Mapping Climate Services Capabilities in Australia

Institute for Sustainable Futures

About the authors

The Institute for Sustainable Futures (ISF) is an interdisciplinary research and consulting organisation at the University of Technology Sydney. ISF has been setting global benchmarks since 1997 in helping governments, organisations, businesses and communities achieve change towards sustainable futures. We utilise a unique combination of skills and perspectives to offer long term sustainable solutions that protect and enhance the environment, human wellbeing and social equity. For further information visit: www.isf.uts.edu.au

Research team

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Executive Summary

This project mapped the national climate services capabilities in Australia. It was undertaken by researchers at the University of Technology Sydney partnering with the National Environmental Science Program (NESP) Earth Systems and Climate Change (ESCC) Hub. The climate services capability in Australia was established around 30 years ago, mainly through development and delivery of Bureau of Meteorology (BoM) seasonal climate forecasts and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) multi-decadal climate projections, with further development of this capability through multiple providers in recent years. The climate services sector has changed rapidly over the last few years with a range of stakeholders interacting from research institutions and associated platforms, government actors (including federal, state and local government), NGOs (both international and national) and the private sector.

For this study, an online survey was developed to provide researchers with information regarding the activities of both providers and users of climate services. This information was analysed to provide advice on the sector to the Australian Government (Department of Agriculture, Water and the Environment) on behalf of the (former) National Climate Science Advisory Committee (NCSAC) as an outcome of the project "Towards a National Climate Services Capability for Australia".

The objective of this research was to map the interactions of current national climate service providers and users in Australia to show how they are linked within a market setting. Social Network Analysis (SNA) was used to analyse and visualise:

- the connections between organisations that source climate services information,
- the connections between organisations that supply climate services information,
- whole of network cohesion measures, and
- optimal channels for information diffusion through the network.

In addition to the SNA, the survey included questions regarding the type of climate services information being accessed, the rationale for selecting the specific sources, the capacity of organisations to access and utilise climate services information, how they develop climate services information products, and their reflections on the development of the sector.

Purposive sampling was undertaken with the survey being sent to contacts within priority sectors including Agriculture, Research, Finance and Insurance, Government, Water and Disaster Response. Although this is a national survey, respondents came primarily from large organisations within these sectors which may cause some level of bias in some of the results. Of the total respondents, 74 were climate service providers, 99 were climate services users, and 60 were both users and providers of climate services.

The findings demonstrated that climate information and associated services are sourced primarily from national climate service providers (e.g. CSIRO, BOM), universities, the Climate Change in Australia website, Geoscience Australia and some international climate service providers (e.g. Intergovernmental Panel on Climate Change (IPCC)). A number of participants sourced information from state and federal agencies, with some looking to the Climate Council, media and events to garner climate information. Climate information was supplied diffusely with some state level cliques.

Most information was derived freely from open sources, mostly from external organisations. Scientific validity, trust and accessibility were key reasons for selecting these sources. Information was mostly used for climate hazard analysis and impact assessments, followed by strategic planning and/or policy development, and to build new tools and products.

Over 80% of organisations felt they had the internal capacity to develop, use and share climate information and products such as decision support tools, dashboards, web applications, training and guidance material. External product development examples included developing dashboards and web mapping applications (e.g. real time air temperature), and guidance materials, to inform industry and government stakeholders, develop asset-level risk analysis and synthesis for third parties, producing reports for government on greenhouse gas emissions, translating the information to third parties in the applied space (e.g. visualisations), incorporating climate change models into existing decision support tools, factsheets and guidance, and tailored data sets to match metrics stakeholders are currently using to understand climate risk, strategic development and decision support tools (e.g. crop suitability maps).

The analysis of the survey data indicated that respondents see the climate services sector in Australia as a space that is currently in development, and identified several strengths, weaknesses and opportunities for further development and enhancement including the following:

Strengths:

- The major service providers have high credibility
- There is a lot of information
- "Climate Change in Australia" is considered a great resource
- Good seasonal forecasts from BoM
- Good international partnerships in climate science and services
- Good national partnerships between science, government and industry

Weaknesses:

- A lack of understanding of climate services within the general public
- Fragmentation, duplication, poor coordination and poor governance
- Lack of government support/investment for climate services, compared to the EU
- "Climate Change in Australia" is complicated and difficult to navigate and use properly
- Access to services can be difficult and costly
- Lack of strong public-private partnerships to deliver climate services
- Limited information on policy effectiveness of climate services
- Lack of trust in some data for decision-making
- Insufficient climate service development and user testing
- Network connections are often made on an individual to individual basis which is fragile due to organisational restructure, shifting roles and staff turnover
- Inadequate downscaled climate projections
- Difficulty translating average climate projections into extreme weather projections
- Seasonal forecasting and multi-decadal climate projections may fall below international best practice
- Difficulty translating climate information into impacts.

Opportunities:

- A coordinated and centralised climate services platform, with improved governance
- More government investment and co-investment
- Better collaboration and strategy within and between government agencies to develop a climate services platform, collaborate on science and develop policy
- Ensure the regulatory needs of the States and Territories are met
- Reinstate NCCARF or a similar national climate change adaptation research facility
- Focus on end-user needs and design principles
- Include climate services in a national climate strategy
- Further develop standards and protocols
- National downscaling simulations
- More networks for sharing information about best practice
- More education and training materials
- More tailored products for industry (e.g. regional summaries of impacts)
- Enhance extension and adoption of climate services
- Data formats that are easily accessible

In summary, the results of this survey identified that there are key actors working as knowledge hubs within the source network for climate services in Australia. These were identified to be BOM, CSIRO, IPCC and universities, with the majority of respondents accessing information from these entities. These organisations also hold key structural positions integral to information provision throughout the network. However, these connections, are highly relational, often held by individuals rather than through formal mechanisms.

It is important to note that this is a pilot study and further detailed analyses are needed. Finally, in future iterations it will be important to encourage existing sector participants to continue to participate to ensure high survey response rates and avoid possible bias due to sample size and missing data.

Contents

Introduction

This project was undertaken by researchers at the University of Technology Sydney (UTS) partnering with the National Environmental Science Program (NESP) Earth Systems and Climate Change (ESCC) Hub and the CSIRO Navigating Climate Change Mission to map the national climate services capabilities in Australia. The climate services capability in Australia was established around 30 years ago, mainly through development and delivery of Bureau of Meteorology (BoM) seasonal climate forecasts and CSIRO multi-decadal climate projections, with further development of this capability through multiple providers in recent years. A range of stakeholders are interacting in this capability, from research institutions and associated platforms, to government actors (including federal, state and local government), NGOs (both international and national) and the private sector.

An online survey was co-designed and developed with project partners at a workshop undertaken in Melbourne on January 16, 2020. This online survey provided researchers with information regarding the activities of both providers and users of climate services to provide advice to the Australian Government (Department of Agriculture, Water and the Environment/DAWE) on behalf of the (former) National Climate Science Advisory Committee (NCSAC) as an outcome of the DAWE funded "Towards a National Climate Services Capability for Australia" project being undertaken by the ESCC Hub.

The objective of this research was to map the interactions of current national climate service providers and users in Australia to show how they are linked within a market setting. Social Network Analysis (SNA) was used to analyse and visualise:

- the connections between organisations that source climate services information,
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Method

Ethics

An online survey that included SNA questions was the primary data collection tool for this research. Within this project, best practice was undertaken when informing participants about the research aims and informed consent.

The anonymised survey data was used by the primary researcher (author) and provided to the ESCC Hub as per the ethics agreement and within the information and consent form provided to participants at the beginning of the survey. As part of the University's obligation to the Australian Code for the Responsible Conduct of Research and the National Statement on Ethical Conduct in Human Research, this research received ethics approval from UTS Human Research Ethics Committee (HREC) through the UTS: ISF ethics procedure.

Data protocols

Once data were shared with research partners, they were stored in a Dropbox folder with access limited to the Project Director and Dropbox super users. Prior to analysis, all survey respondents were made anonymous and findings aggregated to a level that limits any individual being identified. In this report, the aggregated findings are described in ways that prevent individuals being identified (e.g. organisations were all categorised by sector and state-based location).

Data were managed to protect the privacy, confidentially and cultural sensitivities of all workshop participants. Research data were stored on the UTS: ISF server, which is accessible only by UTS: ISF employees through individualised passwords. All data stored on the server were de-identified and files containing master identifying lists were password protected. All versions of files on the UTS: ISF Dropbox sever are backed up for a period of 120 days, i.e. any version of a file created in this period is recoverable if deleted. Deleted files can be restored through the Dropbox interface, either by file name or by user event. Dropbox also provides priority email and live chat support for more complicated restorations.

Recruitment

Recruitment for the survey was targeted through key agents (individuals known to the project team) in various sectors including Research, Agriculture, Finance and Insurance, Government Water and Disaster Risk Response. Distribution of the survey was sent to these sectors by email over 12 – 17 February 2020 (with a reminder in March 2020). The survey was open from 12 February and closed early March 2020. Survey recruitment focused on Australia, however, there were instances of completed surveys from overseas (2 in UK, 2 in NZ). The geographical spread across Australia featured the capital cities in every state and territory, with the exception of the Northern Territory, and some regional representation in Queensland, NSW, Victoria and Tasmania (see Figure 1).

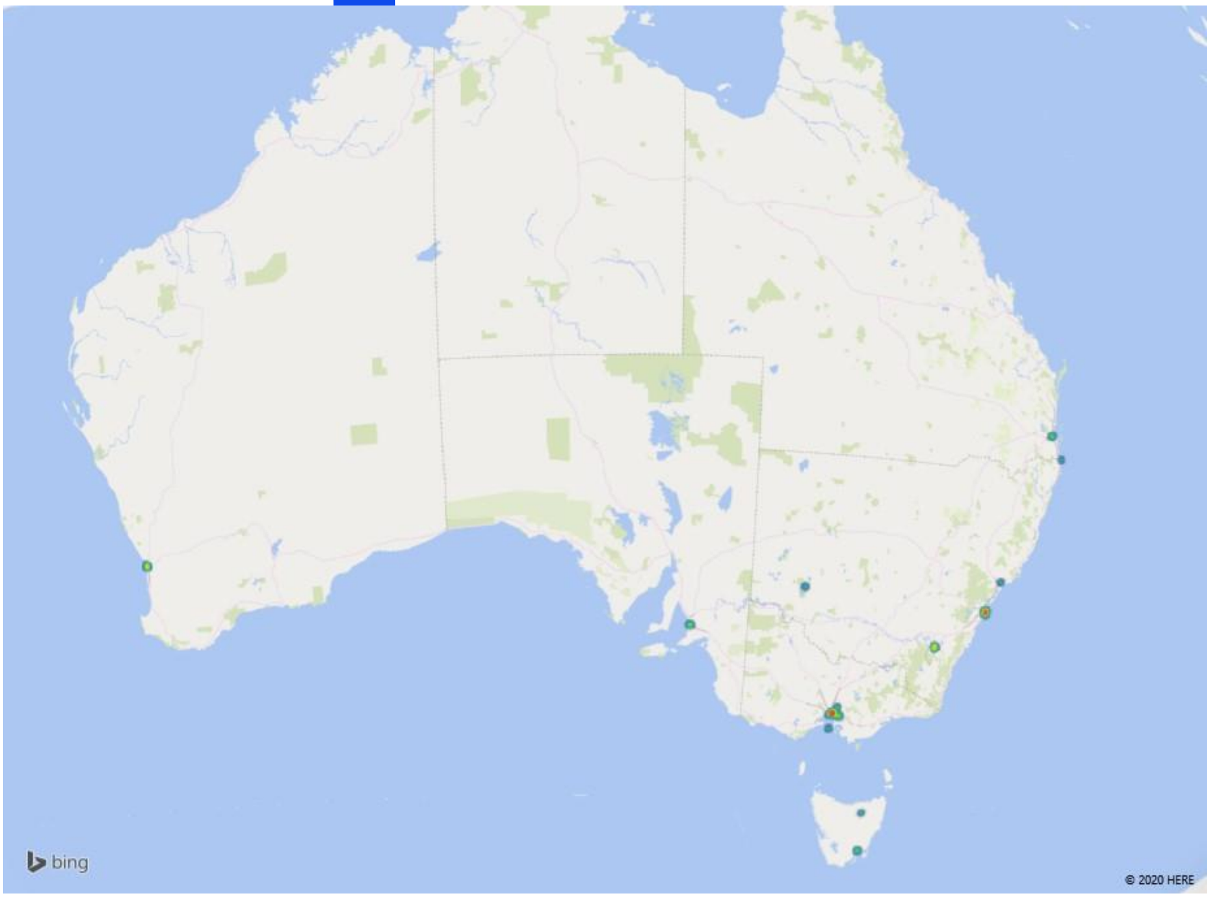

Figure 1: Locations where participants completed the survey

Social Network Analysis Procedure

Individuals were identified in three ways – by organisation size, type and location. Participants were asked to identify to which individuals and organisations they sourced and supplied climate services information. To ensure anonymity in analyses, participants were numbered (S1 – S105). Data were used to create a directed-symmetric matrix so networks could be visualised and analysed. Each participant is represented within the network as a node. Analyses and visualisations were run in UCINet (Borgatti, Everet et al. 2002) and Netdraw (Borgatti 2006). The visualisation layout uses geodesic distance to position the nodes, which forces together nodes with similar characteristics or that have similar structural positions.

Multiple cohesion values were calculated for each network with a focus on number of ties, number of connections, average degree, density, fragmentation and diameter metrics being reported. Definitions of each measure follow:

- **Average degree** is the average number of links in the network.
- **Density** is the total number of connections divided by the total number of possible connections in the network.
- **Fragmentation** measures the lack of connectivity in the network by examining the proportion of nodes that cannot reach each other within the network, with the highest fragmentation = 1.
- **Diameter** is the largest geodesic distance in the network. This metric counts the number of steps to walk through the largest component of the network.

Individual in-degree (number of incoming ties) and out-degree (number of outgoing ties) were calculated for each network.

The Keyplayer analysis involves utilising a diffusion algorithm with the aim of reaching every node in the network. It selects three initial nodes, and takes two steps into the network, offering up to 10 different arrangements of nodes that will reach the maximum percentage of all nodes within the network. Key players (diffuse) were calculated using the key player problem 1 algorithm (Borgatti 2006) which measures the nodes that have the most reach in the network. Keyplayer is a sub-package of UCINET (Borgatti, Everet et al. 2002).

Results

Within the survey, respondents were asked about their organisation (size, sector and if they were a climate services information user and/or provider), the types of information accessed and shared, the reasons why they selected specific information sources, how they used these resources, if they developed, used and shared climate information and products, how they developed and/or value added to this climate service information, the strengths and weaknesses of Australia's climate services capability, and how this capability may be enhanced in the future.

The presentation of results is arranged into four sections: 1. the organisations and climate service information utilised; 2. mapping the climate services sector with SNA; 3. qualitative analysis of how these climate service information resources are developed; and 4. strengths, weaknesses and potential future of the sector.

About the organisations and climate service information utilised

Participants from a range of organisation sizes and types completed the survey (Figure 2) including seven micro-businesses, five small business, 18 medium business, and 82 large businesses.

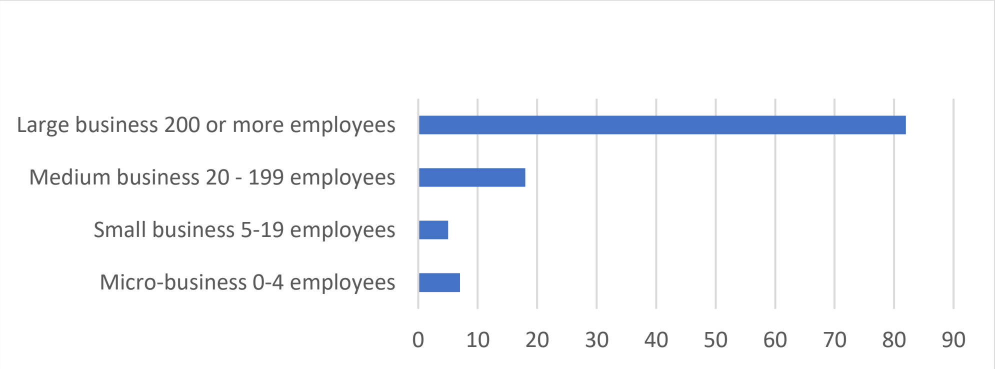

Figure 2: Organisation per size N=112

Respondents were asked to nominate their sector from: accommodation and food services; administrative and support services; agriculture; arts and recreation services; construction; disaster risk and emergency services; education and training; energy (electricity & gas); environmental services; financial and insurance services; fishing and aquaculture; forestry; health care and social assistance; information media and telecommunications; manufacturing; mining; national security (including defense); other services; professional, scientific and technical services; public administration and safety; rental, hiring and real estate services; retail trade; tourism; transport; postal and warehousing; waste and recycling services; water; and wholesale trade.

The majority of respondents were from the professional, scientific and technical services, environmental services, financial and insurance services and water. There was no response from the wholesale trade, retail, rental, hiring and real estate services or accommodation and food services sectors. A significant number of respondents selected more than one sector in which their business operated within (Figure 3).

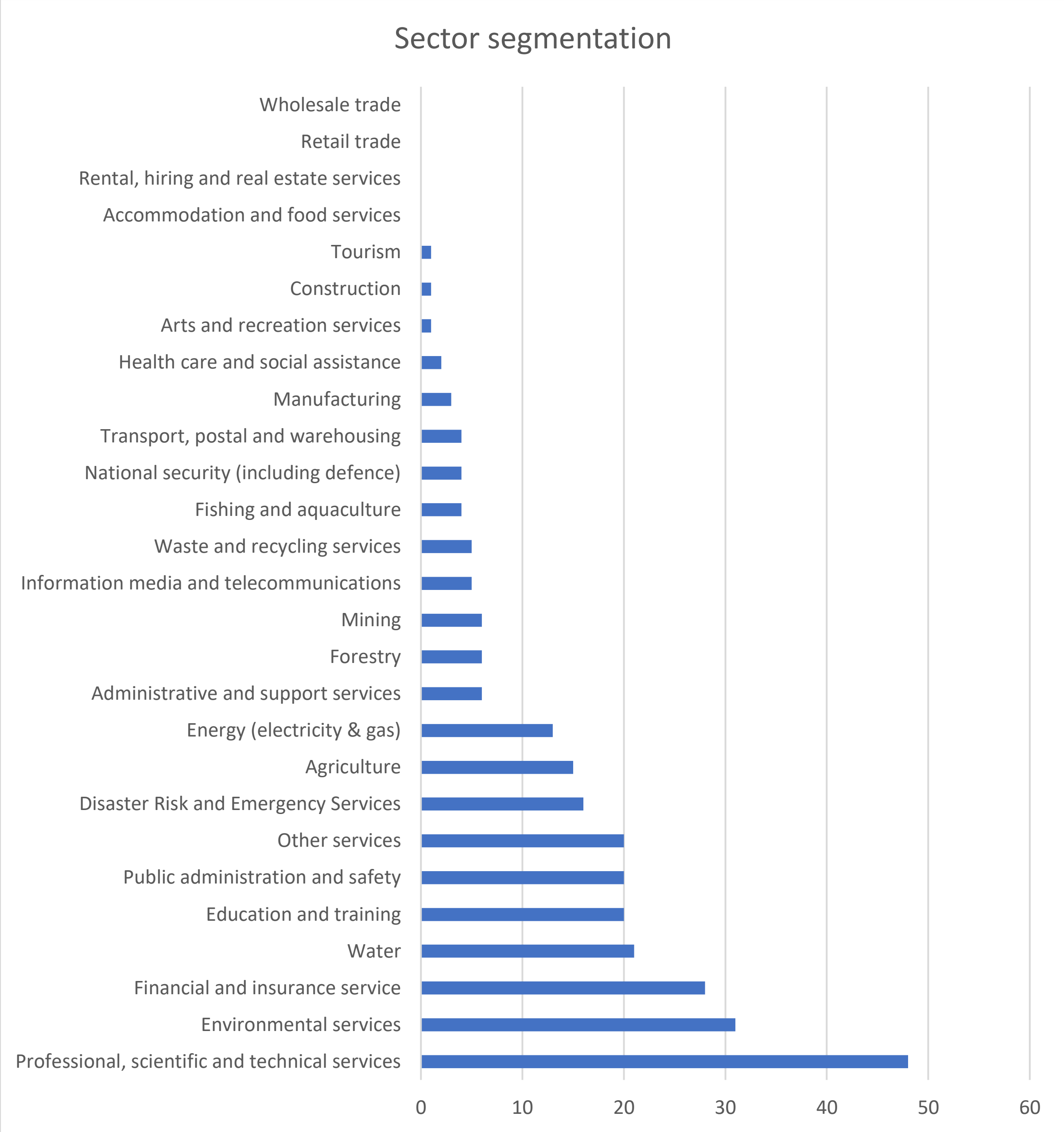

Figure 3: Sector segmentation of respondents (n=280)

When asked if they were climate service providers, 74 respondents confirmed 'yes', with 43 'no'. When asked if they were a climate services user, 99 respondents confirmed 'yes', with 18 'no' (*Figure 4*). Sixty respondents indicated they were both users and providers of climate services.

Of the 60 that responded that they were both climate service providers and users, 27 were from government, 13 from research, 13 from private sector, 5 listed other and 2 were NGOs.

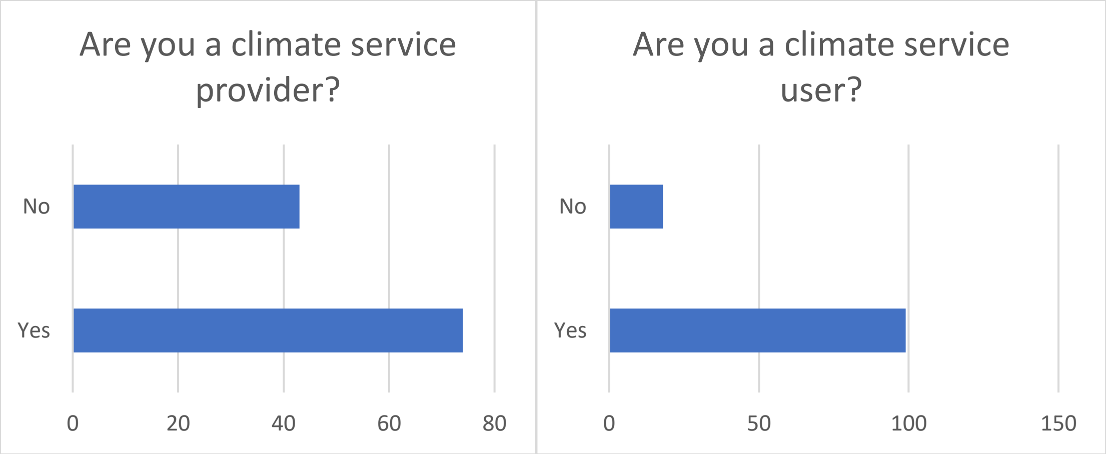

Figure 4: Climate service providers and users (N=117).

Respondents were asked to nominate what types of climate service information they used and selected from (Figure 5): climate analyses and/or scenarios; climate predictions and/or projection; climate research or technical reports; climate observations and/or data; climate scenarios; impact, risk and/or resilience assessment/management frameworks; exposure and vulnerability data and information; climate monitoring products and/or analyses; decision support tools (including portals/platforms/websites/ apps); training and education; knowledge brokering and/or other forms of technical outreach; communities of practice; opportunity and/or investment assessment frameworks; other; or none of the above. Respondents could select multiple categories. 'Other' material was classified as HPC data management and data analysis platforms, and lobbying groups.

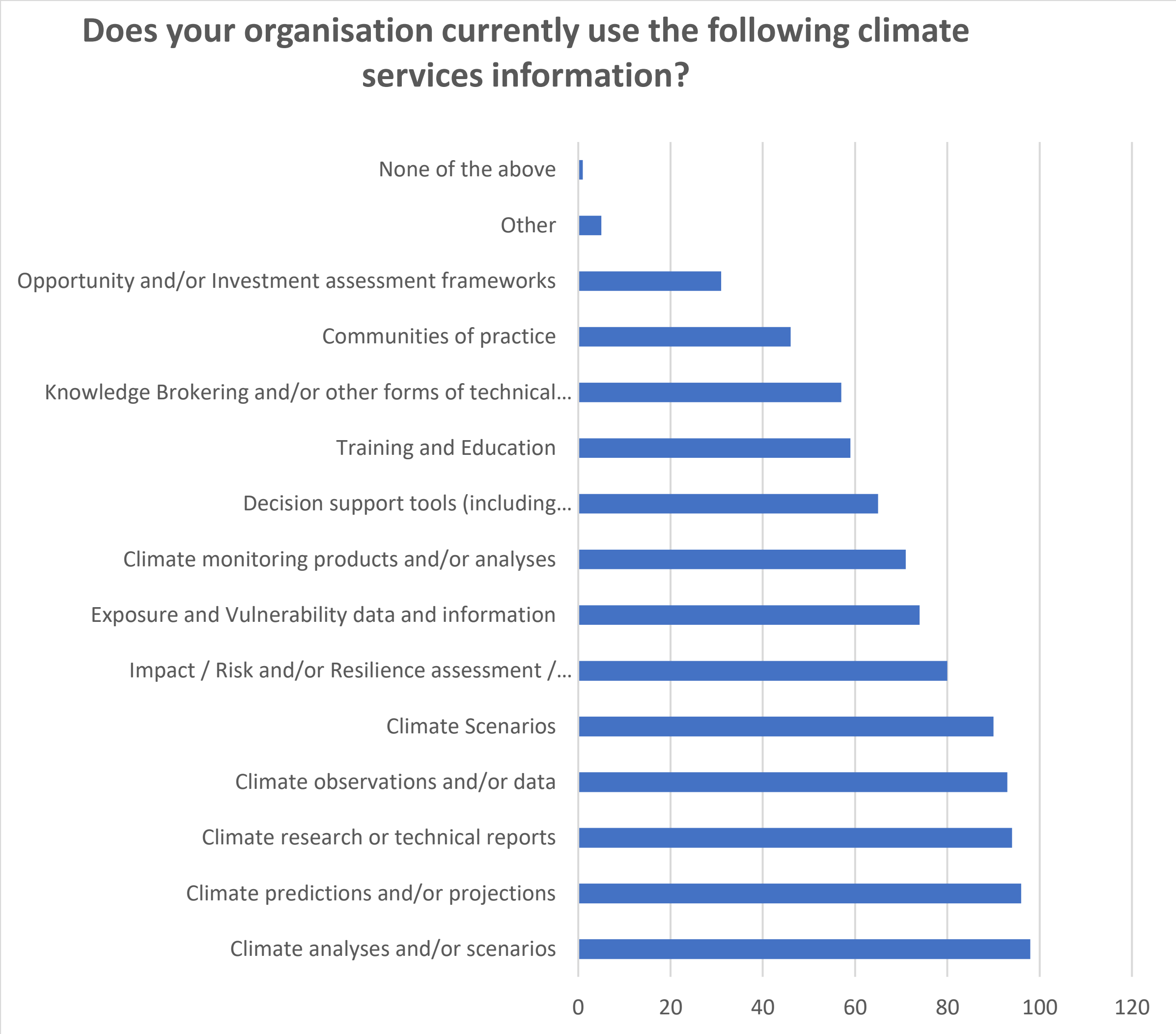

Figure 5. Climate service information used by users and providers

When asked if their organisation has the internal capacity to access and use climate-related information, 108 of 117 respondents reported that they did. This is the same number that confirmed accessing climate services information (108 of n=117) (*Figure 6*). Note: this may not speak to the extent to which the organisation has internal capacity as the individual with the capacity may be completing the survey.

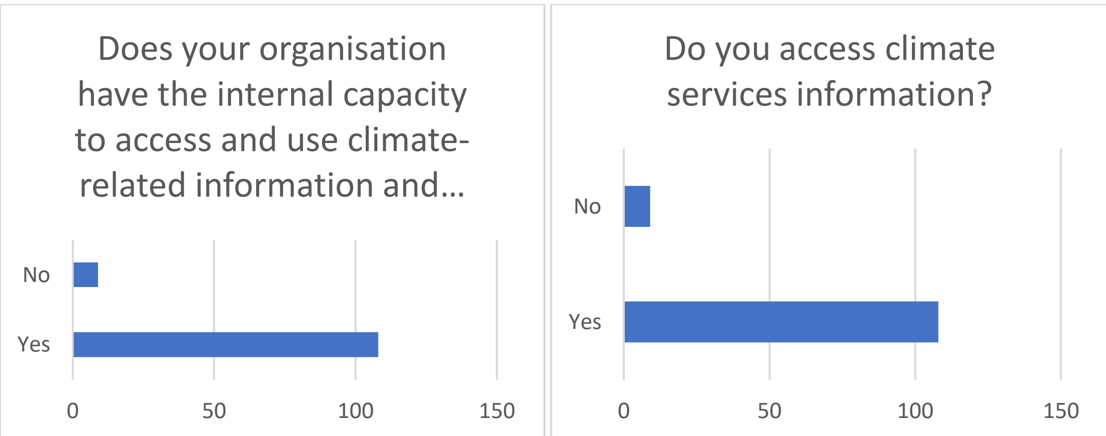

Figure 6: Internal capacity to access and use climate-related information and products; Ability to access climate services information

Mapping the climate services with Social Network Analysis

To map the climate services with social network analysis (SNA), participants were asked four key questions:

- Did they *source* climate services information?
    - (if yes) from whom
- Did they *supply* climate services information?
    - (if yes) to whom

These questions allowed the development of two networks: 1. source climate service information network, and 2. supply climate service information network.

Source Climate Service Information Network

To create the Source Climate Service Information network (hereafter, the 'source network'), participants were asked "From where (or from whom) are you / would you look(ing) to as a source of climate services information?" and were provided a list of 35 organisations including the following:

Australian Antarctic Division
Australian Capital Territory Government
Australian Institute of Marine Sciences
Bureau of Meteorology
Cooperative Research Centres
Commonwealth Scientific and Industrial Research Organisation (CSIRO)
Department of Agriculture and Water
Department of Defence
Department of the Environment and Energy (now DAWE)
Department of Foreign Affairs and Trade
Department of Health
Department of Home Affairs
Department of Industry Innovation and Science (now DISER)
Events
Geoscience Australia
International climate organisation
International Non-Government Organisation
Intergovernmental Panel on Climate Change
Local Government
New South Wales Government
Non-Government Organisation
Northern Territory Government
Other federal government
platforms (e.g. Climate Change in Australia)
Private Sector
Queensland Government
Rural Research and Development Corporations
South Australian Government
Tasmanian Government
The Climate Council
The media
Universities
Victorian Government
Western Australian Government
World Meteorological Organization
Other

Multiple organisations could be selected, and in addition to the supplied list, participants could list additional sources once "other" was selected. In addition to the 36 sources listed above, survey participants nominated an additional 105 sources of information making a total of 141 sources of climate service information. All sources and participants were categorised by organisation size, sector and location (e.g. state or territory). Tables 1, 2 and 3 show this categorisation and form a detailed legend to the network visualisations in Figure 7 and 8.

Two visualisations of the source network show the network structure and the importance of the large central nodes with a high number of inward connections (i.e. high in-degree). Figure 7 shows the network with nodes categorised by sector. Figure 8 shows the network with nodes categorised by location. There are a small number of source nodes that the majority of all participants went to for climate services information. These source nodes (BOM, CSIRO and IPCC) are acting as hubs for climate information to many nodes within the network and appear as large-sized symbols in the visualisations.

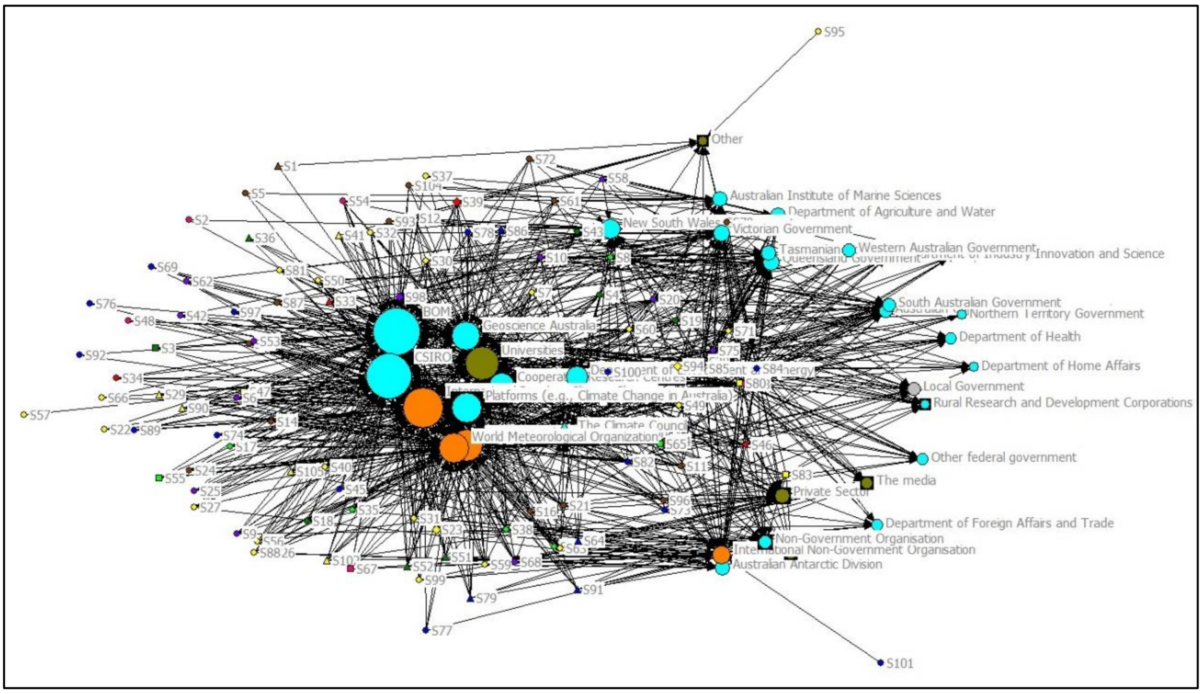

Figure 7: Visualisation of source climate services information network with nodes categorised by sector.
Node colour represents Sector: Green = Agriculture, Fishing and aquaculture, Water; Red = Disaster Risk and Emergency Services; Purple = Education and training; Light green = Environmental services; Blue = Financial and insurance service; Pink = Other services; Yellow = Professional, scientific and technical services; Brown = Public administration and safety; Grey = Local; Light blue = National; Orange = International; Khaki = Various. Shape of nodes represents Organisation type: Various = circle in square; Micro = Square; Small = diamond; Medium = Triangle; Large = Circle. Size of the node denotes in-degree: the larger the node, the greater the in-degree of that node.

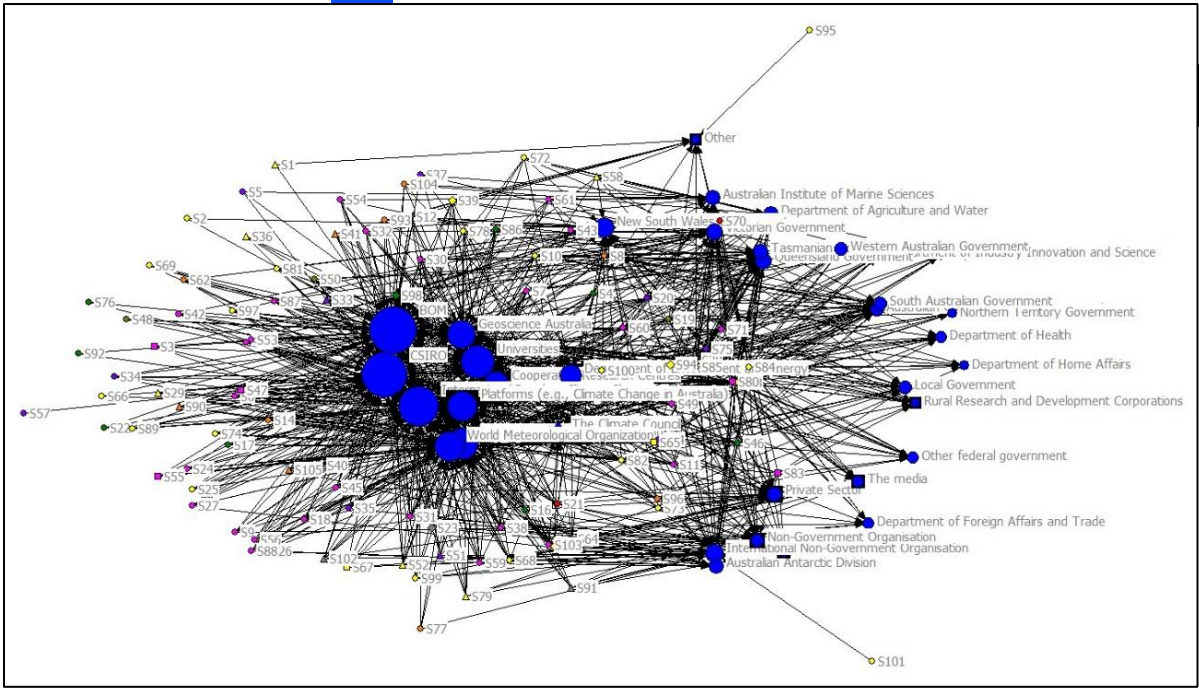

Figure 8: Visualisation of source climate services information network with nodes categorised by location.
Node colour represents organisation location: Blue = Multiple; Orange = ACT; Yellow = NSW; Green = QLD; Red = SA; Purple = Tas; Pink = VIC; Khaki = WA; International = Grey. Shape of nodes represents Organisation type: Various = circle in square; Micro = Square; Small = diamond; Medium = Triangle; Large = Circle. Size of the node denotes in-degree: the larger the node, the greater the in-degree of that node.

Table 1: Participants segmented by organisation size and symbols used in visualisation

Organisation Size	Number of nodes per group	Legend Shape
Various	7	Square in a circle
Micro-business 0-4 employees	7	Square
Small business 5-19 employees	4	Diamond
Medium business 20 - 199 employees	17	Triangle
Large business 200 or more employees	106	Circle

Table 2: Participants and sources segmented by sector type / scale

Participant Sector Type / Source Type	Number of nodes per group	Legend Colour
Agriculture, Fishing and aquaculture, Water	8	Green
Disaster Risk and Emergency Services	4	Red
Education and training	12	Purple
Environmental services	7	Light green
Financial and insurance service	18	Blue
Other services	7	Pink
Professional, scientific and technical services	33	Yellow
Public administration and safety	16	Brown
Local	1	Grey
National	26	Light Blue
International	4	Orange
Various	5	Kaki

Table 3: Participants and sources segmented by location

Organisation location	Number of nodes per group	Legend Colour
Multiple	26	Blue
Australian Capital Territory (ACT)	12	Orange
New South Wales (NSW)	34	Yellow
Queensland (QLD)	9	Green
South Australia (SA)	2	Red
Tasmania (TAS)	10	Purple
Victoria (VIC)	32	Pink
Western Australia (WA)	3	Kaki
International (INT)	3	Grey

Source network multiple cohesion measures

UCINET's whole network multiple cohesion measures, key player 'diffuse', and in and out-degree centrality algorithms were used to analyse how information was sourced within the source climate services information network. The total number of nodes for this network was 141 with total ties of 1094. The relevant measures were (Table 4):

- **Average degree** is the average number of links in the network. The average degree was 7.759.
- **Density** is the total number of connections (n=1094) divided by the total number of possible connections in the network. The density of this network was 0.055.
- **Fragmentation** measures the lack of connectivity in the network. The fragmentation figure was 0.945 indicating this is a highly fragmented network.
- **Diameter** estimates the number of steps to reach everyone in the network, i.e. 'Bacon's Law' and 'six degrees of separation'(Cunningham, Jacobs et al. 2017). The diameter of the network was 1. This indicates that all individuals in the major component of the network could be reached in one step and that the network was connected.

Table 4: Summary of the multiple cohesion measure metrics for the source network

Metric	
# of nodes	141
# of ties	1094
Average degree	7.759
Density	0.055
Fragmentation	0.945
Diameter	1

As there is a high fragmentation figure coupled with a low diameter, this indicates there may be hubs within the network that can contact the majority of nodes.

Keyplayer

The Keyplayer analysis demonstrated that, with the best arrangement of the same three individuals - nodes of S84 (Finance and insurance service – Large organisation), S80 (Professional, scientific and technical services – Micro organisation) and S13 (Education and training – Large organisation), only 26.087% of the network of the network could be reached, i.e. less than a quarter of all nodes (Table 5).

Table 5: Key player (diffuse) in the source climate services information network

Key player query run	Key player (diffuse)	Key player (diffuse)	Key player (diffuse)	Nodes reached (%)
1	S84 – Finance and insurance service – Large	S80 – Professional, scientific and technical services - Micro	S13 – Education and training - Large	26.087%

In-degree and Out-degree Centrality

Individual in-degree (number of incoming ties) and out-degree (number of outgoing ties) were calculated for each node (complete in-degree and out-degree centrality measures for all nodes in the Source Climate Service Information network can be found in Appendix A). These measures demonstrate which nodes were sending (out-degree) or receiving (in-degree) information throughout the network. As each of the survey participants (S1 – S105 in Figures 7 and 8) were not identifying each other, the source nodes receive all the incoming ties with participants having all outgoing ties (out-degree). In-degree figures of sources ranged from 96 (BOM) to 6 (Department of Defence) with participants showing out-degree ranging from 1-36 ties. This is due to the style of survey question wherein participants could list multiple sources. Appendix A shows degree centrality for all nodes sorted by in-degree centrality (highest to lowest) and out-degree centrality (highest to lowest). The main sources of climate information are BoM, CSIRO, IPCC, universities, international climate organisations, the Climate Change in Australia website, WMO, Geoscience Australia, CRCs, the Climate Council and Federal Department of Environment and Energy (now mostly DAWE). The main users of climate information are finance and insurance, professional scientific and technical services, education and training, and the Federal government.

Supply Climate Service Information Network

To create the supply network, participants were asked, “Do you supply climate services information?” If participants answered “yes” they were then asked, “To whom do you supply climate services information?” with the option to list up to five organisations. The response rate for this SNA survey query was very low with only 32 respondents to these questions. In addition, many participants listed organisations or departments rather than specific individuals, or specific groups such as ‘general public’ or ‘media’. The ‘general public’ in this instance was grouped into a single node, although it is made up of an unknown number of individuals across numerous locations.
The supply network consisted of a total of 124 nodes including the 32 respondents. Again, participants were categorised by organisation size, sector and location (e.g, state or territory) (Tables 6 & 7). As with information supply, the source network was visualised in two ways being network: nodes categorised by sector (Figure 9), and by location Figure 10).

The prevalence of the professional, scientific and technical services (yellow nodes) is apparent, as is the public administration and safety (brown) and other services (pink) organisations. Unlike the source network, the supply network was more fragmented with two major components, six star arrangements and five dyads indicating unique networks. Importantly large organisations such as CSIRO appear multiple times within this visualisation as there were multiple staff listed in these organisations. Large businesses count for the majority of nodes with professional, scientific and technical services alongside public administration and safety being the largest sectors. In this network, government departments (Federal and State) are categorised by sector as public administration and safety rather than national or local as in the source network.

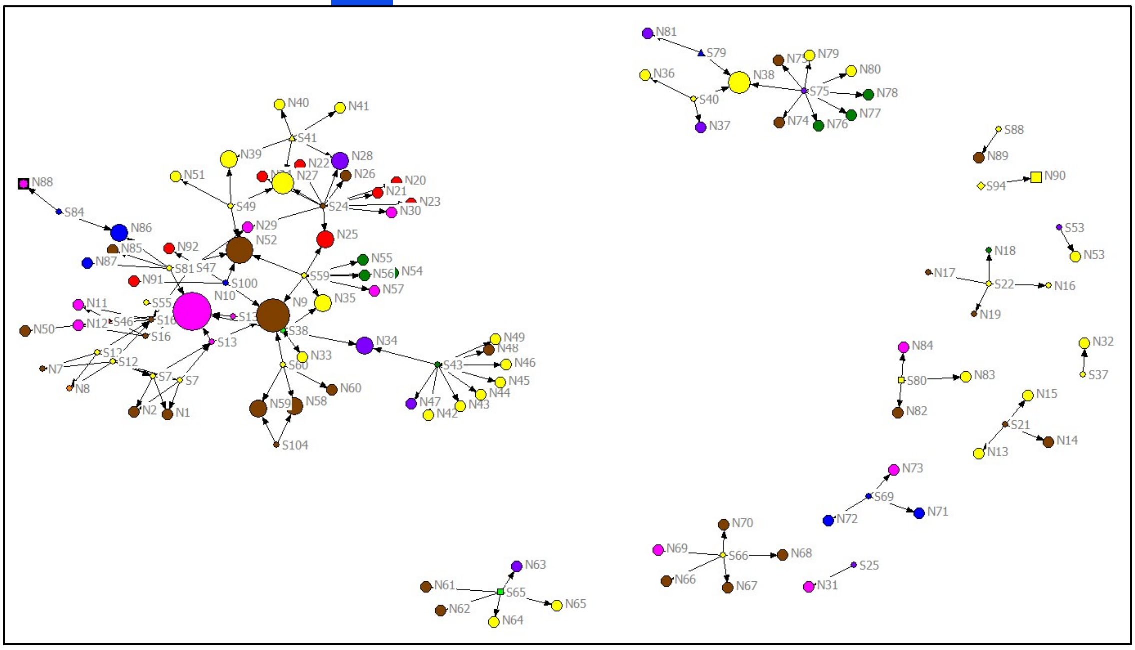

Figure 9: Visualisation of supply climate services information network with nodes categorised by sector.
Node colour represents Sector: Green = Agriculture, Fishing and aquaculture, Water; Red = Disaster Risk and Emergency Services; Purple = Education and training; Light green = Environmental services; Blue = Financial and insurance service; Pink = Other services; Yellow = Professional, scientific and technical services; Brown = Public administration and safety; Orange = International. Shape of nodes represents Organisation type: Various = circle in square; Micro = Square; Small = diamond; Medium = Triangle; Large = Circle. Size of the node denotes in-degree: the larger the node, the greater the in-degree of that node.

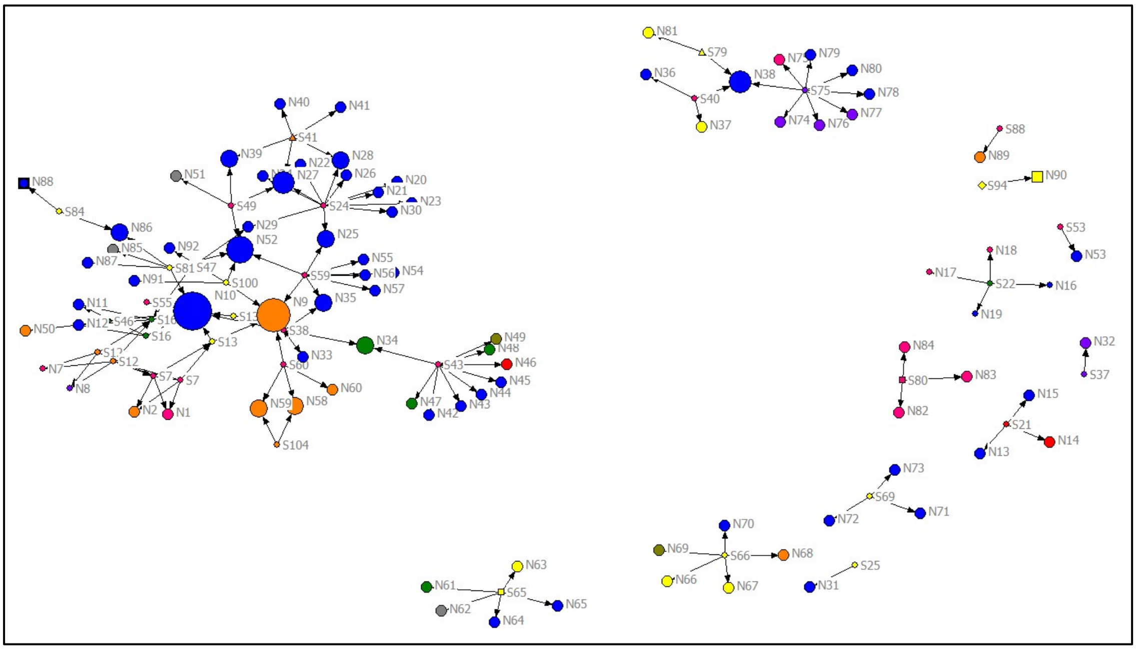

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Table 6: Participants segmented by organisation size

Organisation Size	Number of nodes per group	Legend Shape
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Micro-business 0-4 employees	4	Square
Small business 5-19 employees	1	Diamond
Medium business 20 - 199 employees	2	Triangle
Large business 200 or more employees	116	Circle

Table 7: Participants and sources segmented by sector type / scale

Participant Sector Type / Source Type	Number of nodes per group	Legend Colour
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Financial and insurance service	8	Blue
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Professional, scientific and technical services	43	Yellow
Public administration and safety	32	Brown
Local	0	Grey
National	0	Light Blue
International	1	Orange
Various	0	Kaki

Supply network multiple cohesion measures

UCINET's whole network multiple cohesion measures, and key player diffuse algorithms were again used to analyse how information was shared within the supply network (*Table* 8). The total number of nodes for this network was 124 and total ties was 132.

- **Average degree** (the average number of links in the network) was 1.065.
- **Density** (the total number of connections divided by the total number of possible connections) was 0.009.
- **Fragmentation** (the lack of connectivity in the network) was 0.989 indicating this is a highly fragmented network.
- **Diameter** (estimates the number of steps to reach everyone in the network) was 3 indicating that all individuals in the major component of the network could be reached in three steps.

Table 8: Summary of multiple cohesion measure metrics for the supply network

Metric	
# of nodes	124
# of ties	132
Average degree	1.065
Density	0.009
Fragmentation	0.989
Diameter	3

Keyplayer

The Keyplayer analysis demonstrated that having selected three initial nodes S24 (BoM – Large organisation), S43 (State government – Large organisation) and S7 (CSIRO – Large organisation), when trying to access the whole network, these three organisations were in the best position to diffuse information through the network (S24 (BoM – Large organisation), S43 (State government – Large organisation) and S12 (CSIRO – Large organisation). However, these three entities could reach only 25.620% of the network, i.e. less than a quarter of all nodes (Table 9).

Table 9: Key player (diffuse) in the Supply Climate Services Information network

Key player query run	**Key player (diffuse)**	**Key player (diffuse)**	**Key player (diffuse)**	**Nodes reached (%)**
1	S24 – BoM - Large	S43 – State government - Large	S12 – CSIRO - Large	25.620%

In-degree and Out-degree Centrality

Individual in-degree (number of incoming ties) and out-degree (number of outgoing ties) were calculated for each node. For ethical reasons, data in Appendix B were aggregated to the level of sector and where possible those organisations and departments (e.g. BoM, CSIRO, Federal, State and Local government) appear within the source network.

In-degree to supplies ranged from 0-8 with participants having a range of out-degree from 1-11 (complete in-degree and Out-degree centrality measures for all nodes in the Supply network can be found in Appendix B.). These results are due to the style of survey question wherein participants could list multiple sources. Appendix B shows degree centrality for all nodes sorted by in-degree centrality (highest to lowest) and out-degree centrality (highest to lowest). It is important to note that as some individuals listed individuals from a large organisation (e.g. CSIRO), these appear multiple times. Nodes such as the “general public” “General Media” and “Tourism Sector” in this instance have been grouped into a single node, although it is made up of an unknown number of individuals across numerous locations.

Resource development

Participants were asked if they accessed climate information from free/open sources from external organisations, internal sources, paid services, paid subscriptions or other. The majority identified free/open sources from external organisations followed by internal sources as their primary data (*Figure 10*). Participants were then asked why these sources were selected and respondents were offered the following options including: scientific validity, trust of sources, accessibility, quality, cost effectiveness, legitimacy, utility/ease of access, timeliness, enabling decision support, personal networks, lack of knowledge of alternatives, and other (respondents could select more than one reason). Scientific validity, trust of sources and accessibility were nominated most frequently with lack of in-house climate science capability nominated in the 'other' category (*Figure 11*).

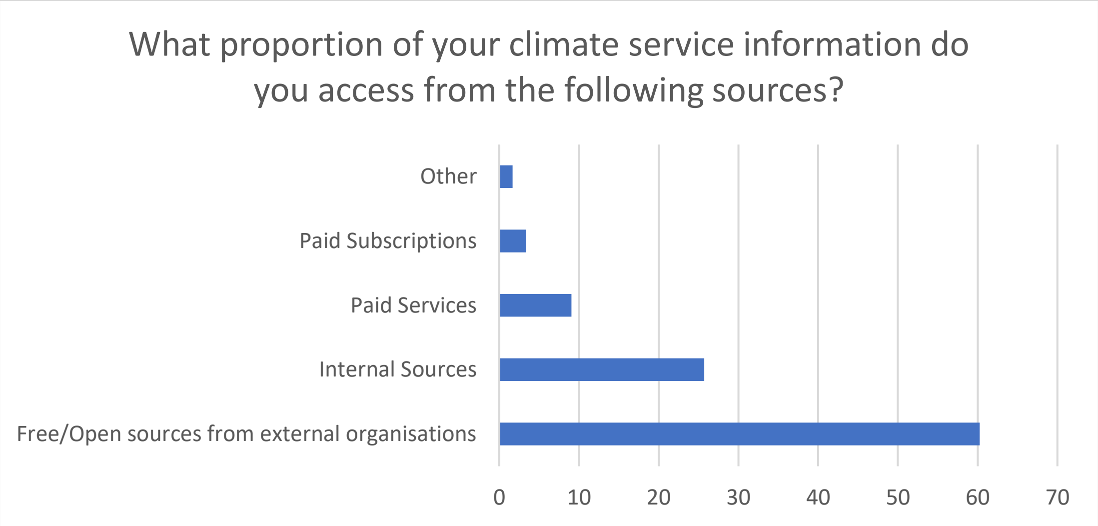

Figure 10: Type of information sources accessed for climate services information as a proportion of total sources accessed

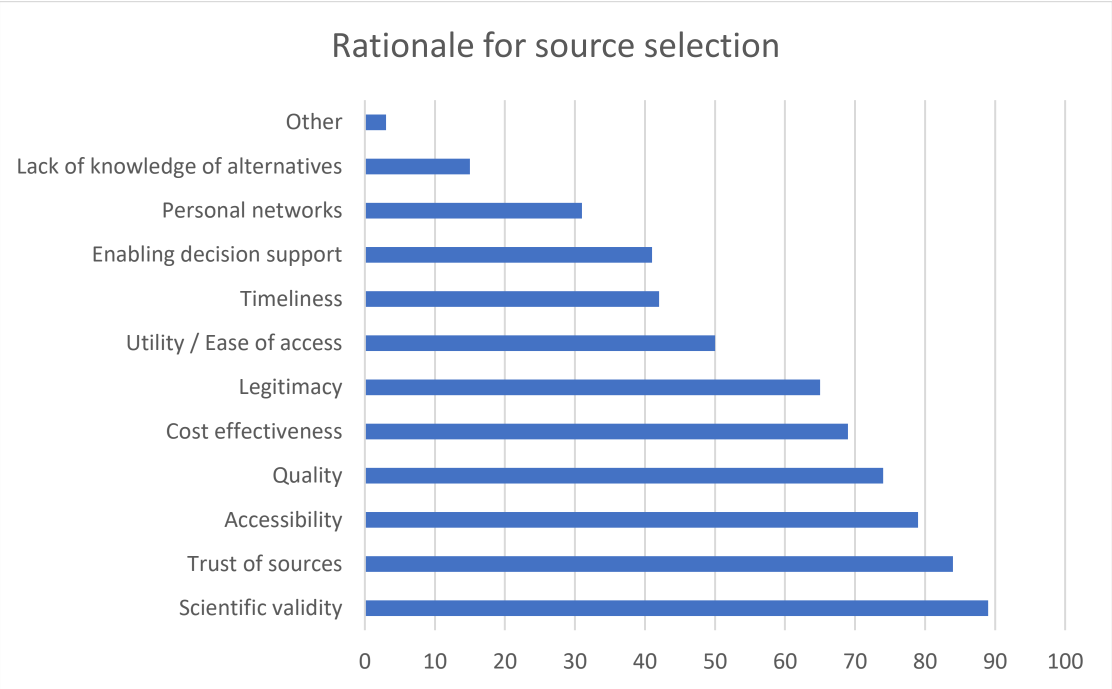

Figure 11: Rationale for climate service information source selection

Participants were asked how these resources were used. They were offered a range of options including: to build new tools and products; capacity building and climate resilience; compliance and regulations; financial decisions (e.g. loans, divestments); improving business efficiencies; inform climate hazard analysis and impact/vulnerability/risk assessments; inform strategic planning and/or policy development; investment decisions (e.g. purchasing assets); operational business decisions; satisfy customer demand and/or meet stakeholder expectations; to raise awareness; or other (Figure 12). Again, participants could select more than one use.

Respondents reported to primarily use these resources to inform climate hazard analysis and impact/vulnerability/risk assessments followed by the desire to inform strategic planning and/or policy development and to build new tools and products. In regards to activities listed as 'other', participants reported to use information for investor reporting, scenario analysis for climate-related disclosures under the Taskforce for Climate Change Financial Disclosures (TCFD) recommendations, as self-regulation, and also marketing climate friendly investment products, for a non-commercial community of practice to develop awareness and capacity building, in research reports and journal articles, briefings, personal education and information gathering for broader communications (Note: the potential for bias due to the types of respondents, e.g. government including State and Local governments, and the private financial sector).

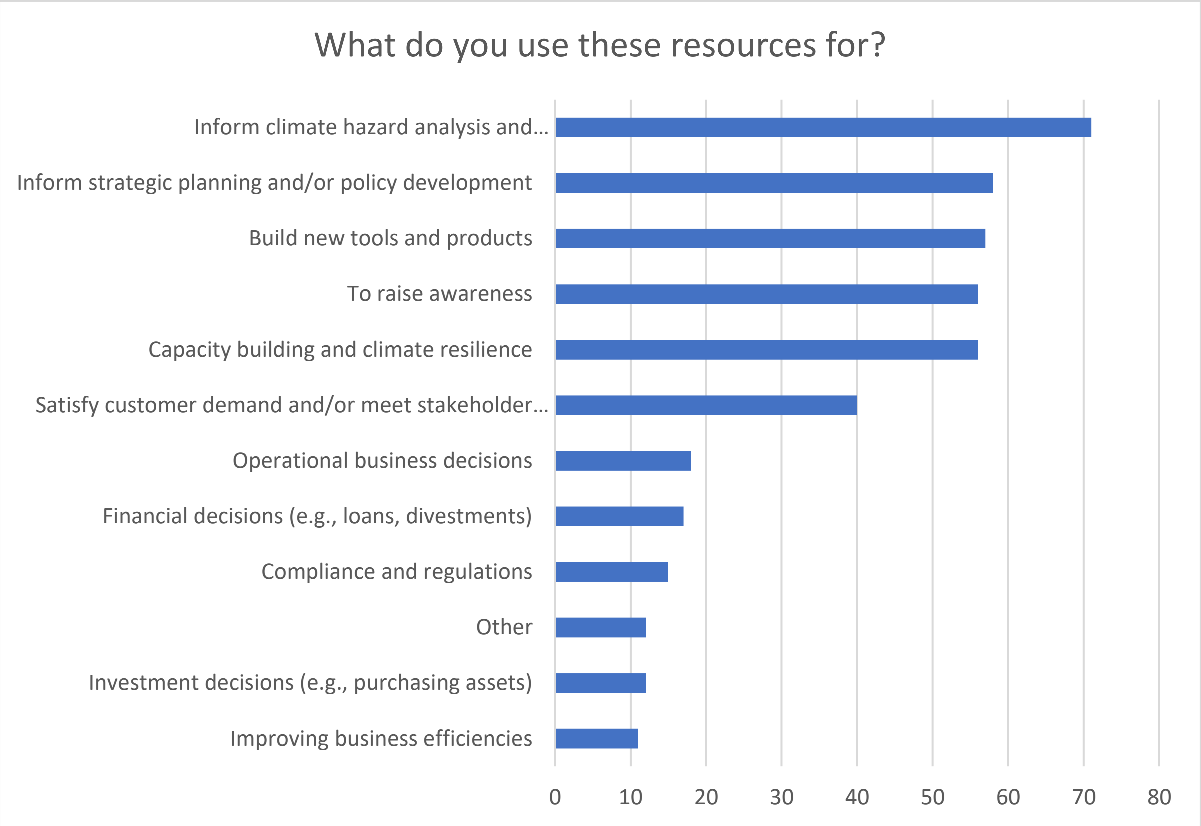

Figure 12: Climate services information resource use

When asked if their organisation has the internal capacity to develop, use and share climate service information and products (e.g. internal climate change or environmental professional), over 80% confirmed they did (88 of 107 responses) (*Figure 13*). How they developed and/or value added to this climate service information varied; however, it could be grouped by products that were internal facing, external facing or were for education, training and broader communication purposes.

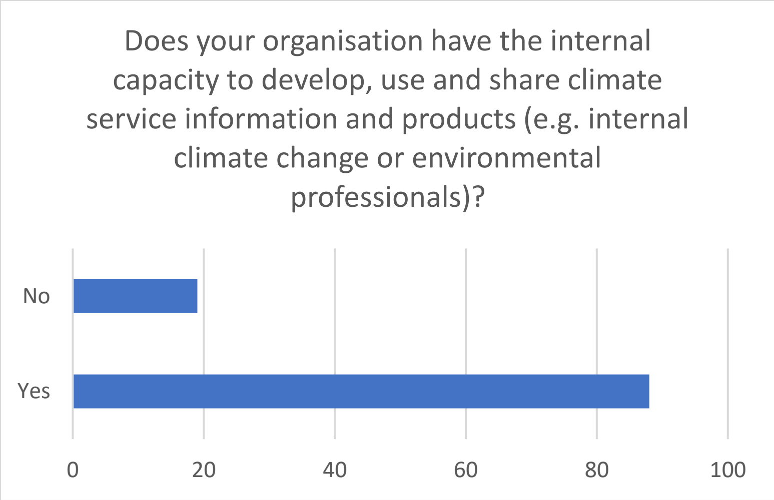

Figure 13: Organisations internal capacity to develop, use and share climate service information and products

Information used for internal product development included examples such as undertaking scientific and risk analysis of physical, transitional and liability risks, creating scenario approaches, decision support tools, climate research translation operational research and advice services, local research projects and for research guidance. External product development examples included developing dashboards and web mapping applications (e.g., real time air temperature), and guidance materials, to inform industry and government stakeholders, develop asset-level risk analysis and synthesis for third parties, producing reports for government on greenhouse gas emissions, translating the information to third parties in the applied space (e.g. visualisations), incorporating climate change models into existing decision support tools, factsheets and guidance, and tailored data sets to match metrics stakeholders are currently using to understand climate risk, strategic development and decision support tools (e.g. crop suitability maps). Education, training and communication purposes included not only the guidance materials themselves but also channels such as face-to-face mentoring, sharing through social media and advocacy.

When asked if respondents supplied climate services information, 52% reported that they did, with 48% reporting they did not (56 and 51 responses respectively n=107) (Figure 14). This suggests that approximately 50% of the climate services information developed as per the previous query, may be utilised internally.

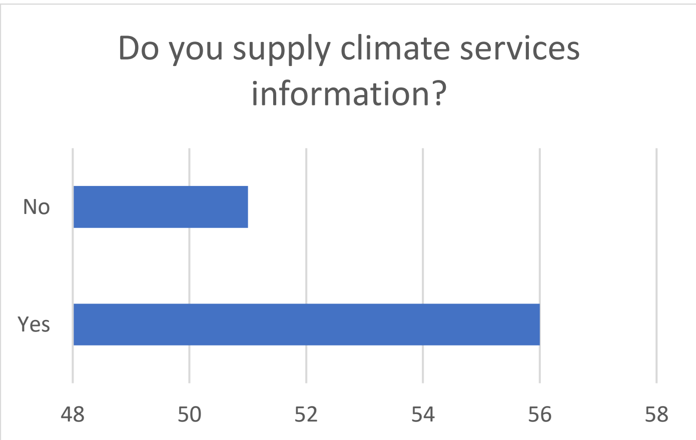

Figure 14: Do you supply climate services information?

Strengths, weaknesses and potential futures for the sector

When asked "what are the strengths and weakness of Australia's climate services capability?" participants were able to provide comments at length. In order to maintain anonymity of responses while garnering insights, qualitative thematic content analysis was undertaken to derive insights around strengths and weaknesses. Some offered opportunities and these are grouped in with responses to the next question regarding how the sector could be enhanced.
The results are ordered into themes and subthemes.

Strengths and weaknesses

Participants reported a number of strengths and weaknesses of the sector and with weaknesses outnumbering the strengths in this instance. It is of note that many of these are reflected in a further report (NESP ESCC Hub, 2020). Within this report, results of the strengths and weakness are separated, although there were some that overlapped including:

- There is a lot of information which can be both a strength and a weakness.
- The climate services sector sees itself to be a small sector which is a weakness, however it requires good collaboration which is a strength.
- "Climate Change in Australia" is considered a great resource but it is complicated and difficult to navigate and use properly.
- The public is ready for action and are actively seeking information. However, there is not a lot of understanding within, nor availability of translated climate services products for, the general public.

Strengths subthemes

- Data
    - Accessibility and legitimacy of science and data sets
    - A lot of information
    - Good seasonal forecasts
    - Good international partnerships in climate science and services

- Skills and expertise
    - Resilience in country communities due to and deep understandings of what risks are in place
    - Strong partnerships between science and government decision makers
    - Strong links between science and industry

Weaknesses subthemes

- Understanding
    - Lack of understanding of what a "climate service" is – the sector is lacking definition
    - Understanding internal data requirements can be difficult
    - A lack of understanding in the different types of communities there are within Australian society
    - Fragmented understanding and lack of systemic knowledge of the wider ecosystems involved.

- Cooperation and coordination
    - Repetition / reinvention of work
    - Limited coordination between states, making it difficult to navigate and collaborate
    - Fragmentation within government departments

- Lack of Federal government support, no bipartisan agreement on climate change, investment by government significantly lower than other jurisdictions (e.g. EU)
- "National" climate services tend to be weak as they are not reflecting the needs of the states and territories that are both users and providers of climate science, but are applying it for assets, industries and services
- Being able to compare national data sets (e.g. greenhouse gas emissions) with international regulations and contexts

- Uncertainties
    - The services are not always easy to access, costs of services can be prohibitive
    - Policy uncertainty
    - Declining government investment
    - Immature user engagement
    - Poor governance
    - Lack of strong public-private partnerships
    - Lack of timely and effective funding and support (short term funding models)
    - Limited information on policy effectiveness
    - No update on Australia's performance towards Paris targets
    - Small capacity with increasing demand for climate services (under resourced staff)
    - Loss of corporate knowledge leads to inefficiencies

- Data
    - Lack of trust in some data for decision-making
    - Not enough development and user testing (user experience needs to be taken into account rather than having products for products' sake)
    - Delays between the release of IPCC research and Australia specific downscaling of climate projections
    - Seasonal forecasting and climate projection modelling capability potentially may fall below best practice internationally
    - Poorly developed platforms (more user experience and testing needed)
    - Inadequate monitoring network (legacy and current) to adequately represent climate across catchment
    - Difficulty translating effects into impacts on infrastructure and the built environment (for insurability, rateability, risk purposes)
    - Difficulty in translating effects of projections generally e.g., how rainfall variability may translate to storm frequencies, cyclones, etc.

Opportunities for the sector to be enhanced

Participants were asked to provide information regarding how the sector may be enhanced in the future. In common with responses regarding strengths and weaknesses, respondents could enter free text. In order to maintain anonymity qualitative thematic analysis was undertaken and responses grouped where possible. The following lists the opportunities identified.

- Coordinated and centralised platform for climate data and decision support tools
- Better collaboration and strategy within and between States, Territories and Federal governments, to develop a platform, collaborate on science and develop policy (many shared resources e.g. water, exist beyond administrative boundaries)
- Include climate services in a national strategy
- Improved governance
- More government investment and co-investment
- Further regulation
- Further develop standards and protocols

- Climate services not simply “handed down” from the Commonwealth with minimal consultation, rather a more integrated approach to ensure the regulatory needs of the States and Territories (which vary) are met
- Focus on end-user needs, user design principles and embed in the user experience
- National downscaling simulations (more useful than multiple independent state level sets)
- Investment focus
- Increased networks for sharing information about best practice
- Increased capacity of low water flow data/ streamflow forecasts (for a drying climate)
- Enhanced / more accessible atmospheric observations at national scale
- Increased education and training materials
- Increased licence to operate
- Additional tailored products for industry (e.g., regional summaries of impacts)
- Develop extension and adoption of climate services
- Reinstatement of NCCARF or similar / model COPERNICUS or similar
- Data in format that is easily accessible in GIB base format

Finally, participants were asked if they were comfortable for further follow up and for additional research. Of 94 respondents, 73% were happy to be contacted (emails supplied) suggesting there is an appetite for further research and development in this space.

Discussion and conclusion

Although a pilot study, the work undertaken within this study is a unique contribution to climate services domain knowledge as it is the first known network analysis of this type to date for this sector in Australia. As such, comparison with published analyses of climate services networks from other locations or other networks generally is not possible. The following discussion outlines a number of network structures and characteristics that have appeared in other SNA studies. This will help inform further discussion of the properties found within the climate services information networks in Australia. This section is followed by examples of other climate science and innovation networks and a synthesis of the results that may be interpreted through these lenses, resulting in final recommendations for next steps.

Network structures and characteristics

We know from previous studies that various network structures perform some functions better than others. The following discussion outlines three key network structures and various characteristics that may emerge within them, and Figure 15 (Perea et al. 2017) shows their network topologies and degree distributions.

Random networks are those wherein nodes are randomly connected to each other (Barabasi and Albert 1999). Although rarely found in nature, random networks are often used in models in order to offer a sample of random networks, having an arbitrary distribution of connections (Newman, Watts et al. 2002).

Small worlds were first identified by Stanley Milgram in the 1960s when he undertook a social experiment to explore the average geodesic distance between citizens in the USA (Milgram 1967). Small worlds have high levels of clustering between nodes and have only a small number of steps between actors (Watts 1999).

A **scale free network** is one that exhibits a power law distribution (e.g. the hockey stick) (Barabási and Bonabeau 2003). A key characteristic of these networks is that nodes act as hubs. An example of a scale free network is the World Wide Web, where hubs are large search engines such as Google and similar.

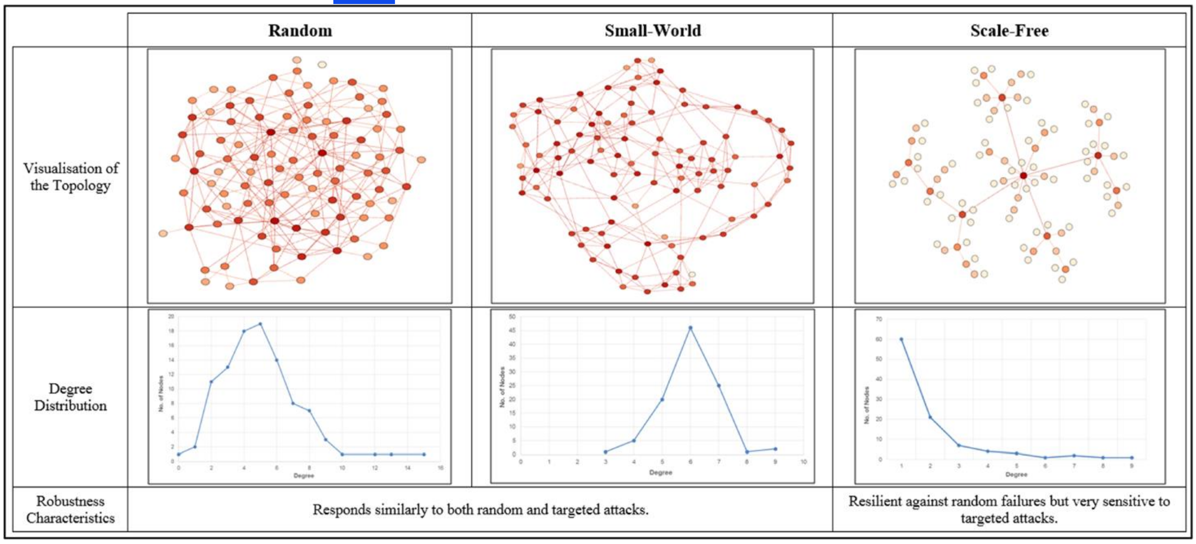

Figure 15: Random Small-World and Scale Free Networks

From Perera, S., Bell, M., G.H.,& Bliemer, C. J. (2017). Network science approach to modelling the topology and robustness of supply chain networks: a review and perspective. *Applied Network Science, 2*(33), 25. doi:10.1007/s41109-017-0053-0 pg 5.

Networks show a number of structural characteristics, such as density, the strength of weak ties and structural holes.

Strong networks with **high density** (or cohesion) have the optimal structure to generate, acquire and spread knowledge, particularly factual, tacit knowledge (Long *et al.*, 2013, Crona and Bodin, 2006). High density provides the opportunity for multiple actors to have the same information, allowing for the redundancy of ties within a network. If multiple actors hold the same information and are connected, it is likely that this information may be flowing through the network. As density is the number of ties divided by the total number of possible ties, it is often linked to the size and context of the network; for example within a small family network, every member may know each other and their plans for the week or holiday occasions. However, within a large family network that is geographically dispersed, there may be less connection and less knowledge of each other's planned activities.

Strength of weak ties is a concept that weakly tied acquaintances (low density) are less likely to interact than strong ties (high density) and therefore may bring in new information to the network (Granovetter 1973, Granovetter 1983). This has been demonstrated in studies of people looking for employment (Granovetter 1973, Granovetter 1983) and has also appeared in transformational adaptation in Australian agricultural networks (Dowd, Marshall et al. 2014). More novel information often lies outside dense networks where information may be readily shared.

Structural holes are components of networks that would otherwise be disconnected without a 'boundary spanner' (Burt 2004). These boundary spanners or knowledge brokers act as 'gatekeepers' to knowledge and opportunities. Sometimes the gatekeepers choose to be the bridge and share information, and at times they may block information flow (acting as gatekeepers). Knowledge brokers may describe an explicit role set up within networks and organisations (Lomas 2007, Cvitanovic, Cunningham et al. 2017) and within industries such as in the biotech industry development in the early 2000s (Liebeskind, Oliver et al. 1996, Owen-Smith and Powell 2004).

Climate science and innovation networks

Feldman and Ingram (2009) identified that scientists, including those working in climate science, tend to work in silos of expertise with boundaries between these various domains considered both the "norm and encouraged" (Feldman and Ingram 2009, p11). Further adding complexity to these networks is that climate information has been historically "producer-driven" rather than "user-driven" (Feldman and Ingram 2009, p9). This often results in an array of climate services being developed for decision makers and end users. However, these products may be used for various reasons, not always for the purpose for which they were made. Audiences for these tools and products are often highly diverse with a range of needs (Feldman and Ingram 2009). Within these settings Feldman and Ingram (2009) purport that effective decision making must be two-way, and in this setting knowledge networks become highly important for communicating how best to facilitate information exchange. Knowledge networks can be built across domains, organisations and governments; however, they are often reliant on boundary spanning organisations and/or individuals.

A recent environmental scan and review of climate service capability literature for Australia by the National Environmental Science Program (NESP) Earth Systems and Climate Change (NESP ESCC Hub, 2020) identified ten key themes within this space. These themes are listed below:

1. The scope of climate services is broad, with various definitions
2. The supply-side of the Australian market for climate services is established but fragmented and uncoordinated. The demand-side is rapidly emerging and evolving
3. Governance has hampered the development and uptake of climate services
4. Services should be demand-driven and science-informed
5. Clients want authoritative, relevant, standardized, accessible and quality-assured products and services
6. There are core and differentiated market needs and associated business models involving public and private sector actors, with implications for public-good vs private-profit
7. Leading practices involve strong and sustained leadership, agreed objectives and scope, a cyclic and iterative process, agreed methods/scenarios/data, targeted products and services, access to enablers, and continuous learning.
8. There are challenges for understanding and meeting user needs
9. Climate services depend on underpinning scientific research, innovation and infrastructure
10. There is an emerging vision for improved climate services

Organisations involved in the provision of climate services information may be seen as innovation organisations (Valente 1996). Social networks within an innovation setting may take on various innovation adopter categories, as suggested by Ryan and Gross (1950), being: (1) early adopters, (2) early majority, (3) late majority, and (4) laggards. This is pertinent as the climate service information sector is in a phase of innovation, growth and transition.

Effective innovation and knowledge networks should be designed for learning rather than knowing, as Feldman and Ingram (2009) note, it is often the non-traditional institutions that operate outside of the institutional norms and channels that can innovate more readily. These may in-turn become boundary spanning organisations that can operate and innovate across the knowledge network, allowing new information to become more diffuse within these networks.

Synthesis of the SNA results in relation to the literature and next steps

The results of this survey identified that there are key actors working as knowledge hubs within the source network for climate services. These were identified to be BOM, CSIRO, IPCC and universities, with the majority of respondents accessing information from these nodes (Appendix A). The network structure, being highly fragmented and with a low diameter, suggests that these nodes are operating as hubs (see Tables 4 and 5). Although this points to the prominent positions these organisations hold within this sector, these positions also hold risks: if these nodes are removed, the network will collapse. In addition, if these entities are ineffective in delivery the information that users need, the network is at risk. It is also important to note that these are large organisations, operating in multiple locations, working in multiple domains with large numbers of staff and which should result in them being relatively stable.

The analysis of the supply network for climate services information demonstrated that information provision is highly relational. Participants reported supplying information to the general public as well as government departments, individual sectors (e.g. tourism, agriculture etc), customers and investors. These were considered to be an individual node, although they are of course made up of multiple actors. In addition, although there were over 100 nodes in the network, there are instances where information was supplied from multiple individuals within the same organisation (e.g. BOM and CSIRO), see Tables 8, 9 and Appendix B. While this indicates the important position of these organisations to information provision within the network, the connection is often made on an individual to individual basis (rather than a more robust organisation to organisation connection). These types of personal relationships are often fragile because individuals are subject to frequent organisational restructure, shifting roles and staff turnover. Therefore, the relational nature of this network is a risk to information supply. The network also demonstrated state level cliques (see Figures 9 and 10).

In both source and supply networks, universities appeared. In the source network they were aggregated as a single node and in the supply network they were disaggregated into education and training providers. It is of note that these entities are located across the country, again, having various disciplinary interests and climate services information needs.

The response rate to the survey was lower than anticipated and this is starkly evident in the supply network. The reasons for the relatively low completion rate of the supply network survey questions are unknown but may be related to: a) the length and detail of the survey; b) the lack of desire to share the details of their personal network contacts; and/or c) an attempt to protect their organisational knowledge. This may again speak to the particular relational nature of the supply network for climate services information. It is important to note that the majority of the survey respondents came from large organisations (Figure 2). Of those who were both climate service information providers and users, the majority were from Local, State or Federal government (page 10). Engagement with the micro, small and medium organisations in further research activities may be needed as these organisations may be acting as boundary spanning organisations, however due to low responses to this survey this is not a finding demonstrated within this report.

Regarding recruitment, the survey was sent to six priority sectors of Agriculture, Research, Finance and Insurance, Water, Energy and Disaster Risk Response, and as such this will cause a level of bias to some of the results. This survey was also issued during disruption from COVID-19, and this may have impacted businesses willingness and/or availability to participate. In future iterations it will be important to encourage existing sector participants to continue to participate to ensure high survey response rates and thereby avoid bias due to small sample size and/or missing data.

Participants reported that they largely utilised free/open sources from external organisations followed by internal sources as their primary data (Figure 7) and that they used these sources due to their scientific validity, trustworthiness and accessibility. This is significant as if services move to a subscription model (in order to recover costs) it may limit information dissemination. Many participant organisations reported to have the internal capacity to develop and/or value add to the climate service information they access. Assessment of their capacity and an evaluation of their-party knowledge products could be a topic of future research. The products they developed varied widely, as did their audience from being internal facing, external facing, for education, training and broader communication purposes.

From the qualitative analysis of strengths, weaknesses and opportunities for this sector, it was clear that the sector continues to lack definition and that a singular platform for information is lacking. There is a need for climate service information to be better communicated and tailored for the end-users. This reflects previous work noting that these issues are common within many climate science networks (Feldman and Ingram 2009, Palutikof, Street et al. 2019), therefore resulting in the need for knowledge networks and boundary spanning organisations.

In conclusion, although the climate services sector in Australia has been established for 30 years, it is now rapidly evolving. This report offers insights from a pilot study and further detailed analyses is needed. Many participants reported they are willing to undertake additional analysis which demonstrates the appetite for further connection and insights within this growing sector.

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Appendix A

Source Out-degree Centrality and In-degree Centrality sorted by In-degree (highest to lowest) then Out-degree (highest to lowest); Node name = Node, Sector, Organisation size

NODE	OUT-DEGREE CENTRALITY	IN-DEGREE CENTRALITY
BOM		96
CSIRO		91
Intergovernmental Panel on Climate Change		79
Universities		65
International climate organisation		61
Platforms (e.g., Climate Change in Australia)		60
World Meteorological Organization		57
Geoscience Australia		51
Cooperative Research Centres		43
The Climate Council		38
Department of Environment and Energy		36
New South Wales Government		33
International Non-Government Organisation		28
Victorian Government		25
Queensland Government		24
Private Sector		23
Non-Government Organisation		22
Tasmanian Government		20
Australian Antarctic Division		19
Australian Institute of Marine Sciences		19
Department of Agriculture and Water		19
South Australian Government		17
Events		16
The media		16
Australian Capital Territory Government		15
Local Government		15
Western Australian Government		15
Rural Research and Development Corporations		13
Department of Industry Innovation and Science		12
Other federal government		12
Other		12
Department of Foreign Affairs and Trade		10
Department of Health		10
Northern Territory Government		9
Department of Home Affairs		7
Department of Defence		6
S84 – Financial and insurance service - Large	36	
S80 – Professional, scientific and technical services - Micro	33	
S13 – Education and Training - Large	31	

S85 – Federal government - Large	30	
S75 – Education and Training - Large	29	
S28 – Other - Medium	27	
S20 – Education and Training - Large	23	
S94 – Professional, scientific and technical services - Small	23	
S65 – Environmental services - Micro	21	
S19 – State Government - Large	20	
S60 – BOM - Large	20	
S82 - Financial and insurance service - Large	18	
S49 – BOM - Large	17	
S71 - Professional, scientific and technical services - Large	17	
S10– Education and Training - Large	16	
S4 – Other - Large	15	
S8 – Federal government - Large	15	
S44 – State government - Large	15	
S100 - Financial and insurance service - Large	15	
S7 – CSIRO - Large	14	
S96 – Federal government - Large	14	
S21 – State government - Large	13	
S46 – Local government - Large	13	
S63 - Professional, scientific and technical services - Large	13	
S11 – Local government - Large	12	
S16 – Local government - Large	12	
S30 – BOM - Large	12	
S38 – BOM - Large	12	
S40 – BOM - Large	12	
S98 – Education and Training - Small	12	
S103 – State government - Large	12	
S31 - Professional, scientific and technical services - Large	11	
S68 – Education and Training - Large	11	
S73 - Financial and insurance service - Large	11	
S12 – CSIRO – Large	10	
S23 - Professional, scientific and technical services - Small	10	
S33 - State government - Medium	10	
S43 – State government - Large	10	
S45 - Financial and insurance service - Large	10	
S59 – BOM - Large	10	
S64 - Financial and insurance service - Medium	10	
S78- Financial and insurance service - Large	10	
S83 - Professional, scientific and technical services - Micro	10	
S91 - Financial and insurance service - Medium	10	
S14 – Federal government - Large	9	
S35 – Environmental services - Large	9	
S39 – Local government – Small	9	
S50 – Federal government - Large	9	

S52 - Agriculture, Fishing and aquaculture, Water – Medium	9	
S53 – Education and training – Large	9	
S72 – State government - Large	9	
S86 - Financial and insurance service - Large	9	
S102 - Professional, scientific and technical services - Medium	9	
S105 – Education and training – Large	9	
S6 – Education and training – Large	8	
S15 – Local government - Large	8	
S17 – State government - Large	8	
S18 – State government - Large	8	
S27 – BOM - Large	8	
S32 – Federal government - Large	8	
S47 - Professional, scientific and technical services - Micro	8	
S51 - Agriculture, Fishing and aquaculture, Water - Medium	8	
S54 – State government - Large	8	
S61– State government - Large	8	
S67 – Other - Micro	8	
S74 - Financial and insurance service - Large	8	
S79 - Financial and insurance service - Medium	8	
S87 – Federal government - Large	8	
S93 – Federal government - Large	8	
S99 - Professional, scientific and technical services - Large	8	
S9 – Education and training - Large	7	
S24 – BOM - Large	7	
S26 – Other - Medium	7	
S29 – Professional, scientific and technical services - Medium	7	
S41 – Professional, scientific and technical services - Medium	7	
S42– Education and training - Large	7	
S56 – BOM - Large	7	
S58 – Education and training - Large	7	
S70 – Local council - Large	7	
S81 - Professional, scientific and technical services - Large	7	
S97 - Financial and insurance service - Large	7	
S25 – Education and training - Large	6	
S34 - Disaster Risk and Emergency Services – Large	6	
S37 – State government – Large	6	
S55 - Environmental services – Micro	6	
S88 – CSIRO - Large	6	
S90 - Professional, scientific and technical services - Medium	6	
S104 – Federal government - Large	6	
S3 - Agriculture, Fishing and aquaculture, Water - Micro	5	
S62 – Education and training - Large	5	

S89 - Financial and insurance service - Large	5	
S36 - Agriculture, Fishing and aquaculture, Water - Medium	4	
S48 – Education and training - Large	4	
S69 - Financial and insurance service - Large	4	
S77 - Financial and insurance service - Large	4	
S5 – State government - Large	3	
S22 – CSIRO - Large	3	
S66 - Professional, scientific and technical services - Large	3	
S1 – Local government - Medium	2	
S2 – Other - medium	2	
S76 - Financial and insurance service - Large	2	
S92 - Financial and insurance service - Large	2	
S57 – CSIRO - Large	1	
S95 - Professional, scientific and technical services - Large	1	
S101 - Financial and insurance service - Large	1	

Appendix B

Supply Out-degree Centrality and In-degree Centrality sorted by In-degree (highest to lowest) then Out-degree (highest to lowest); Node name = Node, Sector, Organisation size

	Out-Degree Centrality	In-Degree Centrality
N10 – Public / Community - various	0	8
N9 – Federal government - Large	0	6
N52 – State government - Large	0	4
S7 – CSIRO - Large	4	3
S16 – Local government - Large	3	3
N27 – CSIRO - Large	0	3
N38 – BOM - Large	0	3
S12 – CSIRO - Large	4	2
S13 – Education and training - Large	2	2
N1 – State government - Large	0	2
N11 – Development Sector – Large	0	2
N12 – Tourism Sector - Large	0	2
N2 – Federal government - Large	0	2
N25 – Disaster Risk and Emergency Services - Large	0	2
N28 – Universities - Large	0	2
N29 – Private Sector - various	0	2
N34 – Education and training – Large	0	2
N35 – Rural development corporations - various	0	2
N39 – BOM - Large	0	2
N58 – Federal government - Large	0	2
N7 – State government - Large	0	2
N8 – Education and training - Large	0	2
N86 – Investors - various	0	2
N13 – BOM – Large	0	1
N14 – State government – large	0	1
N15 – Professional, scientific and technical services – Large	0	1
N16 – BOM – Large	0	1
N17 – State government – Large	0	1
N18 - Agriculture, Fishing and aquaculture, Water - Medium	0	1
N19 - Public administration and safety - Medium	0	1
N20 - Disaster Risk and Emergency Services - Various	0	1
N21 – State government - Large	0	1
N22 - Disaster Risk and Emergency Services – Various	0	1
N23 - Disaster Risk and Emergency Services – Various	0	1
N24 - Disaster Risk and Emergency Services – Large	0	1
N26 – Public administration and safety - Medium	0	1
N30 – NGOs – various	0	1
N31 – General media (print, TV, radio etc.)	0	1
N32 - Professional, scientific and technical services - Medium	0	1

N33 - Professional, scientific and technical services - Medium	0	1
N36 – BOM - Large	0	1
N37 – Education and training - Large	0	1
N40 – Geosciences Australia – Large	0	1
N41 - Professional, scientific and technical services - Medium	0	1
N42 – BOM - Large	0	1
N43 – BOM - Large	0	1
N44 – BOM - Large	0	1
N45 – BOM - Large	0	1
N46 - Professional, scientific and technical services - Large	0	1
N47 – Education and training - large	0	1
N48 – Public administration and safety – Large	0	1
N49 – State government – Large	0	1
N50 – Federal government - Large	0	1
N51– IPCC - Large	0	1
N53 – BOM – Large	0	1
N54 – Water corporations – various	0	1
N55 – Energy Sector – various	0	1
N56 – Agricultural Sector – various	0	1
N57 – Industr - various	0	1
N59 – Federal government – Dept of Home Affairs - Large	0	1
N60 – Federal government – Dept of Agriculture and Water - Large	0	1
N61 – Local Government – various	0	1
N62 - Public administration and safety - Large	0	1
N63 – Education and training – Large	0	1
N64 – CSIRO – Large	0	1
N65 – CSIRO – Large	0	1
N66 – State government – Large	0	1
N67 - Public administration and safety – Large	0	1
N68 – Federal government - Large	0	1
N69 – Other – Medium	0	1
N70 – State government – Large	0	1
N71 - Financial and insurance service - Large	0	1
N72 - Financial and insurance service - Large	0	1
N73 – Customers - various	0	1
N74 – State government – Large	0	1
N75 – State government – Large	0	1
N76 - Agriculture, Fishing and aquaculture, Water - Large	0	1
N77 - Agriculture, Fishing and aquaculture, Water - Large	0	1
N78 - Agriculture, Fishing and aquaculture, Water - Large	0	1
N79 - CSIRO - Large	0	1
N80 – CSIRO – Large	0	1
N81 – Education and training – Large	0	1
N82 – Public administration and safety - Large	0	1
N83 – CSIRO – Large	0	1

N84 – Other – Small	0	1
N85 – International Governments - Large	0	1
N87 – Developers – various	0	1
N88 – Other – various	0	1
N89 – Federal government – Dept of Environment & Energy - Large	0	1
N90 - Professional, scientific and technical services - Small	0	1
N91 – Disaster Risk and Emergency Services - Large	0	1
N92– Disaster Risk and Emergency Services - Large	0	1
S24 – BOM - Large	11	0
S43 – State government - Large	9	0
S59– BOM - Large	8	0
S75 – Education and training - large	8	0
S38 – BOM - Large	5	0
S41 - Professional, scientific and technical services - Large	5	0
S65 – Environmental Services – Micro	5	0
S66 - Professional, scientific and technical services - Large	5	0
S7 – CSIRO – Large	5	0
S81 - Professional, scientific and technical services - Large	5	0
S100 – Financial and insurance services - Large	4	0
S12 – CSIRO - Large	4	0
S22 – CSIRO - Large	4	0
S49 – BOM - Large	4	0
S60 – BOM - Large	4	0
S16 – Local government - Large	3	0
S21 – State government - Large	3	0
S40 – BOM - Large	3	0
S69 – Financial and insurance services - Large	3	0
S80 - Professional, scientific and technical services - Small	3	0
S104 – Federal government - Large	2	0
S13 – Education and training - Large	2	0
S46 – Local government - Large	2	0
S47 – Professional, scientific and technical services - Micro	2	0
S79 – Financial and insurance services - Medium	2	0
S84- Financial and insurance services - Large	2	0
S25 – Education and training - large	1	0
S37 – State government - Large	1	0
S53 – Education and training - Large	1	0
S55 – BOM - Large	1	0
S88 – CSIRO – Large	1	0
S94 - Professional, scientific and technical services - Small	1	0