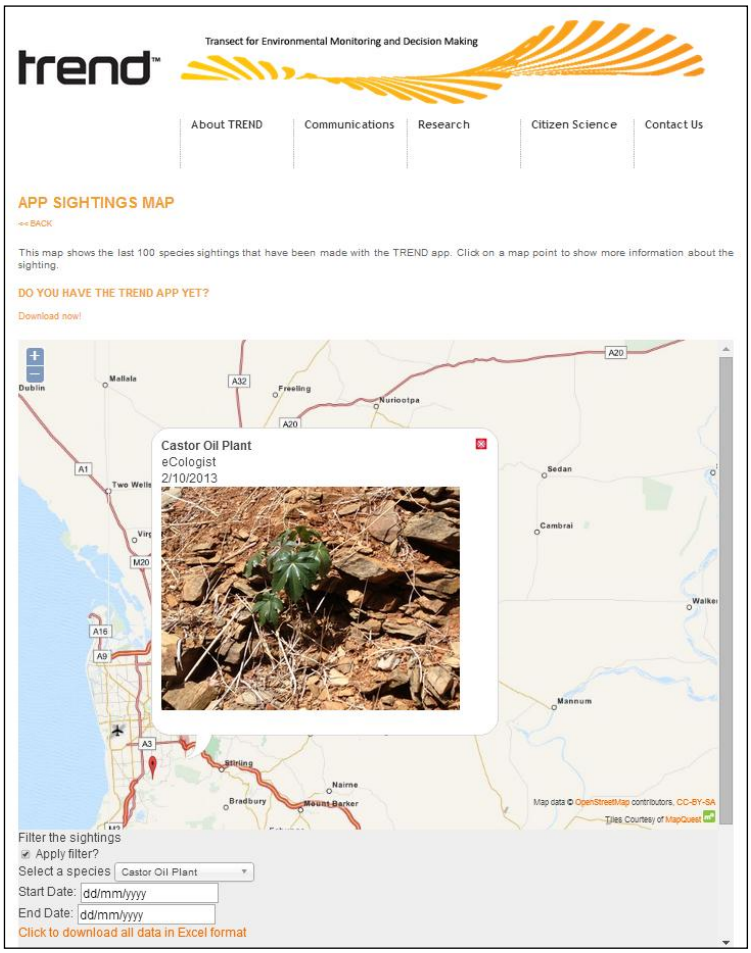

Fig. 24: Users can query the citizen science database through the TREND website by species of interest and/or time period.

Landscape monitoring

Through collaboration with the TERN AusPlots facility and the Australian Centre for Visual Technologies (ACVT), TREND has been successful in developing novel mobile app photo point technology. ACVT have developed a process by which two photographs taken from slightly different angles at a photo point can be merged to create a stereo image of a landscape (Figure 25). This technology allows empirical measurements to be taken from photo point photographs, and could be used to inform measures of carbon storage and cycling; landscape succession (including weed invasion); and plant phenology. This technology is now embedded in our mobile app and we have worked with the SA Department for Environment, Water and Natural Resources to install photo points for a field trial. Three photo points consisting of reference poles and an instructional sign (Appendix 4) have been installed on the Mt Lofty Summit hike in Cleland Conservation Park, which is the most heavily walked trail in South Australia.

Two photo points were installed in sections recently burnt as part of a prescribed burn off to monitor the recovery of native vegetation. It is envisaged that the data collected will allow DEWNR to engage the public in the science behind prescribed burning, which is often controversial as it impacts upon the aesthetic and public amenity, particularly in popular parks like Cleland. The third photo point was installed in an area

currently experiencing weed invasion. The data collected will be a pilot to determine the degree to which the technology developed is able to effectively inform on vegetation metrics of landscapes regenerating from fire and undergoing ecological succession (change in dominant species).

A

B

C

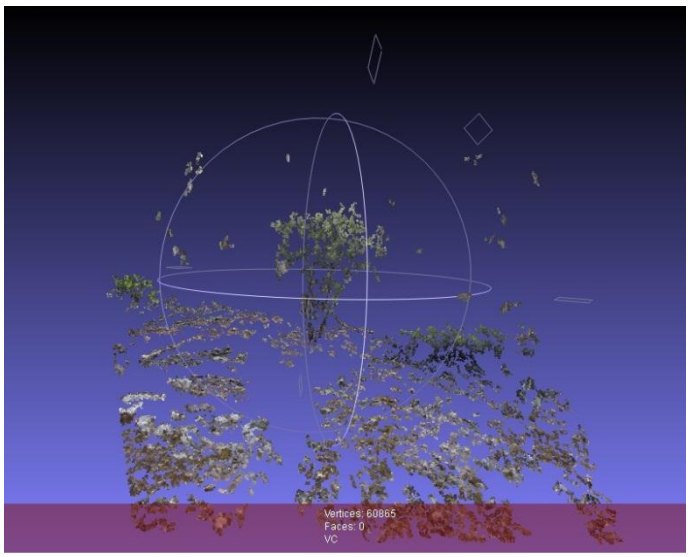

Fig. 25: Users of the TREND citizen science app are guided through the process of using their Apple or Android phone to take two images at a point of interest (A), with instructions provided by an interpretive sign (Appendix 4). The photos are then digitally integrated (B) to form a three-dimensional landscape model (C). This model can infer information on biomass and changes in landscape features over time.

2.3.3 Theme performance against milestones, deliverables and KPIs

Table 6: Performance of the Citizen Science theme against project milestones and KPIs

4.2 Community consultation and engagement 4.3 Community monitoring developed	Public outreach materials produced to allow for the collection, analysis and interpretation of data by the community and industry. Data included in Annual Reports. Public outreach tools allow for perpetual data collection	Citizen science software produced and available for perpetual download. Photo points for monitoring of fire recovery in National Parks established in partnership with DEWNR. Ongoing funding for this work will be pursued. Data exploration and analysis tools have been integrated in to the TREND website to allow data to be downloaded and used by scientists, managers and interested members of the community.
	Data sourced from the community and industry included in the final annual report	Data streams online and continues to be gathered and will be the subject of continued search for funding and partners.
	Mechanism established to ensure ongoing monitoring and reporting of data	Integration of Terrestrial Ecosystem theme in to the Australian Transect Network will ensure ongoing monitoring and reporting of data, however specific ongoing citizen science monitoring will require additional funding to be obtained to ensure maintenance of data collection and storage platforms.
Completed/On track	Delayed	Severe impediment to progress

2.3.4 Industry links and collaborations

The production of the TREND mobile app was a collaborative effort of the University of Adelaide and development company Shifty Jelly, with the Atlas of Living Australia providing the platform for the storage of collected data in the form of the Biological Data Recording System (BDRS).

We collaborated with the Australian Centre for Visual Technologies and the Terrestrial Ecosystem Network's AusPlots facility to integrate point cloud modelling from two dimensional images.

The South Australian Department of Environment, Water and Natural Resources (DEWNR) and environmental consultancy EcoKnowledge contributed their expertise for the selection of suitable taxa on which to focus data collection. DEWNR also worked with us to facilitate the installation of photopoints in the Cleland Conservation Park and have expressed interest in expanding the program more widely.

2.4 Marine Ecosystems

2.4.1 Overview

We took advantage of the naturally occurring variation in temperature and salinity found within Gulf St Vincent of South Australia to test the response of marine invertebrate communities to a changing climate. Sites for monitoring and experimental manipulation were established along the environmental gradients in the Gulf at Rapid Bay, Adelaide Outer Harbour, Ardrossan, Klein Point and Stenhouse Bay (Figure 26).

Fig. 26: Sites used for experimental manipulation in the marine component: Rapid Bay, Outer Harbour (Adelaide), Ardrossan, Klein Point and Stenhouse Bay.

This research pioneered a new approach to marine gradient research, and while progress was made, marine research is often hampered by difficulties not experienced in terrestrial studies. Substantial difficulties were encountered at several stages of the project which has limited success. These have included storms damaging field experiments, and the inconsistent quality of existing datasets (making them unsuitable for planned analyses).

2.4.2 Theme performance against milestones, deliverables and KPIs

Table 7: Performance of the Marine Ecosystems theme against project milestones and KPIs

Milestone	KPI	Response
1.1 Collate existing marine data to analyse climate variability	Develop a data repository and exchange framework Where possible, the submission of synthesised data to peer reviewed periodicals Findings collated in the first annual report	The major marine data sets available were collated and analysed as part of an FRDC (Fisheries Research & Development Corporation) project immediately prior to this project commencing, and are reported on here: http://www.sardi.sa.gov.au/__data/assets/pdf_file/0020/134606/No_438_Effects_Of_Environmental_Variability_on_Recruitment_to_South_Australian_Fisheries.pdf. In addition, data on reef fish abundance from community Reef Watch surveys were sourced and a preliminary examination conducted to determine if there was a temporal signal detactable. Unfortunately, this data set was very noisy, being collected by a large number of individuals with different levels of experience and on an opportunistic basis, both factors exacerbating the inherent noisiness of fish data. As such, we were unable to develop anything useful from this data set.
1.2 Combine the analysis of new and existing marine data	Data entered into database Publication of	No existing marine data that were compatible with the data collected as part of the PSRF project were located.

	synthesised data in peer reviewed periodicals Findings collated in the final report	
2.1 Identify a range of monitoring sites along environmental gradients (transects) in marine systems	Transect locations and sites identified and detailed in the first annual report	A set of potential monitoring sites (jetties in Gulf St Vincent) were identified at the commencement of the study. These were assessed on the basis of accessibility, depth, recreational use, and general habitat characteristics. Six of these jetties were selected as suitable for the study, although Port Giles had to be dropped later due to high levels of ship movements making access problematic. The final sites selected were: Rapid Bay, Outer Harbour, Ardrossan, Klein Point, and Stenhouse Bay.
2.2 Continue monitoring a range of sites along environmental gradients	Data entered into data base Findings outlined in final report	The above five sites were monitored every 3 months for a period of two years (a total of 9 surveys). The results of these surveys are detailed in this report.
3.1 Develop protocols for the experimental manipulation of species or strains along environmental gradients (transects) in marine systems.	Protocols detailed in the first annual report	Three different protocols were developed for experimental manipulation of assemblages: 1. Clearances – a ~ 40cm wide band was cleared as much as possible of all fauna and flora on one side of a jetty pylon in order to monitor recruitment and assemblage development. 2. Experimental plates – to further standardize settlement surfaces, 30 cm x 30 cm PVC settlement panels were deployed at each site. 3. Translocated plates – to assess the response of assemblages to changes in conditions, experimental plates were deployed at 1 location for 3 months, and then translocated to others
3.2 Experimental manipulation of species or strains along environmental gradients (transects) in marine systems	Data entered into data base Findings outlined in final report	The three protocols outlined above were employed at the five final monitoring sites. Full details are presented elsewhere in this report, but in brief: 1. Clearances were established at 3 depths on each of 10 pylons and each site, and monitored at 3-monthly intervals for 2 years. One issue that was encountered in this experiment was slow recolonisation at some sites, especially those where the jetty pylons were uncoated steel. These clearances developed a layer of loose rust, that inhibited colonization, and the settlement panel component of the study was established to overcome this. 2. Settlement panels were deployed in the same experimental design as the clearances 12 months after the clearances were established. All plates were photographically surveyed every 3 months for a period of 1 year. These generally proved to be successful, except at Rapid Bay, where the swell characteristics were such that most plates were lost over the 12 month study period. 3. At the same time as the settlement panels were deployed, we translocated settlement panels that had been deployed at Ardrossan and Stenhouse Bay 3 months earlier to all of the sites. The original intention was to deploy 10 plates from each donor site at each of the recipient sites, however, there were substantial losses of plates from Stenhouse Bay in particular. Again, these losses were due to the highly exposed nature of this location.
4.1 Develop policy questions, issues and first order recommendations from data 4.2 Community consultation and engagement	Policy briefs produced from the analysed data Public outreach tools allow for perpetual data collection Data sources from the	1. We met with the Marine Protected Area Planning committee to discuss implications for monitoring MPA performance, but no firm commitments made by government to fund monitoring program. We will continue to follow the development of this aspect. 2. As detailed above, we examine the Reef Watch fish data to determine if it might be useful for detecting temporal patterns, but found that it was highly noisy and unlikely to be suitable for

4.3 Community monitoring developed 4.4 Incorporate feedback from policy makers, the community and industry into the monitoring sites along the gradient	community and industry included in the final annual report Mechanism established to ensure ongoing monitoring and reporting of data	detecting subtle shifts in assemblage composition. 3. Reef Watch already runs a monitoring program that has received considerable support from The University of Adelaide and SARDI, particularly in the development stages. In addition, the University of Tasmania runs a program called Reef Life Surveys that includes SA. As the techniques used here didn't lend themselves particularly well to community monitoring, and we did not want to dilute the efforts of Reef Watch and Reef Life Surveys, we did not develop any additional community monitoring programs. Due to the specialized nature of marine monitoring, both existing programs have some difficulty in maintaining a consistent survey effort over time, and surveys are conducted on a very ad hoc basis in both time and space. Adding a third program would most likely have targeted the same individuals as those that engage in the existing programs, further diluting effort. 4. Due to the limited number of potential survey sites, and the fact that all accessible sites in sufficiently deep water to undertake the study were utilized, there was no opportunity to incorporate any feedback into site selection. Incorporation of other sites would either not have been logistically feasible, or would have required a complete revision of our monitoring protocols to target a different habitat.
Completed/On track	Substantially achieved	Severe impediment to progress

2.4.3 Project impact and key findings

Here we describe aims and associated experimental protocols:

1. *Quantify the variation in invertebrate community structure using standardised photographic surveys*
   We established permanent photo-quadrats at stations where jetty pylons are covered by at least 7 m at the lowest tides. At each station, we used 10 pylons (mostly square or I-shaped) to monitor invertebrate communities at three depths: 2, 4 and 6 m below the lowest tide mark (Figure 27). Each 20 × 20 cm quadrat (Figure 28) was initially photographed, and then cleared so as to monitor recruitment and subsequent community development. Samples of cleared invertebrates were retained, and identified in the laboratory. We are quantifying total species areal coverage and composition using image analysis software photoQuad. We initially photographed these quadrats in January/February 2011. In February 2012, we photographed an analogous set of quadrats, along with sets on two additional dolphins[1] at those sites where multiple dolphins were available (Rapid Bay and Ardrossan), to determine how small spatial scale variation compares to that at the between-site scale.

[1] A 'dolphin' is a collection of jetty pylons, usually in a square.

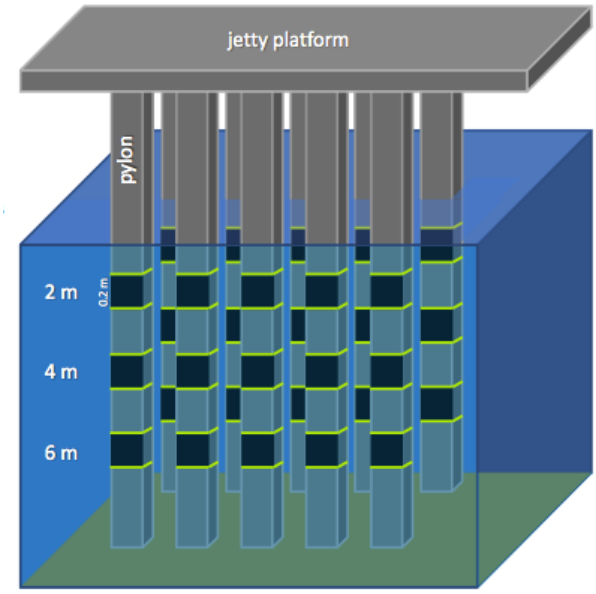

Fig. 27: Jetty pylon monitoring site layout showing position of 20 × 20 cm quadrats on 10 pylons at three depths.

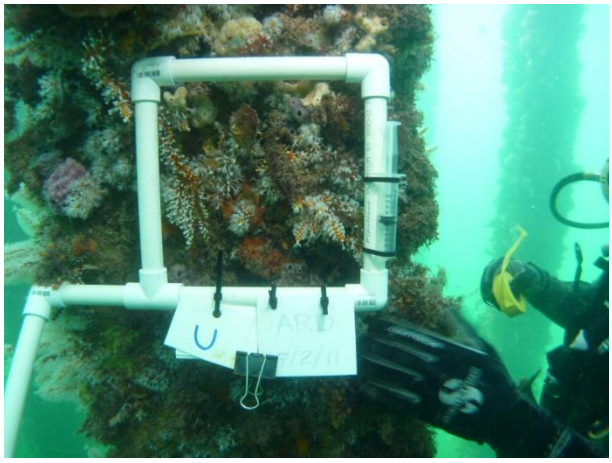

Fig. 28: Jetty pylon with *in situ* sessile invertebrates and field researchers using mobile quadrat to obtain a quantitative photograph.

2. *Develop a modelling tool to predict invertebrate diversity using digital analysis*
   We developed an image analysis tool that can estimate species diversity using simple digital image features quantifying pixel diversity. Mean information gain (MIG) and Mean mutual information (MMI) are indices of image-derived spatial heterogeneity that do not require pre-processing of images. We have used MIG and MMI to predict invertebrate diversity and composition via the application of univariate and multivariate responses within linear mixed-effects models that we have pioneered. We made a preliminary examination of a small subset of the data to determine the extent of image pre-processing required before this technique can be applied. We found no difference in the results obtained using images that have been rectified and cropped versus those that have been cropped only, and thus further use of this technique will be based on cropped images only. These preliminary results also showed differences in MIG and MMI between sites and depths, suggesting that the technique will be useful. On the basis of these preliminary results, we have analysed the spatial variation data from February 2012 using both MIG/MMI and conventional manual image scoring to obtain percent cover of all taxa present (with taxa identified to the lowest possible level, or lowest Operational Taxonomic Unit – OTU). When combined with information on the spatial structure within the dataset (site and depth), MIG and MMI explained ~35% of deviance in invertebrate species richness, ~25% in Shannon's evenness and up to 50% of dissimilarity in species composition. These results corroborate the idea that indices of image complexity can provide useful and cost-effective complements to traditional methods used for describing (or predicting) marine biodiversity patterns.

   A paper on this component of the study has been submitted to *Ecological Indicators*.

3. *Quantify competitive capacity of newly recruited invertebrate species*
   After measuring community composition, we removed the fauna from one side of each experimental

pylon to examine settlement times (i.e., to optimise settlement plate translocation – see Aim 4) and record competitive interactions via photographic monitoring (4 times/year) (Figure 29). To assess recruitment rates and colony growth rates under standard conditions in what are normally crowded assemblages, each clearing was 20 × 20 cm, with an additional 5-10 cm wide cleared border area to minimise effects from established organisms growing into the quadrat.

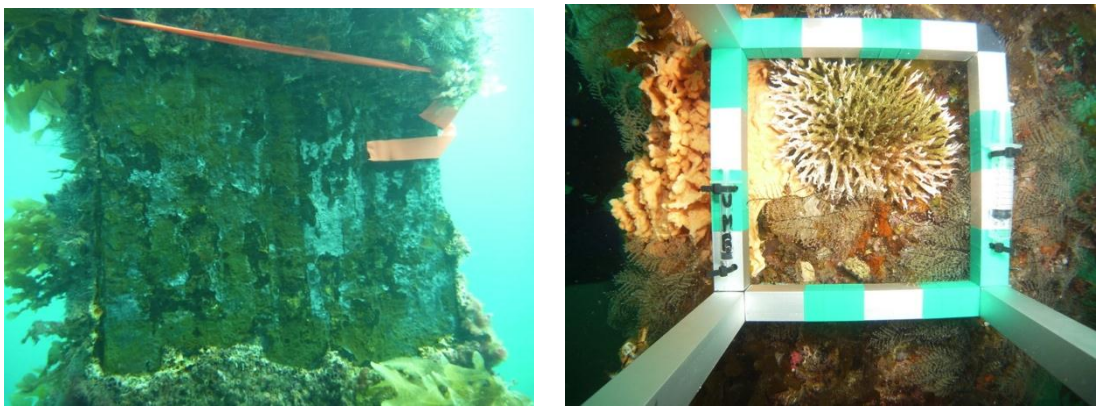

Fig 29: Jetty pylon at Rapid Bay with area cleared of invertebrates for (left) and the same pylon after two years.

We recorded differential competitive success and succession along the transect gradients to determine how mature communities form. In this way, we will be able to establish 'suitability envelopes' for different species. These quadrats were photographed and cleared in January/February 2011, and have been surveyed eight times since, with the final survey in February/March 2013. Images for the August and Nov/Dec 2012 and Feb/Mar 2013 surveys have been scored in photoQuad to determine the percent cover of all identifiable species, and a rigorous process of taxonomic validation undertaken.

The composition of the recovering assemblage in these cleared plots varied significantly as a function of the interaction between Site and Pylon with Depth and Survey, whether analysed at the Phylum/Class level (Table 8), and with all interactions at the lowest OTU (Table 9). Pair-wise tests on data from the final census showed that all sites differed significantly from each other at each depth, with the exception that Stenhouse Bay was the same as Ardrossan and Outer Harbour at the deep depths, and Ardrossan and Klein Point were the same at the other depths at the Phylum/Class level, while the only similarity at the lowest OTU was between Ardrossan and Klein Point at the upper depth. Within Sites, the only differences were between the upper depth and the others at Rapid Bay, and the deep and the others at Stenhouse Bay at the phylum/class level. At the lowest OTU, the differences were between Deep & Upper at Klein Point, all three depths at Rapid Bay, and between Deep & Mid at Stenhouse Bay ($p<0.05$). MDS did not show any clustering by either site or depth at the higher level (Figure 30), but Rapid Bay clustered separately at the lower level, with the final census being separate from the 2 earlier censuses (Figure 31).

Table 8: PERMANOVA results for assemblage composition in clearances at the Phylum/Class level

Source	df	SS	Pseudo-F	P(perm)	Unique perms
Si	4	200540	20.961	0.001	999
De	2	9201.3	3.4095	0.001	999
Su	2	19290	14.121	0.001	999
Py(Si)	45	110700	4.7079	0.001	997
SixDe	8	30018	2.7553	0.001	999
SixSu	8	48063	8.7698	0.001	997
DexSu	4	2510.4	1.2011	0.263	998
DexPy(Si)	90	126380	2.6875	0.001	994
Py(Si)xSu	89	61357	1.3194	0.004	997
SixDexSu	16	7535.4	0.90134	0.667	998
Res	164	85692			

Table 9: PERMANOVA results for assemblage composition in clearances at the lowest OTU

Source	df	SS	Pseudo-F	P(perm)	Unique perms
Si	4	2.92850	22.357	0.001	999
De	2	14390	3.2558	0.001	998
Su	2	33767	10.762	0.001	997
Py(Si)	45	1.50730	2.7432	0.001	993

SixDe	8	38551	2.1659	0.001	999
SixSu	8	1.00070	7.9511	0.001	997
DexSu	4	9301.1	1.9043	0.001	998
DexPy(Si)	90	2.04800	1.8636	0.001	990
Py(Si)xSu	89	1.40860	1.2961	0.001	995
SixDexSu	16	36896	1.8885	0.001	997
Res	164	2.00250			

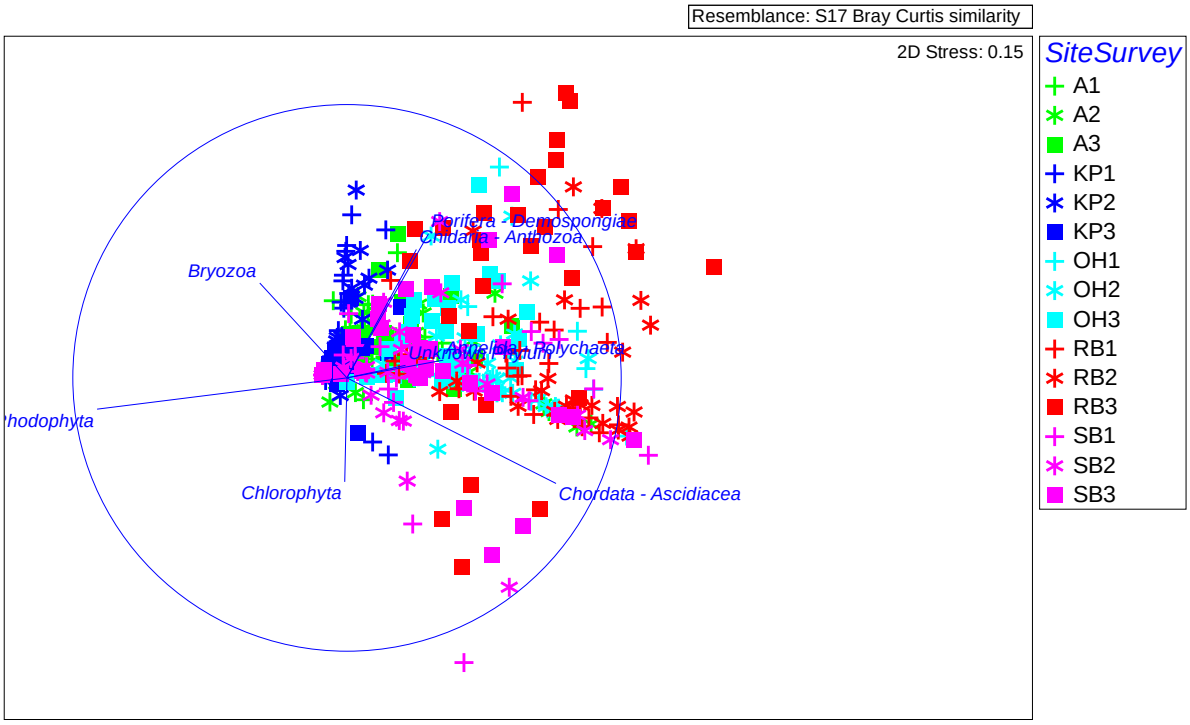

Fig. 30: MDS of Assemblage composition from clearances at Phylum/Class level

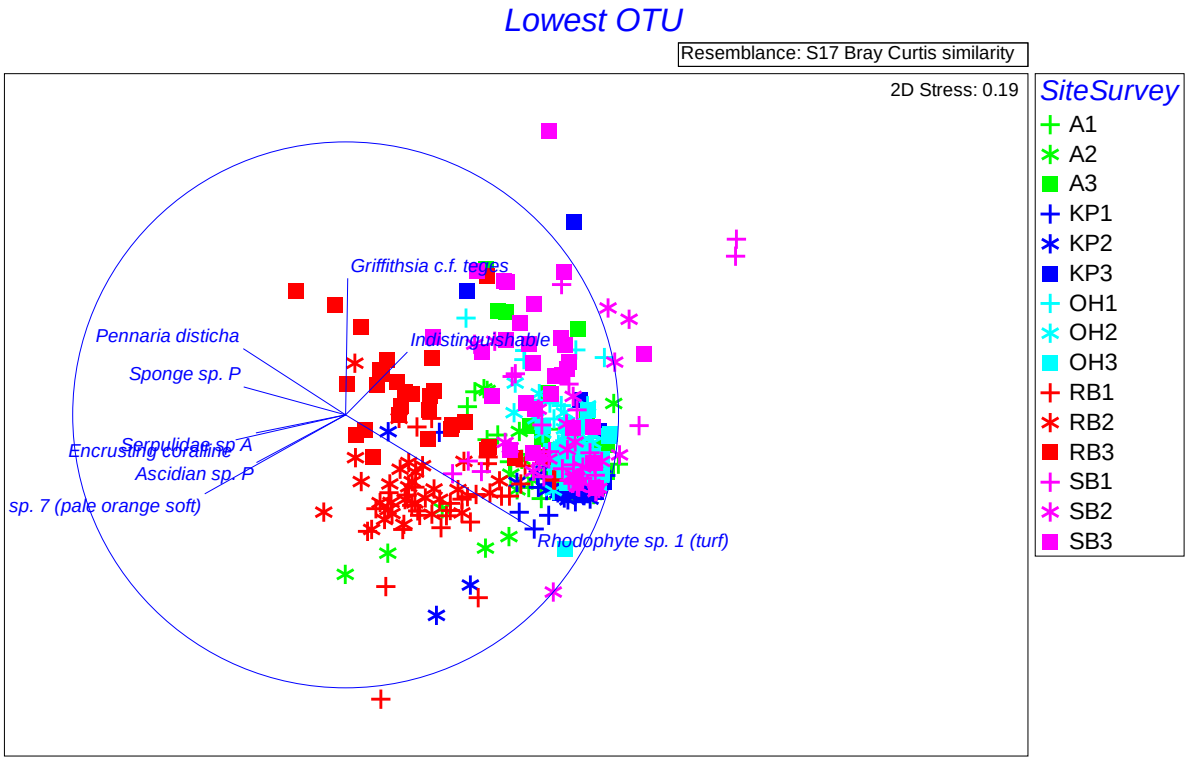

Fig. 31: MDS of Assemblage composition from clearances at the Lowest OTU (note: one outlier from Stenhouse Bay Deep with 100% cover of *Soliera robusta* is excluded).

Due to slow establishment of recruits at some sites, and observations of a trial deployment of settlement panels that showed rapid recruitment to them even when recruitment to the pylons was slow, we have also deployed a series of 30 × 30 cm PVC settlement panels attached to the opposite side of the pylon to each cleared quadrat (Figure 32). These were deployed in February 2012, and have been monitored photographically four times since in conjunction with monitoring of the clearances. While all plates deployed at Rapid Bay were lost, plate survival after one year at the other sites was good (80-90%). Images from these surveys have been analysed in photoQuad, and taxonomic validation undertaken.

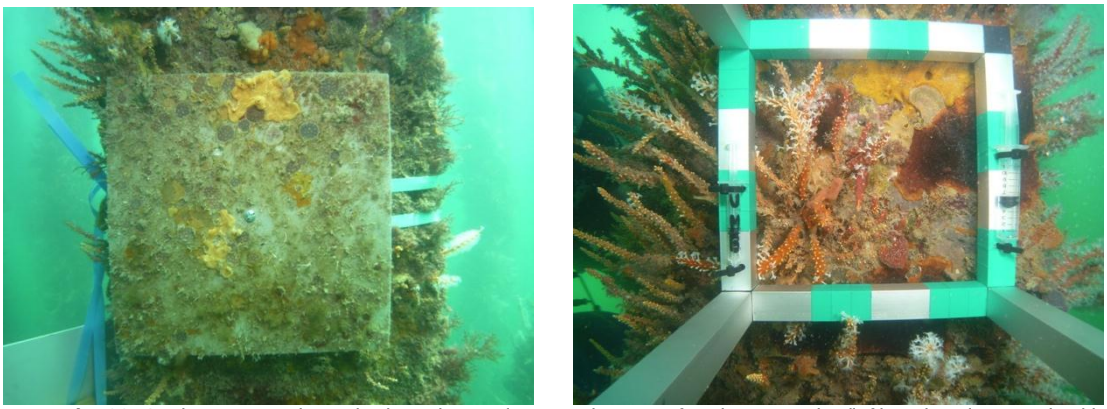

Fig. 32: Settlement panel attached to a jetty pylon at Ardrossan after three months (left) and twelve months (right)

Assemblage composition on these plates varied significantly as a function of the interaction between Site and Pylon with Depth and Survey, whether analysed at the Phylum/Class level (Table 10), or the lowest OTU (Table 11). Pair-wise tests on data from the final census showed that all sites differed significantly from each other at each depth, with the exception that Klein Point and Stenhouse Bay were the same at the mid and upper depths at both taxonomic levels. Within Sites, Deep and Upper plates differed at Ardrossan and Stenhouse Bay, with all other depths being the same ($p<0.05$). Although no clear pattern over time was apparent in the MDS, Ardrossan and Outer Harbour did both separate out from the other sites (Figures 33 and 34).

Table 10: PERMANOVA results for assemblage composition on settlement plates at the Phylum/Class level

Source	df	SS	Pseudo-F	P(perm)	Unique perms
Si	4	182720	83.623	0.001	999
De	2	1180.7	1.9975	0.071	998
Su	3	25498	25.598	0.001	999
Py(Si)	45	27227	2.3506	0.001	996
SixDe	8	4832.3	1.8843	0.027	999
SixSu	10	83421	24.596	0.001	998
DexSu	6	1541.4	0.99808	0.483	999
DexPy(Si)	86	28676	1.2954	0.015	997
Py(Si)xSu	116	40359	1.3517	0.004	995
SixDexSu	19	6168.3	1.2613	0.123	998
Res	189	48648			

Table 11: PERMANOVA results for assemblage composition on settlement plates at the lowest OTU

Source	df	SS	Pseudo-F	P(perm)	Unique perms
Si	4	142760	34.063	0.001	999
De	2	3479.1	2.9885	0.002	999
Su	3	68574	28.611	0.001	999
Py(Si)	45	51898	2.1791	0.001	997
SixDe	8	13470	2.7302	0.001	997
SixSu	10	151440	18.363	0.001	997
DexSu	6	4392.1	1.3832	0.105	997
DexPy(Si)	86	54570	1.199	0.028	994
Py(Si)xSu	116	99337	1.6181	0.001	994
SixDexSu	19	18977	1.8872	0.001	998
Res	189	100030			

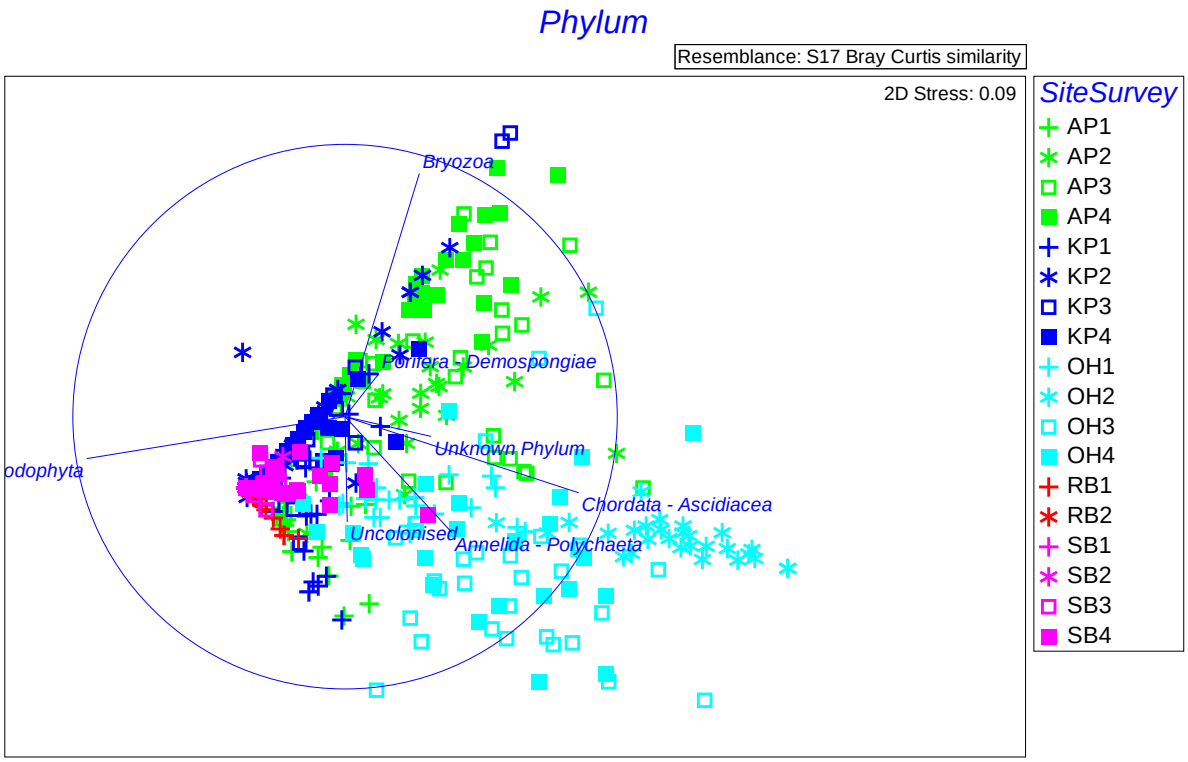

Fig. 33: MDS of Assemblage composition from settlement plates at the Phylum/Class level.

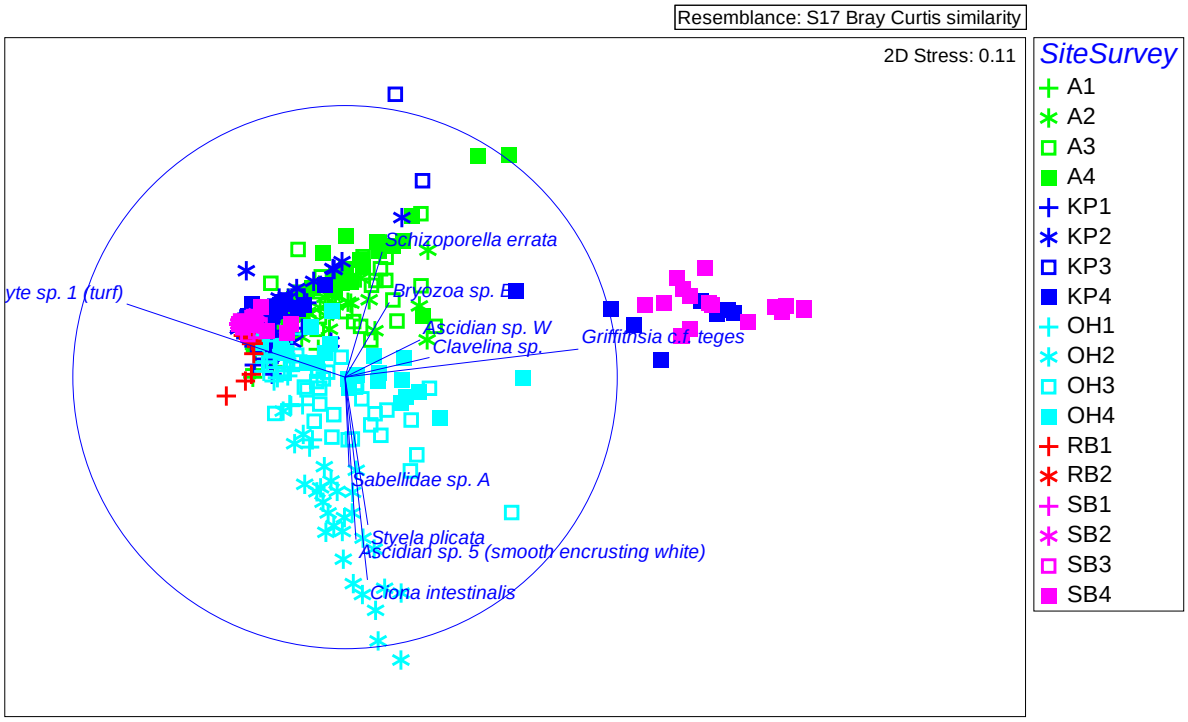

Fig. 34: MDS of Assemblage composition from settlement plates at the Lowest OTU

To compare changes over time, a second-stage MDS and PERMANOVA was used, analysing the Deep plates only (unresolved analysis issues have prevented analysis of other depths). For each plate, a resemblance matrix was calculated over time, and then a second stage resemblance matrix calculated to compare these individual matrices. While the PERMANOVA showed a significant difference between groups of plates translocated to different sites (Phylum/Class $F_{3,32}$=6.21, p=0.001, Lowest OTU $F_{3,34}$=9.80, p=0.001), there were no clear patterns in the MDS. At the Phylum/Class level, pairwise tests indicated that Klein Point was similar to Ardrossan and Outer Harbour, with all other sites significantly different, at both taxonomic levels. The MDS shows the Stenhouse plates were the only group that clustered tightly at both levels (Figures 35 & 36).

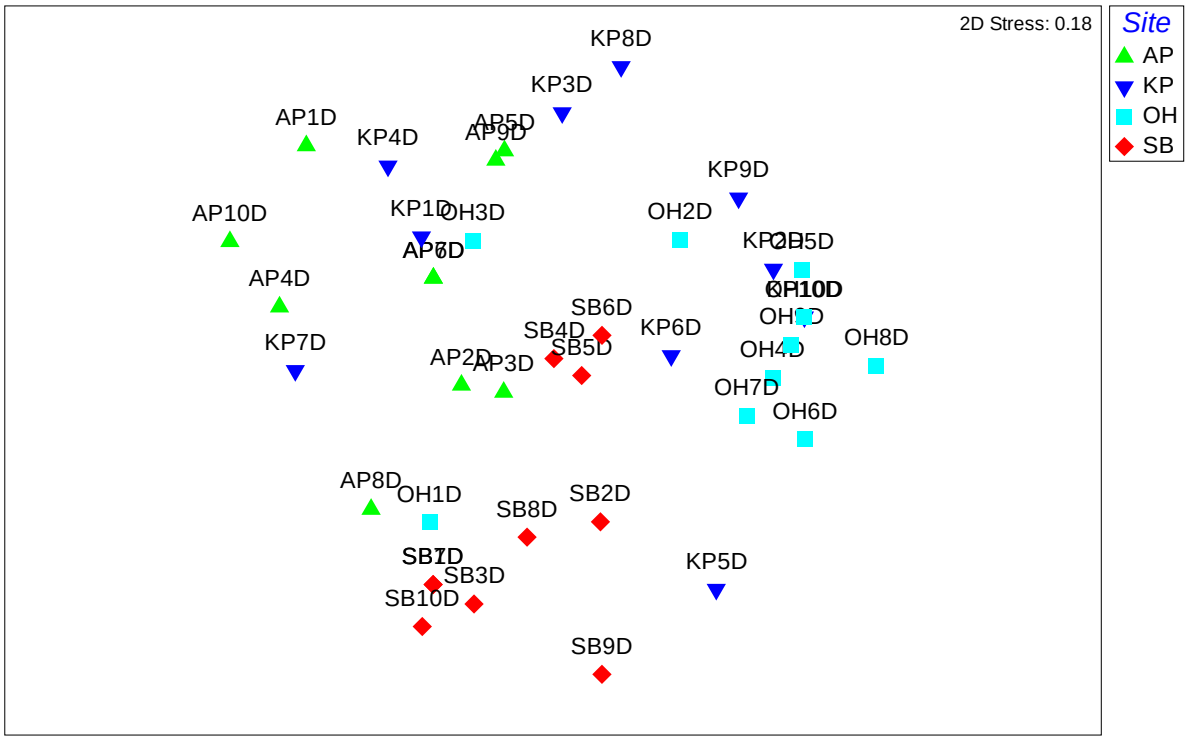

Fig. 35: Second stage MDS of assemblage composition from translocated plates at the Phylum/Class level

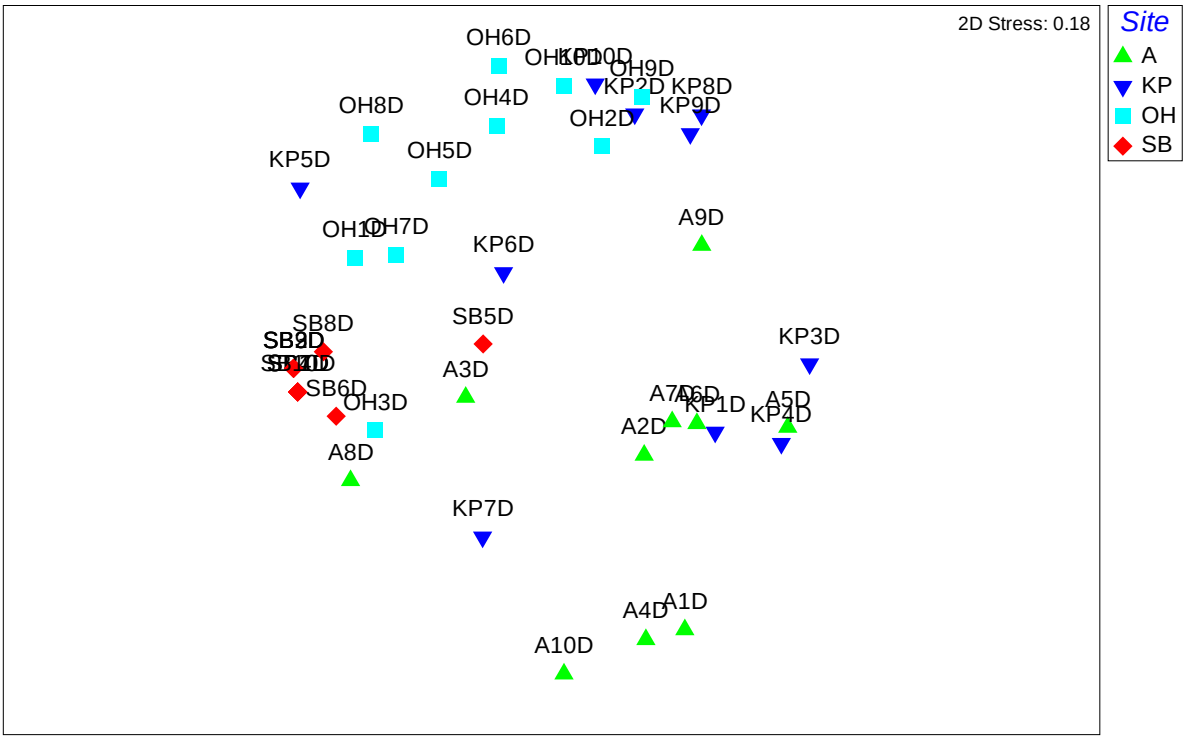

Fig. 36: Second stage MDS of assemblage composition from translocated plates at the Lowest OTU level

4. *Translocation experiment*

At the northern- and southern-most stations, we deployed a total of sixty 30×30 cm PVC settlement plates in October 2011. These were left to attract recruits for three months prior to being translocated to the other sites. The initial intention was for ten plates from each donor site to go to each of the five study sites. However, we lost a large numbers of plates during winter storms, principally at Stenhouse Bay. Consequently, we deployed five plates from Ardrossan at each site, and seven plates from Stenhouse Bay at Stenhouse and at Ardrossan, all in February 2012. Again, all plates deployed at Rapid Bay were lost, but those deployed at other sites generally persisted, and have

been scored in photoQuad.

The intention is to test the hypothesis that sessile invertebrate communities are locally adapted to their temperature and salinity regimes. We predict that (i) invertebrate communities on translocated settlement plates will differ between northern- and southern-most sites in each gulf; (ii) those plates translocated to sites most different to their initial settlement locale will see the most rapid turnover of species and a shift in dominance toward the new local community; (iii) the pace of species turnover and dominance change will be a function of distance from initial settlement site; and (iv) translocated plate communities will eventually come to resemble the control settlement quadrats at each site via differential survival of individuals, re-invasion of locally adapted species and competitive exclusion.

Assemblage composition on these translocated plates varied significantly as a function of the interaction between Site and Survey, whether analysed at the Phylum/Class level, or the lowest (PERMANOVA: Phylum/Class $F_{14,79}$=4.22, p=0.001, Lowest OTU $F_{14,79}$=4.07, p=0.001). Pair-wise tests on data from the final census showed that most sets of translocated plates differed significantly from each other, with the exception, with the exception that those translocated from Stenhouse to Ardrossan were the same as those moved from Ardrossan back to Ardrossan, and from Ardrossan to Stenhouse at the Phylum/Class level, and Ardrossan back to Ardrossan at the lowest OTU (p<0.05). No clear patterns were evident in an MDS at either taxonomic level (Figures 37 and 38).

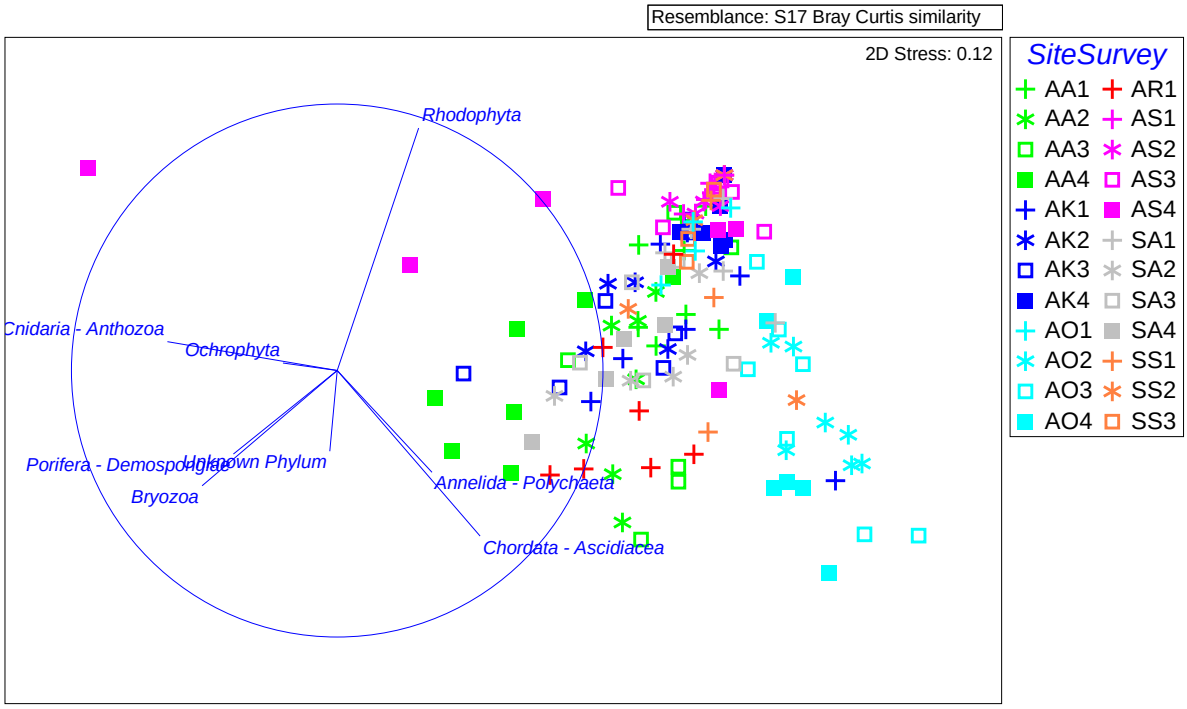

Fig. 37: MDS of Assemblage composition from translocated plates at the Phylum/Class level.

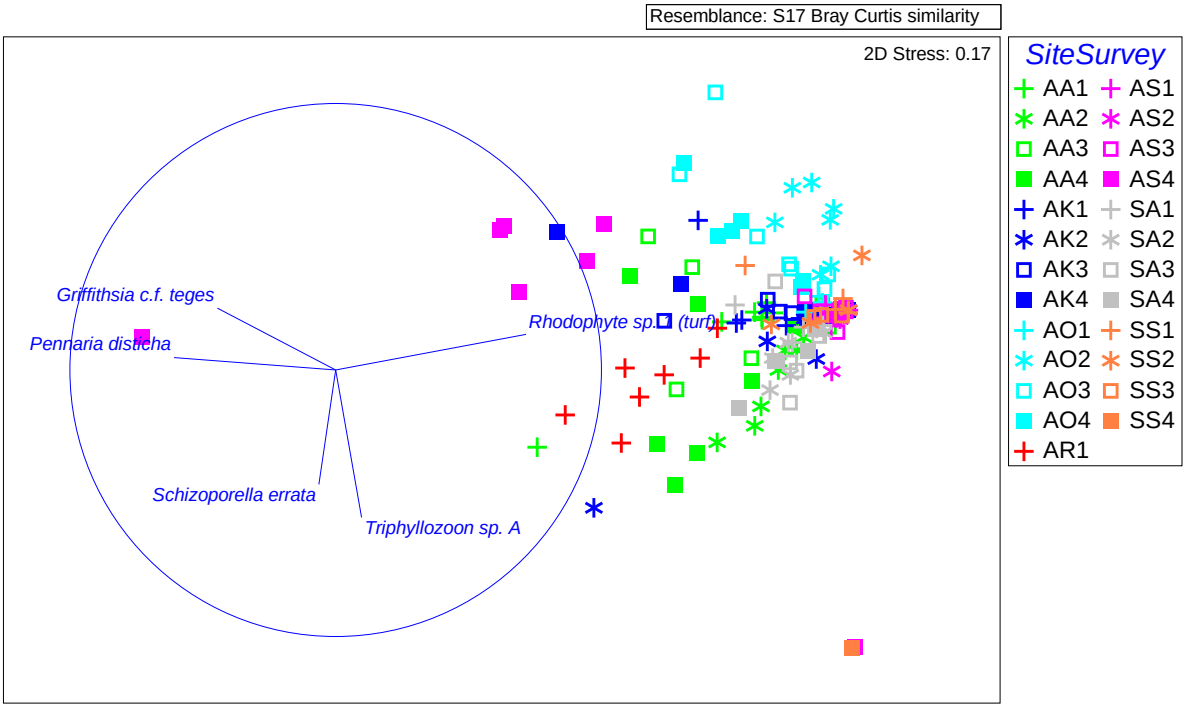

Fig. 38: MDS of Assemblage composition from translocated plates at the Lowest OTU level

To compare changes over time, a second-stage MDS and PERMANOVA were used. For each plate, a resemblance matrix was calculated over time, and then a second stage resemblance matrix calculated to compare these individual matrices. While the PERMANOVA showed a significant difference between groups of plates translocated to different sites (Phylum/Class $F_{4,24}$=3.24, p=0.007, Lowest OTU $F_{4,22}$=4.24, p=0.006), there were no clear patterns in the MDS. At the Phylum/Class level, pairwise tests indicated that plates translocated from Ardrossan to Stenhouse differed from all other groups, but there were no other significant differences. The MDS shows that the Ardrossan to Stenhouse plates were the only group that clustered tightly (Figure 36). At the lowest OTU, Ardrossan to Outer Harbour differed from all other groups (except Stenhouse to Ardrossan which could not be tested), Ardrossan to Stenhouse differed from Ardrossan to Ardrossan and Stenhouse to Ardrossan. Again, only the Ardrossan to Stenhouse plates clustered tightly on the MDS (Figure 37).

Overall, there was no clear indication that the assemblage on plates translocated from Stenhouse to Ardrossan converged on that of plates translocated from Ardrossan to Ardrossan. Indeed, most translocated plates seemed to respond fairly idiosyncratically.

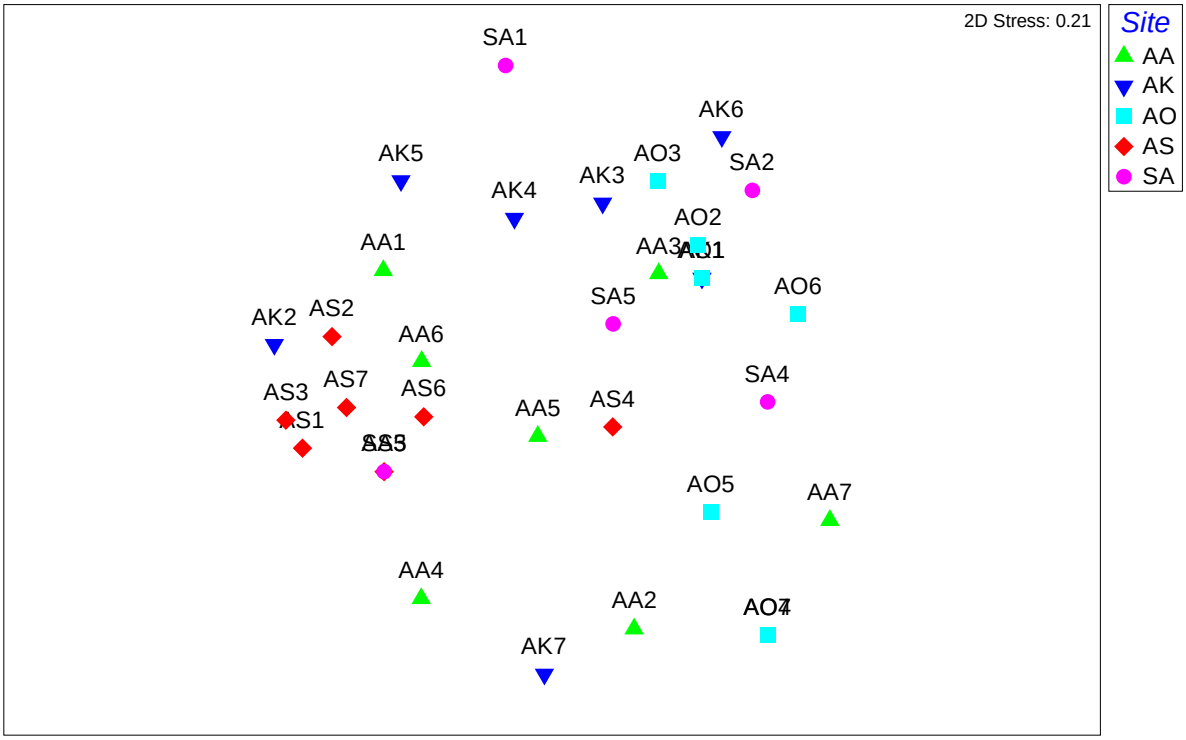

Fig. 39: Second stage MDS of assemblage composition from translocated plates at the Phylum/Class level

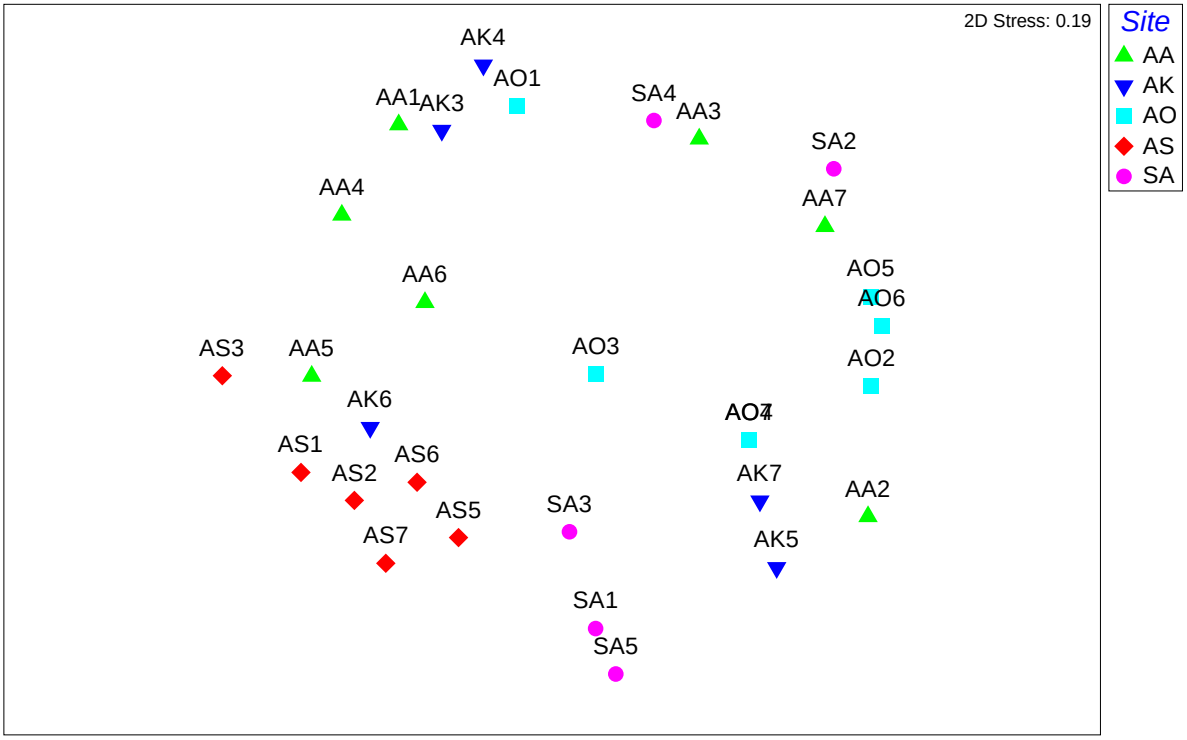

Fig. 40: Second stage MDS of assemblage composition from translocated plates at the Lowest OTU level

5. *Log environmental data*
We have placed Star-Oddi DST CT temperature-conductivity data loggers at each station set to record temperatures each hour; these units were downloaded every 3-6months. Species distributions and relative abundance measures will be mapped against dominant salinities and temperatures (incorporating variance in the latter). We will test the hypotheses that temperature and salinity variation affect the distribution and relative abundance of invertebrates.

6. *Analysis of community data*
   We have obtained the Reef Watch fish monitoring data, and have determined it is too inconsistent to be used to detect reliable trends in fish abundance or species occurrence. The inconsistency is due to the data being collected by a range of community divers from different reefs at different times over the last 15 years.

2.4.4 Future Activities

Data analysis on the clearance experiment and the settling panel work will continue. It is anticipated that one to two papers will be submitted on this work.

Concurrently, the Reef Watch database is being further explored, and has the potential to lead to a paper on community monitoring.

2.5 Policy Translation

2.5.1 Overview

The policy translation theme of TREND aims to ensure that the research undertaken in TREND is policy relevant and supports evidence based decision making by government.

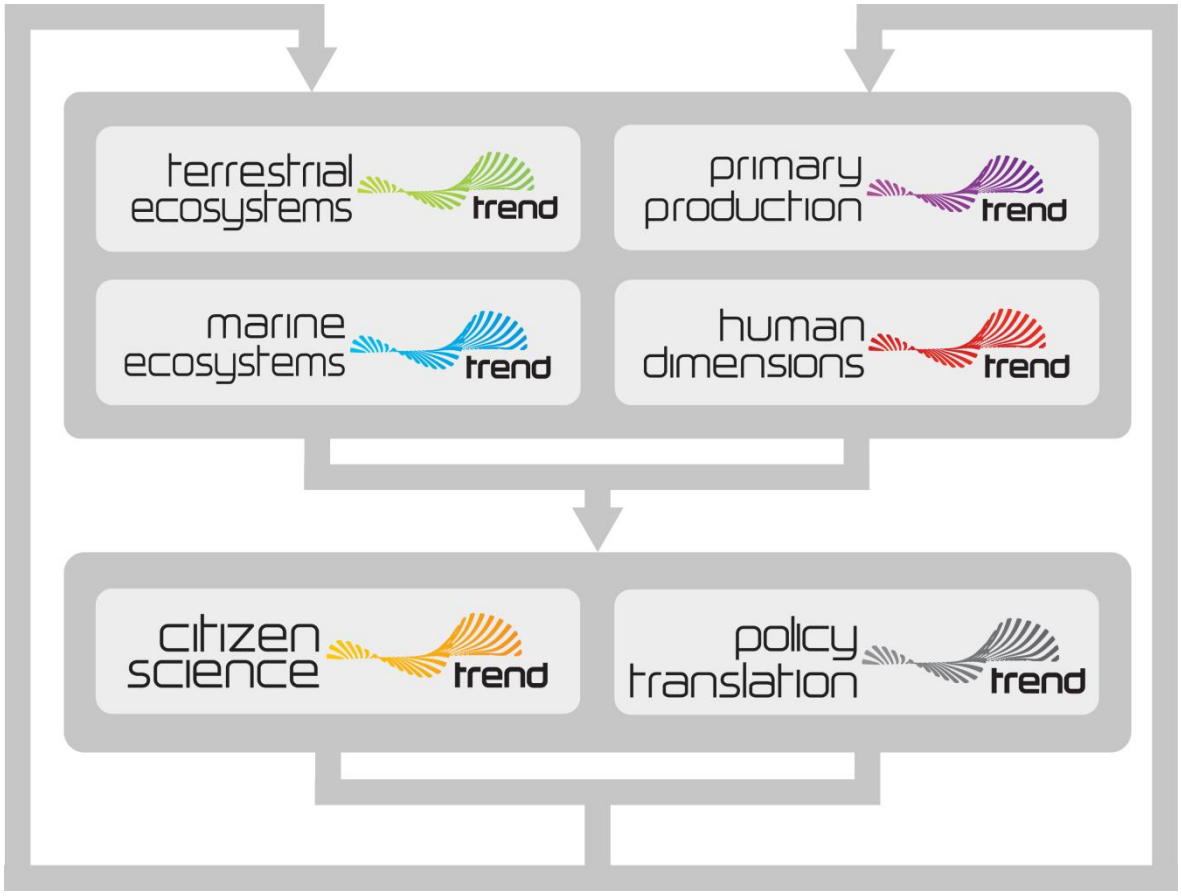

Fig. 41: Together with the Policy Translation theme, Citizen Science provides a feedback link between primary research and its uptake to influence decision making. This subsequently feeds back to the primary research, providing opportunity to the community and policy makers to influence the work conducted by scientists as well as shape its presentation and communication.

Policy questions were developed through workshops involving researchers and key South Australian government employees, including representatives from the then Department of Environment and Natural Resources (DENR), PIRSA, SARDI and the Department of Premier and Cabinet. Policy officers, primarily from DENR and PIRSA, were invited to workshops relevant to their area of expertise. Prior to each workshop, invitees were provided with information about TREND and guidance on the main policy drivers directing climate change adaptation research in SA (mainly critical considerations from the *Draft Climate Change Adaptation Framework*, *a first step to developing a coordinated and integrated response to climate change in South Australia* and relevant objectives from DENR Science Directions 2010-2015).

Invitees were then asked to provide three to four draft policy questions which were compiled and synthesised prior to the workshops. At each workshop, the appropriate theme leader (i.e. Corey Bradshaw, Andy Lowe and Peter Hayman) provided a detailed description of the aims and proposed methodology of their research. Susan Sweeney delivered an overview of the policy translation requirements for TREND. Primed with this greater understanding of the TREND project and keeping in mind the main policy drivers, workshop participants then considered, discussed, refined and prioritised the previously compiled draft policy questions, with guidance from the theme leaders as to what was realistically achievable from their research. Therefore policy issues were identified prior to the workshops and the workshops focused on the synergies between the policy issues and the research that was planned.

This iterative working between science and policy areas to derive and address key questions was a very useful approach and one which has been described in a scientific publication (see Fig 39) to try to promote this type of working in other areas.

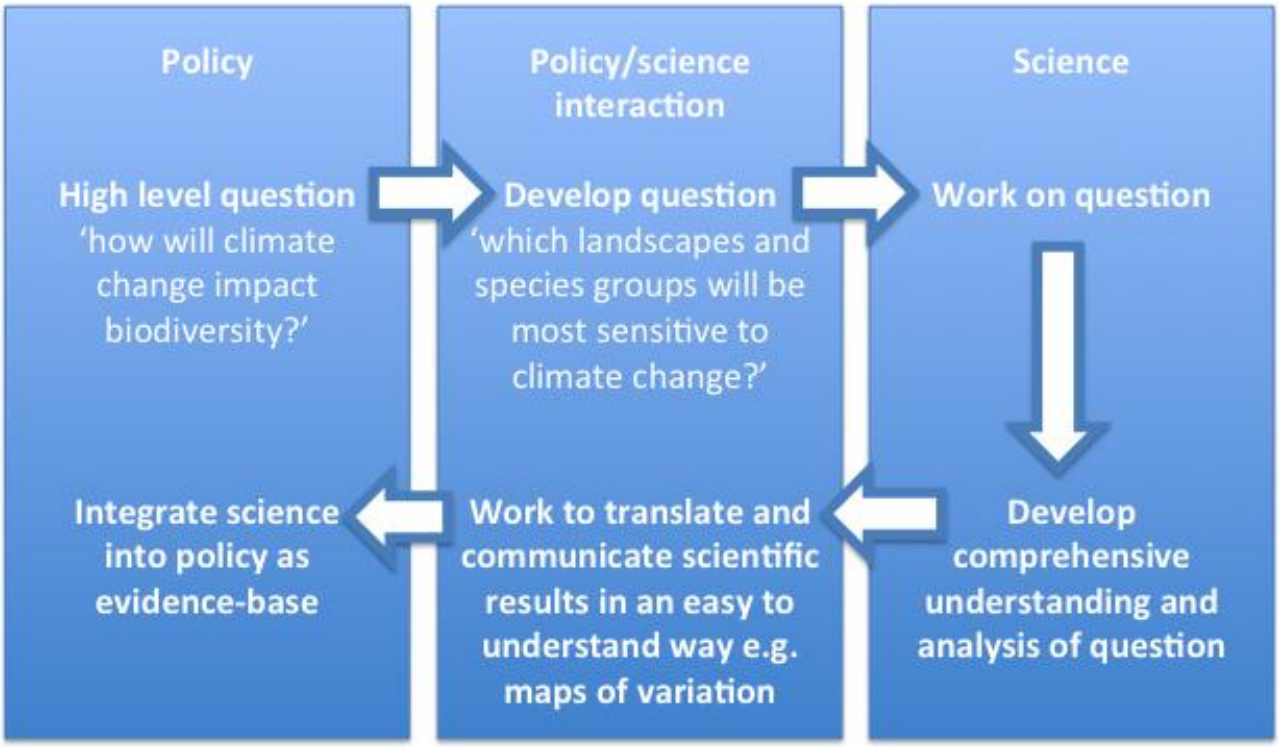

Fig 42: The Science/policy interaction for successful deriving and addressing policy-relevant questions on climate change

The following policy questions were derived from the workshops:

Terrestrial Ecosystems

1. Which are the most important species/abiotic components/processes for supporting and maintaining, or degrading or undermining, driving species' composition which impacts upon ecological function (e.g. carbon sequestration, nitrogen fixation) and how might these be affected by climate change?
    - Are there any particular species or ecosystems that would provide early indicators of systems that are under stress? And what are the implications for ecosystem health?
    - What are the species and ecological communities that are most and least at risk from climate change and what are the expected impacts?
    - How will climate change interact with other major stressors (i.e. synergistic effects, such as fire, invasive species and other disturbance) to influence ecosystem structure and function?
2. What adaptation strategies, including improvements to current strategies and management, including new thinking, could be used to improve the resilience of key species and communities?

- What will be the distribution shifts and traits/characteristics associated with this change of native and exotic species studied and what are the implications for conservation planning and landscape design?

Marine Ecosystems

1. In sessile marine invertebrates, which taxa and attributes are effective as indicators of the condition and trend in marine habitats?
    - In environments such as marine areas, where comparatively little is known about biodiversity and ecosystem processes, what can we do to strengthen and validate the use of surrogates for identifying biodiversity for protection?
    - What implications might changing marine invertebrate distributions have for the representativeness of marine parks?
2. Which species (within context of species being studied in TREND) and which environmental settings are most likely to be impacted – positively or negatively – as a result of climate change? What will change (e.g., growth, survival)? When are changes likely to be observed?
3. What are the implications of these results for developing adaptation strategies in the marine environment?
4. Where are the centres of sessile invertebrate biodiversity and endemicity that can be used as inputs of representativeness of biodiversity for marine park planning? How do we model these inputs? How will these centres change over time?
5. How can TREND inform considerations for marine adaptation and management? That is, how will changing marine invertebrate distributions affect the representativeness of marine parks?
6. Which species within assemblages being studied in TREND are the most vulnerable to climate change? What are likely to be the impacts? Which species should we be focusing our adaptation efforts on, and what are likely to be the best adaptation measures to implement?
7. What are the fine scale changes we expect in oceanography in the gulf? (e.g. salinity, temperature)

Primary Production

1. What is the residual vulnerability (impact from climate change after cost effective adaptation steps have been taken), in terms of farm viability of different agricultural regions and industries?
2. What is the vulnerability in terms of environmental degradation (e.g. wind and water erosion) of different agricultural regions and industries?

2.5.2 Theme performance against milestones, deliverables and KPIs

Table 12: Performance of the Policy Translation theme against project milestones and KPIs

Milestone	KPI	Response
4.1 Develop policy questions, issues and first order recommendations from data	Policy briefs produced from analysed data (at least one key issue from each area) Mechanism established to ensure ongoing monitoring and reporting of data	Policy briefings have been produced with at least one public workshop for each theme.
Completed/On track	Delayed	Severe impediment to progress

3 Project outputs

3.1 Presentations

- Alexander, A., Atkinson, I., **Mills, S.**, Higgs, P. & Baird, J. (2010) A look at the role mobile devices might play in the changing research environment *eResearch Australasia Conference*, Gold Coast QLD, November 2010
- **Caddy-Retalic, S.** (2013) TREND Citizen Science *4th Annual Terrestrial Ecosystem Research Network Symposium*, Canberra ACT, January 2013
- **Caddy-Retalic, S.**, Sparrow, B. & **Thurgate, N.** (2013) Building new ecological plot infrastructure to enable Australian science *EcoTas2013: 5th Joint Conference of the New Zealand Ecological Society and Ecological Society of Australia*, Auckland New Zealand, November 2013
- **Caddy-Retalic, S.** & Fox, I. (2014) The Australian Transect Network *TERN AusPlots and Australian Transect Network Seminar,* CSIRO Darwin NT, March 2014
- **Guerin G.R**. (2011) TREND: Transect for Environmental Monitoring and Decision Making: Use of collections and collections data in climate change research *Connecting Collections. For a New Generation of Interdisciplinary Research, Scientific Collections International*, Melbourne Museum, VIC, February 2011.
- **Guerin, G. R.** (2011) TREND: Transects for Environmental Monitoring and Decision Making *Terrestrial Ecosystem Research Network Multi-Scale Plot Network: Facility Establishments and Planning Workshop*, Adelaide, March 2011
- **Guerin, G. R.** (2014) Are the Flinders Ranges a good climate change analogue for future vegetation in the Mount Lofty Ranges? *South Australian Climate Change Adaptation Show Case*, Adelaide, February 2014
- **Hayman, P. T.** (2011) Four ways to think about future climates: Combining spatial and temporal analogies with climate change projections and sensitivity analysis *NCCARF workshop on uncertainty in adaptation*, Cairns QLD, April 2011
- **Hayman, P. T.** (2012) Goyder, the man and the map *Friends of the Arid Lands Botanic Gardens*, Pt Augusta SA, August 2012
- **Hayman, P. T.** (2012) *Northern and Yorke NRM Board Meeting* Clare SA, May 2012
- **Hayman, P. T.** (2012) Presentation and workshop with Upper North Farming Systems Group, Orroroo SA, 2012
- **Hayman, P. T.** (2013) Presentation to the *Future Farming Workshop*, Eudunda SA, March 2013
- **Hayman, P. T.** (2013) Shifting Cropping Zones *Mallee Sustainable Farming Systems Annual Conference* Mildura VIC, June 2013
- **Hayman, P. T.** (2013) Modelling the future, playing with the future, remembering the future and visiting the future – four complementary ways to think about future climate change *NCCARF Climate Adaptation, Knowledge and Partnerships* Sydney NSW, June 2013
- **Hayman, P. T.** (2013) South Australian experience in climate change adaptation *NSW Department of Primary Industries Climate Change Program*, Canberra ACT, September 2013
- **Hayman, P. T.** (2013) Applying climate science in South Australia: lessons from the last decade [Plenary Presentation] *Greenhouse 2013* Adelaide SA, October 2013
- **Hayman, P. T.** (2013) Climate change: a state and regional context [Keynote Presentation] *Goyder's Line Sustainability Hub Launch* Pt Pirie SA, March 2014
- **Hayman, P.** & Mudge, B. (2012) Drought or Aridity; notes from the northern edge of the South Australian Grains Belt and southern end of the Murray Darling Basin *NCCARF Climate Adaptation in Action Conference*, Melbourne VIC, June 2012
- **Hayman, P. T.** & Nidumolu, U. (2010) Is Goyder's Line relevant in a changing climate? Keynote presentation to *Australian & New Zealand Maps Society* Adelaide, July 2010
- **Hayman, P. T.** & **Thomas, D.** (2012) Visiting the future by walking down the hill: using spatial analogues for impacts and adaption planning in viticulture *Climate Change Research Strategy for Primary Industries Conference* Melbourne, November 2012
- **Lowe, A. J.** (2013) Space as a proxy for time: The Australian Transect Network *4th Annual Terrestrial Ecosystem Research Network Symposium*, Canberra ACT, January 2013
- **Lowe, A. J.** (2013) Creating Resilient Landscapes *Barossa Grape and Wine Association Workshop*, Tanunda SA, March 2013

- **Lowe, A. J.** (2013) Life Strikes Back: How the explosion in genomic information is helping to protect life on Earth *Macquarie Bank Foundation*, Adelaide SA, April 2013
- **Lowe, A. J.**, **Caddy-Retalic, S., Guerin,** G., Andersen, A., Rossetto, M., van Leeuwen, S. & **Sweeney, S.** (2013) TREND and the Australian Transect Network: Windows to our future environment *TREND Human Dimensions Symposium*, Adelaide SA, April 2013
- **Sweeney, S.** (2012) Turning science into policy: An Example of Science – Policy Translation from the South Australian Government *NCCARF Climate Adaptation in Action Conference*, Melbourne VIC, June 2012
- **Sweeney, S.** & **Caddy-Retalic, S.** (2013) Climate change science into policy: the TREND experiment in South Australia *4th Annual Terrestrial Ecosystem Research Network Symposium*, Canberra ACT, January 2013
- **Thomas, D. S.** (2013) Visiting the future by walking down the hill: Vineyard temperature and grapevine phenology *SARDI Divisional Science Symposium*, Adelaide SA, September 2013
- **Thomas, D. S.** & **Hayman, P. T.** (2012) Visiting the future by walking down the hill: Using spatial analogues for impacts and adaption planning in viticulture *Climate Change Research Strategy for Primary Industries (CCRSPI)*, Melbourne VIC, November 2012
- **Thomas, D. S.** & **Hayman, P. T.** (2013) Understanding vineyard temperature variability and implications on grape quality *Creating Resilient Landscapes in the Barossa: Barossa Grape and Wine Association* Barossa Valley SA, September 2013
- **Thomas, D. S.**, **Hayman, P. T.** & McCarthy, M. (2013) Can temperature mesoclimates within vineyards be used as spatial analogues for climate change? *Presentations on Goyder's Line and Spatial Analogues* Adelaide SA, November 2013

3.2 Publications

Published:

- **Breed, M. F.**, **Christmas, M. J.** & **Lowe, A. J.** (2014) Higher levels of multiple paternities increase seedling survival in the long-lived tree *Eucalyptus gracilis* PLoS ONE (accepted Feb 2014)
- **Breed, M. F.**, Marklund, M. H., Ottewell, K. M., Gardner, M. G., Harris, J. B. & **Lowe, A. J.** (2012) Pollen diversity matters: revealing the negelected effect of pollen diversity on fitness in fragmented landscapes *Molecular Ecology* 21(24) pp. 5955-68
- **Breed, M. F.**, Ottewell, K. M., Gardner, M. G. & **Lowe, A. J.** (2011) Clarifying climate change adaptation responses for scattered trees in modified landscapes *Journal of Applied Ecology* pp. 637-641
- **Breed, M. F.**, Ottewell, K. M., Gardner, M. G., Marklund, M. H. K., **Dormontt, E. E.** & **Lowe, A. J.** (2014) Mating patterns and pollinator mobility are critical traits in forest fragmentation genetics *Heredity* DOI: 10.1038/hdy.2013.48
- **Breed, M. F.**, Ottewell, K. M., Gardner, M. G., Marklund, M. H. K., Stead, M. G., Harris, J. B. C. & **Lowe, A. J.** (2012) Mating system and fitness resistance to habitat fragmentation in *Eucalyptus incrassata* *Heredity* DOI: 10.1038/hdy.2012.72
- **Breed, M. F.**, Stead, M. G., Ottewell, K. M., Gardner, M. G. & **Lowe, A. J.** (2013) Which provenance and where? Seed sourcing strategies for revegetation in a changing environment *Conservation Genetics* 14 (1) pp. 1-10
- **Guerin, G. R.**, **Biffin, E.**, **Jardine, D.**, **Cross H. B.** & **Lowe, A. J.** (2014) A predictive framework for monitoring multivariate species occurrences and phylogenetic shifts along a landscape-scale transect in Mediterranean southern Australia *Journal of Vegetation Science* 25(2) pp. 338-348
- **Guerin, G. R.**, **Biffin, E.** & **Lowe, A. J.** (2013) Spatial modelling of species turnover identifies ecotones, climate change tipping points and vulnerable taxonomic groups *Ecography* 36(10) pp. 1086-1096
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- **Hayman, P. T.**, Nidumolu, U. B., Howden, S. M., **Thomas, D. S.** and **Alexander, B. M**. (in prep) Future shifts in the margins of the South Australian grains belt depend on climate and technology: grower perceptions and model projections *Climatic Change*
- **Mills, S., Thomas, D.S.** & **Hayman P. T.** (in prep) Low cost temperature sensors for viticulture *Agricultural and Forest Meteorology*
- Ottowell, K. M., Bickerton, D. C., Byrne, M. & **Lowe, A. J.** (submitted) A genetic assessment framework for population-level threatened plant conservation priorities and decision-making *Diversity and Distributions*
- **Tanner, J. E.**, Mellin, C., Parrott, L. & **Bradshaw, C. J. A.** (submitted) Fine-scale benthic biodiversity

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- **Thomas, D. S.** & **Hayman, P. T.** (in prep) Testing APSIM phenology in SA grains belt – the importance of local temperature recording *Crop and Pasture Science*

4 Industry Links and collaborations

The Primary Production theme has been collaborating with Dr Scott Mills from ScienceMob and the Bureau of Meteorology (BoM) to test and standardise temperature sensors in the field and at the BoM Kent Town office and field weather stations. These sensors are used at the National Variety Trials (NVT) instigated by the Grains Research Development Corporation (GRDC) where a wide range of wheat varieties are sown for industry comparison. Experimental work on grape development was conducted in partnership with the Grape and Wine RDC through the SA North group and collaboration with Yalumba wine company in the Eden Valley and Henshke's at Lenswood.

TREND Terrestrial Ecosystems have established strong collaborations with several organisations and leveraged the initial PSRF funds to secure substantial in-kind contributions for DNA analysis. Through partnership with the Terrestrial Ecosystem Research Network, BioPlatforms Australia have made available Next Generation Sequencing capabilities to allow investigation of variation in expressed genes across plant families and environmental gradients in the TREND region. BioPlatforms Australia has also provided initial metagenomic screenings of soil samples from sites along the transect. This work will help develop rigorous protocols for the genetic sampling of Australian biomes (particularly in arid regions).

TREND continues to heavily collaborate with the Terrestrial Ecosystems Research Network (TERN). The methodology used to survey terrestrial ecosystems sites is based upon (and compatible with) the methodology developed by the TERN AusPlots Rangelands facility. All data collected from the TREND plots are compatible with the TERN Eco-informatics facility's Australian Ecological Knowledge and Observation System (ÆKOS), a project to house, integrate and make publicly available, systematically collected, plot-based ecological data. Data ingestion into AEKOS have commenced, which once finalised, will allow all terrestrial data to be accessed by any member of the public, and combined with other data sets (including DEWNR land data sets). TREND data is also being used as an exemplar data set for the new Soils to Satellites tool, which facilitates the online visualisation and manipulation of complex data sets to answer novel research questions. TREND has developed a relationship with the CSIRO National Soils Archive and South Australian Herbarium to house the plant and soil samples collected in field surveys.

5 Whole Program report against Activities, Deliverables & KPIs

On 22 May 2012, TREND Program Manager Stefan Caddy-Retalic wrote to DFEEST requesting a one year, no-cost extension to the TREND program to allow additional data to be collected and synthesised. On 8 June 2012, Adrienne Niewenhuis, in her capacity as Delegate for the Minister for Science and Information Economy agreed to this extension (Appendix 1). As a result of this change, final milestones have been extended to April-May 2014.

Table 7: Overall performance of the program against project milestones and KPIs

TREND Activities and KPIs		
Activity	KPI	Tracking
1.2 Combine analysis of new and existing terrestrial biodiversity, productive and marine system data	Data entered in to the database Publication of synthesised data in peer reviewed periodicals Findings collated in the final report	All new data terrestrial ecosystems data have been either published as online datasets with journal articles, or in TERN's AEKOS database (for sharing ecological plot data). Primary production data has been collated and stored in PIRSA's secure database, Objective. A number of syntheses have been published in peer reviewed journals (listed and summarised above). Further publications are currently in the process of being drafted and reviewed.
2.2 Continue monitoring a range of sites along environmental gradients (transects) in terrestrial biodiversity, productive and marine systems	Transect locations continued to be monitored and collected data detailed in the final report	Data has been collected and databased for all themes. Several synthesis papers from terrestrial themes have been published in leading journals. Primary production and marine syntheses currently in preparation with publication expected this year. Collected data are summarised above. Terrestrial Ecosystems sites have been taken up as a part of the Commonwealth-funded Australian Transect Network. The TREND Transect continues to be monitored and extended. To date the ATN has funded an additional 35 TREND sites. The concept of space as proxy for time to be used in new 3 year project on primary production funded as part of DAFF Filling the Research Gap. Led nationally by CSIRO with 5 transects. SA transect to be led by SARDI.

3.2 Experimental manipulation of species or strains along environmental gradients (transects) in terrestrial biodiversity, production and marine systems	Data entered into the database Findings outlined in the final report	Terrestrial Ecosystem common garden experiment to test seed provenancing strategies completed and results published. Production theme translocations completed. Results of experimental manipulations are summarised in theme reports above.
4.1 Develop policy questions, issues and first order recommendations from data 4.2 Community consultation and engagement 4.3 Community monitoring developed 4.4 Incorporate feedback from policy makers, the community and industry into the monitoring sites along environmental gradients (transects) in terrestrial biodiversity and marine systems.	Policy briefs produced from analysed data	Policy workshops and briefs have been produced. Key findings made available for planning through briefings with NRM groups. Economic analysis and journal paper on thresholds for cropping on SA transect prepared as part of linked NCCARF project
	Public outreach tools allow for perpetual data collection	Citizen science software produced and available for perpetual download. Photo points for monitoring of fire recovery in National Parks established in partnership with DEWNR. Ongoing funding for this work will be pursued.
	Data sourced from the community and industry included in the final annual report	Data streams online and continues to be gathered and will be the subject of continued search for funding and partners.
	Mechanism established to ensure ongoing monitoring and reporting of data	Terrestrial Ecosystems plots have been adopted by the Australian Transect Network within the Terrestrial Ecosystem Research Network (TERN), ensuring continued data collection and reporting.
Completed/On track	Delayed	Severe impediment to progress

6 Budgetary Statements

7 Appendices

1. Agreement to extend the TREND program by one year
2. Budgetary statements
3. TREND Personnel
4. TREND Citizen Science Photopoint sign

Appendix 3: TREND Personnel

Name	Theme	Role	% FTE
Bronya Alexander[2]	Primary Production	Climate Scientist	0.2 (2011-12)
Ed Biffin[1]	Terrestrial Ecosystems	Postdoctoral Fellow	1.0 (2010-14)
Corey Bradshaw[1, 2]	Marine Ecosystems	Research Leader	0.1 (2010-14)
Martin Breed[1]	Terrestrial Ecosystems	Postdoctoral Fellow	0.1 (2012-13)
Stefan Caddy-Retalic[1]	All	TREND Coordinator	0.8 (2012-14)
Aria Colton[1]	All	Communications	0.5 (2011-2)
Hugh Cross[1,3]	Terrestrial Ecosystems	Postdoctoral Fellow	0.5 (2010-13)
Eleanor Dormontt[1]	All	Science Communication & GIS	0.3 (2012)
Alex Dobrovolskis[2]	Marine Ecosystems	Marine Ecologist	0.45 (2011-12)
Kieren Fleming[1]	Citizen Science	Mobile App Developer	1.0 (2011-12)
Greg Geurin[1]	Terrestrial Ecosystems	Postdoctoral Fellow	1.0 (2010-14)
Peter Hayman[2]	Primary Production	Research Leader	0.25 (2010-14)
Duncan Jardine[1]	Terrestrial Ecosystems	Research Assistant	1.0 (2010-12)
Andy Lowe[1, 3]	All	Primary Investigator	0.25 (2010-14)
Leonardo Mantilla[2]	Marine Ecosystems	Marine Biologist	0.06 (2011)
Irene Martín-Forés[1]	Terrestrial Ecosystems	Visiting Fellow	0.2 (2013)
Michael McCarthy[2]	Primary Production	Viticulture Scientist	0.2 (2012-13)
Kimberly McCallum[1]	Terrestrial Ecosystems	Honours Student (2011)	1.0 (2011)
Scott Mills	Primary Production	Technology Consultant	(2010-2012)
Ian Moody[2]	Marine Ecosystems	Researcher	0.1 (2012)
Jason Nichols[2]	Marine Ecosystems	Researcher	0.1 (2011)
Kathy Ophel-Keller[2]	Primary Production	Research Scientist	0.05 (2010-13)
Susan Sweeney[3]	Policy Translation	Senior Project Officer	0.25 (2010-13)
Shirley Sorokin[2]	Marine Ecosystems	Research Officer	0.1 (2011)
Jason Tanner[2]	Marine Ecosystems	Researcher	0.2 (2010-14)
Dane Thomas[2]	Primary Production	Researcher	1.0 (2010-14)
Nikki Thurgate[1]	Terrestrial Ecosystems	Ecologist	0.2 (2011-13)
Andrew Tokmakoff[1]	Citizen Science	Mobile App Developer	0.1 (2012-14)
Haixia Wen[1]	Terrestrial Ecosystems	Visiting Fellow	0.5 (2011-12)
Kathryn Wiltshire[2]	Marine Ecosystems	Researcher	0.02 (2011)
[1]University of Adelaide [2]SARDI [3]DENR			

In addition to staff, TREND projects support a number of student projects:

Completed

- Martin F. Breed BSc MSc attained a PhD with a thesis entitled *Restoration Genetics of Murray Mallee and Neotropical Forests* (2013)
- Fran MacGillivray BSc attained a PhD with a thesis entitled *Tracking phenological shifts and evolutionary impacts related to climate change* (2013)
- Irene Martín-Forés completed a three month internship to contribute towards a PhD from the Universidad Complutense de Madrid, Spain (2013)
- Kimberly McCallum BSc (Ecology & and Evolutionary Biology) attained 1st class Honours with a thesis entitled *An integrated approach to evaluating species vulnerability and conservation*

strategies in a changing climate (2011)

- Taj Arndell BSc has completed the requirements for his Honours degree with a thesis entitled *Conservation genomics of the threatened Leafy Greenhood Orchid* Pterostylis cucullata (2013)

Ongoing

- Matthew Christmas BSc is currently in his second year of a PhD program in Ecological Genetics. He is currently investigating genetic and transcriptomic patterns of species common along the Terrestrial Ecosystems transect, namely *Dodonaea viscosa*.
- Nicholas Gellie BSc is currently in his first year of a PhD program in Conservation Biology. His project is focusing on seed provenancing and ensuring ecological plantings are robust.
- Stefan Caddy-Retalic BSc BIE is in his first year of a PhD program in Ecology. His project is focusing on optimal ways to measure environmental change.

Help us monitor our native ecosystems

How does it work?

Our native ecosystems are constantly changing. Fires, introduced species, rainfall and climate all have a strong impact on the plants and animals in our parks.

This area was burnt in October 2013. By taking photographs with your smart phone, you can help us better understand how the vegetation at Cleland responds to controlled burning.

Our scientists will combine multiple photos to form 3D models of this landscape, and how it changes over time. We can use this information to understand ecological changes, fluctuations in carbon stocks and how this ecosystem responds to disturbance.

The TREND program is a collaboration between the University of Adelaide and the South Australian government to help understand local ecosystem change and how we can best manage our parks.

How can I learn more?

You can visit the Cleland website at **www.clelandwildlifepark.sa.gov.au** or **www.trend.org.au** to see how this landscape is changing over time.

How can I help?

1. Download the TREND app using the QR code below or from www.trendsa.org/mobile.

2. Select "Record Photo Points" and use your phone to scan the QR code below.

3. Following the prompts on the app, place your phone on the left post. Line the range poles with those on your phone as shown and take the first image.

4. Repeat the previous step from the right post and submit your photo.

Government of South Australia
Department of Environment, Water and Natural Resources

PREPARE. ACT. SURVIVE. BUSHFIRE READY

trend

THE UNIVERSITY of ADELAIDE

Australian Centre for Visual Technologies

TERN

Australian Transect Network