Final Report

A national map of protected cropping systems

Project leader:

Craig Shephard

Delivery partner:

University of New England – Applied Agriculture Remote Sensing Centre (AARSC)

Project code:

AS20003

Project:

A national map of protected cropping systems (AS20003)

Disclaimer:

Funding statement:

The project *A national map of protected cropping systems* (AS20003) is an investment through the Hort Frontiers strategic partnership.

Publishing details:

Published and distributed by: Hort Innovation

Level 7
141 Walker Street
North Sydney NSW 2060

Telephone: (02) 8295 2300

www.horticulture.com.au

Contents

List of tables

List of figures

Public summary

The 'National Mapping of Protected Cropping Systems' project delivered the first national baseline map of all commercial protected cropping systems (PCS) in Australia, published as the 'Australian Protected Cropping Map Dashboard' (Figure 1). The map developed with the Future Food Systems CRC, Protected Cropping Australia Ltd and NSW Local Land Services identifies 13,932 ha of protected cropping systems – including 4,473 ha of greenhouses (glasshouses, polyhouses and polytunnels) and 9,459 ha of nets (shadehouses and permanent nets). As well as intuitively presenting the spatial extent (location, area and type) of all PCS (over 2000 m^2), the metrics for total area of production by structure type is be summarised by state / territory and local government areas (LGA).

The map was built on the collation and digitisation of existing industry and online data, remote sensing analytics (including machine learning and computer vision), citizen science through industry specific location-based web applications and extensive on-ground validation. The map is freely available, adheres to national standards and respects grower privacy by not presenting any information other than the location and type of PCS.

The spatial information not only provides the wider industry with a current benchmark of industry extent but also presents essential baseline data that is fundamental for current and future market development, infrastructure planning, labour and transport logistics, traceability, biosecurity and natural disaster preparedness and response. More specifically, the 'Australian Protected Cropping Map Dashboard' and associated metrics have already been used for the following applications:

- Federal government coordination of the Harvest Trail program, connecting workers with farmers (https://www.dewr.gov.au/harvest-trail);
- Response to the current Varroa mite biosecurity incursion in NSW. The mite – is the most serious pest of honey bees worldwide, impacting the pollination of horticulture crops. The map is presented in the Varroa mite Rapid Response Map (https://arcg.is/1nD9S11) including analysis for potential impacts to PCS based upon the eradication and surveillance zones;
- The map has been used as a layer in other web map applications, including the Queensland Government's AgTrends Spatial Tool, and the Greenlife Industry Association (Nursery) of Australia's mapping application;
- The Australian Bureau of Statistics (ABS) are using the map to validate their Agricultural Census information and will use the data in future to support compilation of their national statistics for agriculture;
- The map supports the update of national catchment scale land use mapping programs, across all jurisdictions of the Australian Collaborative Land Use and Management Program (ACLUMP) and is published in national compilation of commodities data.

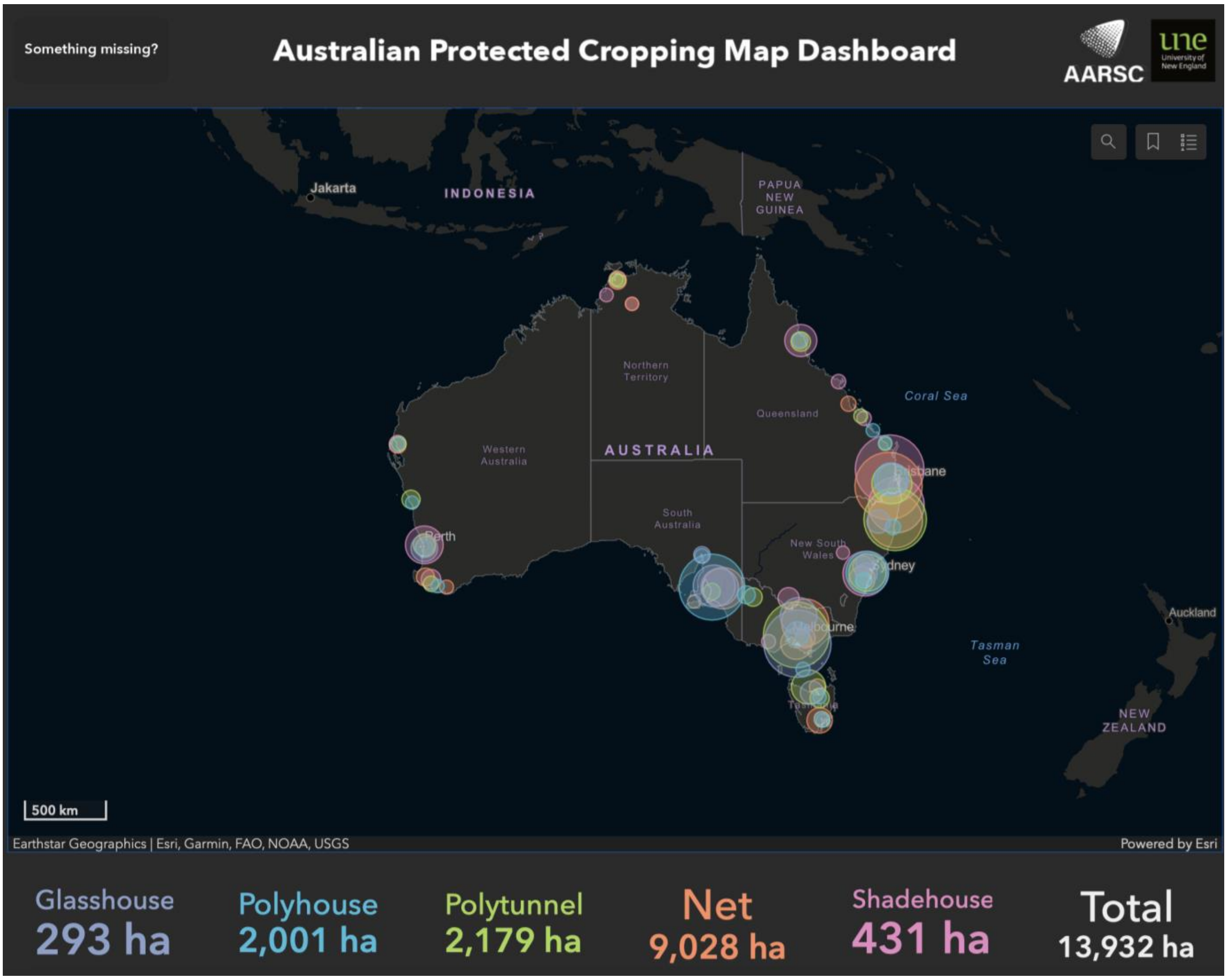

Figure 1: Australian Protected Cropping Map Dashboard.

Technical summary

The following technical summary is presented as an overview of the scope of work and outcomes achieved.

- The national map of protected cropping systems (PCS) includes all commercial glasshouses, polyhouses, polytunnels, permanent nets and shadehouses in Australia. Through consultation with project stakeholders, a minimum mapping unit of 0.2 ha (2,000 m^2) and classification of structure type was agreed.
- The map was informed using multiple sources of information including: existing industry data, government land use mapping, remote sensing analytics, ground-based field surveys and citizen science enabled through web mapping applications.
    - Publicly accessible imagery provided the primary resource of high-resolution data suitable for interpretation of PCS (e.g., Google Earth Imagery, Esri Basemap Imagery, Google Street-view and other government image services).
    - Field validation improves both the thematic accuracy (correct structure class) and currency of the map, particularly where new structures are found (which are not visible in imagery).
- Direct engagement with industry and stakeholders to contribute to the map was supported by location-based tools developed by AARSC, including:
    - The PCS Survey which is optimized for mobile devices, has received over 400 surveys from non-project people.
    - Draft mapping was published for peer review in the Industry Engagement Web App. The desktop optimised app includes simple capabilities that allow anyone to add (draw) a feature (as a point or polygon) on the draft map and provide their feedback comment directly to the mapping team.
- The deep learning models developed for this project can identify PCS up to an accuracy of 0.94 when applied to a different sensor type over a different geographical area. However, due to their transparent nature, net structures are difficult to identify within the imagery.
- Despite the accuracy of the models, deep learning alone cannot be successfully used to create a national map of PCS to the level of accuracy required to be a fundamental dataset. However, with the assistance of deep learning, it is possible to expedite the compilation of the map and assist in identifying PCS features which may not easily be found without this assistance.
- The map is published in the Australian Protected Cropping Map Dashboard, which includes summary metrics for each structure type (area of production in hectares) based on the zoom/view extent of the user. The dashboard includes the functionality to return metrics by state and territory and local government area (LGA) in a pop-up window. All summary statistics derived from the map is based on analysis extracted 2nd June 2023.
- Additional summary analysis of total production area by Natural Resource Management Regions, Federal and State Electoral boundaries, and the ABS Census SA2 areas have been provided direct to industry in the form of Excel spreadsheets (pivot tables).

- The PCS map is supporting the biosecurity response to Varroa mite in NSW. AARSC built the Varroa mite Rapid Response Map, where viewers can query the eradication and surveillance zones, and return the total area of PCS within each zone summarised by structure type.
- No personal or commercial information is contained in the map, which is built to the national standards of the Australian Collaborative Land Use and Management Program, coordinated by ABARES. The published map is freely available as a publicly accessible feature service.

Keywords

protected cropping; greenhouse; net; glasshouse; polyhouse; polytunnel; shadehouse; remote sensing; national mapping; deep learning; computer vision; spatial analytics; satellite imagery

Introduction

The lack of broad scale mapping of protected cropping systems (PCS) in Australia has resulted in uncertainty in understanding of the spatial distribution and area (size) of the industry. In addressing this data gap, the key objectives of this project were:

- **Develop a national map of diverse protected cropping systems using relevant and cost-effective state-of-the art technologies.**
- **Validate and calibrate the map so that it is freely available to relevant industry stakeholders.**

Mapping the current extent of PCS across Australia provides industry and stakeholders with essential baseline data that supports improved decision-making at multiple-scales, including the location and distribution of current production areas, and future opportunities for growth. The accurate mapping of PCS is fundamental for improving response strategies to biosecurity incursions. The inclusion of additional spatial information such as topography, water ways, human travel and supply chain routes etc. greatly informs where potential vectors may move and thus lead to the more effectively placed exclusion zones and for better coordinating on-ground surveillance. The spatial information also assists with assessing the impact of natural disasters. Additionally, identifying the precise locations of specific farming systems currently and into the future provides valuable information regarding supply chains, traceability, transport, water, power and processing infrastructure, labour requirements and markets.

The geospatial data developed within this project follows the proven methodology used by the 'Rural R&D for Profit Project: Multi-scale Monitoring Tools for Managing Australian Tree Crops: Phase 1 & 2', which included the mapping of all commercial avocado, mango, macadamia, and citrus orchards, banana plantations and olive groves across Australia, presented in the Australian Tree Crop Map Dashboard.

The spatial layers and associated applications (apps) developed for this project are designed with direct industry engagement (Protected Cropping Australia and NSW Local Land Services) to ensure it's well validated and delivers the necessary information in a format that is practical and accessible, and adheres to appropriate privacy requirements. The project is delivered with the Future Food Systems CRC to access their extensive partnership network and to create the greatest opportunity for engaging with industry in building the map.

The national map of PCS has established a 'baseline' of the current extent and distribution of production area across Australia. The map presents all PCS > 0.2 ha (2,000 m^2), and includes all commercial glasshouses, polyhouses, polytunnels, shadehouses and permanent nets.

The map was derived using multiple sources of evidence including: existing industry data, government land use mapping, remote sensing analytics, validation by on-ground field surveys and citizen science enabled through web mapping applications. Information sources used to develop the map included remotely sensed data (imagery), state and national spatial information, with validation undertaken through field observations and expert knowledge engaged in peer review.

The map simply presents a polygon feature that denotes the system type, no property information (block, variety, yield, etc) or personal information (grower, enterprise, owner) is included in the map. The map is built to the national standards of the Australian Collaborative Land Use and Management Program (ACLUMP), coordinated by Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and is freely available.

The map will serve as a valuable tool for the industry and stakeholders, supporting numerous initiatives, including the *'Australian Protected Cropping Strategy (2021–2030)'* (AS19005); the *'Road map for Protected Cropping in Australia'* being developed by Strategic Journeys for Food Innovation Australia Limited (FIAL) and QDAF; as well as for the *Hunger Map* currently being developed by FoodBank Australia.

The completion of this initial map sets the groundwork for future iterations including annual updates and the inclusion of higher resolution information such as crop type, productivity etc. This evolution of data collation and access will underpin future protected cropping strategic planning and support the industry in line with the 'Agriculture 4.0' philosophy.

Methodology

The national mapping program to map the location and extent of all commercial protected cropping systems (PCS) was set based upon known intensive growing regions across Australia. The methodology is based on direct industry engagement (Protected Cropping Australia and NSW Local Land Services), to ensure it is well validated and delivers the necessary information in a format that is practical, accessible and adheres to appropriate privacy requirements.

Multiple sources of evidence were compiled in the derivation of the map (within a desktop Geographic Information System (GIS)), including remotely sensed data (imagery) and analytics (deep learning), state and national ancillary data, field validation and expert knowledge (peer review) (Figure 2).

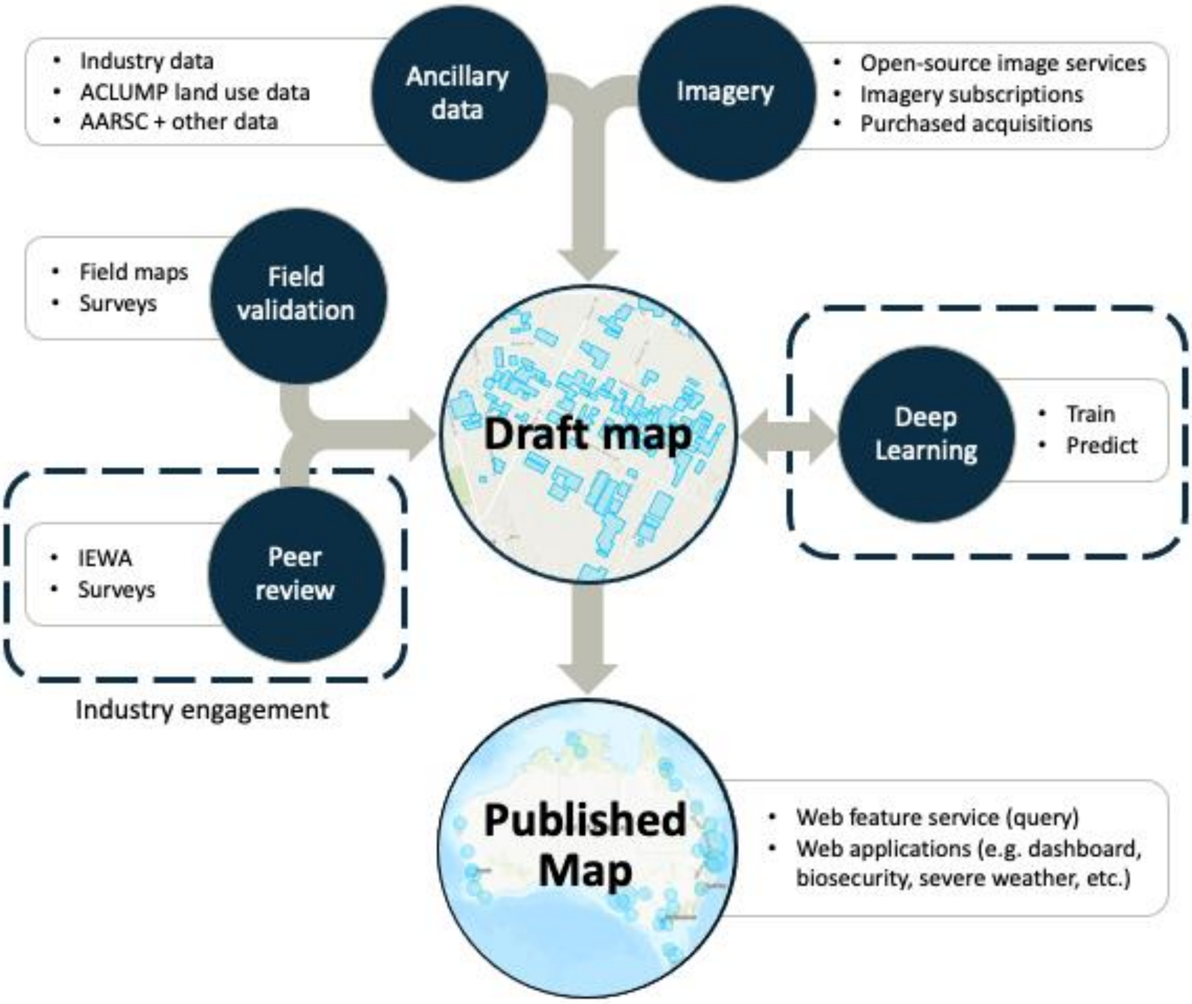

Figure 2: Australian Protected Cropping Systems mapping methodology.

Publicly accessible imagery provided the primary resource of high-resolution satellite and aerial imagery, with interpretation of PCS aided by other (ancillary) information including existing industry data and land use information (sourced through the ACLUMP). Extensive on-ground field validation was also conducted over each major growing region, which targeted areas of known uncertainty and/or new systems (which are not visible in publicly accessible high-resolution imagery). The field validation improves the accuracy (certainty of correct PCS structure class), and currency by inclusion of new systems in the map.

Industry engagement (citizen-science) was enabled through location-based tools developed by AARSC, including the PCS Survey and Industry Engagement Web App. Stakeholders and growers were encouraged to contribute by viewing the draft mapping and adding their feedback directly to the mapping team. This engagement is extremely valuable and is essential for mapping new systems (which are not visible in satellite imagery due to the currency (date) of image acquisition).

The map was also informed by deep learning techniques, specifically computer vision, to automatically map the location and extent of PCS features within high-resolution imagery. The developed method is robust, generalised, able to use a combination of aerial and satellite sensors and able to identify PCS features in geographical areas different to where the model was trained.

The published map presents the location and extent of PCS classified by structure type: glasshouse, polyhouse, polytunnel, net and shadehouse, as a publicly accessible feature service shared across numerous web applications. The benefit of publishing the map as a service is that when the map is updated in future the changes are instantly reflected for all who access it.

Results and discussion

The full results achieved can be found in Appendix 1 of this report. In brief the KPI addressed in the project were:

1. ***Deliver PCA and Hort Innovation a consistent and accurate understanding of the spatial extent (type, area, location) of commercial protected cropping structures across Australia including (nets, polytunnels, polyhouses, shadehouses and glasshouses).***

AARSC have published the first baseline map of all commercial protected cropping systems (PCS) across Australia, classified by structure type. The map not only provides a spatial reference of industry extent (location and area), it also supports the extraction of summary statistics for area of production at multiple-scales. The total production area of PCS mapped in Australia is 13,932 ha, including:

- 293 ha of glasshouses
- 2,001 ha of polyhouses
- 2,180 ha of polytunnels
- 9,028 ha of permanent nets
- 431 ha of shadehouses

The map is presented in the freely accessible Australian Protected Cropping Map Dashboard, which summarises the total area of PCS interactively (on-the-fly) based on the map view extent. Clicking on the map in the dashboard will return summary metrics of PCS structures by state / territory (at national scale), while zooming in will show local government areas (LGA).

Analysis by structure type shows that Victoria has the largest proportion of glasshouses in Australia with 125 ha (43%), followed by South Australia with 87 ha (30%). South Australia has the largest proportion of polyhouses with 1,103 ha (55%) – 768 ha is in the Playford LGA. For polytunnels, NSW has the most with 649 ha (30%), followed by Tasmania with 505 ha (23%) and Queensland has 399 ha (18%). NSW has the largest proportion of nets, with 3,005 ha (33%) – 1,109 ha is in the Southern Downs LGA and the Coffs Harbour LGA has 1,091 ha.

All features in the map are current (mapped in year) to 2022 or sooner.

2. **Establish an ongoing capacity to maintain and refine the national GIS database of commercial protective cropping structures in Australia.**

On-going updates to the national map of PCS (and the GIS database) are supported by the location-based tools developed by AARSC, which were fundamental for building the baseline map. Both the PCS Survey and Industry Engagement Web App, enable the contribution of industry to review the map, and provide feedback directly to the mapping team, who can interpret the information submitted and update the map. Having industry directly contribute is essential for mapping new PCS structures which cannot be mapped accurately with satellite imagery alone.

Included within the Australian Protected Cropping Map Dashboard is a feature (button) – "Something missing? Submit a survey!" (launches the PCS Survey). This tool provides a simple-to-use mechanism to support on-going updates to the map in future. The engagement tools developed within this project also include the capability to collect crop information. The potential to include additional information for commodity (e.g., blueberries, strawberries, tomatoes) in the map in future is possible, with the support of industry and the engagement tools developed by AARSC.

The research and development (training) of a deep learning model (computer vision) to map the location and extent of PCS in high-resolution imagery was successful. The accuracy of the model was assessed across multiple platforms/sensors including both aerial and satellite imagery, and in different locations (geographies). The model's best results were observed in predicting greenhouses (glasshouses, polyhouses and polytunnels), in either aerial or satellite imagery of 50 cm spatial resolution. Nets were more difficult to predict due to their transparent nature. Including deep learning within the mapping methodology has expediated the compilation (digitisation) of PCS features. Pending suitable imagery acquisition, the model could be used in future to update the map.

At minimum, updating the map for temporal currency and change (for new and removed PCS) is required to maintain the map as 'fit-for-purpose' – foundation information for provisioning the location and extent of PCS across Australia. The AARSC has investigated a range of options to secure ongoing funding to update the map ideally annually, and maintain the numerous location-based tools (apps) which support it.

The same challenge beset the Australian Tree Crop Map, with complete annual updates now supported for the avocado, citrus and macadamia orchards and banana plantations. AARSC together with industry partners are now updating and maintaining the map, as well as 'spatially enabling the Australian tree crop industries' by increasing the level of information (detail) by building separate 'industry only' maps. These 'industry only' maps include additional information (e.g., variety, tree age, productivity, grower information etc.), which is not available in the tree crop map. The key capability of the new project is enabling industry to directly edit the map in-house and assign the block-level information, within simple secured web applications. Importantly all data is managed and secured by AARSC under strict sign-in access only.

Extension of project outcomes: Photos/images/other audio-visual material

The project team delivered over 44 pieces of extension materials during the project. These including many forms of photo/images and audio-visual material, conference presentations and social media posts. The full list of these materials and corresponding web links are provided in the Appendix 3 of this report (refer Table 7).

A few of the outstanding examples are provided below, including field validation of polytunnels at Hillwood Berry Farm, Tamar Valley, Tasmania (Figure 3), and a drone-to-satellite video which includes the PCS map at that location (Figure 4).

Figure 3: Hillwood Berry Farm, Tamar Valley, Tasmania.

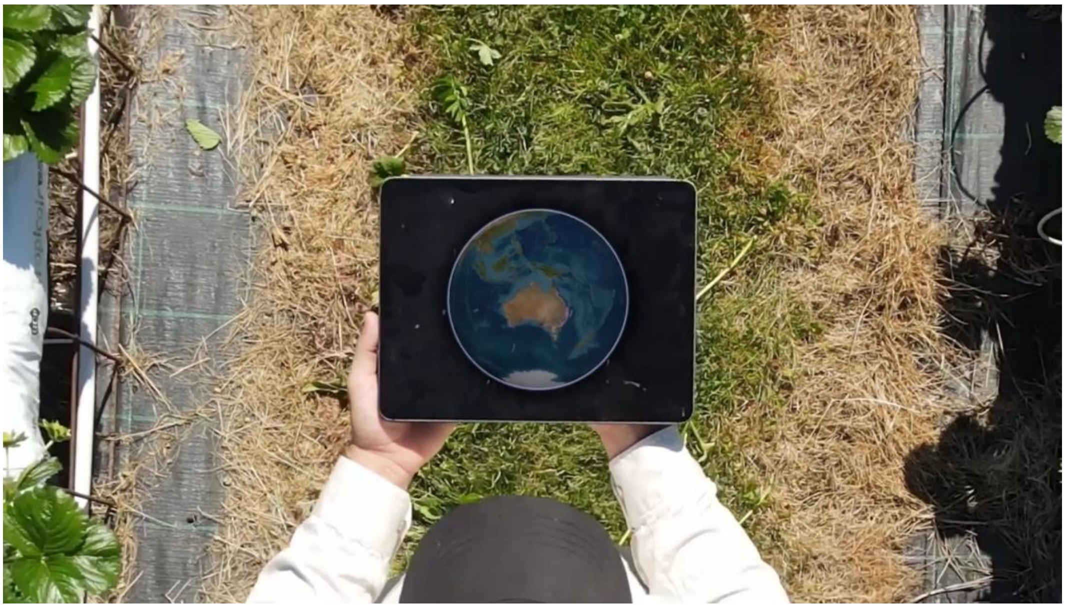

Figure 4: PCS Map (Drone to satellite video).

Outputs

Table 1: Output summary

Output	Description	Detail
Freely available national map of Protected Cropping Systems	This will provide the industry with an accurate baseline of the distribution and extent of national production as well as serving as an essential tool to assist biosecurity response and post natural disaster monitoring.	The mapping of all commercial protected cropping systems (PCS) has provided industry with an accurate understanding of extent (location and area) of their systems, critical baseline information to better quantify annual change, traceability, infrastructure and labour requirements, production estimates and forward selling, and for better preparedness and response to biosecurity threats and natural disasters. The map is published in the Australian Protected Cropping Map Dashboard, presented by structure type. The map developed directly with industry, is built to national mapping standards, and is freely available as a feature service. In terms of industry statistics, the total production area of PCS in Australia is 13,932 ha, including: ○ 293 ha of glasshouses ○ 2,001 ha of polyhouses ○ 2,180 ha of polytunnels ○ 9,028 ha of permanent nets ○ 431 ha of shadehouses All features in the map are current (mapped in year) to 2022 or sooner. The map of PCS is featured in the Varroa mite Rapid Response Map, which the project team developed in response to the current biosecurity event in NSW.
Industry engagement tools (PCS Survey & Industry Engagement Web App)	Location-based tools developed by AARSC support the contribution of industry to inform the map, and as a legacy of this project provide a support mechanism for on-going updates in future.	Industry engagement tools support the peer review of draft mapping and are essential for mapping new systems (which cannot be mapped with satellite imagery alone). During the project these tools provided: • 402 PCS Survey forms were received • 12 comments (specific for PCS) were submitted via the Industry Engagement Web App As a mechanism to support future updates to the map, the Australian Protected Cropping Map Dashboard includes a button (link) launching the PCS Survey form, to bring missing structures to the attention of the mapping team.
Media coverage: print, digital, radio interviews and social media; and PCA run conferences and webinars, direct contact with stakeholders, project	Promotion of project outputs to industry and growers via digital and traditional media. Project team will extend project updates through media throughout the project.	• 44 media pieces that communicated the project and progress were captured from September 2021 to the conclusion of the project in August 2023. • The project was presented at three industry conferences including the annual Protected Cropping Australia event, and Berries Australia's Berry Quest International event.

reference group meetings, academic paper published.	The impact of project extension can be clearly seen by the number of growers who contributed to the mapping through the PCS Survey.	• Three articles were published in the industry magazine, Soilless Australia. • One journal (paper) article is in progress. • The project was extensively promoted across social media with 14 posts across numerous platforms (LinkedIn, Twitter). • Two media releases. • Four stakeholder meetings were held.

Outcomes

Table 2: Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Deliver PCA and Hort Innovation a consistent and accurate understanding of the spatial extent (type, area and location) of commercial protected cropping structures across Australia including (nets, polytunnels, polyhouses, shadehouses and glasshouses)	• **Final map delivered**	The national mapping of PCS offers significant benefit to national plant biosecurity by identifying the location and distribution of all systems, as the extent and distribution of production is now known. This freely available mapping layer supports the rapid deployment of surveillance staff and the establishment of exclusion zones to prevent further spread. Additionally, this layer can determine the areas of each industry impacted by natural disaster, in near real time. The outputs of this project will also include technologies and analytics that offer improved surveillance and response to biosecurity incursions.	The PCS map is published in the Australian Protected Cropping Map Dashboard, includes all commercial PCS (over 0.2 ha), presented by structure type. This freely available, accessible map is featured in the AARSC applications gallery website, supported by other 'theme-based' applications including the Varroa mite Rapid Response Map, which the project team developed in response to the current biosecurity issue in NSW. This application leverages the power of spatial data (i.e., the PCS map), and when analysed with the extent of the eradication and surveillance zones, quantifies the impacts to impacted systems.
Establish an ongoing capacity to maintain and refine the national GIS database of commercial protected cropping systems in Australia	• **Future update mechanism to maintain the mapping of PCS in place with industry**	Creation and delivery of PCS Survey and the Industry Engagement Web App (IEWA) support the citizen science contribution of growers and industry to the map. Data provided via the PCS Survey and comments submitted via the IEWA offers additional validation data to	Location-based tools support the contribution of industry, in peer review and additionally to bring new systems to the attention of the mapping team. The PCS Survey (best for mobile devices) has already received 402 responses, whilst the Industry Engagement Web App (best

		scientists, for interpretation and updates to the map.	for desktop) has provided 12 comments. Each survey or comment is interpreted by the mapping team and actioned as updates to the map. The project team have commenced discussions on appropriate mechanisms and funding to see the PCS maintained annually post project.
R&D of new deep learning (computer vision) techniques to inform the map	• **Future update mechanism to maintain the mapping of PCS in place with industry**	This project has undertaken research into applying deep learning techniques, specifically computer vision, to automatically map the location and extent of PCS features within high resolution imagery.	The outcomes of this research indicate that imagery with a spatial resolution of 50 cm is required to map (predict) PCS features accurately and efficiently. The developed deep learning methods can identify greenhouse features to a high level of accuracy but netting structures are more difficult to identify due to their transparent nature.

Monitoring and evaluation

Table 3: Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
Effectiveness: 1. To what extent has the project achieved its expected outcomes?	To what extent has the project complemented and collaborated with existing Hort Innovation investments? To what extent has the project established an ongoing capacity to maintain and refine the national GIS database of commercial protective cropping systems? To what extent has the industry-acceptance of this mapping application been evaluated?	The project delivered on its main objectives by delivering a freely available national map of PCS, built from the collation of existing industry information and cutting-edge remote sensing analytics. Extensive industry engagement has ensured the accuracy of the map.
Relevance: 2. How relevant was the project to the needs of intended beneficiaries?	To what extent has the project delivered a national map of protective cropping systems for the protective cropping industry? To what extent has the national map of protective cropping supported decision-making within the protective cropping industry?	A complete national map of PCS was delivered. The map has presented the industry with an accurate understanding of the extent (location, area and type) of PCS at multiple-scales. The data has also been used to quantify the area of impact from the Varroa mite eradication and surveillance zones, floods and to inform other land use mapping programs.

Process appropriateness 3. How well have intended beneficiaries been engaged in the project? 4. To what extent were engagement processes appropriate to the target audience/s of the project?	Have growers who use protective cropping systems for their commercial crops and industry stakeholders been engaged in the development of the project outputs? Were growers and industry informed about project updates and achievements in an accessible and engaging way? What forms of communications have been used in this project to engage with the protective cropping Industry?	The project has directly engaged with PCA and LLS as well as their existing networks. The continual presentation of the project at industry forums, various media and direct engagement has enabled the contribution by industry to inform the map. A full list of conferences and published media has been provided in this report, as well as participant numbers at the various forums and views (usage) of the map.
Efficiency: 5. What efforts did the project make to improve efficiency?	What efforts did the project make to improve efficiencies throughout the project to ensure appropriate use and allocation of time, money, effort and other resources? How well did the project engage with other complimentary projects and initiatives to evaluate what was being achieved?	The Industry Engagement Web App and PCS Survey enabled the wider industry to assist in informing the map (e.g., citizen-science). Where available high-resolution imagery was sourced from the extended remote sensing network of the AARSC and ACLUMP which reduced the need to purchase it. The mapping of PCA was shared at many science forums, such as plant biosecurity, natural disaster response, Earth Observation Australia, ACLUMP, ABARES and as such offered outcomes that directly benefited those initiatives.
Other: 6. How well were the project outputs received by the respective industry as well as external entities?	What feedback has been received from industry and external entities to demonstrate interest in the project and future adoption of project outputs?	The mapping has been extremely well received by industry and Local Land Services (as demonstrated by the continual positive press and invitations to present at relevant industry forums). More broadly the mapping has been directly used by ACLUMP and ABARES and has set a new standard of mapping resolution for PCS (thematic and temporal resolution). The mapping also directly used for analysing potential impacts to PCS in response to the Varroa mite biosecurity event in NSW.

Intellectual property

A table of background IP and newly created IP through this project is provided in Appendix 4 in the Full research report.

Acknowledgements

The project team acknowledge the funders of this project, that being the Future Food Systems CRC and Hort Innovation. The AARSC would also like to acknowledge the wider project team partners including Protected Cropping Australia (Matthew Plunkett and Sam Turner), NSW Local Land Services (Jonathon Eccles) for working so well together to achieve a common goal. The AARSC gratefully acknowledge the ongoing support from the respective industry bodies and the many growers and consultants that have collaborated on this project. Finally, a very sincere thank you to the AARSC team for their hard work and support of each other to see the delivery of this project. More specifically Prof Andrew Robson (Director), Craig Shephard, Joel McKechnie, Dr Andy Clark, R. Blake Morrison, Abbie Rankin (mapping); and Georgia Pearlman, Casey Naughton and Sophia Clark (business management, extension material, contracting, report writing).

Appendices

Appendix 1: Full Research Report

Final Report: National Map of Protected Cropping Systems (AS20003)

Authors:

Professor Andrew Robson

Craig Shephard

Dr Andrew Clark

Joel McKechnie

R. Blake Morrison

Abbie Rankin

Sophia Clark

Summary (Impact and Legacy)

Overall, the project delivered 44 extension pieces that communicated all derived outcomes and outputs to the wider community. The project was presented in events across Australia, including major industry conference proceedings:

- Protected Cropping Australia (Brisbane, 2023 & Coffs Harbour, 2022)
- Northern Australia Food Futures (Darwin, 2023)
- BerryQuest International (Gold Coast, 2022)
- Future of Food Summit (Brisbane, 2022)
- Advancing Earth Observation Forum (Brisbane, 2022)

The national map of PCS received extensive industry engagement during the life of the project but there are clear examples of industry adoption as well as future opportunities to continue maintain and update the map in future.

- The Australian Protected Cropping Map Dashboard has been opened 1,497 times, and the feature service within has been accessed 9,252 times.
- 402 PCS Surveys received, with 12 comments submitted from non-project staff that were actioned in the Industry Engagement Web App.
- The map is actively being applied in supporting the current biosecurity response to Varroa mite in NSW.
- Personal communications with stakeholders from industry both in Australia and internationally (Netherlands) have identified the map being used to explore and identify potential future development opportunities for protected cropping in Australia. A significant economic investment decision.
- The success of mapping output and the process of development via direct industry engagement has set a new precedent both domestically and overseas. The AARSC team are currently mapping all rice (AgriFutures, SunRice and NSW DPI) across Australia, soybeans in Queensland (QDAF), and macadamia and pecan orchards across South Africa (SAMAC & SAPPA).
- The Australian Protected Cropping Map Dashboard has been used by the Federal government to coordinate the Harvest Trail program, connecting workers with farmers (https://www.dewr.gov.au/harvest-trail).
- The PCS map layer (feature service) has been used as a layer in other web map applications, such as the Queensland Government's AgTrends Spatial Tool and the Greenlife Industry Association (Nursery) mapping applications.
- The map supports the update of national catchment scale land use mapping programs, across all jurisdictions of the Australian Collaborative Land Use and Management Program (ACLUMP) and is published in national compilation of commodities data.
- The Australian Bureau of Statistics (ABS) are using the map data to validate their Agricultural Census information and will use the data in the future to support compilation of their national statistics for agriculture.
- The national mapping outputs were presented at many industry and government events and media during the project (refer to Table 7), including:
    - Soilless Australia
    - Australian Berry Journal
    - Future Food Systems CRC Research profile

- UNE AARSC conducted three workshops in 2020 to initiate a national collaborative approach to map all commercial crops annually across Australia, to extend what has been achieved in this project. These workshops were well attended by current industry mappers, industry representatives, government and NGOs and have led to the development of a strategy to achieve this outcome being developed and shared with the Federal DAWE. This initiative is supported by the Australian Bureau of Statistics, ABARES, Plant Health Australia, Hort. Innovation, Earth Observation Australia, the National Committee for Land Use and Management Information (NCLUMI) and Citrus Australia.

Contents

List of tables

Cover image: Hillwood Berry Farm, Tamar Valley, Tasmania (22nd March 2022).

List of figures

Introduction

Mapping the extent of protected cropping systems (PCS) across Australia provides industry and stakeholders with essential foundational data that supports improved decision-making around industry extent (location and area) at multiple-scales, including the scope and pattern of current production area and future opportunities for growth. The accurate mapping of PCS is essential for improving response strategies to biosecurity incursions through the establishment of exclusion zones and the coordination of on-ground surveillance, and assessing the impact of natural disasters on agricultural areas. Furthermore, having precise measurements of production area and understanding the different growing systems employed in PCS are essential for the development and advancement of the industry, with valuable information regarding value chains, traceability, governance, transport logistics, and market access.

The geospatial data developed within this project follows the proven methodology used by the 'Rural R&D for Profit Project: Multi-scale Monitoring Tools for Managing Australian Tree Crops: Phase 1 & 2', which included the mapping of all commercial avocado, mango, macadamia, and citrus orchards, banana plantations and olive groves across Australia.

The spatial layers and associated applications (apps) developed for this project are designed with direct industry engagement (Protected Cropping Australia and NSW Local Land Services) to ensure it's well validated and delivers the necessary information in a format that is practical, accessible and adheres to appropriate privacy requirements. The project is delivered with the Future Food Systems CRC to access their extensive partnership network and to create the greatest opportunity for engaging with industry in building the map.

The national map has established a 'baseline' of the current extent and distribution of PCS production area in Australia. The map includes all commercial glasshouses, polyhouses, polytunnels, shadehouses and permanent nets > 0.2 ha (2,000 m^2).

The map was informed using multiple sources of evidence including existing industry data, government land use mapping, remote sensing analytics, ground-based field surveys and citizen-science enabled through web mapping applications.

No personal or commercial information is contained in the map. The map is built to the national standards of the Australian Collaborative Land Use and Management Program (ACLUMP) coordinated by ABARES and is freely available. The University of New England is a partner and active contributor to the ACLUMP, joining the consortium of other state and territory members and major stakeholders. Privacy concerns are acknowledged and respected as no personal or confidential or commercial information is collected as a part of the mapping process nor contained within the mapping product.

The success of the map lies in the collaboration between industry, research and government. The support of industry bodies ensured the mapping outcomes were not perceived as an invasion of privacy and supported compilation of the map with access to existing industry data and their contribution through the industry engagement tools ensures ongoing validation of the mapping, both of which are integral to the accuracy and currency of the map.

Section Summary

- Total production area of protected cropping systems (PCS) in Australia is 13,932 ha, including:
    - 293 ha of glasshouses
    - 2,001 ha of polyhouses
    - 2,180 ha of polytunnels
    - 9,028 ha of permanent nets
    - 431 ha of shadehouses.
- The Australian Protected Cropping Map Dashboard application has been viewed 1,497 times;
- The map is accessible as a feature service by numerous web applications – the Dashboard and Industry Engagement Web App (IEWA) are just two examples (built by AARSC). Analysis of total number of views (access) of the feature service returns a total of 9,252 (as of 11th August 2023);
- All features in the map are current (mapped in year) to 2022 or sooner;
- Field validation was completed in each intensive growing region, with 20% of all features in the map physically validated (ground-truthed); and
- Industry engagement is essential for accurately mapping new systems, enabled by location-based tools, including:
    - 402 PCS Survey forms received
    - 12 comments (specific for PCS), actioned in the Industry Engagement Web App.

Definitions

The derived map aligns with the guidelines for land use mapping in Australia, which sets the national standards and agreed classification of land use mapping. Classes of PCS as defined by Version 8 of the Australian Land Use and Management Classification (ALUMC) are mapped within the secondary land use classes of intensive horticulture and production nurseries.

For this project, we have used a three-level hierarchical classification to classify the PCS (Figure 5). The primary level of the classification simply classifies all features within a single class as a 'protected cropping system'. At the secondary level of the classification, the features are defined as either a greenhouse or netting. The tertiary level adds additional detail, with greenhouses classified as either a glasshouse, polyhouse or polytunnel; and netting classified as either net or shadehouse.

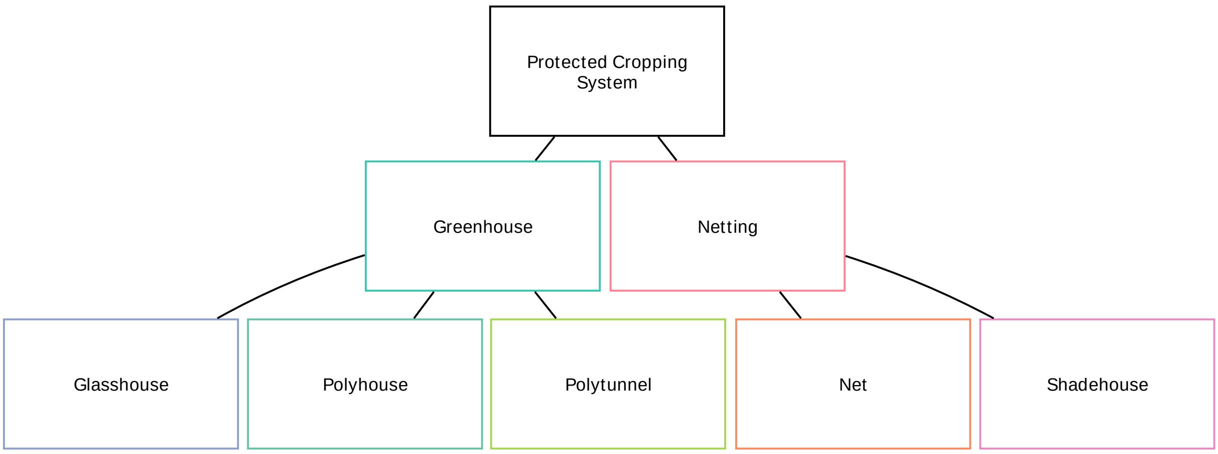

Figure 5: Hierarchical classification for Protected Cropping Systems.

Figure 6: PCS Structure classes. Imagery © Maxar; Map data © OpenStreetMap contributors (Esri Basemaps); and Street-view imagery © Google Maps.

Figure 6 provides detailed examples of each tertiary class (structure) of PCS – as shown in: aerial imagery; the feature as shown in the published PCS map; and street-view imagery.

Temporary netting typically does not consist of any supporting infrastructure – such as poles. Figure 7 shows the netting is simply draped over the crop in 2022 and is not present in the imagery in 2023. As a result of the transient nature of this type of PCS, temporary nets are not included in the map.

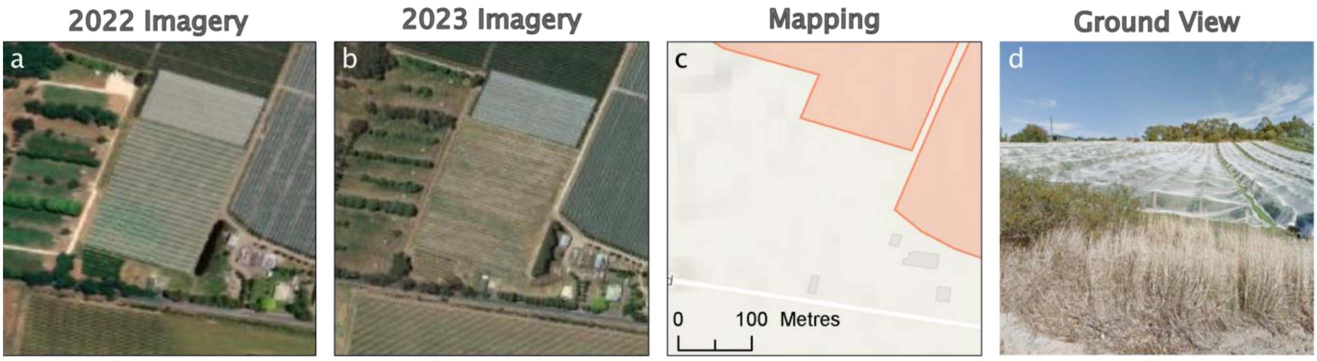

Figure 7: Temporary netting example including 2022 (a) and 2023 aerial imagery (b) PCS mapping (c) and ground view (d). (138°52'30"E 34°58'34"S) Imagery © Maxar; Map data © OpenStreetMap contributors (Esri Basemaps); and Street-view imagery © Google Maps.

Methodology

The national map of protected cropping systems (PCS) was compiled following proven methodology as successfully developed in the *'Rural R&D for Profit Project: Multi-scale Monitoring Tools for Managing Australian Tree Crops: Phase 1 & 2'*, which included the mapping of all commercial avocado, mango, macadamia and citrus orchards, banana plantations and olive groves across Australia.

Mapping program and workflow

The national mapping program to map the location and extent of all commercial PCS was set based upon known intensive growing regions across Australia (Figure 8). The workflow is managed progressively, with each mapping stage recorded by individual 1:100K map tiles (managed by growing region).

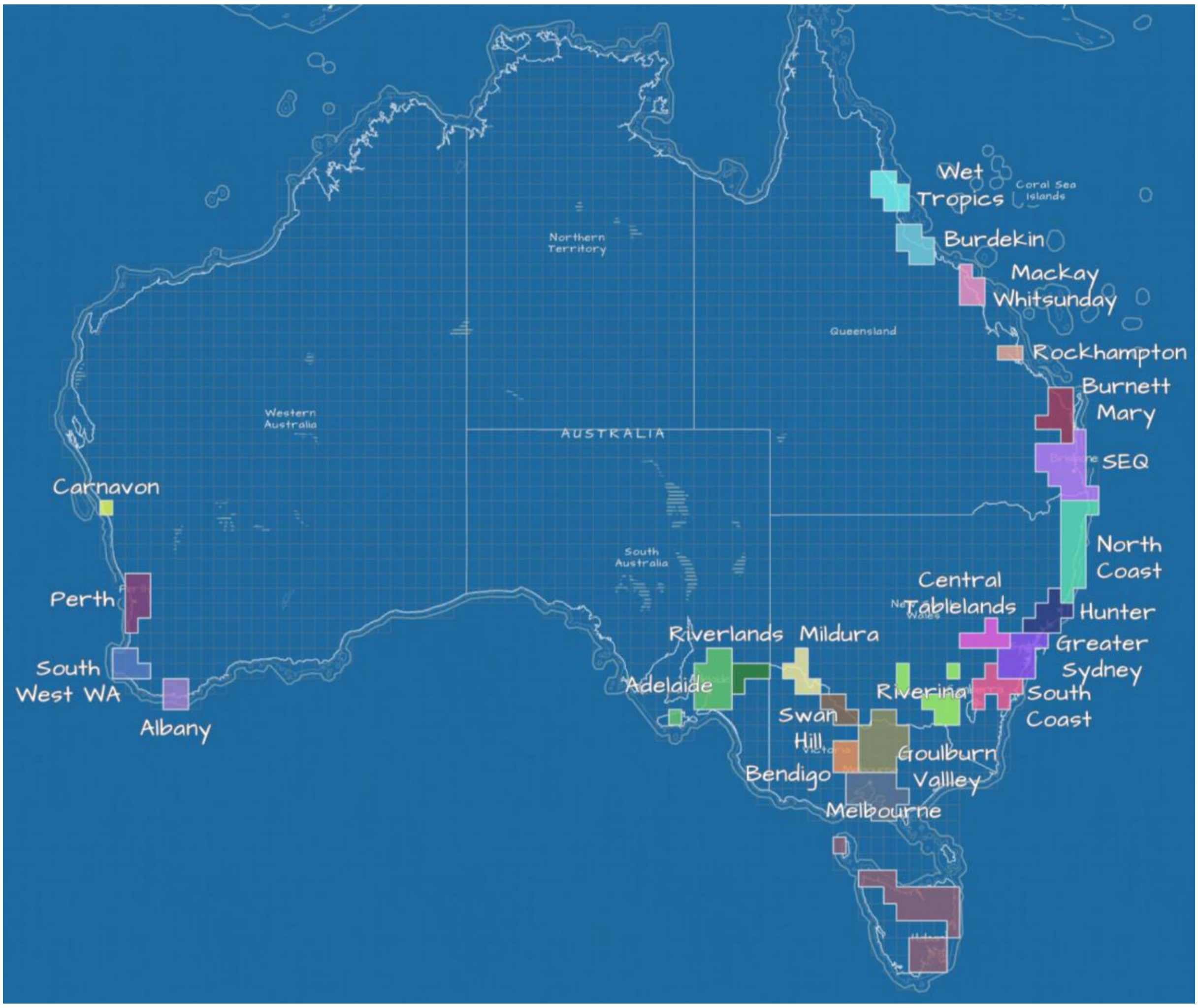

Figure 8: National mapping program by growing region.

The progress of the national mapping program was updated 'live' during compilation, available for stakeholders to view and track in the PCS Project Progress Dashboard application (Figure 9). The workflow stages follow the sequence of: In progress > Draft > Field validation > Peer review > Published.

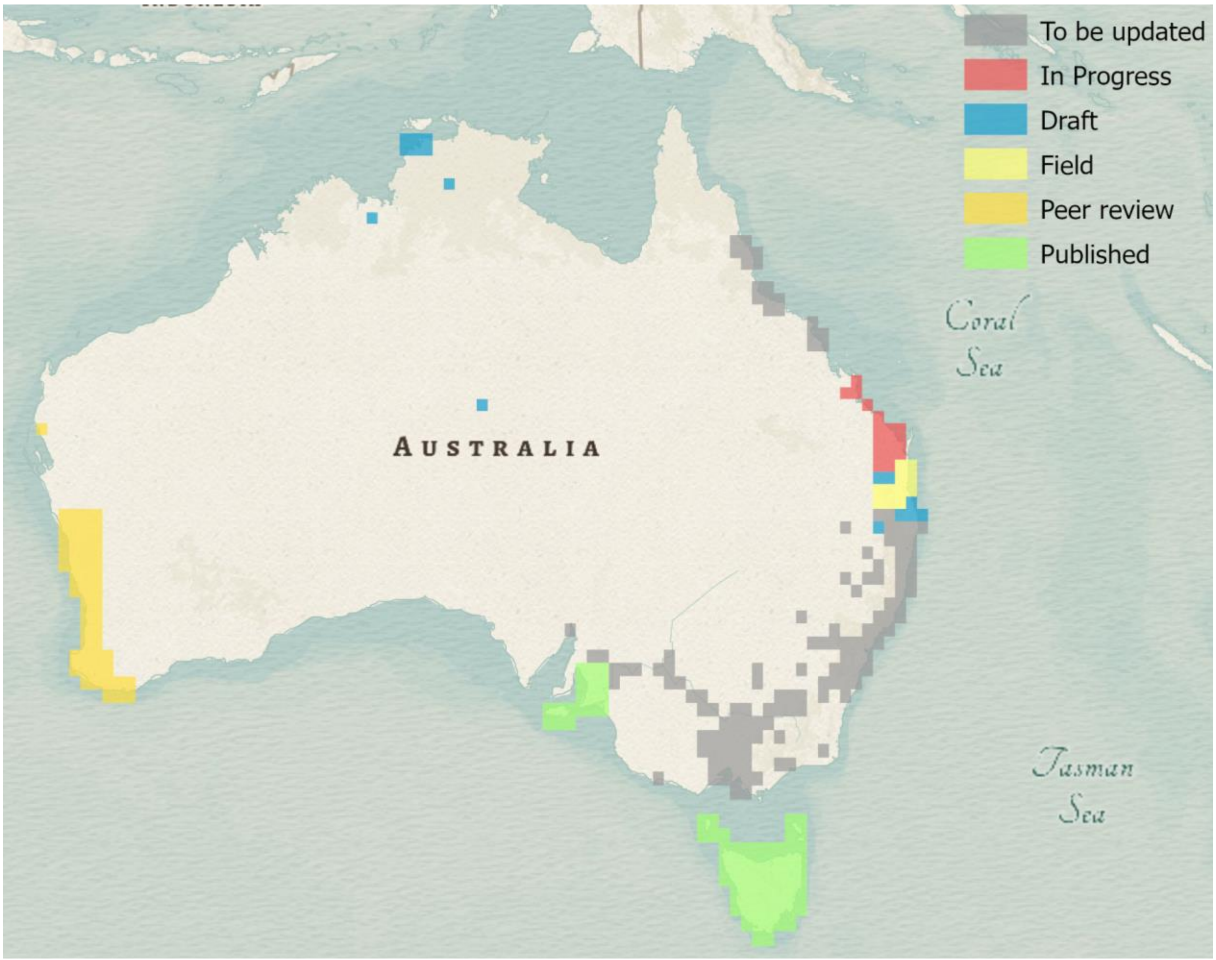

Figure 9: Mapping Progress Dashboard (during compilation).

Compilation of the map was informed from multiple sources of evidence (Figure 10) including:

- **Remotely sensed imagery**, including open-source image services (e.g., Esri Basemaps and Google Earth), imagery subscriptions (e.g., Planet) and purchased acquisitions (e.g., aerial photography, Skysat and KOMPSAT3).
- **Ancillary data** including existing industry data and government land use information.
- **Field validation**.
- **Industry engagement** (citizen-science), including peer review – enabled via location-based tools developed by AARSC.
- **Deep learning**, using existing draft mapping to train a convolutional neural network model and use predictions on other geographic area, dates and sensors to assist in the updating of the PCS map.

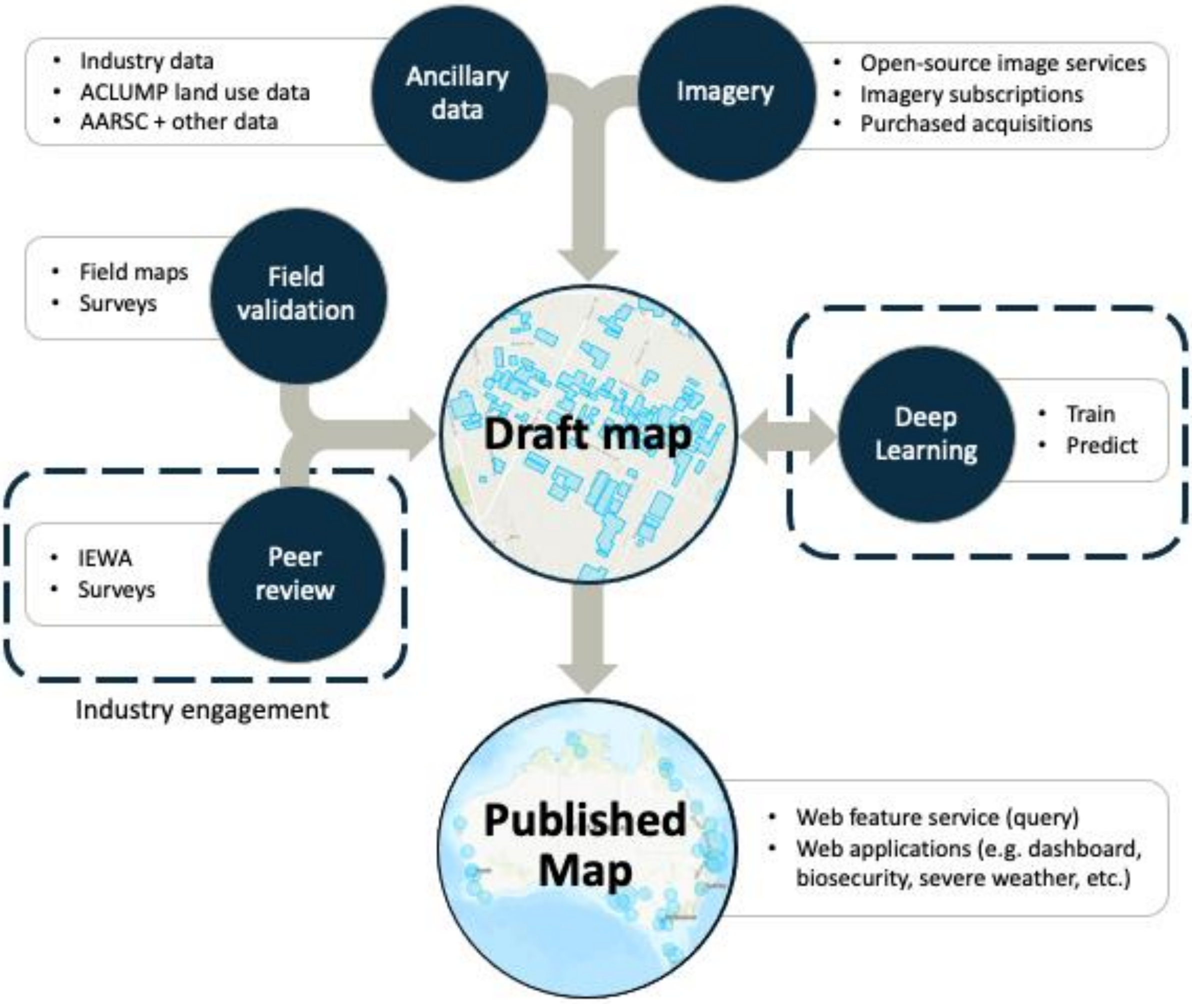

Figure 10: Australian Protected Cropping Systems mapping methodology.

Remotely sensed imagery

Publicly accessible imagery provided the primary resource of high-resolution data suitable for interpretation of PCS (e.g., Google Earth Imagery, Esri Basemap Imagery, Google Street-view and other government image services). In collaboration with ACLUMP partners, jurisdictions shared recent high-resolution imagery to inform the map, including the intensive growing region of Adelaide Hills (17 cm aerial orthophotography captured in 2020, supplied by South Australia's Department for Environment and Water) and Queensland's Spatial Imagery Subscription Plan imagery, which included aerial orthophotography from 6–20 cm, supplied by the Queensland Department of Environment and Science.

Generally, the currency of high-resolution imagery was very timely (acquired < 2 years). However, elsewhere the imagery capture date effectively limits the currency of the map as the newly established structures were not visible as the land use change event followed the date of image acquisition. To overcome this challenge, we accessed and interpreted coarser resolution (but very current) satellite imagery (e.g., PlanetScope) to map the new PCS. This was only undertaken where other ancillary data (e.g., industry engagement or field observation) identified the location of new structures. This ancillary information was also used to classify the structure type, as it was not possible to classify new PCS with coarse imagery alone.

Ancillary data

Classifying the type (structure) of PCS is more robust when informed by supplementary information as ancillary data, including geocoded industry data, publicly accessible property information and existing government land use information.

Industry membership information (shared confidentially by Protected Cropping Australia) was geocoded based on the supplied address information which included 225 records (Figure 11). Typically, these point locations related to postal addresses rather than actual PCS location. As an ancillary data layer, industry data informs the mapping program (where to look for PCS), and further aids in the image interpretation of structure type. It's especially valuable for classifying new PCS which cannot be accurately mapped by imagery alone.

Figure 11: Geocoded industry data records.

The University of New England is a partner of the Australian Collaborative Land use and Management Program (ACLUMP) (observer status), joining the consortium of other state and territory members and major stakeholders in the compilation of land use mapping products to national standards. Existing land use information for intensive horticulture and nurseries was sourced through the ACLUMP. Limitations of this information include currency (some features current to 2008), inconsistency in scale (varies) and coverage (incomplete).

Another source of information that informed the map as ancillary data was sourced by property and business internet searches. Often properties are advertised for sale through real-estate websites share location information and details of PCS associated with the property, or businesses may advertise their protected crop (often including area of production). This is frequently the case for nurseries, which may double as a tourist attraction, venue or directly sell products.

Field validation

Field validation improves both the thematic accuracy (correct structure class assigned) and currency of the map, particularly where new structures are found (which are not visible in imagery).

Physical field validation of the map was conducted over each major growing region and scheduled in the mapping program to immediately follow compilation of the draft map to minimise the amount of time between the desktop interpretation (image acquisition date) and the field observations. 14 separate field trips were undertaken during this project (Figure 12).

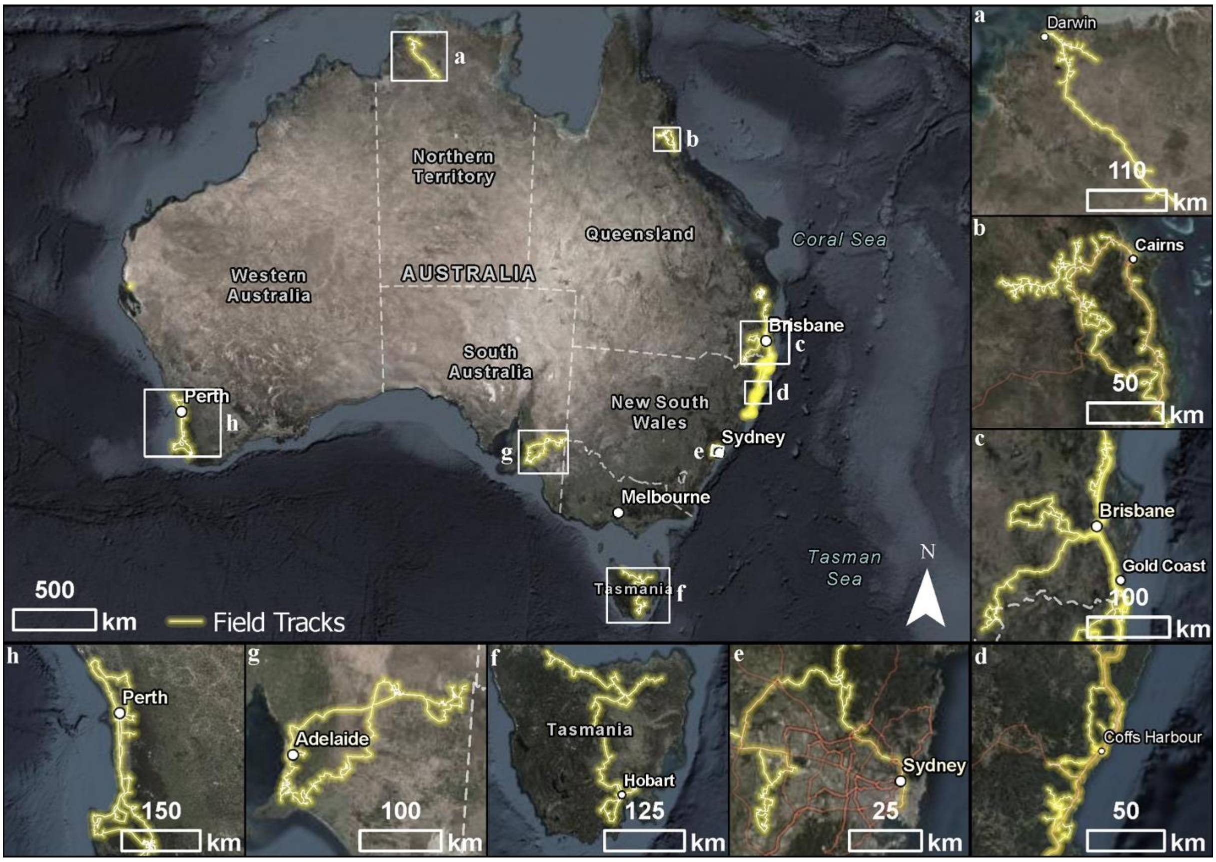

Figure 12: Field validation GPS tracks across Australia.

Routes were pre-planned based on publicly accessible roads, with the infield recording of edits supported by the Field Maps for ArcGIS mobile mapping application using an Apple iPad Pro tablet device. The PCS map was edited directly (as a feature service), with observations of PCS confirmed by checking the structure type and changing the source attribute to field. New or missed features were either directly added to the feature service or a PCS survey created. Where possible, other information such as the crop grown was captured.

Post-field, additional edits are made elsewhere given the insights and information gathered which can further highlight omissions and misclassifications in the map, which are then resolved at the desktop.

Figure 13 shows the mapped feature (polytunnels), with validation completed in field (photo) at location X.

Figure 13: PCS mapping (a) and on-ground field observation (b) at, Hillwood Berry Farm, Tamar Valley, Tasmania. The red 'x' in (a) represents the location of field observation in (b).

Peer Review (Industry Engagement)

Peer review (or direct feedback) from local experts and stakeholders in reviewing (validating) the map is extremely valuable. As defined in the mapping program, the mapping was published and updated progressively by growing region and published as draft for peer review in the publicly accessible Industry Engagement Web App (IEWA), designed for desktop use. Peer review was anonymously sought through local experts in each major growing region, to review the draft mapping and provide feedback as comments, either in point (location only) or as polygons (including extent).

Each observation received is interpreted by the mapping team and actioned as updates to the map, including a response. This information validates existing data and can highlight omissions in the map which are then resolved, improving both the accuracy and currency of the map.

Industry engagement was also supported with the PCS Survey, designed for mobile or tablet devices. The survey captures location-based information (point only), with additional information for PCS structure type.

The growth in horticulture in Australia raises an additional challenge for accurately mapping new structures, as the open-source high-resolution imagery (< 1.5 m pixel size) accessed is typically several years old. This is not a significant limitation in mapping the established structures but is when mapping new ones – as they are not visible in the open-source imagery due to its currency (age). To overcome this challenge, more recent coarser resolution imagery (e.g., Planet) was used, but only where other information was available (e.g., an observation submitted through the PCS Survey or comments in the IEWA). Figure 14a presents an example for a comment submitted through the IEWA for a new 'polyhouse' PCS – which is not visible in the high-resolution image (© Maxar, Esri basemaps, acquired 30th July 2022). Figure 14b shows the new constructed PCS in the coarser Planet satellite basemap imagery, acquired in June 2023. This example clearly demonstrates the value of industry engagement to accurately map and classify the new structures.

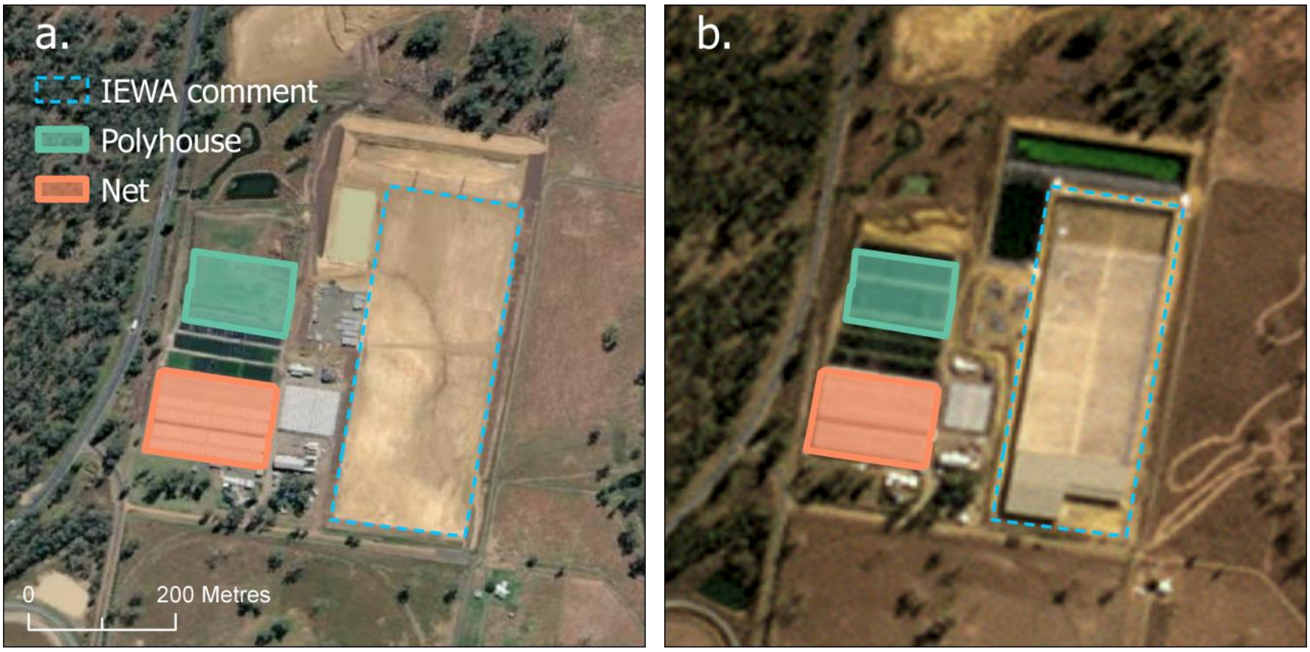

Figure 14: Industry engagement comment (blue dotted line) for new PCS. (a) High-resolution image (© Maxar, Esri basemap, captured 30th July 2022); and (b) Coarse resolution image (© Planet basemap, captured in June 2023).

This process directly engages the industry and provides them with the tools and the opportunity to collate the information on behalf of the greater industry, it also exposes them to the concepts of spatial data. This process and direct participation improved the accuracy of the data, acceptance of the mapping by the industry, and the likelihood that the updates to the mapping will continue post project.

Deep Learning (Computer vision)

This project has undertaken research into using deep learning techniques, specifically computer vision, to automatically map the location and extent of PCS features within high-resolution imagery. The outcomes of this research indicate that imagery with a spatial resolution of 50 cm is required to map PCS features accurately and efficiently. The developed deep learning methods can identify greenhouse features to a high level of accuracy, but netting structures are more difficult to identify due to their transparent nature.

The developed method is robust, generalised, able to use a combination of aerial and satellite sensors and able to identify PCS features in geographical areas different to where the model was trained. However, deep learning alone cannot be used to create a national map of PCS without the assistance of human operators to check the output.

Using deep learning to identify PCS features has expedited the compilation of the map (particularly in Queensland and Greater Sydney) and assisted in identifying structures which were not easily found without this assistance.

Further details describing the research in full can be found in Appendix 2.

Draft mapping

The draft mapping was compiled at the desktop using the Esri ArcGIS Pro Geographic information System (GIS), within a service-based editing environment, hosted within the UNE ArcGIS Online organisation.

All edits were compiled in a polygon feature class 'edit layer' with observations for structures recorded at feature level. The source and year of observation for each feature in the map was recorded, reflecting the most recent date of observation from the image capture date and (when completed) date of validation in the field.

Additional attributes assigned in compilation of the draft map included the observation of management status of each feature, either: future, intact, damaged, abandoned or removed. Note that only features with a management status of 'intact or 'damaged' were published in the map.

Published map

To publish the final mapping product, polygon features representing the location and extent of PCS were derived from the editing layer by aggregating and dissolving features with common attributes (structure type, source and year of observation), relative to the map scale (minimum mapping unit of 0.2 ha and a width of 10 m). Figure 15 shows an example of the level of detail shown in the final mapping product (b) after the edit layer (a) is aggregated and dissolved relative to map scale.

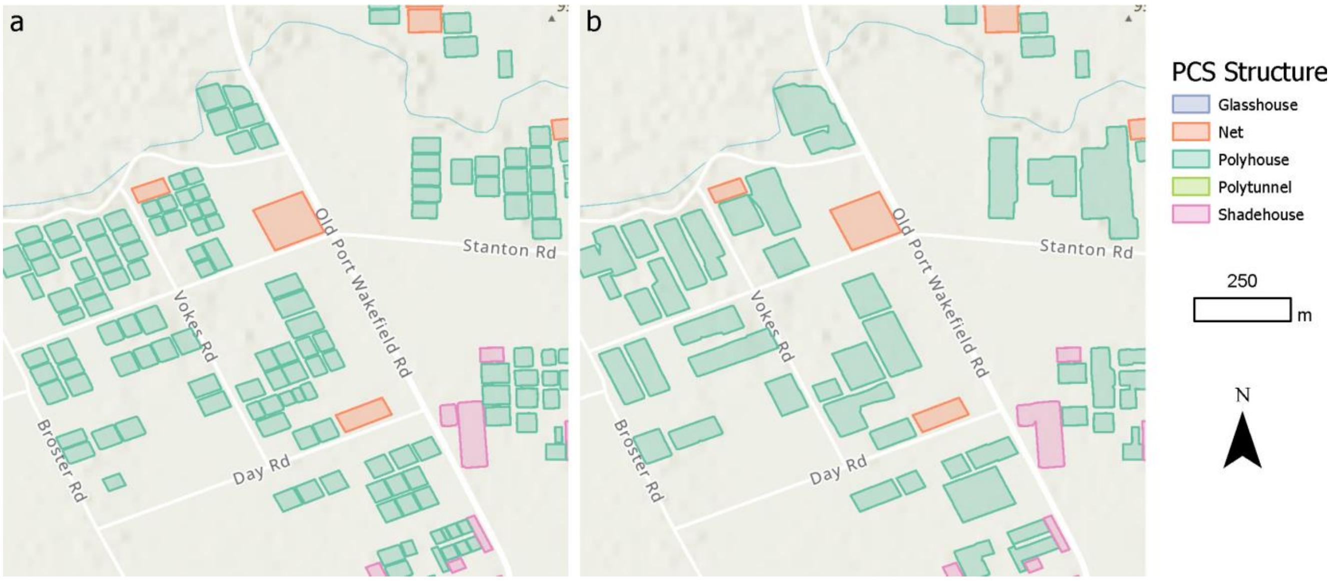

Figure 15: Features as mapped in edit layer (a) and the derived mapping product as published (b).

Updates to the published map were completed as each growing region was finalised. These updates typically followed the field validation as draft mapping was published for peer review. During the life of the project, the published map was updated six times.

The published map is shared as a publicly accessible feature service. The benefit of publishing the map as a service is that when the map is updated the changes are instantly reflected for all who access it. Note the feature service supports query operations only. The data is not available to copy, export or download.

The PCS map is presented in multiple-scales to aid usability. Point clusters (based on the centroid of each feature) present the map at small scale (zoomed out) which are clustered dynamically relative to the viewers zoom level. The bigger the point feature (circle) the more PCS at that location. At large scale (zoomed in) the map is presented as polygon (area) features, showing both location and the extent of the PCS. Presentation of the data is consistent across all maps and apps in terms of symbology.

Results and discussion

Applications summary

The following section presents the mapping applications developed through project AS20003 that support both the development and extension of the PCS map to industry.

The PCS map is shared across a range of location-based web applications, all available for access from the AARSC Industry Applications and Maps Gallery webpage (www.une.edu.au/webapps) (Figure 16).

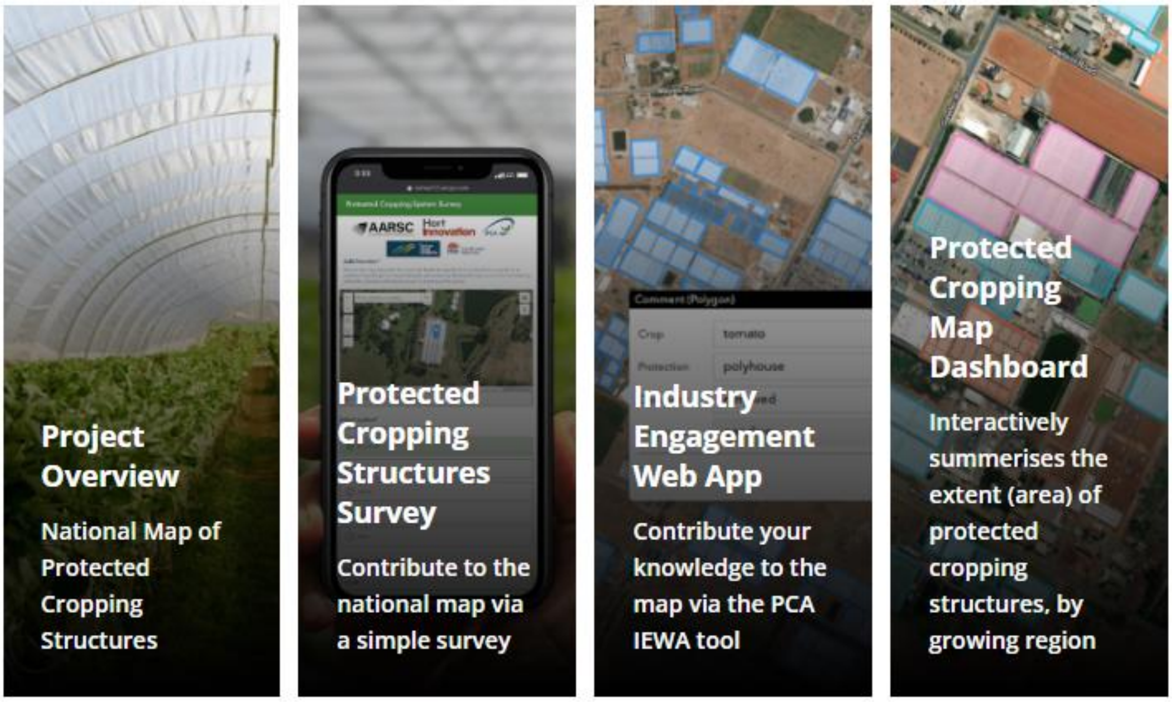

Figure 16: AARSC Industry Applications and Maps Gallery available at www.une.edu.au/webapps.

Each app is designed for simplicity (ease-of-use) for the capture and/or sharing of location-based information.

- PCS Dashboard (https://arcg.is/1CXbrW)
- PCS Survey (https://arcg.is/0H0L9P)
- Industry Engagement Web App (https://arcg.is/1WyWDa0)

Finally, value-added mapping applications developed through this project including the Varroa mite Rapid Response Map (https://arcg.is/1nD9S11) are also presented.

Australian Protected Cropping Map Dashboard

The Australian Protected Cropping Map Dashboard (Figure 17) was developed to present the final mapping product and summarises the total area of PCS according to structure type.

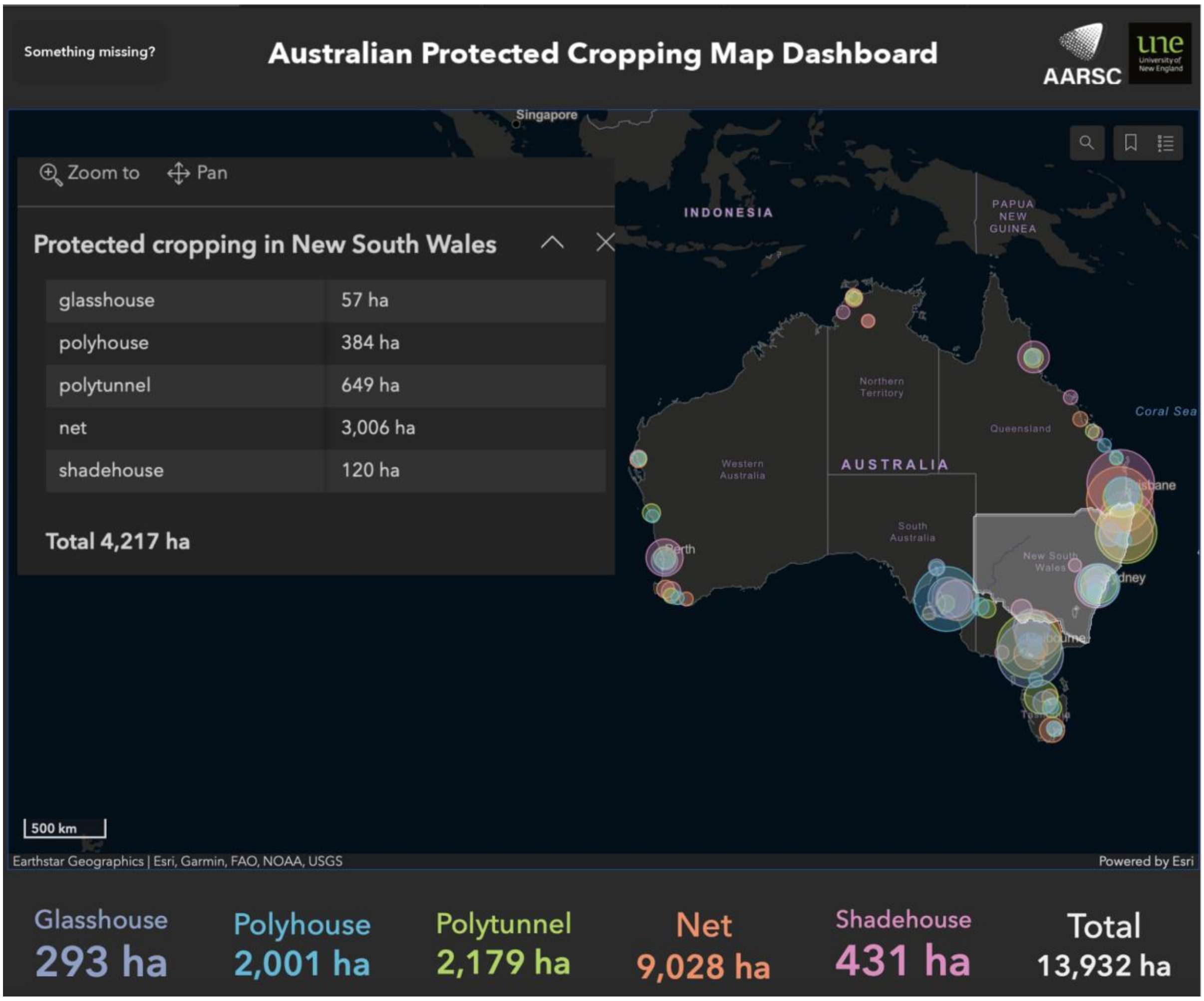

Figure 17: Australian Protected Cropping Map Dashboard, showing total production area in NSW (pop-up).

This dashboard-style web application features the latest map and presents summary metrics for each structure type (area of production in hectares) based on the zoom/view extent of the user. The dashboard includes the functionality to return metrics by state and territory and local government area (LGA) in a pop-up window as well as interactively based on the view extent of the user. Navigation around the map can be undertaken using the bookmark tool, or the user can simply type an address or place name into the search box and/or simply pan and zoom the map, which the dashboard will update the statistics for each PCS (at bottom) on-the-fly, based on the map view extent.

Since launching in December 2022, the dashboard has been viewed (opened) 1,497 times (Figure 18). Peaks in views correlate with media releases and social posts sharing map updates (e.g., LinkedIn, Twitter, refer Appendix 3, Table 7).

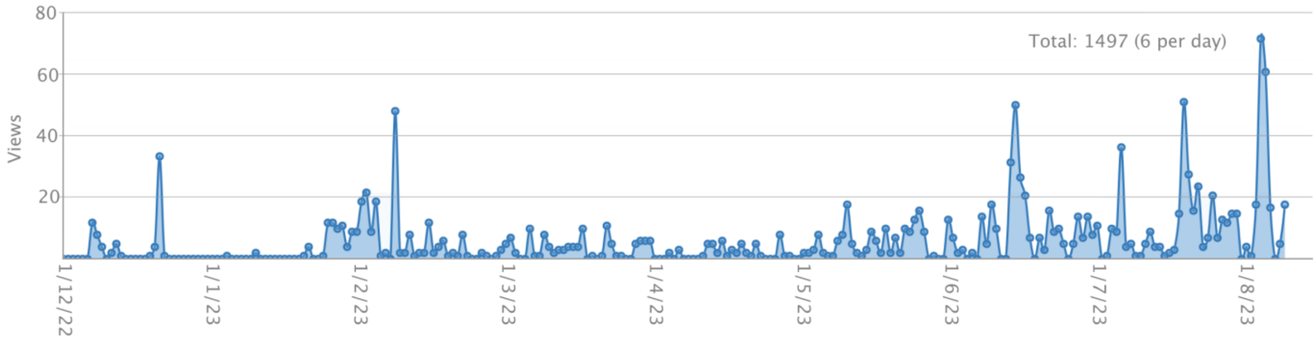

Figure 18: PCS Map dashboard usage (views) as of 8 August 2023.

PCS Survey

The survey form (built using Esri Survey123 for ArcGIS) has been configured to run in any browser on any device – mobile, tablet or desktop (Figure 19). The survey provides an extremely reliable and efficient means of engaging with industry and stakeholders to contribute to the mapping. Point observations submitted via the survey include the location and system type and optionally the crop type, comment and photo. The survey location map includes both existing (submitted) surveys and the latest PCS map to orientate the user.

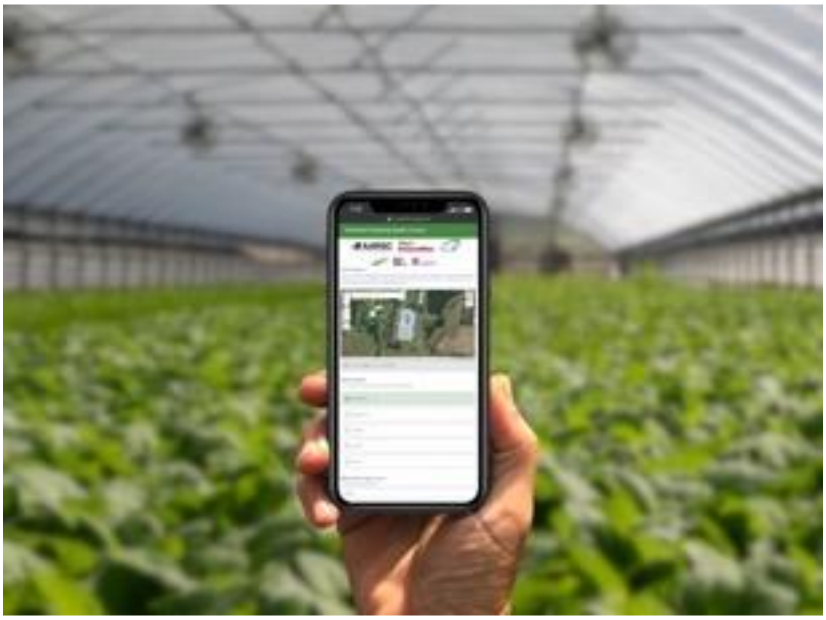

Figure 19: PCS Survey, launch by scanning the QR Code

Each PCS survey observation was interpreted and actioned as an update to the map. Figure 20 shows an example of survey observation submitted for a glasshouse (including photo). This information is extremely valuable in correctly classifying structures (type) and essential for mapping new structures.

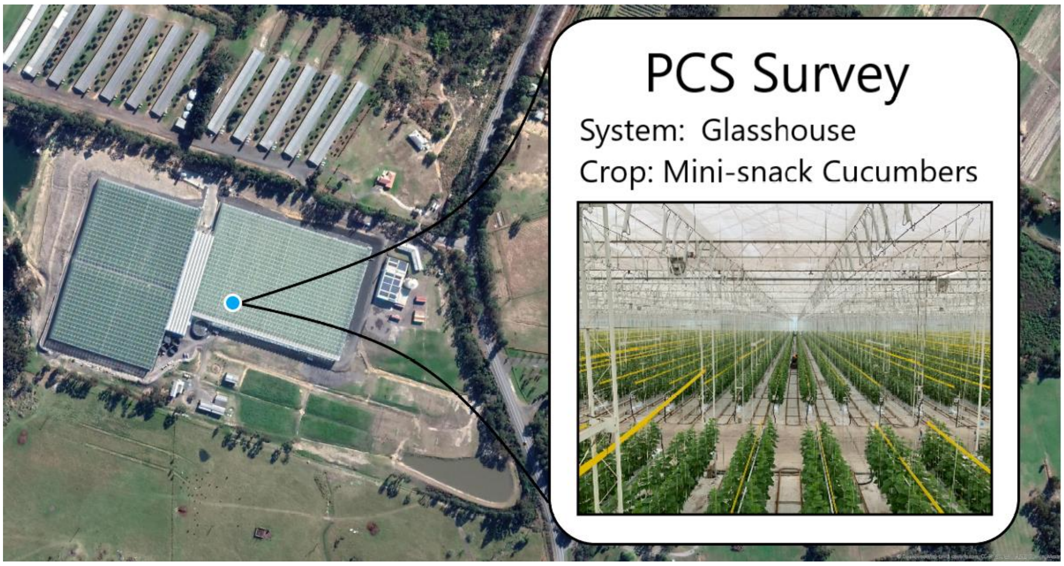

Figure 20: PCS Survey observation.

Analysis of the survey data shows a total of 402 new surveys were submitted during this project (Figure 21), which accounts for 1,555 ha of PCS either added or confirmed in the map. Table 4 presents the analysis of responses by structure type, and the total area (hectares) added or confirmed in the map.

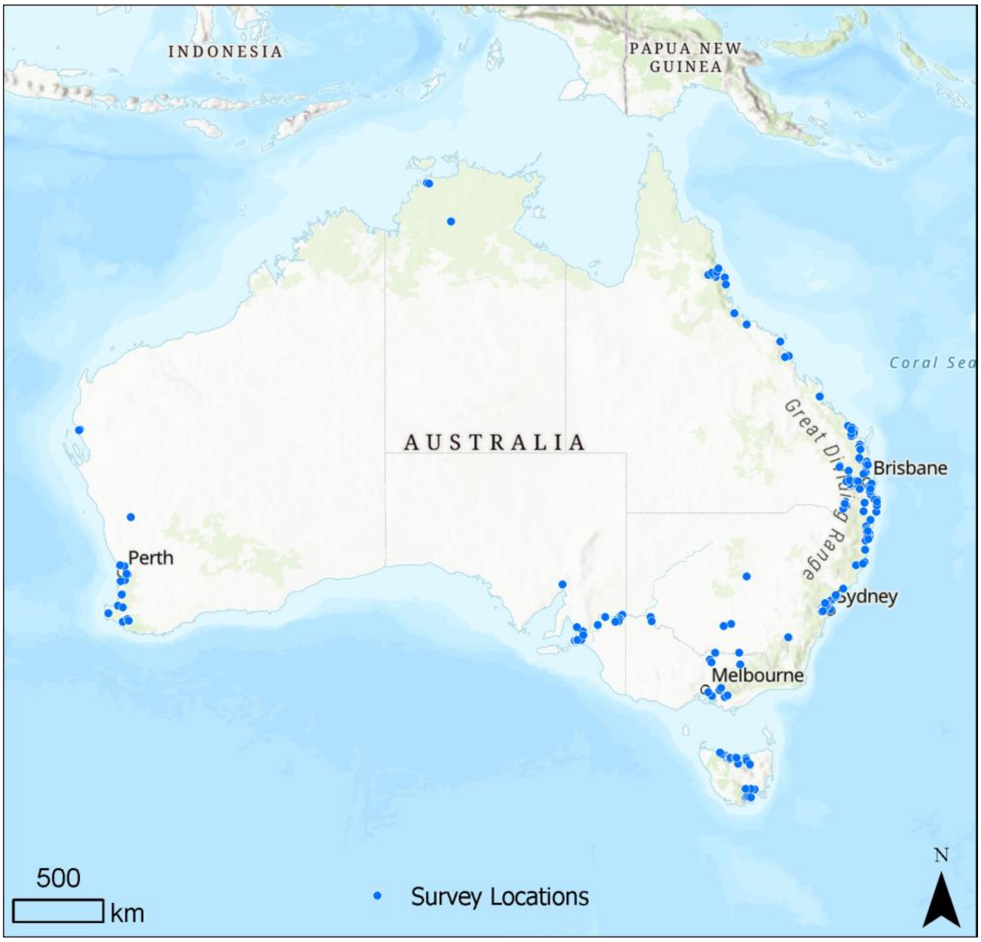

Figure 21: PCS Surveys. The blue dots represent the location of each survey observation.

Table 4: PCS Surveys summary analysis

PCS Survey	Surveys (count)	Area added or confirmed (hectares)
Glasshouse	39	52
Polyhouse	48	78
Polytunnel	87	316
Net	187	1,090
Shadehouse	16	19
Other	25	NA
Total	**402**	**1,555**

Industry Engagement Web App

The Industry Engagement Web App (IEWA) presents draft mapping and enables comments to be added directly (anonymously). The app includes simple web-GIS capabilities that allow anyone to add (draw) a feature (as a point or polygon) on the draft map (Figure 22). AARSC interpret the information submitted and action updates to the map, which supports both the addition (and confirmation of existing) features in the map and removal of features either misclassified or removed. This application is critical to inform the mapping of new structures which cannot be mapped with satellite imagery alone.

Figure 22: Industry Engagement Web App.

The IEWA (which also features the Australian Tree Crop Map), has been viewed a total of 7,057 times (since launching in 2019). Comments provided by participating growers include both point (location) and polygon (extent) observations. The total number of comments received (specifically for PCS) through this tool was 12, which has confirmed and/or added 23 ha of PCS into the map. Some comments also corrected misclassifications in the map.

Value-added Applications

Varroa mite Rapid Response Map

The PCS map is supporting the current biosecurity response to Varroa mite in New South Wales. AARSC developed the Varroa mite Rapid Response Map, which includes the national map of PCS and the emergency response zones (sourced from NSW DPI). Viewers query the map and return the total area of PCS within each zone, summarised by structure type (Figure 23).

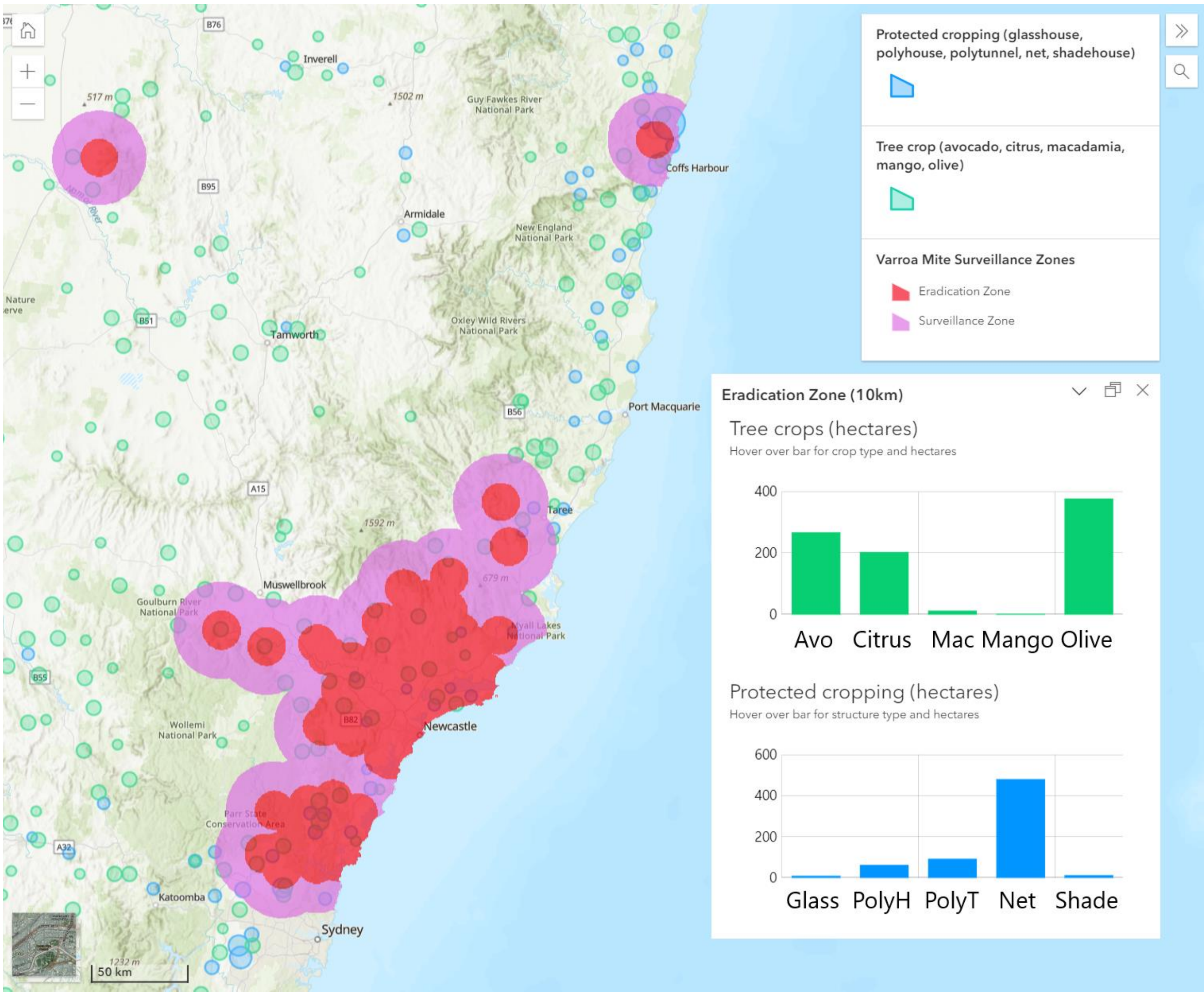

Figure 23: Varroa mite Rapid Response Map, showing protected and tree crops within the Eradication zone (10km).

Clicking each surveillance zone on the map interactively returns charts (pop-up), presenting the total area of PCS within that zone. Based on the emergency response zones from 12th July 2023, the map currently shows a total 641 ha of PCS are within the eradication zone (10 km) and a further 1,216 ha are located within the surveillance zone (25 km) (Table 5).

Since launching on 28th March 2023, the Varroa mite Rapid Response Map has been viewed 664 times.

Table 5: Varroa-mite zone analysis (12th July 2023).

PCS Structure	Eradication zone (10 km) (ha)	Surveillance Zone (25 km) (ha)	Total (ha)
Glasshouse	6	1	7
Polyhouse	59	50	109
Polytunnel	89	379	468
Net	478	778	1,256
Shadehouse	9	8	17
Total	**641**	**1,216**	**1,857**

Mapping Analysis

The mapping of all PCS across Australia not only provides a spatial reference of industry extent (location and area), but it also supports the automated extraction of summary statistics at multiple-scales. The following results section presents analysis of the final map for each structure type, including metrics of total production area (hectares) summarised at the national, state and local government area (LGA) scales. All summary statistics derived from the map is based on analysis extracted 2nd June 2023. The data is also available within the PCS Dashboard (as pop-ups) by state / territory and LGA. Additional summary analysis of total production area by Natural Resource Management Regions, Federal and State Electoral boundaries, and the ABS Census SA2 areas have also been provided direct to industry in the form of Excel spreadsheets (pivot tables).

Summary statistics are based on analysis of administrative boundary data sourced from the Australian Statistical Geography Standard, Edition 3 (2021–2026), Australian Bureau of Statistics. Although numerous data formatting and cleansing steps have been undertaken to prepare these data for robust analysis at national scale, some artefacts may remain.

National totals for production area (hectares) are shown in Figure 24 and summarised by each state / territory in Table 6.

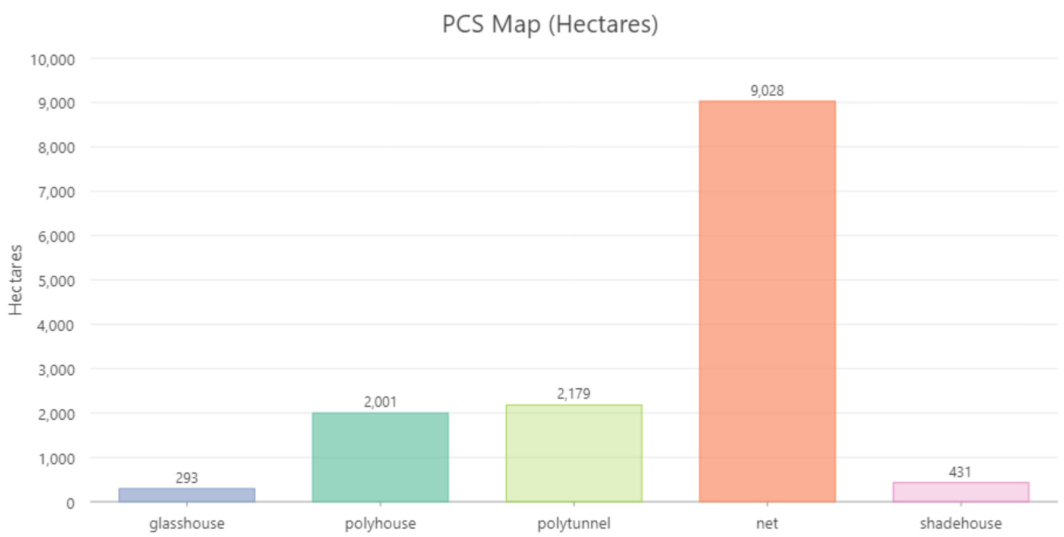

Figure 24: PCS structure type area.

Table 6: PCS structure production area by state / territory.

State / Territory	Glasshouse (ha)	Polyhouse (ha)	Polytunnel (ha)	Net (ha)	Shadehouse (ha)	Total (ha)
ACT	0	0	0	1	3	4
New South Wales	57	384	649	3,005	120	4,216
Northern Territory	0	0	1	73	12	86
Queensland	5	292	399	1,872	130	2,698
South Australia	87	1,103	22	816	20	2,048
Tasmania	9	7	505	803	0	1,323
Victoria	125	166	354	1,925	29	2,598
Western Australia	9	49	249	532	118	958
Total	**293**	**2,001**	**2,180**	**9,028**	**431**	**13,932**

Figure 25 to Figure 29 present the total area of PCS (hectares) by LGA, for each structure class.

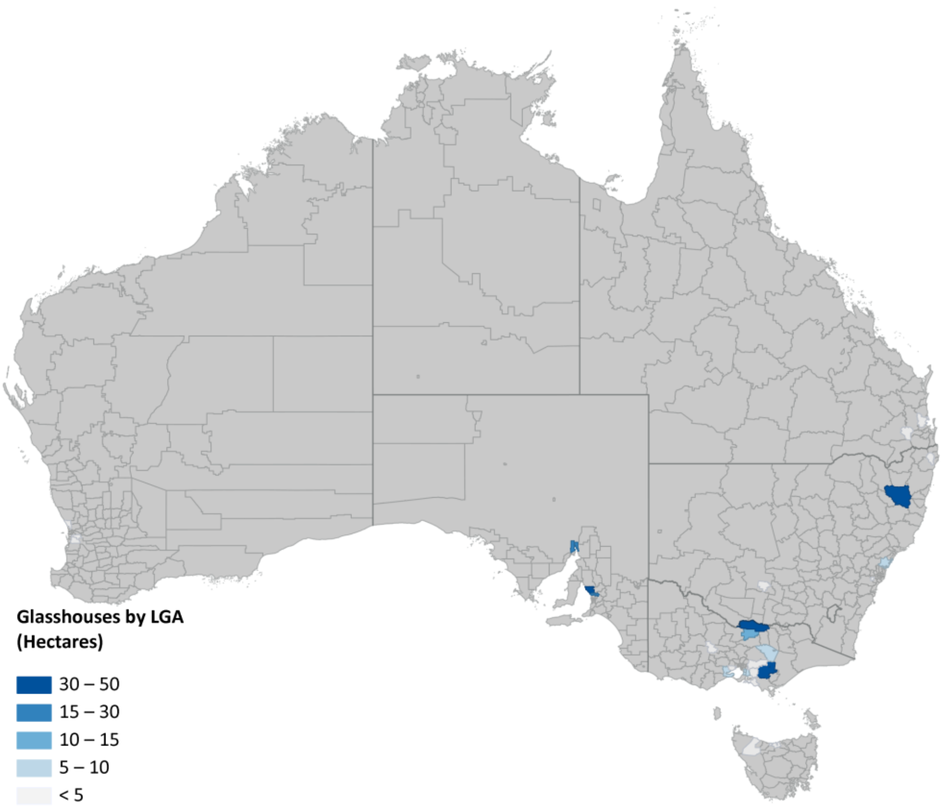

Figure 25: Glasshouses by LGA (Hectares).

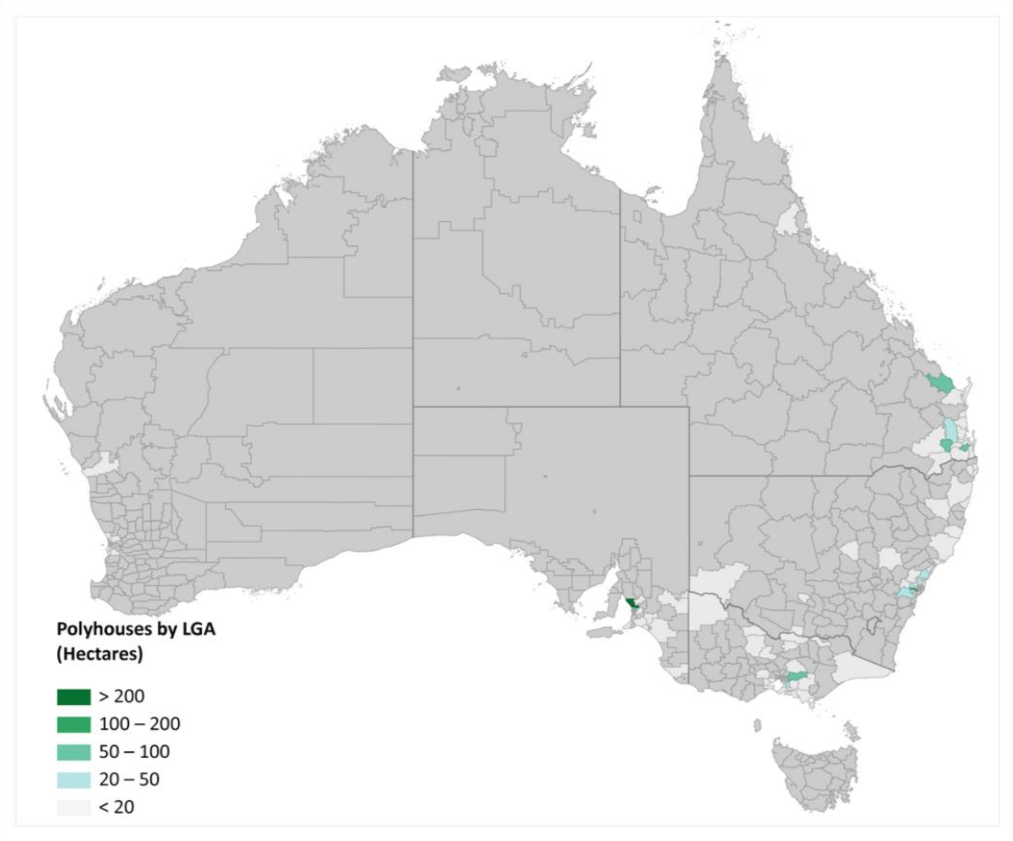

Figure 26: Polyhouses by LGA (Hectares).

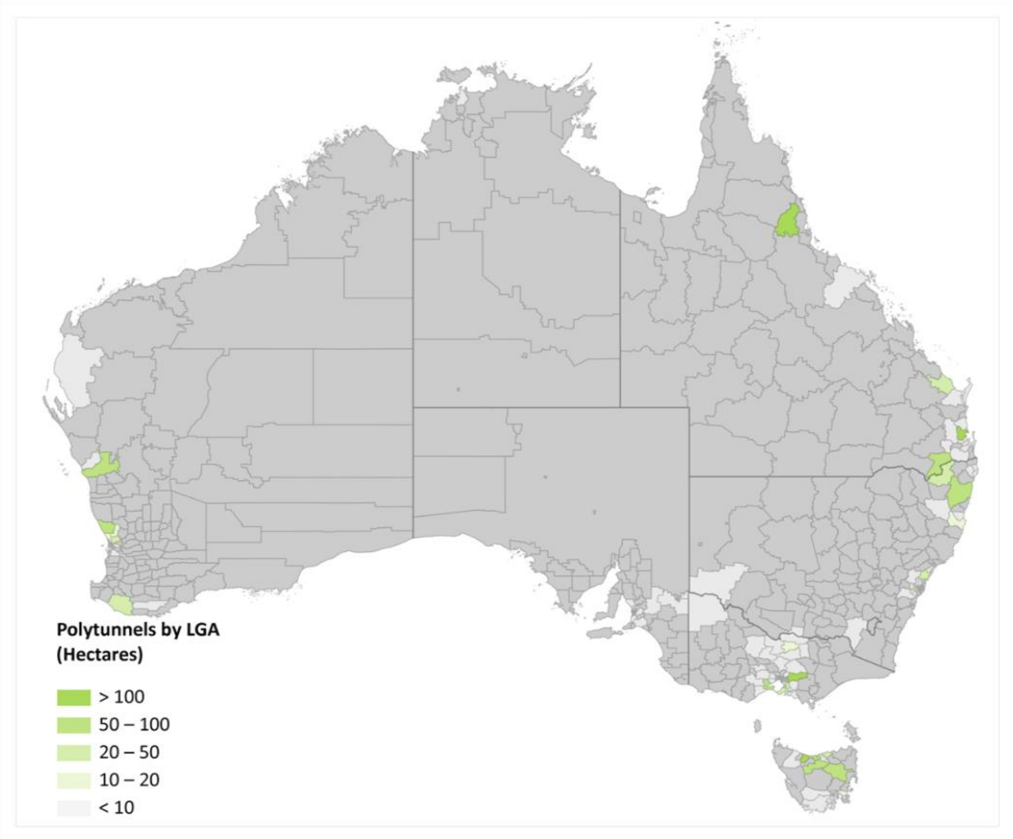

Figure 27: Polytunnels by LGA (Hectares).

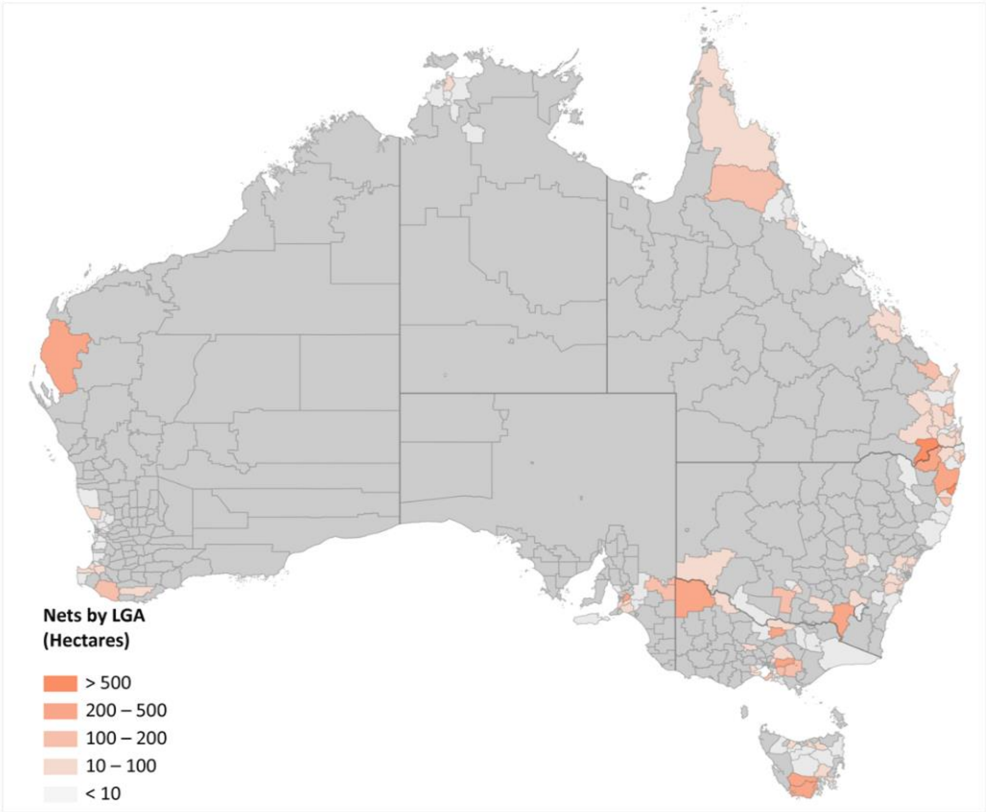

Figure 28: Nets by LGA (Hectares).

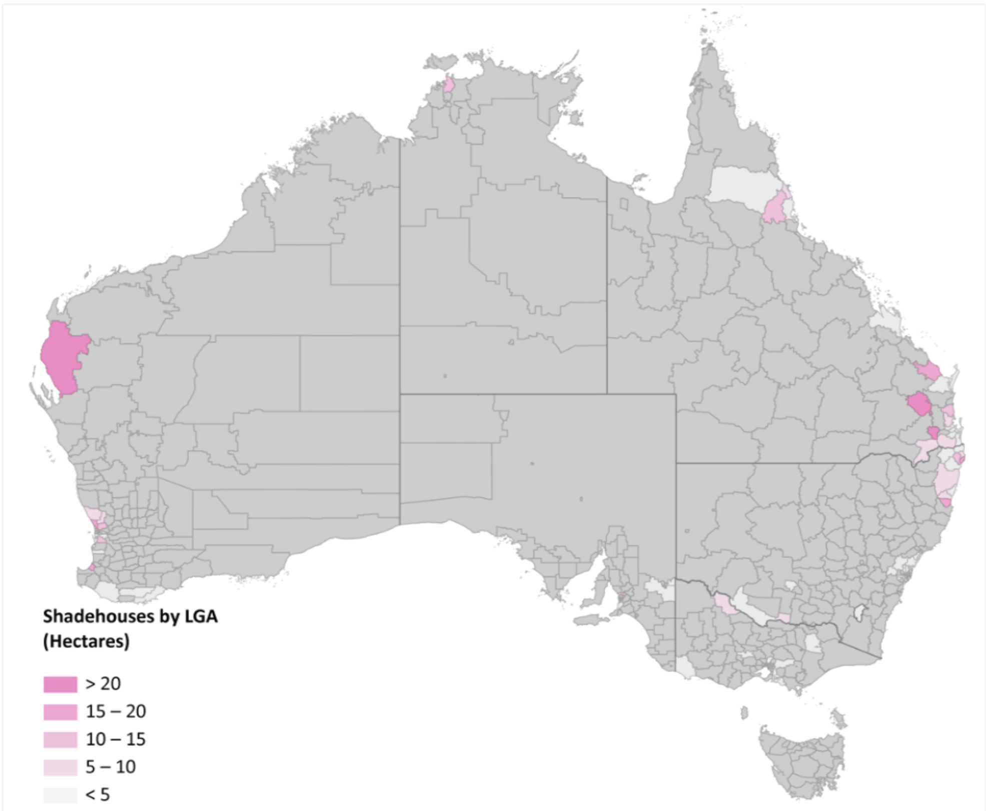

Figure 29: Shadehouses by LGA (Hectares).

All features in the map are current to at least 2022 with 2% mapped to 2023. This metric is recorded based on the most recent observation at feature level, from either image acquisition date or field validation.

Analysis of the data by source of observation shows that 20% of features were field validated. This information can be used as a surrogate for thematic accuracy of the map, with higher certainty for mapped features where source includes field validation.

Further analysis at feature level (individual polygons) illustrates the level of detail contained in the map (edit layer) relative to the published (dissolved and aggregated) mapping product (map layer). Figure 30 and Figure 31 present the feature counts by structure type in each map respectively.

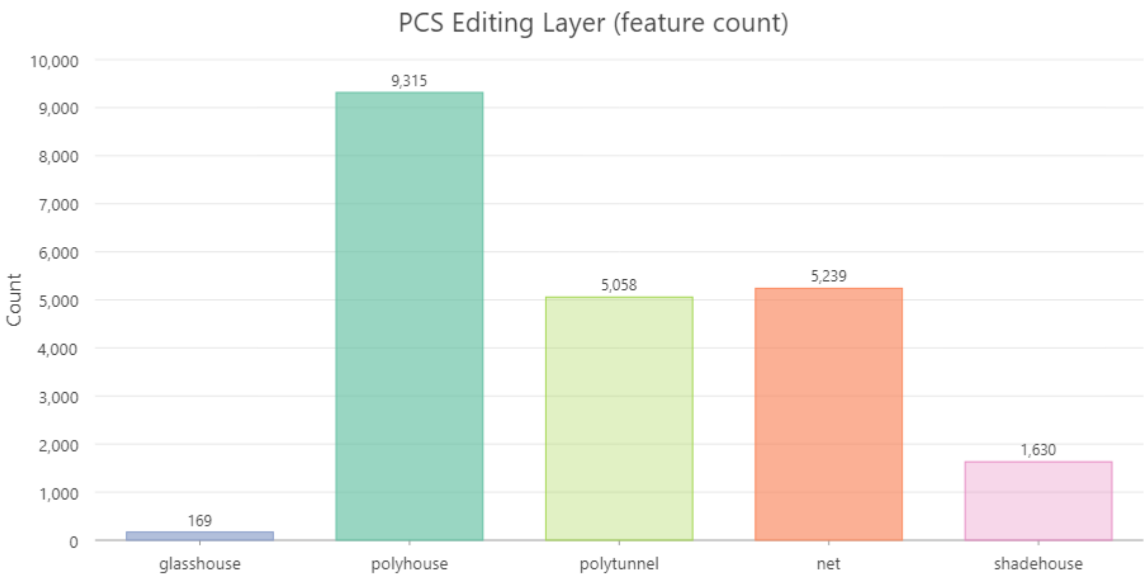

Figure 30: Feature count for PCS map edit layer

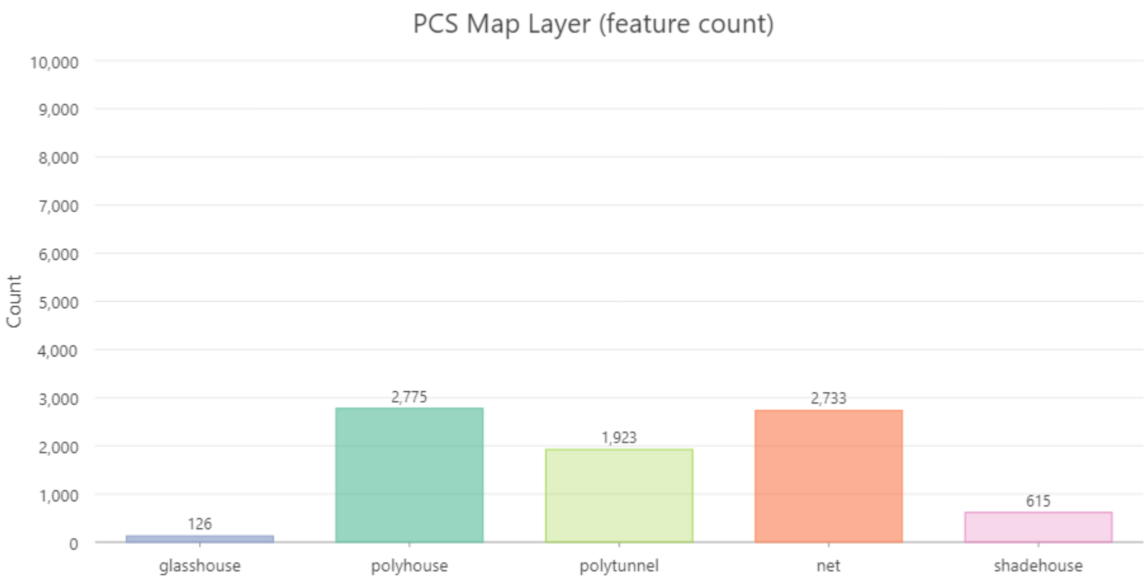

Figure 31: Feature count for PCS map product (derived layer)

Future recommendations for the national map of PCS

The final stakeholders meeting (16th June 2023) agreed the need to maintain the map and discussed possible scenarios that would see the map updated (annually), and potentially value-added to include additional information (such as crop type) and integrated into the ABS Agricultural statistics, ABARES, etc. These discussions will continue with the main goal to find an ongoing mechanism that sees the map updated for currency and new/removed systems to ensure it remains accurate and fit-for-purpose.

Other potential options include enhancement of the current mapping layer by working with PCA and industry stakeholders to include additional information, such as crop/commodity type for individual features, and potentially other commercial information (e.g., ownership, productivity, etc). This would be a larger project that secures both the on-going update of publicly available PCS map (dashboard) and an 'industry only' map for PCA only (as the industry body). AARSC have similar projects for the avocado, macadamia, banana and citrus tree crops funded by the industry bodies, FFS CRC, Hort Innovation and UNE.

Appendix 2: Deep learning modelling

Methodology

The U-Net deep learning architecture

For this project, the U-Net architecture (Ronneberger et al., 2015) was evaluated to determine if deep learning technology, specifically computer vision, could assist with the updating of the national map. The U-Net architecture consists of two parts, an encoding stage which down-samples the resolution of the input images and a decoding stage which up-samples and restores the images to the original resolution (Figure 32). At each level, convolutions (filters) and pooling (resolution reduction) operations are applied which allow the model to learn and represent data with multiple levels of abstraction, mimicking how the human brain perceives and understands information (Voulodimos et al., 2018).

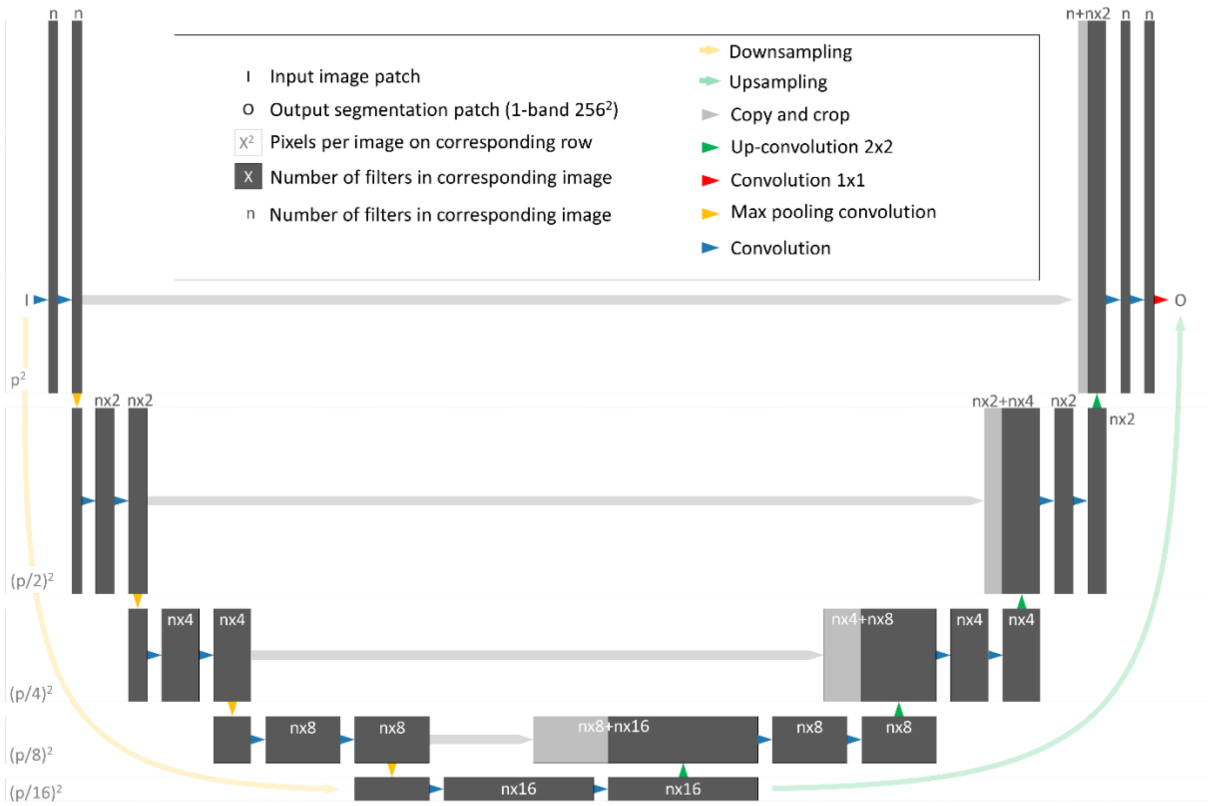

Figure 32: The U-Net architecture (Clark & McKechnie, 2020; Ronneberger et al., 2015)

The U-Net architecture has been used in a range of agricultural studies including mapping of tree fruit and nut crops (Clark & McKechnie, 2020; Yin et al., 2023). Chen et al., 2022 used U-Net architectures to map greenhouses in China and achieved accuracy of 74.92%. However, there are no studies which have attempted to use deep learning techniques to map PCS in Australia.

Deep learning using earth observation data

The U-Net was originally developed for biomedical imaging and applying this technology to earth observation data can present challenges unless the training data has been correctly prepared for a deep learning application (Clark et al., 2023). This is especially true for aerial imagery which can have poor calibration and varying imagery quality and resolution, particularly between capture dates because the same vendor, aircraft, camera and camera condition may not be used. As a result, spectral reflectance and spatial distortions can affect the appearance of features within the data. In addition, varying climatic and seasonal conditions can also affect the spectral reflectance of features.

To attempt to capture these variations, the training data can be augmented by flipping, rotating and changing the brightness of the image (Dosovitskiy et al., 2013; Wieland et al., 2019), which creates a more robust model for these image types and prevents overfitting of the data (Kattenborn et al., 2021). The python package imgaug v0.4.0 (https://imgaug.readthedocs.io/en/latest/) was used to apply random augmentations to the training data, to mimic varying environmental and climatic conditions, different resolutions, capture angles and aircraft roll effects which are not always fully corrected in provided imagery.

The types of augmentation include:

- altering the contrast and colourations
- adding noise to the image
- altering the geometry and scale of the image by rotating, zooming and stretching the image
- adding blur and artificial clouds/fog/smoke.

Figure 33 shows examples of the augmentations applied to each patch. Note the examples provided do not represent the patch size used in this study but are intended to demonstrate examples of the augmentations applied. The augmentations were applied to each patch in every epoch, resulting in different versions of the patches on every iteration.

Figure 33: Example of randomly applied augmentation combinations over an area consisting of protected cropping structures including the original image (a) and three augmented versions (b–d). Note these examples do not represent the patch size used in this study.

Applying the model

When applying the deep learning model, it has been found the edges of each image patch have a lower accuracy than the centre region (Sun et al., 2019). To overcome this, a two-pass classification strategy was used (Clark et al., 2023). The method iteratively applies the model to the original image patch and three rotated (augmented) versions with the results averaged. The second pass is offset by half a patch resulting in the centre of the patches being located at the boundary of four of the first pass patches. The results from the two passes were combined using a weighted average based on distance, with pixels towards the centre of the patch given a higher weight than the pixels towards the edge.

The final binary classification was produced by applying a threshold to the prediction values. The optimal threshold was found by using a precision-recall curve which is useful for imbalanced data sets (Davis & Goadrich, 2006). Pixels which were equal to or above this threshold were classified as the PCS feature and below this threshold, not PCS.

Spatial resolution trials

Earth observation data can be captured with a range of spatial resolutions. Generally, the higher spatial resolution, the higher the cost of acquiring the imagery. A balance between spatial resolution and classification accuracy needed to be determined to reduce imagery costs and processing time to train a deep learning model and produce a high accuracy classification which can be interpreted by a human operator to assist with the PCS national map.

To achieve this, we conducted a range of spatial resolution trials to ascertain the optimal resolution for the mapping of PCS. This was conducted by generating training data over South East Queensland and validation data over the Greater Adelaide region. The training and validation datasets consisted of two classes, PCS and not PCS. These data were derived from RGB orthorectified aerial imagery mosaics which was captured between June and August 2021 for South East Queensland and March 2020 for Greater Adelaide (Figure 34). Both project areas were captured at a resolution of 10 cm.

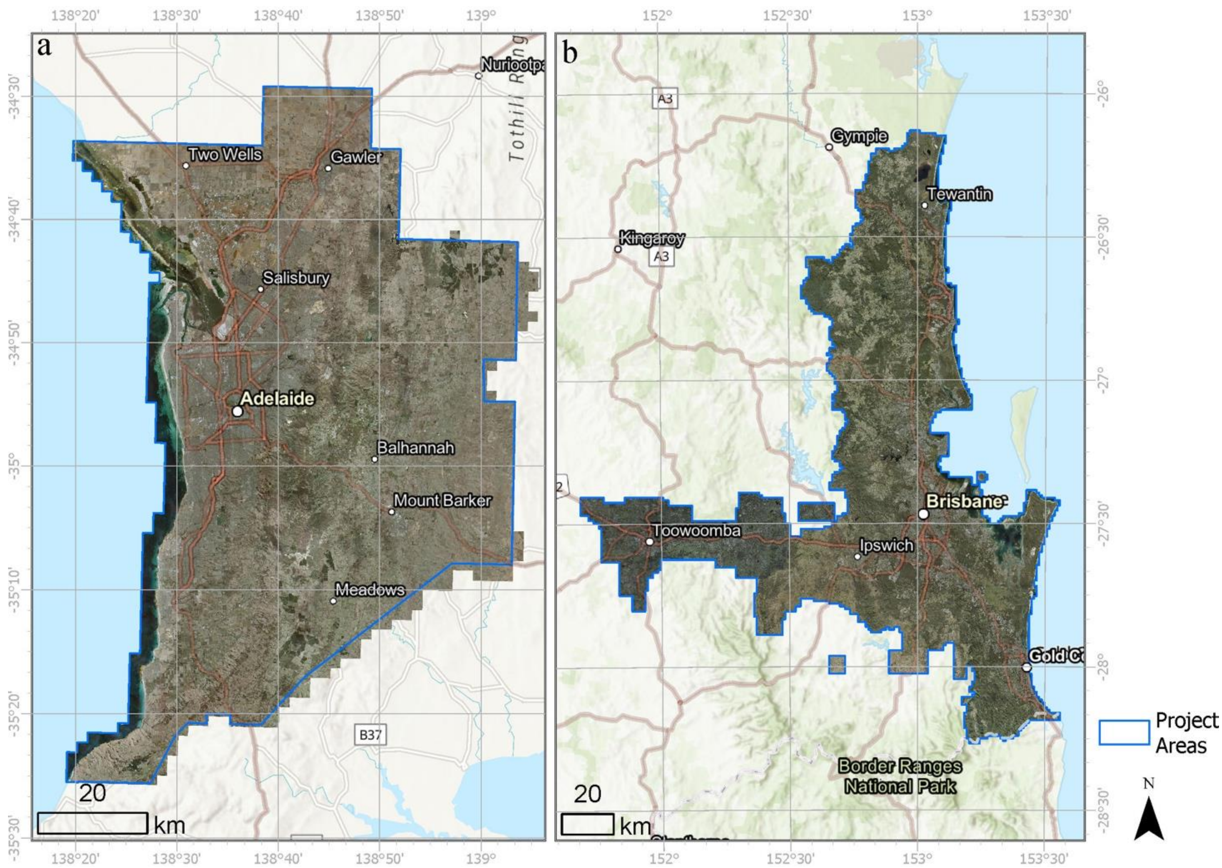

Figure 34: Training imagery for Greater Adelaide (a) and South East Queensland (b).

The 10 cm aerial data were resampled using cubic convolution to a range of spatial resolutions from 20 cm to 300 cm. For each spatial resolution trial, the models were trained using 20,000 patches over South East Queensland and 2,000 validation patches over Adelaide generated using a stratified random sampling method as described in Clark et al., 2023. The method ensures the PCS class has enough representation in the data. The patches were 512 x 512 pixels in size regardless of the resolution. This results in the same volume of data used to train the models but patches generated on lower spatial resolution imagery cover a larger area compared to higher spatial resolutions. In total, there were

7,164 PCS and 12,837 non-PCS training patches and 856 PCS and 1,144 non-PCS validation patches however, a single patch can contain a mix of PCS and non-PCS features.

Figure 35 shows the spatial distribution of training patches in Redlands, South East Queensland. Areas of PCS have clusters of patches to ensure this class has good representation within the training dataset.

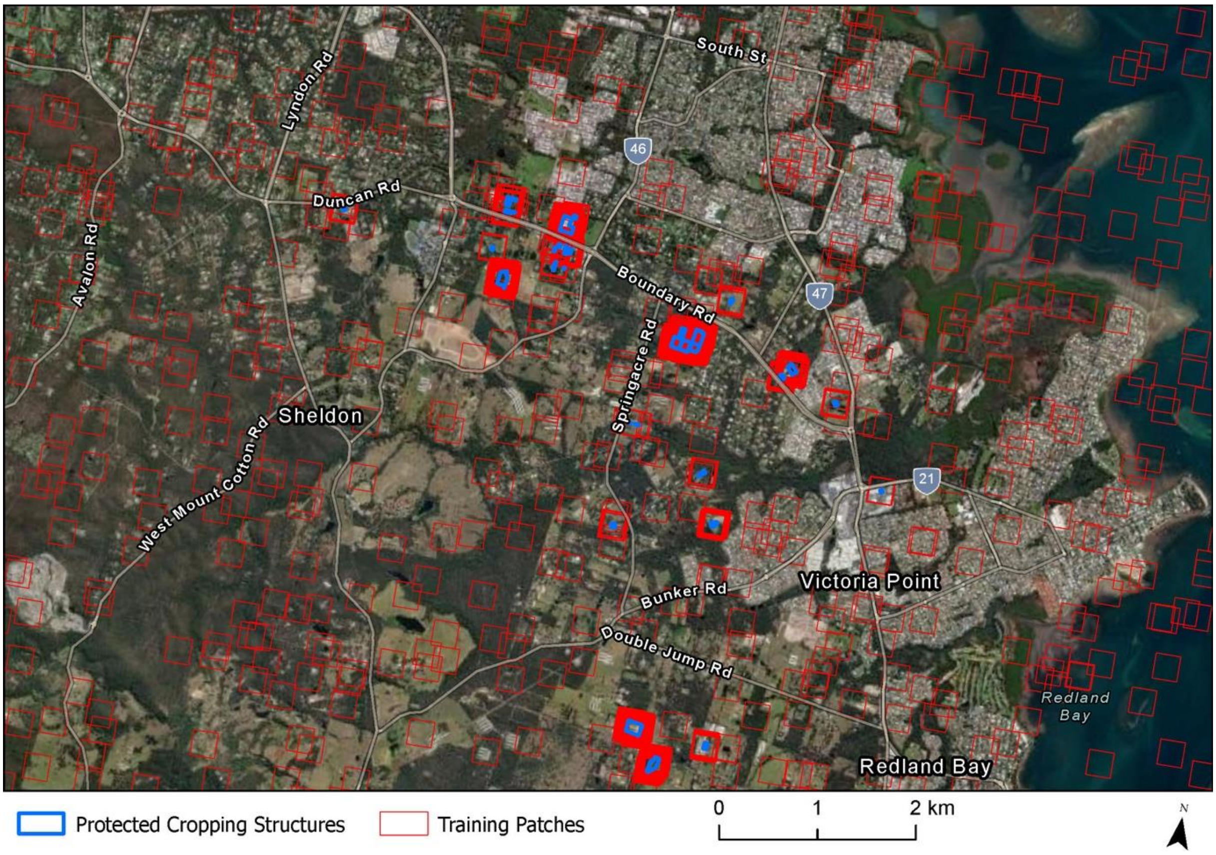

Figure 35: Example of the spatial distribution of training patches in Redlands, South East Queensland.

To ensure the random variability inherent in deep-learning models was captured, the model training was repeated five times for each resolution. This resulted in a total of 70 models being trained to determine the optimal spatial resolution for PCS classification.

The accuracy of the resulting classifications was assessed by comparing it to the manually derived PCS mapping for the over Greater Adelaide region. This was conducted using Cohen's Kappa (Cohen, 1960) statistic where values of < 0 indicate no agreement and values above 0.8 very good agreement.

Mapping PCS structure type

Once the optimal image spatial resolution was found, the ability for a deep learning model to identify PCS structure needed to be determined. Furthermore, the generalisability of the model is important to enable the identification of PCS outside the model training area.

When compiling a national map in a country the size of Australia, it is not feasible to purchase imagery over all areas of interest. As a result, existing imagery sources were used where available and targeted purchasing of imagery over intensive PCS areas. This results in a variety of imagery sources and types from aerial photography to satellite imagery. When using a modelling approach to update a national map of PCS, it is important to assess the ability of the developed model to accurately identify PCS in different geographical areas and within different types of imaging sensors (e.g., satellite imagery).

To assess the ability of a deep learning approach to generalise across geographical areas and sensors, the data from South East Queensland and Greater Adelaide were used to train a deep learning model. The trained model was then applied to aerial and satellite imagery captured over an intensive area of PCS, Dirty Creek, north of Coffs Harbour, New South Wales (Figure 36).

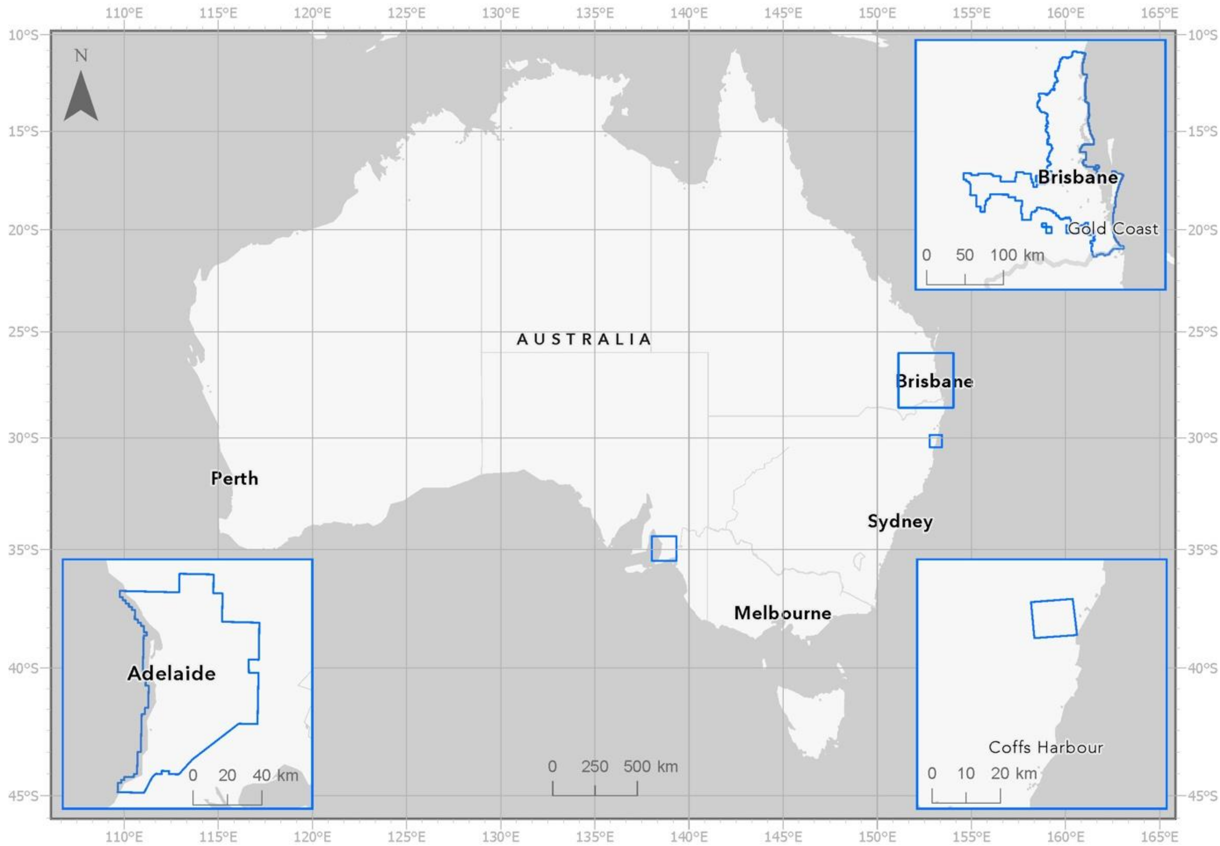

Figure 36: Australian protected cropping systems modelling project areas.

Aerial imagery from 2009 and 2010 and SkySat satellite imagery from February 2023 were provided by the NSW government. Additionally, imagery from the Korean Multi-purpose Satellite 3 (KOMSAT3) acquired in October 2022 was also used in the trial. All imagery had a spatial resolution of 50 cm. As the aerial imagery is RGB, only these colour channels from the satellite imagery were used. Figure 37 shows the imagery extent along with the mapped PCS structures within the area of interest.

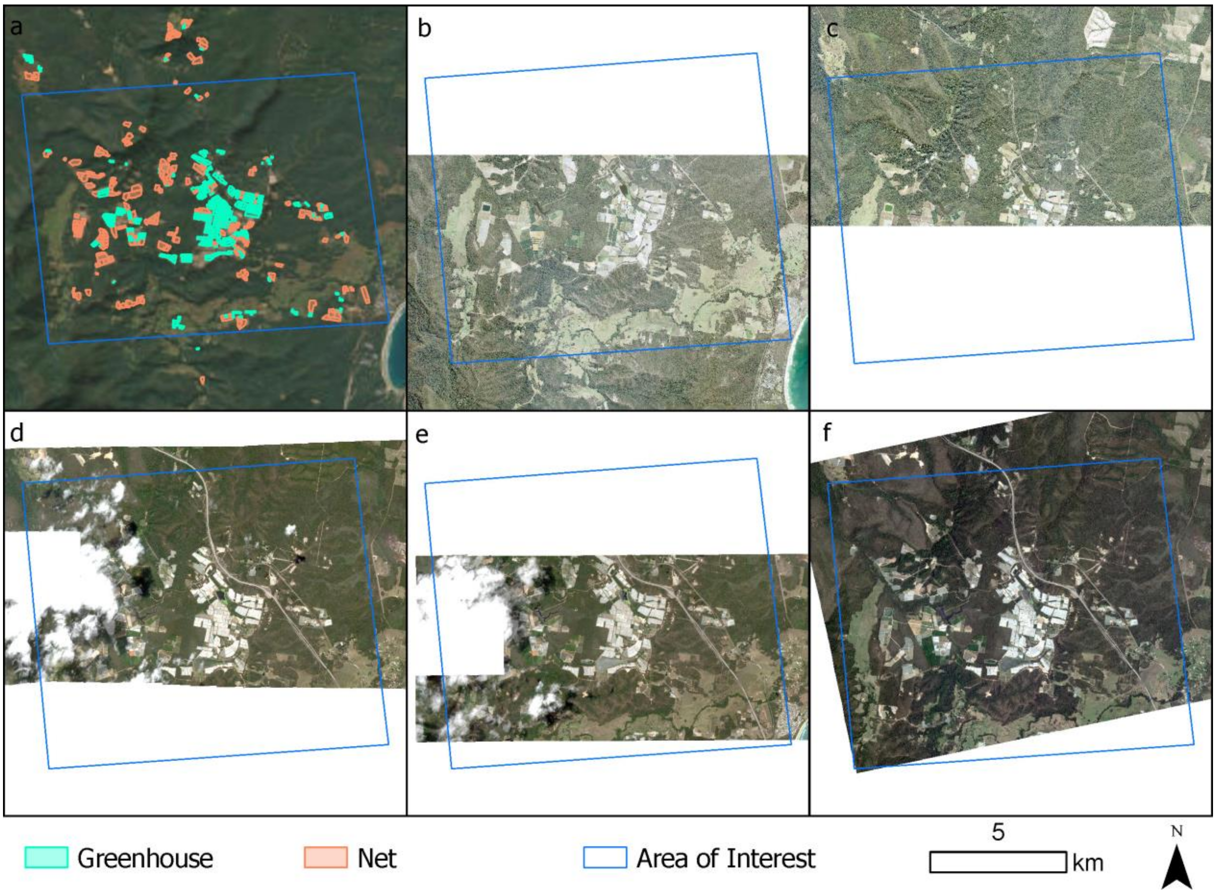

Figure 37: Protected cropping systems validation imagery near Dirty Creek, New South Wales including training data (a), 2009 aerial imagery (b), 2010 aerial imagery (c), Skysat satellite imagery 1 (d), Skysat satellite imagery 2 (e), KOMPSAT3 satellite imagery (f).

Additionally for this part of the project, the ability of a deep learning model to identify different PCS structure types was investigated. Three types of models were created:

1. Protected Cropping: including all nets and greenhouses
2. Greenhouses: only consisting of polyhouses, polytunnels and glasshouses
3. Nets: consisting of all nets and shadehouses.

For each of the three model types, five models were trained using PCS mapping and aerial imagery from Adelaide and South East Queensland (Figure 34). Deep learning models are initialised using random weights and repeating the model training assists in capturing any random variance in the method. In total, 15 models were trained. Once trained, the models were applied to the Dirty Creek test area (Figure 37).

To assess the accuracy of the resulting classification, PCS validation data were manually collected within each image and compared against the model classification. Cohen's Kappa (Cohen, 1960) was used to assess the agreement between the output classification and validation data.

Results and Discussion

Spatial resolution Trials

Figure 38 shows the results from the spatial resolution trials. Although most spatial resolutions between 10 cm and 100 cm have a similar kappa statistic, a resolution of 50 cm is the optimal compromise between resolution and project area coverage and tends to produce the most consistent result.

All the models were trained with the same amount of data which has resulted in lower spatial resolutions covering more of the project area compared to higher resolutions. It is likely with additional training samples for higher spatial resolution (e.g., 10 cm), these models will achieve a higher accuracy however would take longer to train leading to high acquisition and computational costs.

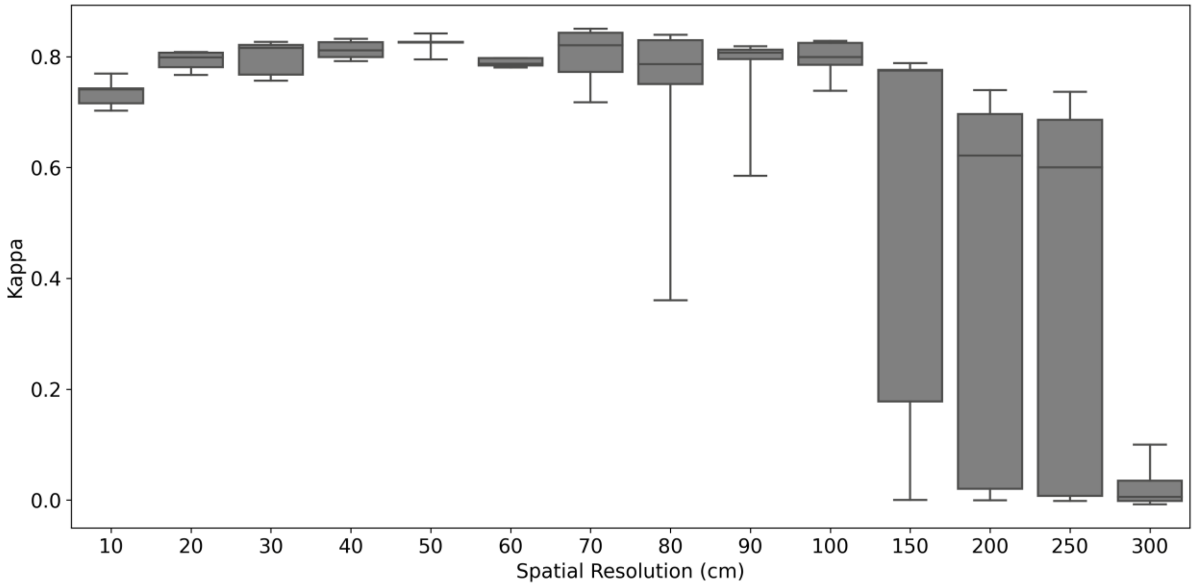

Figure 38: Box and whisker plots displaying the results from the spatial resolution experiment. For each spatial resolution, five models were trained on South East Queensland PCS data and validated of Adelaide PCS data. The Kappa value represents the accuracy of each model. For each spatial resolution plot, the range of accuracies are represented by the lines and the box shows the quartiles of the resolution accuracy.

PCS structure type

The three model types (PCS, greenhouses, nets) were applied to each imagery type and the results from the analysis can be found in Figure 39. The top performing models mapping all PCS structures ranged from 0.52 for the 2009 aerial image and 0.94 for 2010 aerial image (Figure 39a).

The model for detecting greenhouses achieved an accuracy of at least 0.9 except for the 2009 aerial image where the top performing model scored 0.77 (Figure 39b). This result indicates greenhouses are easily identifiable by the model. In contrast, the accuracy for the net models were generally below 0.8 except for the 2010 aerial photography (Figure 39c). This result indicates netting structures are difficult to identify within the imagery types.

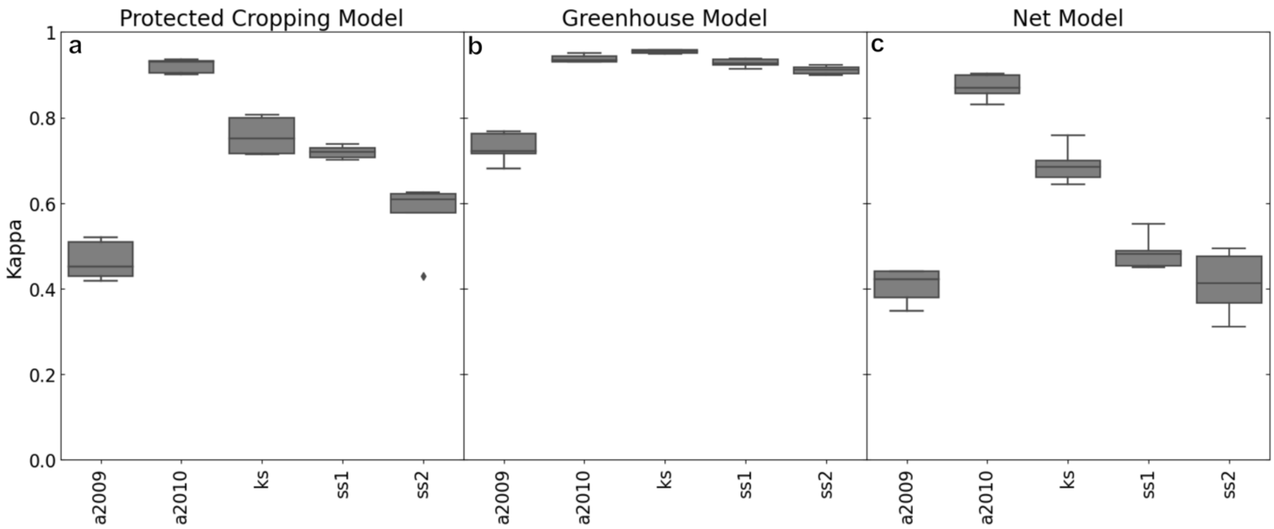

Figure 39: Results from the PCS class trials including all protected cropping systems (a), greenhouses (b) and nets (c). a2009 and a2010 represent the aerial photography for 2009 and 2010 respectively, ks represent KOMPSAT3 satellite imagery and ss1 and ss2 the two Skysat satellite images.

The nature of some of the netting structures caused confusion with other similar land use features such as unprotected tree crops. The presence of temporary netting around Adelaide caused confusion as these were not explicitly mapped for the national map. As temporary structures look similar to permanent structures (Figure 7), it was decided to include these structures for this region. In addition, the project team members had difficulties in identifying some transparent nets (e.g., bird/bat netting) when compiling the mapping, training, and validation dataset. These features look very similar to unnetted crops and any confusion in the dataset would have affected the model accuracy.

The KOMPSAT3 satellite imagery was the top performing sensor for detecting greenhouses and achieved a higher accuracy compared to the Skysat satellite imagery for the other model types. The Skysat images contained cloud which partially obstructed some PCS features in the validation data. Although cloud obstruction was taken into account when compiling the validation dataset, these artifacts reduced the model's confidence and resulted in these areas not meeting the threshold for a PCS feature.

Figure 40 visually shows the output model classification of the PCS, greenhouse and net model types. It demonstrates confusion in the net model outputs. Although this may indicate the inability for this method to successfully identify this type of PCS feature, it also may be as a result of the confusion within the training and/or validation datasets. This confusion may also be adversely affecting the classification result for the PCS model type.

In contrast, the greenhouse model has effectively identified greenhouses in all image types. Greenhouses are easily identifiable and were mapped with high confidence in the training and validation datasets. There was confusion in areas where it appeared new greenhouse structures were being constructed or did not have a plastic covering. Due to the uncertainty, these features were not included in the validation dataset. However, the model has identified these areas as greenhouses. An example of this can be found in Figure 40 in the north-west portion of the 2009 and 2010 aerial photography, north of the net in the 2009 example.

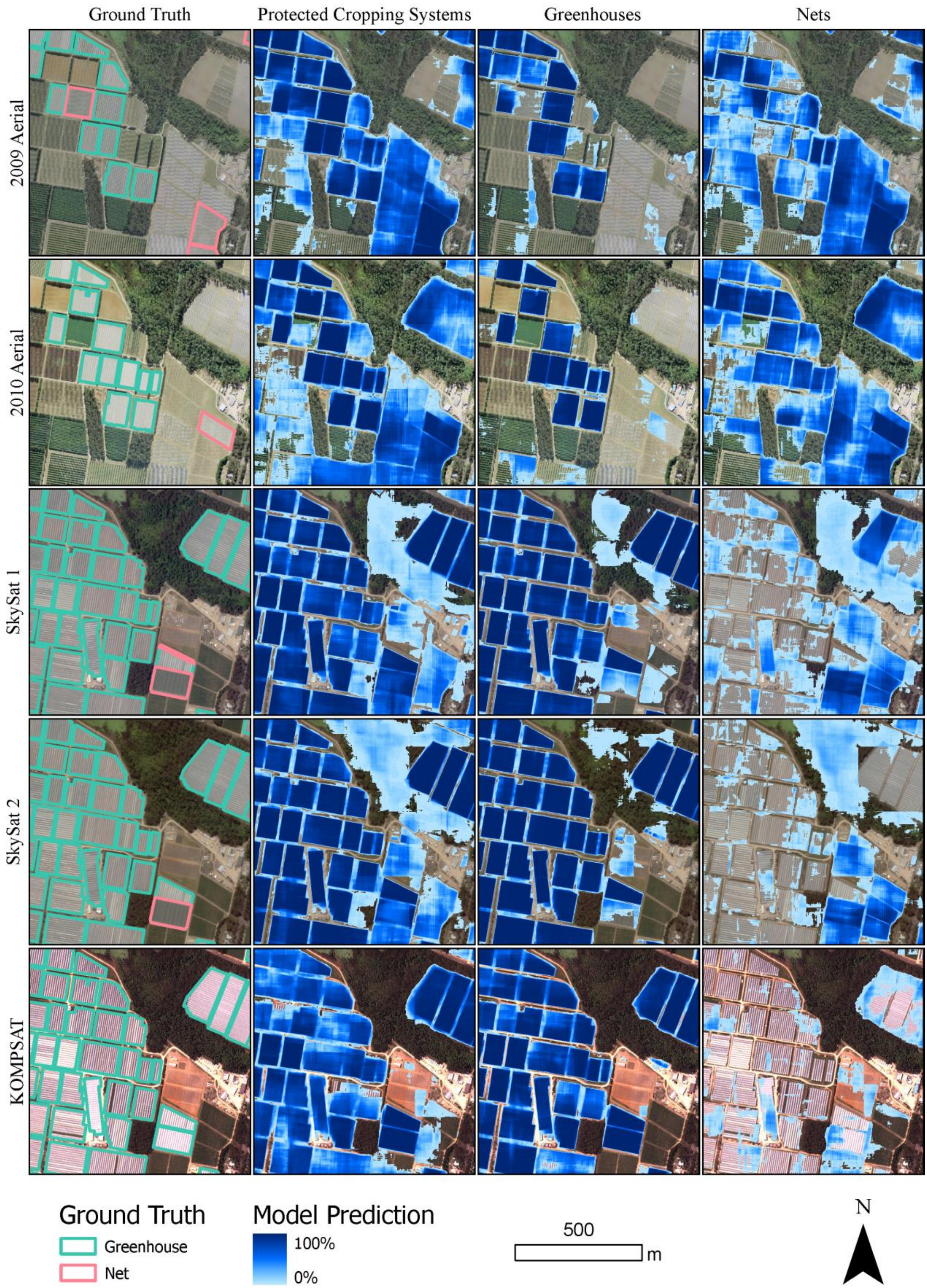

Figure 40: Protected Cropping Systems model output classifications showing ground-truth data, protected cropping systems model, greenhouses model and nets model. The blue shading represents the model confidence with light blue indicating a low probability and dark blue a high probability of the target feature type.

It is unclear why the 2009 aerial imagery consistently performed poorly compared to the 2010 aerial imagery. Analysis of the image pixel values for each of the colour channels (Figure 41) reveal different attributes for 2009 (solid) and 2010 (dashed). However, as augmentations were applied during training, the influence of this variation is likely to be minimal.

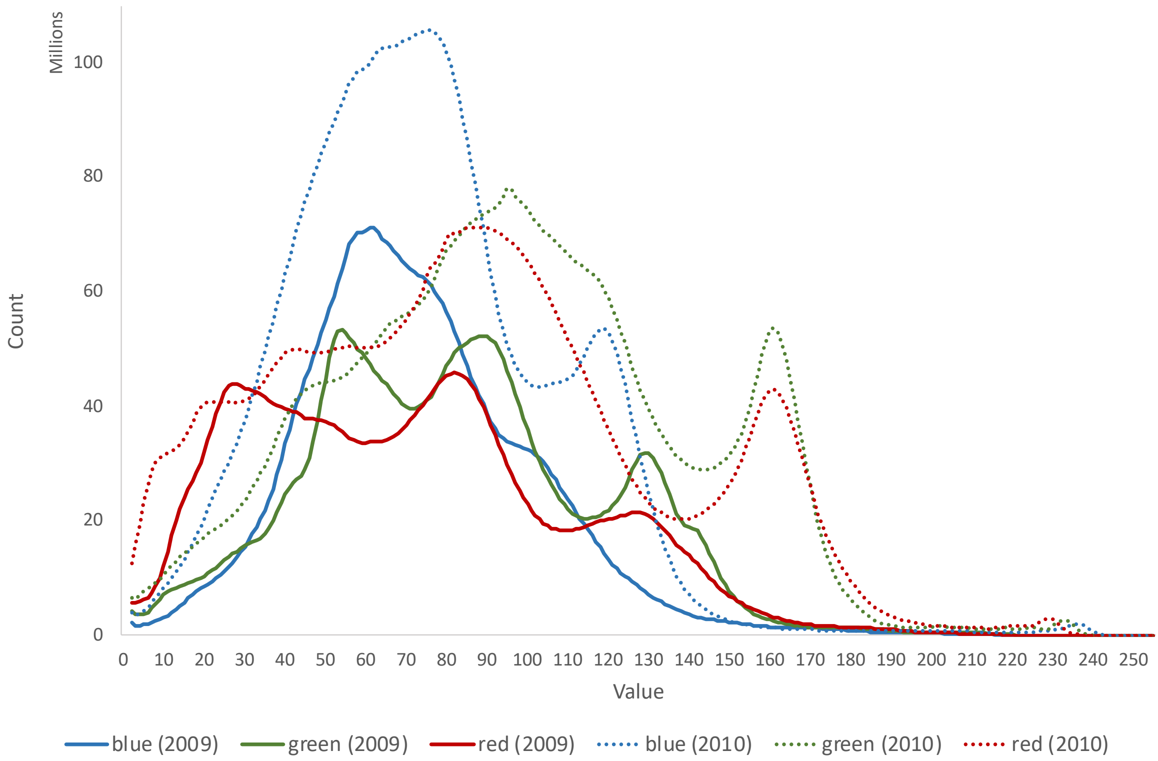

Figure 41: Image histogram for 2009 (solid) and 2010 (dashed) for the red, green and blue colour channels.

Additional research into data augmentations and data scaling may be needed to better represent the variations found in earth observation data.

Integrating deep learning into the national map

The output model classifications of PCS were integrated into the national map once interpreted by the mapping team. As the modelled PCS features contain omission and commission errors (incorrectly identifying PCS features), the mapping team make the final decision on the feature type and extent.

PCS models were applied to all available imagery along the Queensland coast (which included most agricultural areas) and parts of the Greater Sydney region (Figure 42). The ability to know where to look for PCS feature over large geographical areas accelerated the mapping compilation for these regions.

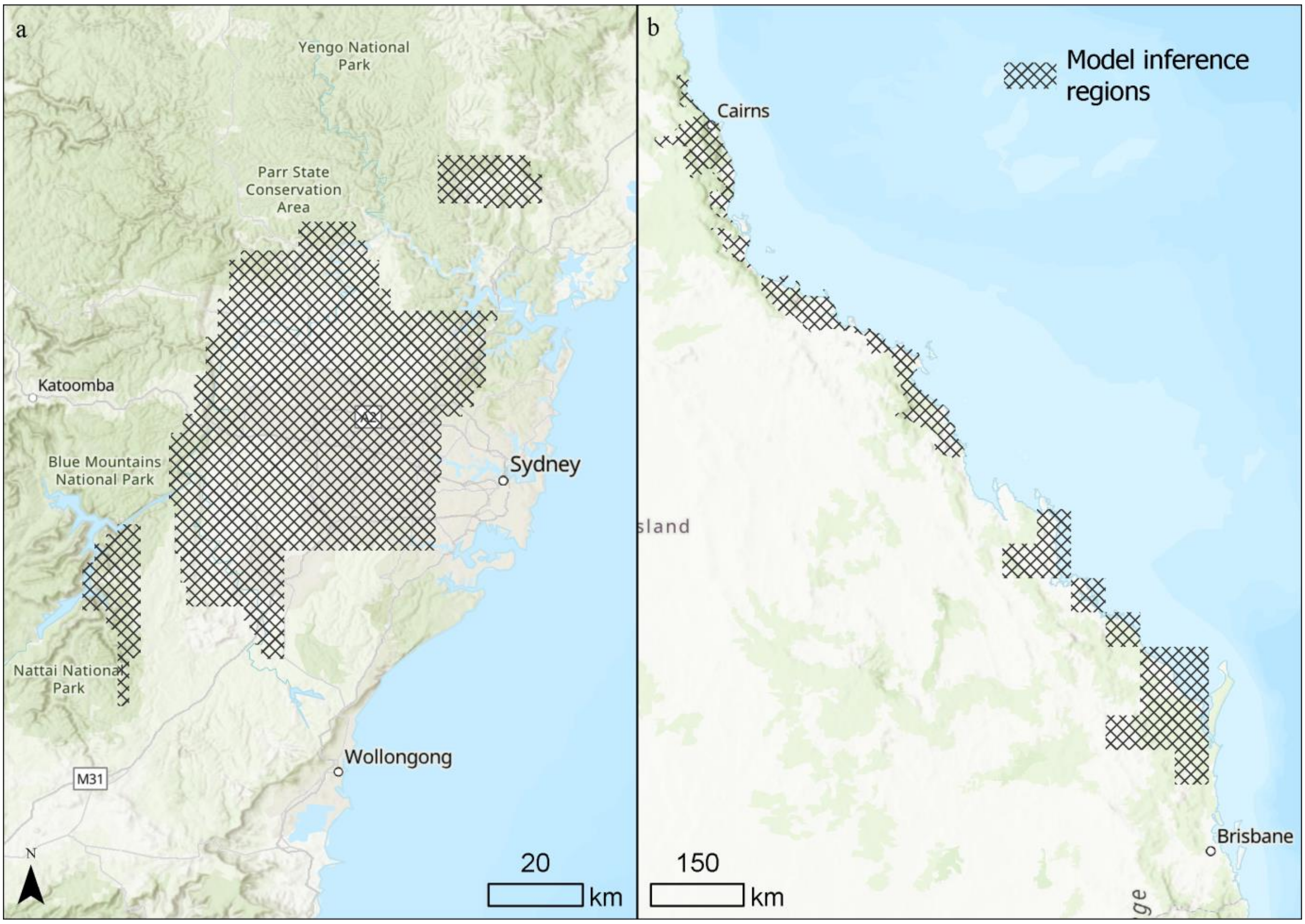

Figure 42: Areas the computer model was applied in Greater Sydney (a) and Queensland (b).

Conclusion

The results from the deep learning trials indicate that the use of computer vision technology can assist in the compilation of the PCS map. The outcomes of this research indicate that imagery with a spatial resolution of 50 cm is required to map PCS features accurately, and can be applied to different sensors and geographical areas. The developed deep learning methods can identify greenhouse features to a high level of accuracy, but netting structures are more difficult to identify due to their transparent nature.

The models can identify PCS up to an accuracy of 0.94 when applied to a difference sensor type over a different geographical area. However, due to their transparent nature, net structures are difficult to identify within the imagery which caused some confusion within the models with some achieving an accuracy of < 0.5. Mapping the greenhouses separately increased the accuracy to between 0.77 and 0.96. The KOMPSAT3 satellite imagery was the top performing sensor for detecting greenhouses and achieved a higher accuracy compared to the Skysat images which could be the result of cloud contamination.

Despite the accuracy of the models, deep learning alone cannot be successfully used to create a national map of PCS to the level of accuracy required to be a fundamental dataset. However, with the assistance of deep learning, it is possible to expedite the compilation of the map and assist in identifying PCS features which may not easily be found without the model output predictions.

Limitations of this approach is the requirement of high spatial resolution imagery and high computational resources (GPU). The method requires a high-quality training dataset. Extensive areas of PCS were mapped in South Australia and Queensland, allowing for the creation of deep learning models for this project. However, confusion within the netting class clearly caused issues.

Future work should focus on the maintenance of the map. A modelling solution to identify new and removed structures will assist in ensuring the map remains current. Additional research should focus refining the data augmentations to better represent the sensor, atmospheric and environmental differences between images.

Appendix 3: Project media captured

44 media pieces that communicated the project and progress were captured from September 2021 to the conclusion of the project in August 2023. Refer to the table below.

Table 7: Project media summary

Date	Project Coverage	Press Type	Publication	Article	Publication Link
10/08/2023	PCA	E-News	Future Food Systems E-News Issue 38	First national map of Australia's protected cropping structures launched	https://www.futurefoodsystems.com.au/first-national-map-of-australias-protected-cropping-structures-launched/?mc_cid=5896b07b77&mc_eid=843ef409c2
20/07/2023	PCA	E-News	Pulse - UNE Staff Newsletter	Launch of first national map of Australia's protected cropping structures	sent out to UNE's internal staff list (1200+)
19/07/2023	PCA	TV	NBN News	Interview by Rob Douglas	n/a
18/07/2023	PCA	Radio	2SM Newsroom	n/a	n/a
18/07/2023	PCA	Social media	Twitter	Launch of first national map of Australia's protected cropping structures	@une_aarsc
18/07/2023	PCA	Social media	LinkedIn	Launch of first national map of Australia's protected cropping structures	https://www.linkedin.com/company/28872527/admin/feed/posts/
17/07/2023	PCA	E-News	UNE Connect	Launch of first national map of Australia's protected cropping structures	https://www.une.edu.au/connect/news/2023/07/launch-of-first-national-map-of-australias-protected-cropping-structures

17/07/2023	PCA	Conference	PCA Conference Brisbane 2023	Craig Shepherd (Conference Speaker)	https://www.pcaconference.net.au/invited-speakers
8/06/2023	PCA	Social media	LinkedIn	Promotional post by FFS of updated National Map of Protected Cropping Systems	Future Food Systems : Posts | LinkedIn
24/05/2023	PCA	Conference	Northern Australia Food Futures Conference 2023 (Darwin)	Craig Shepherd (Conference Speaker). Spatially Enabling the Horticulture Industry in Australia	https://www.foodfuturesntfarmers.org.au/program
23/03/2023	PCA	Conference	ACLUMP (NCLUMI) Annual Technical Workshop	Craig Shephard (Presentation), Tatura, Victoria	n/a
4/03/2023	PCA	E-News	Australian Berry Journal	National Map of Protected Cropping Systems now available in draft	https://issuu.com/berriesaustralia/docs/aus_berry_journal_ed_14_autumn_2023
9/02/2023	PCA	E-News	Pulse - UNE Staff Newsletter	Mapping Australia's protected crops	sent out to UNE's internal staff list (1200+)
24/01/2023	PCA	E-News	UNE Connect	Mapping Australia's protected crops	https://www.une.edu.au/connect/news/2023/01/mapping-australias-protected-crops
1/12/2022	PCA	Conference	Future Food Systems Summit	Craig Shepherd (Summit Speaker)	https://www.futurefoodsystems.com.au/future-of-food-summit-22/#1666743718596-5c8040d1-cd3a
1/09/2022	PCA	Journal	Soilless Australia (PCA)	Progress on mapping Australia's protected cropping systems	Volume 12 - Spring 2022 pages 22-24

23/08/2022	PCA	Online article	AARSC Blog	AARSC wins at the Earth Observation Australia Inc. Awards 2022!	https://blog.une.edu.au/aarsc-blog/2022/08/23/aarsc-wins-at-the-earth-observation-australia-inc-awards-2022/
24/08/2022	PCA	Conference	Advancing Earth Observation Forum (Brisbane)	Andy Clark (Speaker)	
27/07/2022	PCA	Conference	Berries Australia	Mapping Protected Cropping Systems in Australia	https://berries.net.au/craig-shephard/
20/07/2022	PCA	E-News	Future Food Systems E-News Issue 26 August 2022	National PC mapping team calls for peer review of latest draft maps	https://www.futurefoodsystems.com.au/national-pc-mapping-team-calls-for-peer-review-of-latest-draft-maps/?mc_cid=128c25b146&mc_eid=843ef409c2
28/06/2022	PCA	Social media	LinkedIn	Validation of fieldwork underway in NT	https://www.linkedin.com/feed/update/urn:li:activity:6947396958307110912
7/04/2022	PCA	E-News	Future Food Systems CRC E-News	Meet Craig Shephard: land-use mapping expert	https://www.futurefoodsystems.com.au/meet-craig-shephard-gis-tech-expert/
7/04/2022	PCA	Social media	LinkedIn	Validation of fieldwork underway in WA	https://www.linkedin.com/feed/update/urn:li:activity:6917707874915823616

30/03/2022	PCA	Social media	LinkedIn	Update on project and conference presentation	https://www.linkedin.com/posts/protected-cropping-australia-ltd_university-investment-team-activity-6914704492458381312-_cND?utm_source=linkedin_share&utm_medium=member_desktop_web
30/03/2022	PCA	Social media	LinkedIn	Update on project and conference presentation	https://www.linkedin.com/feed/update/urn:li:activity:6915072958185058304
29/03/2022	PCA	Conference	PCA Conference Coffs Harbour 2022	Update on project and seeking industry engagement and feedback	Presented live online (due to floods and covid)
9/02/2022	PCA	Social media	Twitter	first map of PCS published	(@une_aarsc)
9/02/2022	PCA	Social media	LinkedIn	first map of PCS published	https://www.linkedin.com/feed/update/urn:li:activity:6897091990035554304
30/09/2021	PCA	E-News	Future Food Systems CRC E-News	High-tech mapping project to help safeguard Australia's protected cropping sector	https://www.futurefoodsystems.com.au/new-map-to-help-safeguard-nations-protected-cropping-industries/?mc_cid=49ea63811c&mc_eid=83dff2aeb5
16/09/2021	PCA	TV	NBN News	Safeguarding Australia's protected crops	n/a
16/09/2021	PCA	E-News	Pulse - UNE Staff Newsletter	Safeguarding Australia's protected crops	sent out to UNE's internal staff list (1200+)

15/09/2021	PCA	Social media	Twitter	New mapping to help safeguard Australia's protected crops	(@FutureFoodCRC) 214 followers
15/09/2021	PCA	Social media	Instagram	New mapping to help safeguard Australia's protected crops	(@uneagriculture)
15/09/2021	PCA	Radio	ABC New England North West	New mapping to help safeguard Australia's protected crops	n/a
15/09/2021	PCA	Online article	Future Food Systems CRC	New map to help safeguard nation's protected cropping industries	https://www.futurefoodsystems.com.au/new-map-to-help-safeguard-nations-protected-cropping-industries/
14/09/2021	PCA	Social media	Facebook	New mapping to help safeguard Australia's protected crops	(@uneagriculture) 11,022 followers
14/09/2021	PCA	Social media	Twitter	Spatially Enabling the Nation's Protected Cropping industries	(@une_aarsc)
14/09/2021	PCA	Online article	AARSC Blog	New map to help safeguard nation's protected cropping industries	https://blog.une.edu.au/aarsc-blog/2021/09/14/new-map-to-help-safeguard-nations-protected-cropping-industries/
14/09/2021	PCA	Social media	LinkedIn	Spatially Enabling the Nation's Protected Cropping industries	https://www.linkedin.com/feed/update/urn:li:activity:6843419692447731712
14/09/2021	PCA	Online article	Hort. Innovation - news and events	New map to help safeguard nation's protected cropping industries	https://www.horticulture.com.au/hort-innovation/news-events/New-map-to-help-safeguard-nations-protected-cropping-industries/

14/09/2021	PCA	Online article	The Land	New mapping to help safeguard Australia's protected crops	https://www.theland.com.au/story/7430611/new-mapping-to-help-safeguard-australias-protected-crops/
14/09/2021	PCA	Online article	Stock and Land	New mapping to help safeguard Australia's protected crops	https://www.stockandland.com.au/story/7430611/new-mapping-to-help-safeguard-australias-protected-crops/
14/09/2021	PCA	Online article	North Queensland Register	New mapping to help safeguard Australia's protected crops	https://www.northqueenslandregister.com.au/story/7430611/new-mapping-to-help-safeguard-australias-protected-crops/?cs=4735
14/09/2021	PCA	Online article	Mirage News	New map to help safeguard nation's protected cropping industries	https://www.miragenews.com/new-map-to-help-safeguard-nations-protected-631285/

Appendix 4: Intellectual property

Part 1. Pre-Existing/Background IP (BGIP) and Third Party IP (TPIP) to be used in the Project Previous projects of the Parties.

Related projects:

- ST1503 Multi-scale Monitoring Tools for Managing Australian Tree Crops – Industry Meets Innovation Phase 1 (RRND4 Profit / Hort. Innovation funded)
- ST19015 Multi-scale Monitoring Tools for Managing Australian Tree Crops – Industry Meets Innovation Phase 2 (RRND4 Profit / Hort. Innovation funded)
- AV18002 Implementing precision agriculture solutions in Australian avocado production systems (Hort. Innovation funded)

BACKGROUND INTELLECTUAL PROPERTY (BGIP) AND THIRD PARTY INTELLECTUAL PROPERTY (TPIP) REGISTER								
	Date (ie date on which details were initially listed and/or modified)	Owner(s) of BGIP or TPIP (If TPIP - list the name of the organisation which provided it)	IP Category (eg plant variety, gene, formulation, software, thesis, report, data etc)	Specific Description of IP	Nature of IP (eg copyright, patent, trade mark, design, PBR) Form in which the IP subsists (eg device, process, formulation, document)	Registration/ application details (if registered) (eg registration number, date of registration and expiry)	Intended purpose and value of the IP that is provided	Used or may be used for Commercialisation of Project IP (yes/no) and, if **yes**, how it is used
Details of restrictions on use (eg licence conditions, security conditions, encumbrances, confidentiality requirements, including any restrictions on publication of the BGIP/TPIP as part of publication of Project results and use of BGIP/TPIP which is part of Project IP): The IP can be used for commercial purposes with an appropriate licence issued by Digital Globe.								
Details of restrictions on use:								
1.	BASED ON PROJECT START DATE TBC AND SCHEDULE	DEPARTMENT OF AGRICULTURE, WATER AND THE ENVIRONMENT	METHODOLOGY	Australian Collaborative Land Use and Management Program – National standard and classification	OPEN ACCESS UNDER CC-BY LICENCE		NATIONAL STANDARD	PUBLISHED
2.	BASED ON PROJECT START DATE TBC AND SCHEDULE	AARSC, UNIVERSITY OF NEW ENGLAND	DATA	FOUNDATIONALS PATIAL DATA (AARSC WORKING MAP): NATIONAL MAP OF AUSTRALIAN TREE CROPS	COPYRIGHT (SPATIAL DATA)		ANCILLARY DATA OF EXISTING PCS FROM THE ATCM FOR INFORMING NATIONAL MAP OF PCS	NO, RESTRICTED ACCESS TO AARSC AND PROJECT STAKEHOLDERS
3.	BASED ON PROJECT START DATE TBC AND SCHEDULE	AARSC, UNIVERSITY OF NEW ENGLAND	APP	AUSTRALIAN TREE CROP MAP (APP)	COPYRIGHT (APP)		WEB-GIS MAP	YES-MAPPING PRODUCTS PUBLISHED THROUGH
4.	BASED ON PROJECT START DATE TBC AND SCHEDULE	AARSC, UNIVERSITY OF NEW ENGLAND	APP	PCS SURVEY APP & INDUSTRY ENGAGEMENT WEB APP	COPYRIGHT (APP)		LOCATION-BASED INDUSTRY ENGAGEMENT TOOLS	YES-MAPPING PRODUCTS PUBLISHED THROUGH

Part 2 - Intellectual Property to be developed (Project IP)

PROJECT INTELLECTUAL PROPERTY REGISTER							
No	Date (ie date on which details were initially listed and/or modified)	IP Category (eg plant variety, gene, formulation, software, thesis, report, data etc)	Specific Description of IP	Nature of IP (eg copyright, patent, trade mark, design) and the form in which the IP subsists (eg device, process, formulation, document)	Registration/ application details (if registered) (eg registration number, date of registration and expiry)	Intended purpose and value of the IP that is provided	Contains BGIP and/or TPIP (yes/no) and, if **yes**, description of the BGIP and TPIP
Details of restrictions on use of Commercialisation of Project IP: <TBD>							
1.	BASED ON PROJECT START DATE TBC AND SCHEDULE	MAPPING SPATIAL LAYER	NATIONAL MAP OF PROTECTED CROPPING SYSTEMS (MAPPING PRODUCT)	COPYRIGHT (SPATIAL DATA)		LOCATION AND EXTENT OF PCS (SPATIAL POLYGONS)	PUBLISHED AS OPEN DATA, RESTRICTED TO QUERY ONLY (NO DOWNLOAD)
2.	BASED ON PROJECT START DATE TBC AND SCHEDULE	FOUNDATIONAL SPATIAL DATA	FOUNDATIONAL SPATIAL DATA (INFORMING AARSC WORKING MAP);	COPYRIGHT (SPATIAL DATA)		LOCATION AND EXTENT OF PCS (SPATIAL DATA) INC. RESTRICTED ACCESS TO AARSC AND PROJECT STAKEHOLDERS	CONTAINS BGIP (SPECIFIC GROWER INFORMATION) FROM PCA, LLS, FFSCRC DATA SETS AND INDUSTRY PARTNERS). THE CULIMINATED FOUNDATIONAL DATA SET HOLDS SENSITIVE GROWER INFORMATION PROVIDED BY NUMEROUS SOURCES AND THEREFOR IS RESTRICTED ACCESS TO AARSC AND PROJECT STAKEHOLDERS

Appendix 5: References

Australian Bureau of Agricultural and Resource Economics and Sciences. (2016). *The Australian Land Use and Management Classification Version 8*. Australian Bureau of Agricultural and Resource Economics and Sciences. http://www.agriculture.gov.au/abares/aclump/land-use/mapping-technical-specifications

Australian Bureau of Agricultural Resource Economics and Sciences (ABARES). (2021). *Catchment Scale Land Use of Australia – Update December 2020* [dataset]. Australian Bureau of Agricultural Resource Economics and Sciences (ABARES). https://doi.org/10.25814/AQJW-RQ15

Chakraborty, S., & Newton, A. C. (2011). Climate change, plant diseases and food security: An overview: Climate change and food security. *Plant Pathology*, *60*(1), 2–14. https://doi.org/10.1111/j.1365-3059.2010.02411.x

Chawla, I., Karthikeyan, L., & Mishra, A. K. (2020). A review of remote sensing applications for water security: Quantity, quality, and extremes. *Journal of Hydrology*, *585*, 124826. https://doi.org/10.1016/j.jhydrol.2020.124826

Chen, Z., Wu, Z., Gao, J., Cai, M., Yang, X., Chen, P., & Li, Q. (2022). A Convolutional Neural Network for Large-Scale Greenhouse Extraction from Satellite Images Considering Spatial Features. *Remote Sensing*, *14*(19), 4908. https://doi.org/10.3390/rs14194908

Clark, A., & McKechnie, J. (2020). Detecting Banana Plantations in the Wet Tropics, Australia, Using Aerial Photography and U-Net. *Applied Sciences*, *10*(6), 2017. https://doi.org/10.3390/app10062017

Clark, A., Phinn, S., & Scarth, P. (2023). Pre-Processing Training Data Improves Accuracy and Generalisability of Convolutional Neural Network Based Landscape Semantic Segmentation. *Land*, *12*(7), 1268. https://doi.org/10.3390/land12071268

Foodbank. (2021). *Foodbank Hunger Report 2021—The reality of the food crisis facing Australia*.

Jensen, M. H., & Malter, A. J. (1995). *Protected agriculture: A global review*. World Bank. https://www.google.com.au/books/edition/_/F1eghGKD6bwC?hl=en&gbpv=0&kptab=overview

Karthikeyan, L., Chawla, I., & Mishra, A. K. (2020). A review of remote sensing applications in agriculture for food security: Crop growth and yield, irrigation, and crop losses. *Journal of Hydrology*, *586*, 124905. https://doi.org/10.1016/j.jhydrol.2020.124905

Kumar, K. S., Tiwari, K. N., & Jha, M. K. (2009). Design and technology for greenhouse cooling in tropical and subtropical regions: A review. *Energy and Buildings*, *41*(12), 1269–1275. https://doi.org/10.1016/j.enbuild.2009.08.003

Rahaman, A., Kumari, A., Zeng, X.-A., Khalifa, I., Farooq, M. A., Singh, N., Ali, S., Alee, M., & Aadil, R. M. (2021). The increasing hunger concern and current need in the development of sustainable food security in the developing countries. *Trends in Food Science & Technology*, *113*, 423–429. https://doi.org/10.1016/j.tifs.2021.04.048

The State of Food Security and Nutrition in the World 2021. (2021). FAO, IFAD, UNICEF, WFP and

WHO. https://doi.org/10.4060/cb4474en

United Nations. (2015). *Transforming Our World, the 2030 Agenda for Sustainable Development. General Assembly Resolution A/RES/70/1*.

van Dijk, M., Morley, T., Rau, M. L., & Saghai, Y. (2021). A meta-analysis of projected global food demand and population at risk of hunger for the period 2010–2050. *Nature Food*, *2*(7), 494–501. https://doi.org/10.1038/s43016-021-00322-9

Vuković, M., Jurić, S., Maslov Bandić, L., Levaj, B., Fu, D.-Q., & Jemrić, T. (2022). Sustainable Food Production: Innovative Netting Concepts and Their Mode of Action on Fruit Crops. *Sustainability*, *14*(15), 9264. https://doi.org/10.3390/su14159264

Yin, L., Ghosh, R., Lin, C., Hale, D., Weigl, C., Obarowski, J., Zhou, J., Till, J., Jia, X., You, N., Mao, T., Kumar, V., & Jin, Z. (2023). Mapping smallholder cashew plantations to inform sustainable tree crop expansion in Benin. *Remote Sensing of Environment*, *295*, 113695. https://doi.org/10.1016/j.rse.2023.113695