Australian Government

Australian Centre for International Agricultural Research

Final report

Project full title	**Climate-smart landscapes for promoting sustainability of Pacific Island agricultural systems**
project ID	ASEM/2016/101
date published	11/09/2023
prepared by	Bryan Boruff
co-authors/ contributors/ collaborators	Eleanor Bruce and John Duncan
approved by	Dr Todd Sanderson, Research Project Manager, Social Systems
final report number	FR2023-045
ISBN	978-1-922983-52-7
published by	ACIAR GPO Box 1571 Canberra ACT 2601 Australia

Contents

1 Acknowledgments

We would like to express our gratitude to the following individuals and organizations for their invaluable assistance in the execution of this project: Viliami Manu, Leody Cruzat Vainikolo and the Ministry of Agriculture, Food and Forests team in Tonga. Your contributions were instrumental in the successful delivery of our project.

We also express our thanks to the community members of Nawaqarua, Koronubu-Vunibaka and Etatoka in Fiji, and Talasiu, Kala'au and Afa in Tonga for providing their time and responses in our data collection initiatives. Thank you.

2 Executive summary

The maplandscape project represents the culmination of a multi-year Information and Communication Technologies for Development (ICT4D) co-development effort. The project has resulted in a stack of open-source applications designed for mapping and monitoring diverse agricultural landscapes. These applications have been successfully deployed in the Ministry of Agriculture, Food and Forests (MAFF), Tonga and are now gaining traction in the Fiji Ministry of Agriculture and Waterways (MoA). The project's workflow facilitates geospatial and non-spatial data collection, large-scale team efforts, disaster response, and monitoring programs. The platform has been utilized to map over 12,000 farms across various applications, including monitoring cropping systems and disaster response.

Key Components and Features:

- The maplandscape platform consists of three main components: Field data collection using QField, QFieldCloud for managing large-scale data collection projects, and a custom data visualization and analytics tool built using R Shiny and ShinyProxy.
- QField enables mobile geospatial data collection, integrating with databases, supporting spatial layers, and offering a touch-optimized map interface.
- QFieldCloud facilitates project management, user collaboration, secure cloud storage, and versioning for data collected in low-bandwidth settings.
- The custom data visualization and analytics tool allows non-experts to analyse QField data using web maps, interactive tables, charts, and automated reporting.

Applications and Impacts:

- maplandscape has been integral to Tonga's Ministry of Agriculture, Food, and Forestry (MAFF) operations, conducting crop surveys and supporting disaster response efforts.
- The platform was employed for assessing damage after the Hunga Tonga-Hunga Ha’apai volcanic eruption and for monitoring recovery efforts.
- It has been adopted for the annual Tonga crop survey, transitioning from paper-based to digital data collection, streamlining reporting and resource allocation.
- In Fiji, maplandscape supported a cross-departmental survey of rice production landscapes.
- Extensive training programs, using a 'learn by doing' approach, have been conducted for stakeholders in Fiji and Tonga, enhancing their geospatial capabilities.

Gender and Social Inclusion:

- The project incorporated gender dimensions from the beginning, ensuring inclusivity and considering gender roles in community-level data collection and analysis.
- Efforts were made to address the information needs of different social groups and incorporate them in geospatial tools and approaches.
- The project successfully implemented gender-sensitive participation in decision-making processes and ensured data collection was gender-disaggregated.

Scientific, Capacity, and Community Impacts:

- The project resulted in six peer-reviewed publications, providing insights into the development of ICT4D tools, integrated landscape approaches, and climate resilience in livelihood systems.
- Over 200 stakeholders across Fiji and Tonga have been trained in geospatial data collection, analysis, and communication.
- The annual Tonga crop survey, supported by maplandscape, has engaged over 40 extension officers, enhancing their geospatial skills.
- Project partners identified that the outcomes have enabled better landscape management and decision-making processes, benefiting communities at large.

Future Outlook:

The maplandscape project has successfully developed a suite of open-source tools for geospatial data collection, analysis, and visualization. It has contributed to scientific research, enhanced local capacities, and positively impacted community-level landscape management. As these tools continue to be utilized in Tonga and Fiji, they hold the potential to support better decision-making, disaster response, and sustainable agricultural practices well into the future.

3 Background

A large proportion of the population in Fiji and Tonga rely on services from the landscape to support their livelihoods. These same populations remain acutely vulnerable to the impacts of climate change and variability. The agricultural sector in both locations has been identified as a sector for growth to support economic development and poverty alleviation. As in many parts of the world, livelihoods and landscapes are highly interconnected in the Pacific, thus climate impacts and interventions can propagate throughout coupled human and environmental systems and across scales, making it difficult to predict impacts on livelihoods. As such, interventions in landscapes need to be assessed in terms of their potential systemic impacts on livelihoods, landscape sustainability, and capacity to respond to climate stressors.

However, due to the complexity of landscape systems, and multiple factors operating at different scales, fully assessing the impact of change or interventions in landscapes is challenging. Moreover, a lack of detailed and reliable geospatial information provides a barrier to developing projects and policies that support a sustainable, resilient growth-orientated vision for the future. Collaborative mapping approaches, which draw upon principles of participatory action research and geospatial science, have been utilised to capture and understand the complexities of livelihood-landscape interactions. These approaches also empower community members and a range of landscape stakeholders with respect to environmental decision making. However, to date, several limitations have been identified with contemporary mapping approaches including their time intensive nature, the static representation of landscapes-livelihood systems that fail to capture the dynamic nature of vulnerabilities, and the difficulties in sharing information collected through various mapping activities. This project sought to address these limitations through the co-development of a dynamic collaborative geospatial platform to bring together communities and higher-level stakeholders for more effective information communication, through the collation and dissemination of geographic information across multiple scales in order to help facilitate improved multi-functional agricultural landscape management.

The project presented here built upon SRA research (ASEM/2016/030), which focused on the evaluation of how a multifunctional agricultural landscape approach could utilise geospatial agricultural information within the South Pacific to identify pathways for enhancing climate-smart practices within agricultural landscapes. This initial research identified opportunities and constraints in the use of participatory geographic approaches to inform landscape management in data-poor, geographically heterogeneous regions, with field research undertaken in the Ba River catchment of northwest Viti Levu, Fiji. Given the receptiveness of multi-level stakeholders to engage with mapping media, results highlighted that geospatial information provides great potential as a decision-support medium to improve cross-level stakeholder communication for enhanced landscape management. Institutions highly value geospatial information for decision-making, yet accessibility remains limited, particularly with regard to remotely sensed spatial data and accurate agricultural production information.

To improve cross-level communication between stakeholders, and communities needing access to information, this research project developed a collaborative geospatial platform that facilitated the identification of climate-smart landscape adaptation responses. This aim was realised through iterative, co-development of maplandscape, a stack of open-source applications for mapping and monitoring diverse agricultural landscapes. The workflows and tools developed by the project can be used for geospatial and non-spatial data collection tasks, large team data collection efforts, rapid mapping after disasters, and household surveys for monitoring programs and projects. The result has fostered the co-production of knowledge that is now being used to better understand diversity within agricultural landscapes across both Fiji and Tonga in order to enhance livelihood and farm decision making and agricultural management efforts.

4 Objectives

1. **Critically review and evaluate existing collaborative geospatial tools, platforms and methodologies.**
    - 1.1. Review of existing collaborative geospatial approaches assessed against a gradient of metrics.
    - 1.2. Assessment of landscape uses and climate stressors to provide baseline data that will inform collaborative geospatial approaches review process.
    - 1.3. Parallel exercise to link approaches (identified in 1.1) suitable for assessing landscape uses and climate stressors (identified in 1.2).
    - 1.4. Community evaluation of approaches identified/developed in 1.3.
    - 1.5. Multi-stakeholder evaluation of approaches identified/developed in 1.3.

2. **Develop a collaborative geospatial platform with an interface that is accessible and appropriate for a range of landscape stakeholders.**
    - 2.1. Co-develop a collaborative geospatial platform following outcomes of 1.4 and 1.5 that incorporate landscape-livelihood-climate interactions and builds upon functionality of existing geospatial approaches.
    - 2.2. Develop specific platform tools to enable land use/land cover mapping and integration of seasonal climate forecasts.

3. **Identify community level landscape-livelihood-climate stressor interactions.**
    - 3.1. Use the collaborative geospatial platform in case study landscapes to generate information on landscape-livelihood-climate stressor interactions.
    - 3.2. Use the Environmental Livelihoods Security (ELS) matrix to identify links and feedbacks between livelihoods, landscapes, and climate stressors using data collected in 3.1.
    - 3.3. Use ELS matrix to establish a typology of landscape activities under climate stressors to be able to classify an input procedure for future data collection using the collaborative geospatial platform – through understanding response relationships from data collected in 3.1 and processed in 3.2 develop a rule-based classification technique.

4. **Identify capacity for multi-stakeholder knowledge sharing into the collaborative geospatial platform.**
    - 4.1. Develop a spatially-enabled database that optimises the exchange of information and knowledge co-produced using participatory action research.
    - 4.2. Establish digital geospatial protocols for the documentation and sharing of traditional knowledge and mapping.

5. **Evaluate the effectiveness of the collaborative geospatial platform for promoting community and multi-stakeholder exchange and engagement with landscape knowledge.**
    - 5.1. Evaluate the functional transferability of the platform for data collection and multi-stakeholder engagement in knowledge sharing processes.
    - 5.2. Evaluate the effectiveness of the final collaborative geospatial platform for supporting higher-level landscape stakeholders.
    - 5.3. Incorporate evaluation findings to refine the collaborative geospatial platform following 5.1 and 5.2.
    - 5.4. Develop collaborative geospatial platform instruction materials, guidelines and case study demonstrations.

6. **Identify adaptation objectives for communities within the landscape to foster climate resilience and enhance environmental livelihood security (ELS).**
    6.1. Use collated data derived from the collaborative geospatial platform to understand patterns in the landscape regarding climate stress on ELS.
    6.2. Through multi-stakeholder co-development across the landscape identify adaptation objectives to foster climate resilience.
    6.3. Investigate options with higher level stakeholders for developing and refining mechanisms for supporting future climate-smart landscapes based on outcomes of 6.1 and 6.2.

5 Methodology

The overarching aim of ACIAR project ASEM/2016/101 was to develop a collaborative geospatial platform that facilitates climate-smart landscape adaptation responses. The result of the project is maplandscape, an open source large scale geographic data capture and analysis platform developed to address the management needs of key landscape stakeholders. As an information and communication technology (ICT) platform, the co-development of maplandscape was guided by the ICT for development (ICT4D) framework established by Bon and colleagues (2013). The ITC4D framework provides an approach for developing ICT-enabled services in limited resource environments. The framework, as adopted for this project (Figure 1) provides for an agile and iterative co-development methodology with a strong 'learn-by-doing' component.

Figure 1: Needs assessment criteria used to prioritised stakeholder geospatial data and analytic needs.

The following describes each of the phases of the ICT4D methodology as applied to the development of maplandscape.

Context Analysis

Community context

Tools developed to aid in the management process must be appropriate for the local context in which they are applied. To understand the local context in which maplandscape would be applied, six communities were selected for in-depth community engagement to identify landscape services supporting livelihoods, the value of these landscape service flows, and impacts from recent climatic stressors on these flows. Three communities in both Fiji (Etatoko, Koronubu-Vunibaka, Nawaqarua) and Tonga (Afa, Kalaau, and Talasiu) were selected for further engagement based on the teams previous work in the region and/or through recommendation from project partners (i.e. MAFF, Tonga).

Community engagement approaches were drawn from the participatory rural appraisal manual developed by Schreckenberg et al. (2016). In Fiji, insights into which landscape services were used to support livelihoods, as well as the information used to assist with landscape-related decision making was collected through a survey of all households in each of the three study communities (Etatoko, Koronubu-Vunibaka, Nawaqarua). Causal loop diagram modelling, as outlined by Inam et al. (2015), was then conducted with a cross-section of residents providing further insight into how anthropogenic and environmental shocks resonate through local landscape and livelihood systems.

In Tonga, interviews with community leaders were found to be preferred over household surveys, with the approach aimed at developing a similar understanding of local livelihood contexts and landscape management issues. Here, causal loop participatory modelling activities were also conducted with members of each of the three study communities (Afa, Kalaau, and Talasiu) to gain insight into local landscape and livelihood systems.

In both cases, a review of available climate data was used to validate community member's understandings of climate related landscape and livelihood impacts. The results from these exercises were in part published in comprehensive review articles found in the *Journal of Environmental Management* and *Regional Environmental Change*.

Stakeholder context

A stakeholder context analysis was also undertaken to identify key individuals and groups involved in landscape management across Fiji and Tonga. Semi-structured interviews with national and regional-level stakeholders engaged in climate change adaptation, land use planning, agriculture and spatial data management were conducted prior to the start of the project. The process targeted representatives from Government, The Pacific Community, The UN, USP, and local and regional NGOs. A snowball sampling approach was used.

Specific motivating factors for undertaking the stakeholder analysis included the following:

- Identify which stakeholder groups the project needs to engage at various stages of the co-development process;
- Identify marginal stakeholders to facilitate benefits across a broad range of user groups;
- Capture diverse perspectives from a range of stakeholders to enable sound decision making during the tool co-development process; and
- Identify how different stakeholder groups may influence the co-development process and resulting products.

Initial stakeholder engagement activities informed the selection of organisations which were then targeted engaged in thefor co-development of maplandscape. The approach drew from methods outlined by Reed et al. (2009) in order to prioritise stakeholders for inclusion in the ongoing collaboration.

Needs Assessment

Here, ‘Needs Assessment’ refers to the identification and prioritisation of unmet needs for the use of geospatial data, or an unmet need which could be clearly/directly alleviated through the use of geospatial information. Bon et al. (2016) defined needs as a 'state of deprivation of some basic satisfaction' which can be independent of a specific technology or system. To this end, the needs assessment conducted here focused primarily on stakeholder engagement at the landscape management level and was informed by the initial Context Analysis.

Desktop review - mobile GIS applications

To further inform the maplandscape co-development process, a desktop review of collaborative geospatial platforms with multi-user GIS functionality was first conducted. Over 100 mobile GIS applications were identified and comprehensively assessed to identify gaps in functionality. The review focused on factors of usability, scalability, affordability, security, user support and a range of sub-indicators. Initially screened used an abridged set of criteria including android compatibility, offline data collection and open source licenses. A final set of thirteen applications were then subject to a full screening using a comprehensive set of criteria including the following:

- Android compatibility
- Offline data collection
- Open source licenses
- Geotagging capabilities
- Geographic feature collection (points, lines, polygons),
- Geographic feature attribution
- Multiuser data collection

- Local and/or 3rd party server hosting

Stakeholder needs assessment

A selection of priority landscape management stakeholders identified through the stakeholder context analysis, were invited to a series of focus group discussions in both Fiji and Tonga. The broad aim of these focus groups were to determine gaps in landscape management data and information relevant to understanding the impact of anthropogenic and environmental shocks on local livelihoods. Specifically, the focus groups aimed to:

- determine the role of different stakeholders in the landscape management process;
- determine what existing (geospatial) information stakeholders use on a regular basis;
- determine how stakeholders access and collect (geospatial) information;
- determine what (geospatial) information stakeholder needs are unmet; and
- Identify barriers (technical or organisational) to accessing existing (geospatial) information.

Stakeholder needs were categorised into 5 groups and assessed using a prioritisation framework (Table 1):

- Spatial Data Needs
- Data Collection Needs
- On-The-Fly Data Analysis Needs
- Pre-Computed Data Analysis Needs
- Data Sharing / Data Communication Needs

Table 1: Needs assessment criteria used to prioritised stakeholder geospatial data and analytic needs.

	High Priority	Medium Priority	Low Priority
Cost	• Free • Already an occurring cost that is budgeted for	• Not free - costs incurred in development, data collection, or maintenance	• Prohibitively expensive
Technical Feasibility	• Validated method exists	• Can be developed with acceptable work / adapted from existing products	• Untested development
Data Availability	• Desired data exists - provision only	• Data does not exist but can be generated	• Data does not exist. • Impossible / costly to generate
User Capacity	• User capacity exists	• User capacity building possible with existing or reasonable resources	• No user capacity to implement ICT solution to need
Scalability	• Need has wide / global applicability with no modification	• ICT solution to need could be adapted for global application	• Need is Fiji / Tonga specific

The Needs Assessment workshops were used to prioritise needs for geospatial data, analysis services, and applications not currently available to landscape management stakeholders. In addition, the process provided further understanding of the data collection and analytic features that would be required of a landscape management tool balanced with what is technically feasible.

Use Case and Requirements Analysis

Use case selection

The Needs Assessment phase resulted in the identification of a target user group, agricultural extension officers with the MoA, Fiji and MAFF, Tonga. As well as high priority geospatial data which is not currently available for decision making purposes. Due to the complexity of working with more than one stakeholder organisation in a software design process, co-development initially focussed on meeting the needs of MAFF, Tonga extension officers (EOs) with later application to MoA, Fiji.

Moving forward, a use case analysis was conducted with Tongan stakeholders to develop a suite of use case models and user narratives that describe how an end-user could use maplandscape to complete a landscape management task.

This step focused on understanding how an extension officer would work with geospatial data to assist in landscape management decision making. A set of 10 use case narratives were developed and grouped by the priority needs identified in the previous step:

1. Crop type and locations of fallow land
2. Land use/land-cover data
3. Climate Change information
4. Responses to weather events and natural hazards
5. Planning for weather events and natural hazards

For each use case, narratives were developed that describe how an EO could use maplandscape to perform a landscape management task (Figure 2). The use cases were designed to prompt discussion concerning the ways in which a tool such as maplandscape could be employed by an EO.

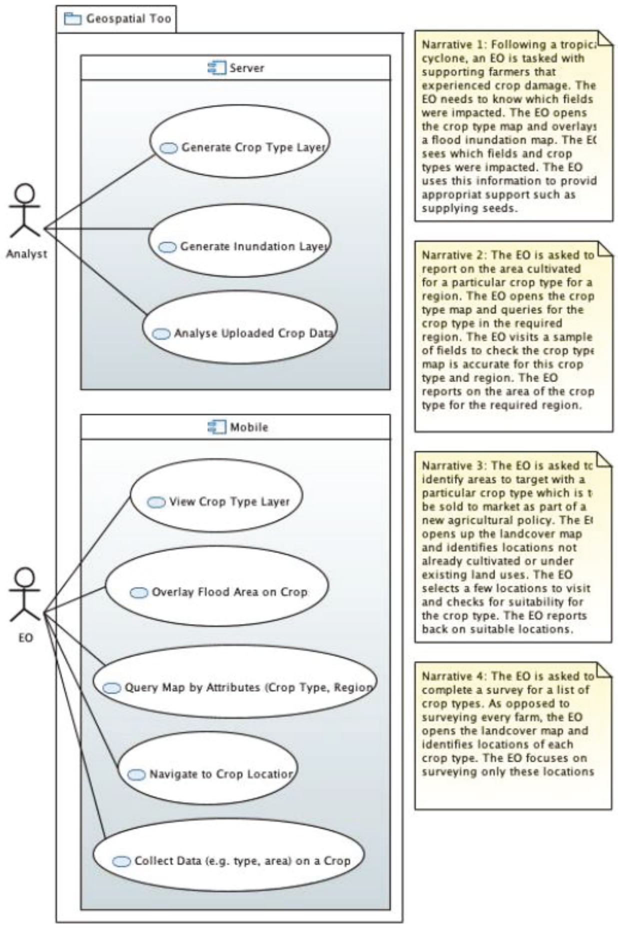

Figure 2: Example use case narratives for the crop type use case.

Interviews were then held with stakeholders to obtain feedback on how maplandscape could be used by an EO in the context of each narrative. The following questions were used to guide this process:

- Is each use case relevant to the current activities performed by EOs?
- Could a use case be modified to better reflect how an EO might interact with the tool?
- Are there other activities the EO performs related to the priority areas that we have not captured and where the tool might be helpful?
- Are there any use cases for planned or future activities that EOs might perform that have not been captured here?
- For these use cases, do you see any conflict, overlap or potential integration with other tools used by the EOs?

The feedback gathered from the use case interviews were then used to develop prototype tools that were field-tested in consultation with stakeholders and EOs.

Development Testing and Deployment

Prototype development

A general overview of the maplandcsape prototype development, testing and employment process is provided in Figure 3.

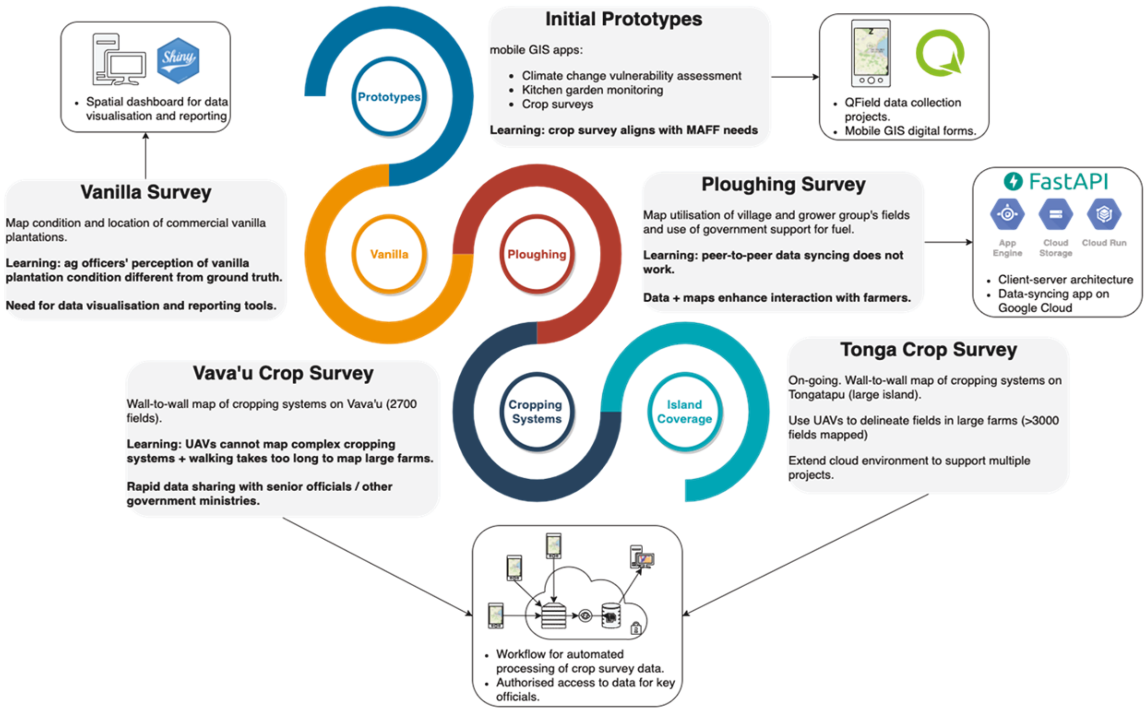

Figure 3: Schematic of the maplandscape development process (as seen in Duncan et al 2020).

Through the needs assessment and requirements analysis process, it was decided that maplandscape would be developed to support MAFF, Tonga with mobile GIS based data collection in order to survey and capture agricultural landscape characteristics. Specifically, the mobile GIS based data solution allowed the collection of detailed crop information required for MAFF, Tonga's annual crop survey. As such, several data collection projects were developed using QField/QGIS technologies (best solution as identified from our desktop review). The prototype was designed for deployment on tablet and smartphone device architecture and applied to three co-developed use cases:

- Vava'u vanilla plantation survey – mapping the plant number and condition in vanilla plantations across Vava'u.
- Vava'u crop survey – mapping the plant number and area per-field for several crops across major agricultural operations on Vava'u (> 2,500 fields).
- Vava'u ploughing survey – mapping agricultural utilisation of village lands to calculate fuel subsidies for reactivation of fallow land.

A key reason for using QField for mobile geospatial data collection was that data is stored in relational data model inside GeoPackage files and QGIS projects. This means that data collected in the field through digital forms maps onto a database structure that mirrors a central database and permits SQL-based queries of data. This minimises data processing and cleaning effort and permits automated data syncing which speeds up the transition from data collection to visualisation, reporting, and decision making. Through the co-development process, it was identified that many of MAFF, Tonga's data analysis and reporting requirements can be expressed as SQL-style queries (often spatial joins and group-by and summarise operations). This further motivated the use of a relational data model to represent landscape data. The maplandscape dashboard therefore was designed to provide a user friendly/no code interface for the organisations standard database query operations.

Through successive rounds of field testing and application development, the workflow was expanded to support large teams of data collectors, and provide data syncing, management, and analytics services. QFieldCloud was identified as the best solution for data storage and user management to meet MAFF, Tonga's requirements. QFieldCloud fully integrates with the QField mobile data collection device and provides functionality for authenticated logins using institutional email accounts, user management tools (i.e. assign different users to different data collection projects with different permissions), deltas API (to record each change to a data collection project), and the QFieldCloud API to support retrieval and querying of geospatial data stored in the QfieldCloud system. QfieldCloud is a Django project developed by OPENGIS.ch. A modified instance of QfieldCloud was deployed on Digital Ocean for testing and MAFF, Tonga's data collection projects.

A geospatial analytics dashboard that interfaces with QFieldCloud provides support for quick analysis and visualisation of data collected in the field via a web browser. This dashboard was developed as an R package and uses the Shiny web application framework, bootstrap and DataTables for the user interface, Leaflet and leafgl for web mapping, and PostGIS for data processing. The dashboard is deployed using docker swarm with ShinyProxy running as a middleware and Traefik as a load balancer and reverse proxy.

Again, through co-development activities, it was identified that GeoPackages stored in S3 cloud storage buckets would be the most suitable solution for primary data storage and exchange within the maplandscape workflow. GeoPackages are file-based data storage based on SQLite with spatial extensions. They store data using a relational tabular structure and support SQL queries (i.e. meeting end users database requirements) but being file-based do not require maintenance of an always-on server (which is a technical burden and cost). Importantly, S3 storage buckets provide versioning and backup functionality.

Full deployment

Full deployment of maplandscape was realised for the Kingdom of Tonga's national crop survey (2021 and 2022) and recent rice survey conducted by the MoA, Fiji (May 2022). Figure 4 provides a detailed overview of the fully tested and deployed maplandscape architecture. As discussed above, maplandscape is comprised of three primary components, the data collection component, build on QField technology, a cloud based storage component drawing from QFieldCloud technology with associated S3 Cloud Storage, and a visualisation and analytics component built with Shiny.

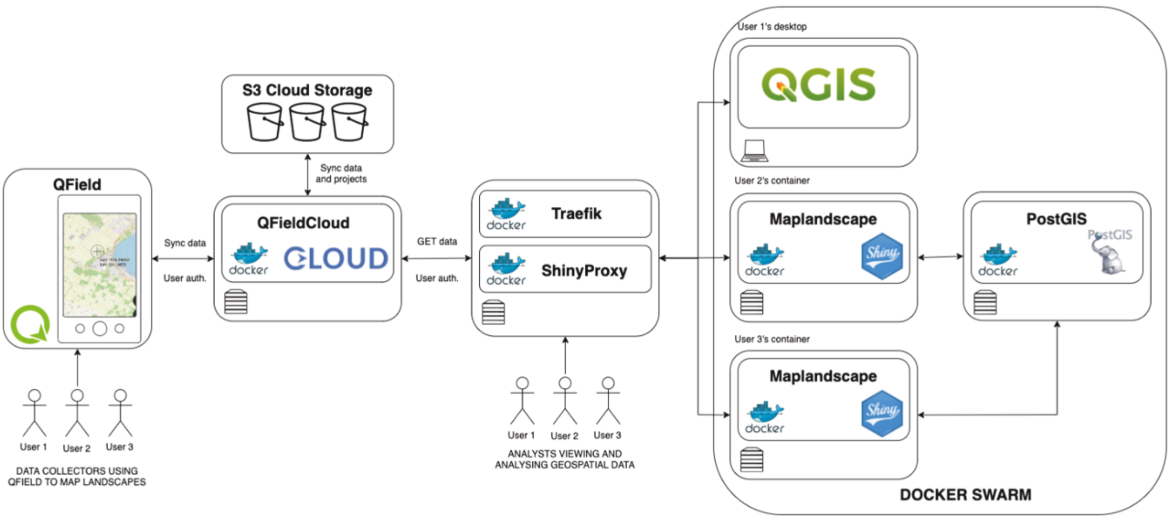

Figure 4: Schematic of the maplandscape development process (as seen in Duncan et al 2020).

A detailed overview of maplandscapes design characteristics and architecture is published in the *The International Archives of The Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVIII-4/W1-2022*.

Sustainability Assessment

Tool evaluation

Use case prototyping and deployment was used as a mechanism for iterative and ongoing tool evaluation. Given the iterative and agile co-development process resulting in maplandscape, the ability of MAFF, Tonga staff to deploy maplandscape for large scale data collection initiatives was viewed as an indication of a well-developed geospatial decision support tool that would prove a sustainable asset for the organisation. However, for added assurance a code audit was conducted by the QGIS developer's consortium to enhance both the operational and deployment efficiency of the maplandscape platform.

Training

A 'learn by doing' training approach was adopted for the project, delivering frequent and consistent small group trainings across the life course of the project. Details of individual training sessions can be found in Appendix 1. Further discussion of the breadth of our training initiatives is provided in Section 7 Results.

Gender Review

Across the final six months of the project, a review was conducted of gender inclusion based on the premise that the open-source geospatial platform has the potential to improve the analysis, visualization and collection of gender-related information and approaches in supporting agricultural and climate-related policy in the Pacific. The review was conducted by Aliti Vunisea, a Pacific Island Gender Expert and former lecturer at the University of the South Pacific.

Here, "gender" was used as a relational concept and not an alternative term for "women" and from the perspective that gender and social inclusion should be a priority in all stakeholder discussions relating to the agriculture sector. The original goal for gender inclusion in this project was to have gender responsive interventions through information gathered and geospatial mapping. As such, the gender review examined, post-hoc, the relationships between men and women and their respective access to and control of information resources, within the context of a co-developed, participatory development project (Tool development).

The approach consisted of a review of project material (particularly training materials) and documentation as well as methods used for data collection and analysis. Particular attention was paid to equity in the extensive training program the project delivered (see Appendix 1) and the approaches used for gender inclusion in the outputs from this research that aim to build climate resilience and enhance environmental livelihood security. The review also examined the role of gender in the Information and Communications Technologies for Development (ICT4D) approach used in this project to make recommendations for integrating gender in future technology based projects.

6 Achievements against activities and outputs/milestones

Objective 1: Critically review and evaluate existing collaborative geospatial tools, platforms and methodologies.

no.	activity	outputs/ milestones	completion date	comments
1.1	Review of existing collaborative geospatial approaches assessed against a gradient of metrics.	• Desktop review of over 100 mobile GIS applications. • Review paper on potential role of collaborative geospatial platforms in participatory landscape resource assessment, understanding complex inter-linkages within socio-ecological landscape systems and exploring responses to climate stressors.	Nov 2018	A comprehensive assessment of the functionalities of existing collaborative geospatial platforms identified gaps in functionalities of existing geospatial tools.
1.2	Assessment of landscape uses and climate stressors to provide baseline data that will inform collaborative geospatial approaches review process.	• Household survey of all households in Nawaqarua, Natutu, Etatoko, and Koronubu-Vunibaka identifying which landscape services were used to support livelihoods, the value of these landscape service flows, impacts from recent climatic stressors on service flows, and other information related to adapting and responding to climate shocks. • Desktop review of local and regional policy documents and climate data. • Interviews with extension officers and community leaders in Tonga. • Interviews with community leaders and key stakeholders in Fiji. • Participatory modelling activities (causal loop diagrams) with landscape users to identify stressors and shocks affecting landscape resources and coping and response strategies.	Aug 2018	Internal report integrating primary and secondary data presented a typology of livelihood data for use within the collaborative geospatial platform. Findings from these outputs were presented at an in-country research forums.

1.3	Parallel exercise to link approaches (identified in 1.1) suitable for assessing landscape uses and climate stressors (identified in 1.2).	• Analysis of household survey data from 1.2, interviews and shadowing extension officers, and analysis of desktop review of applications from 1.1. Prototype applications built using early releases of QField and ODK. • Iterative analysis of applications to align software features and functionality with end-user requirements.	Nov 2018	Identification of collaborative geospatial approaches that can be used to assess key landscape uses and climate stressors relevant to landscapes and livelihoods in case study communities.
1.4	Community evaluation of approaches identified/developed in 1.3.	• Needs assessment workshops with landscape stakeholders in Suva, Lautoka, and Tongatapu to identify needs for geospatial data, analysis services, or applications. Used to priorities features for geospatial tool development to align with end user and stakeholder needs and technical feasibility.	Dec 2018	Identification of optimum geospatial approaches to undertake livelihoods, landscapes, and climate stressor assessments.
1.5	Multi-stakeholder evaluation of approaches identified/developed in 1.3.	• Needs assessment workshops with landscape stakeholders in Suva, Lautoka, and Tongatapu to identify needs for geospatial data, analysis services, or applications. Used to prioritise features for geospatial tool development to align with end user and stakeholder needs and technical feasibility. • Use case analysis with key stakeholders–presented and discussed a suite of use case models and user narratives describing how an end-user could use a geospatial tool to complete a task.	May 2019	Evaluation of the optimum geospatial approaches for use by higher-level stakeholders engaged in landscape activities.

Objective 2: Develop a collaborative geospatial platform with an interface that is accessible and appropriate for a range of landscape stakeholders.

no.	activity	outputs/ milestones	completion date	comments

2.1	Co-develop a collaborative geospatial platform following outcomes of 1.4 and 1.5 that incorporate landscape-livelihood-climate interactions and builds upon functionality of existing geospatial approaches.	• maplandscape workflow co-designed with end users to meet needs for collecting, storing, and analysing agricultural landscape data. • maplandscape geospatial analytics dashboard to support quick analysis and visualisation of data collected in the field via a web browser. • Docker swarm based deployment of maplandscape dashboard and associated applications (PostGIS for geoprocessing; ShinyProxy middleware for deploying Shiny applications). Adapted version of the QFieldCloud Django application to deploy organisation’s own instances, handle data syncing of surveys from multiple devices, manage user accounts. Deployed on Digital Ocean for MAFF. Supported by two-week long workshop and code review sessions with OPENGIS.ch developers. • Iterative analysis of applications to align software features and functionality with end-user requirements. • Development of various data collection projects using QField mobile GIS. • Engaged OPENGIS.ch to develop features for QField including “fast editing mode” for auto save functionality.	Dec 2021	Technical development of platform with a user interface that encourages interactive engagement of community members and other stakeholders in data collection, interpretation and evaluation processes and enables co-production of knowledge.

2.2	Develop specific platform tools to enable land use/land cover mapping and integration of seasonal climate forecasts.	• Vanilla plantation survey, MAFF, Vava'u 2020–mapping the plant number and condition in vanilla plantations across Vava'u. • Vava'u crop survey, MAFF, Vava'u 2020–mapping the plant number and area per-field for several crops across major agricultural operations on Vava'u (> 2,500 fields). • Tonga crop survey, MAFF, Vava'u, Tongatapu, Ha'apai, and 'Eua island groups, 2021-mapping the plant number and area per-field for several crops across major agricultural operations (>10,000 fields). • Tonga crop survey, MAFF, Vava'u, Tongatapu, Ha'apai, and 'Eua island groups, 2022/23-mapping the plant number and area per-field for several crops across major agricultural operations (> 7,000 fields–Vava'u ongoing). • Geospatial analysis of Tonga's Cropping System. • Damage assessment after Hunga Tonga Hunga Ha'apai eruption, Tongatapu, 2022–MAFF staff used existing crop survey data and collected data after the eruption to estimate agricultural areas damaged and monitor use of resources for agricultural recovery. • Fiji Rice survey, MoA, Viti Lavu Fiji, mapping planted area and information on agricultural operations (>1500 farms). • Training on setting up farm and crop survey projects using maplandscape workflow.	Jan 2023	Through agile and iterative development activities with MAFF, Tonga, mobile GIS based data collection projects which permit estimating the number of plants per-crop type in a field /plantation were developed and tested. These data collection projects were developed using QField / QGIS and are based on a relational data model which was used to drive conditional logic in digital forms. A similar workflow was later implemented with MoA, Fiji to map rice production.

Objective 3: Identify community level landscape-livelihood-climate stressor interactions.

no.	activity	outputs/ milestones	completion date	comments

3.1	Use the collaborative geospatial platform in case study landscapes to generate information on landscape-livelihood-climate stressor interactions.	Participatory modelling activities (causal loop diagrams) with landscape users to identify stressors and shocks affecting landscape resources, and coping and response strategies.	Jan 2020	Participatory approaches were used to identification key landscape services associated with community members' livelihoods, vulnerabilities to climate stressors, and response strategies of community members to climate stressors.
3.2	Use the Environmental Livelihoods Security (ELS) matrix to identify links and feedbacks between livelihoods, landscapes, and climate stressors using data collected in 3.1.	-	-	During community engagement initiatives it was realised that communicating landscape information using an ELS associated typology was not preferred by community members. Communication of geospatial information was therefore simplified and constrained to single layers of relevant information.
3.3	Use ELS matrix to establish a typology of landscape activities under climate stressors to be able to classify an input procedure for future data collection using the collaborative geospatial platform – through understanding response relationships from data collected in 3.1 and processed in 3.2 develop a rule-based classification technique.	-	-	During community engagement initiatives it was realised that communicating landscape information using an ELS associated typology was not preferred by community members. Communication of geospatial information was therefore simplified and constrained to single layers of relevant information.

Objective 4: Identify capacity for multi-stakeholder knowledge sharing into the collaborative geospatial platform.

no.	activity	outputs/ milestones	completion date	comments
4.1	Develop a spatially-enabled database that optimises the exchange of information and knowledge co-produced using participatory action research.	Through agile and iterative development activities with MAFF, Tonga, mobile GIS based data collection projects were developed to enable capturing and storing of detailed information about landscape characteristics.	Jan 2023	Data collection projects were developed using QField / QGIS and are based on a relational data model which was used to drive conditional logic in digital forms and support querying and analysis of data.

4.2	Establish digital geospatial protocols for the documentation and sharing of traditional knowledge and mapping.	GeoPackages stored in S3 cloud storage buckets were identified as the most suitable solution for primary data storage and exchange within the maplandscape workflow. Geopackages store data using a relational tabular structure and support SQL queries (i.e. meeting end users database requirements) but being file-based do not require maintenance of an always-on server (which is likely too much of a technical burden and cost for many end users). S3 storage buckets provide versioning and backup functionality.	Jan 2023	QFieldCloud was identified as the optimum solution for overall data storage and user management to meet MAFF, Tonga requirements. These include authenticated logins using institutional email accounts, user management tools (i.e. assign different users to different data collection projects with different permissions), deltas API to keep a record of each change to a data collection project, and QFieldCloud API to support retrieval and querying of geospatial data stored in the QFieldCloud system.

Objective 5: Evaluate the effectiveness of the collaborative geospatial platform for promoting community and multi-stakeholder exchange and engagement with landscape knowledge.

no.	activity	outputs/ milestones	completion date	comments
5.1	Evaluate the functional transferability of the platform for data collection and multi-stakeholder engagement in knowledge sharing processes.	• See Outputs 5.2.	-	Quantitative evaluation of platform usage metrics was replaced with assessment of platform performance in MAFF, Tonga crop surveys and post disaster data analysis by MAFF, Tonga staff.
5.2	Evaluate the effectiveness of the final collaborative geospatial platform for supporting higher-level landscape stakeholders.	• Vanilla plantation survey, MAFF, Vava'u 2020 – mapping the plant number and condition in vanilla plantations across Vava'u. • Damage assessment after Hunga Tonga Hunga Ha'apai eruption, Tongatapu, 2022 – MAFF staff used existing crop survey data and after the eruption to estimate damage to agricultural areas and monitor use of resources for agricultural. • Rice farming household survey, MoA, Fiji 2023 – collect and map information on the structure and status of rice production, farming system, processing and marketing in Fiji.	Latest example – July 2023	Proposed simulation exercises were replaced with several real-world applications highlighting the agility and utility of the maplandscape tool to support the use of geospatial data across a range of landscape management applications.

5.3	Incorporate evaluation findings to refine the collaborative geospatial platform following 5.1 and 5.2.	-	Dec 2022	Co-development process required and resulted in integrative testing and evaluation of the maplandscape tool. Evaluation and refine occurred at numerous points in the development process therefore a final evaluation was not required.
5.4	Develop collaborative geospatial platform instruction materials, guidelines and case study demonstrations.	• Tutorials and Best Practice guides can be found here - https://livelihoods-and-landscapes.com/docs/docs.html. • Use case examples available here - https://livelihoods-and-landscapes.com/examples.html. • Technical reference material for software and applications developed is all open source and available here - https://github.com/livelihoods-and-landscapes.	Dec 2022	Training materials for the maplandscape platform can be linked to from the Livelihoods and Landscapes website.

Objective 6: Identify adaptation objectives for communities within the landscape to foster climate resilience and enhance environmental livelihood security (ELS).

no.	activity	outputs/ milestones	completion date	comments
6.1	Use collated data derived from the collaborative geospatial platform to understand patterns in the landscape regarding climate stress on ELS.	Identification of climate related landscape stressors, perceived causes and livelihood impacts. • Review of evidence published in *Regional Environmental Change*. • Identification of stressors, causes and impacts identified from data collected through community level participatory approaches.	Dec 2022	ELS associated typology was not preferred by community members, climate related stressors, causes and impacts were identified through community engagement approaches. Rather than through the use of the maplandscap platform. Information collected by MAFF Tonga and MoA Fiji using the maplandscap tool, information that can be used to patterns of climate stress in the landscape.
6.2	Through multi-stakeholder co-development across the landscape identify adaptation objectives to foster climate resilience.	Workshop in Ba, Fij with community members from Votua, Nawaqarua, and Koronobu-Vunibaka, and local MoA extension officers. • Envisioning approach used to identify community member's vision of their village's future in the face of a changing climate.	June 2023	An Envisioning workshop was held in Ba Town, Fiji bringing together local landscape managers and community members. The workshop allowed for an exchange of ideas and a better understanding of the barriers and constraints landscape manager's face. Together the group identified viable approaches to addressing local climate related impacts on landscapes and livelihoods.

6.3	Investigate options with higher level stakeholders for developing and refining mechanisms for supporting future climate-smart landscapes based on outcomes of 6.1 and 6.2.	Workshop in Ba, Fij with community members from Votua, Nawaqarua, and Koronobu-Vunibaka, and local MoA extension officers. • Envisioning approach used to identify landscape managers vision of the region's future in the face of a changing climate	June 2023	See above.

7 Key results and discussion

maplandscape

The culmination of our multi-year ICT4D co-development process was maplandscape, a stack of open-source applications for mapping and monitoring diverse agricultural landscapes (Figure 5). The workflow can be used for geospatial and non-spatial data collection tasks, large team data collection efforts, rapid mapping after disasters, and household surveys for monitoring programs and projects. The platform has been widely used in Tonga with ongoing work in Fiji. To date, over 12,000 farms have been mapped across a range of applications including cropping system monitoring to disaster response.

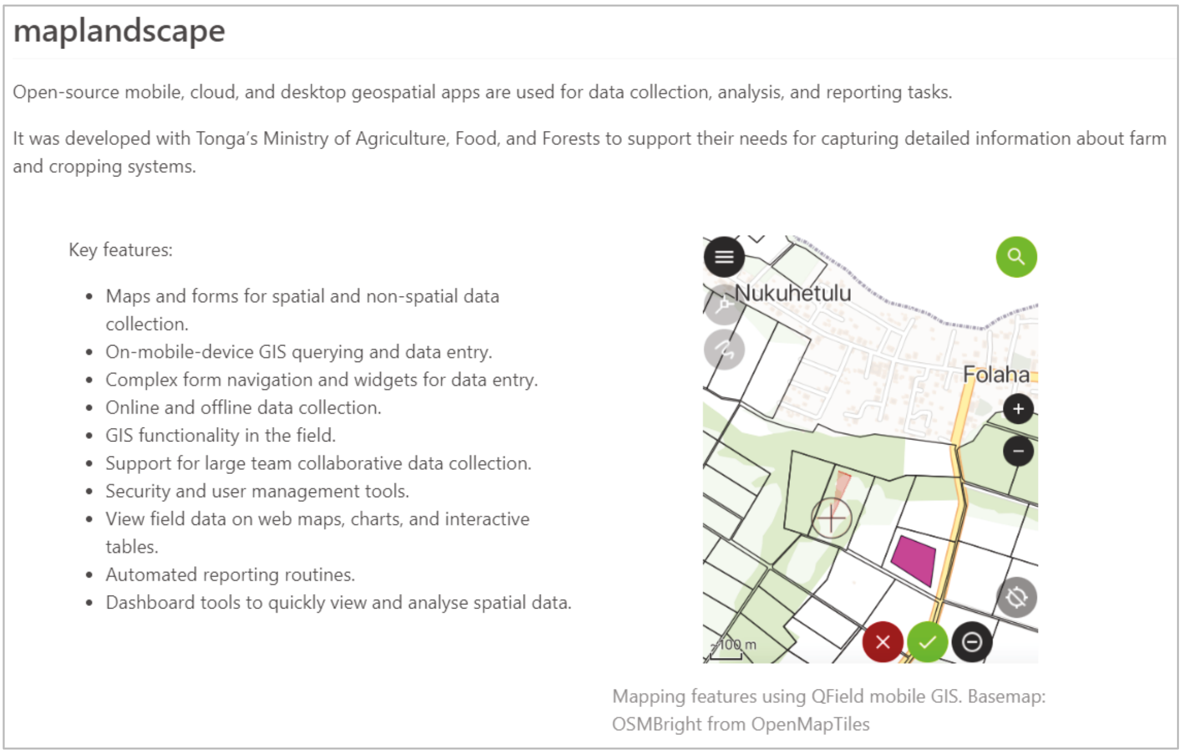

Figure 5: maplandscape features overview.

More specifically, the research used the collaborative software development methodology ICT4D to:

- Develop a workflow for mapping and monitoring agricultural landscapes and farming systems at fine spatial resolutions.
- Develop tools for spatial and non-spatial data collection using phones and tablets.
- Build the capacity of landscape stakeholders to use GIS and geospatial data for landscape management.

The platform is comprised of three components (Figure 6), starting with a Field data collection component built with QField, a mobile open-source geospatial data collection tool that easily integrates with relational databases, supports viewing spatial layers in-the-field, and provides a touch-optimised map interface for digitising spatial features and digital forms in order to capture attribute and non-spatial information (Figure 7).

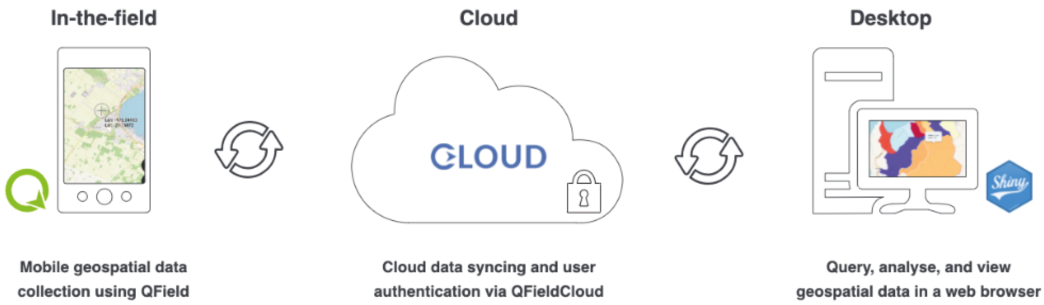

Figure 6: maplandscape features overview.

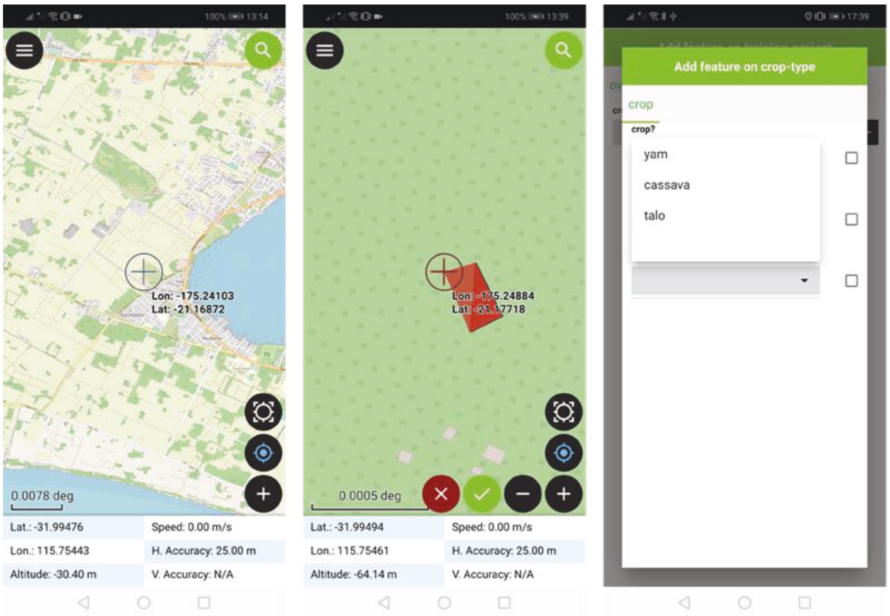

Figure 7: maplandscape data collection interface.

To manage large scale data collection initiatives, maplandscape next draws on QFieldCloud, an open-source Django web service app developed by OPENGIS.ch. QFieldCloud provides tools for managing users and collaborators in large scale data collection projects, provides secure cloud storage for project data, and allows for comprehensive versioning of project data. Importantly, QFieldCloud's 'push changes' mode lets data collectors operating in low bandwidth environments back up their local data into the cloud in order to avoid data heavy full project synchronisation.

Unique to maplandscape, is the bespoke data visualisation and analytics component built for MAFF, Tonga and MoA, Fiji using R Shiny (Figure 8-10). The application allows non-GIS experts the capabilities to analyse QField data within their own web browser. This applications makes QField data quickly accessible to decision makers as the data can be viewed and analysed using web maps, interactive tables, and charts. Additional tools for automated reporting from QField data and geospatial and relational database analysis operations can be accessed via this simple user interface.

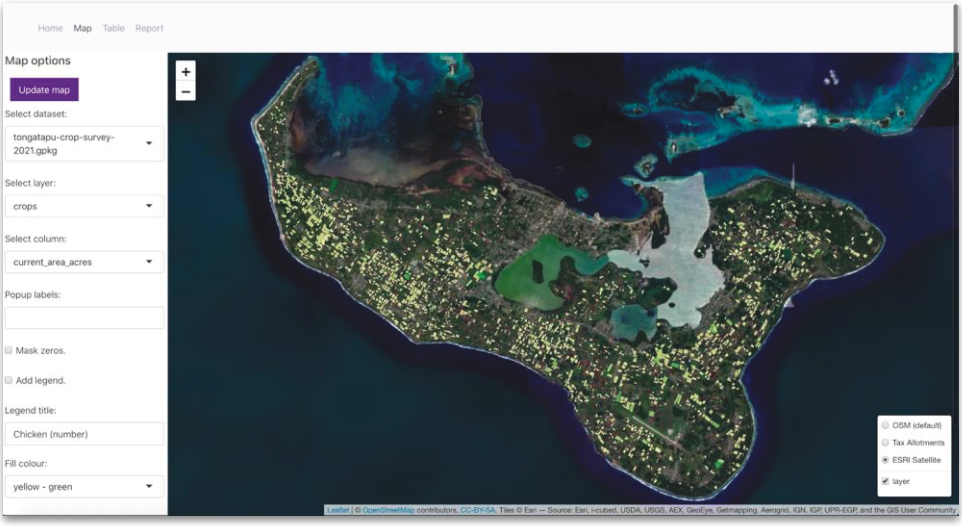

Figure 8: maplandscape mapping interface.

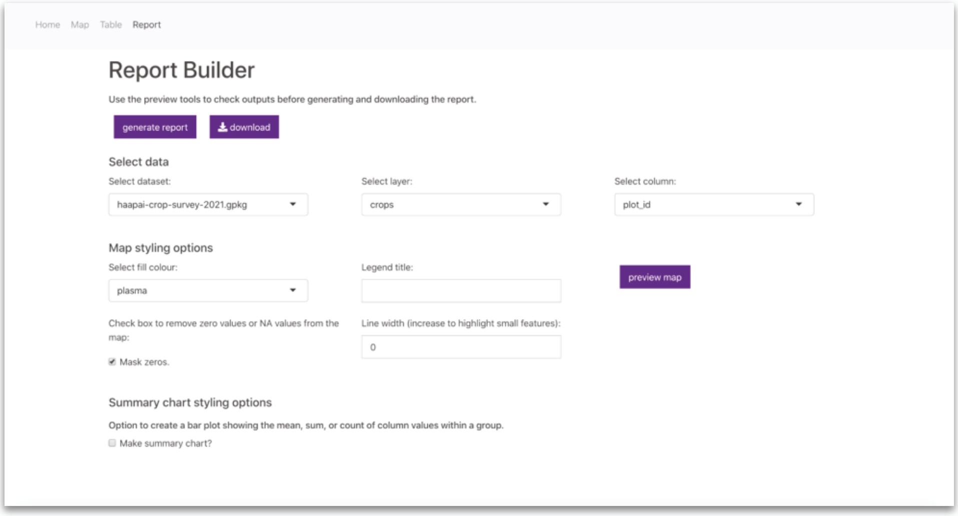

Figure 9: maplandscape report builder interface.

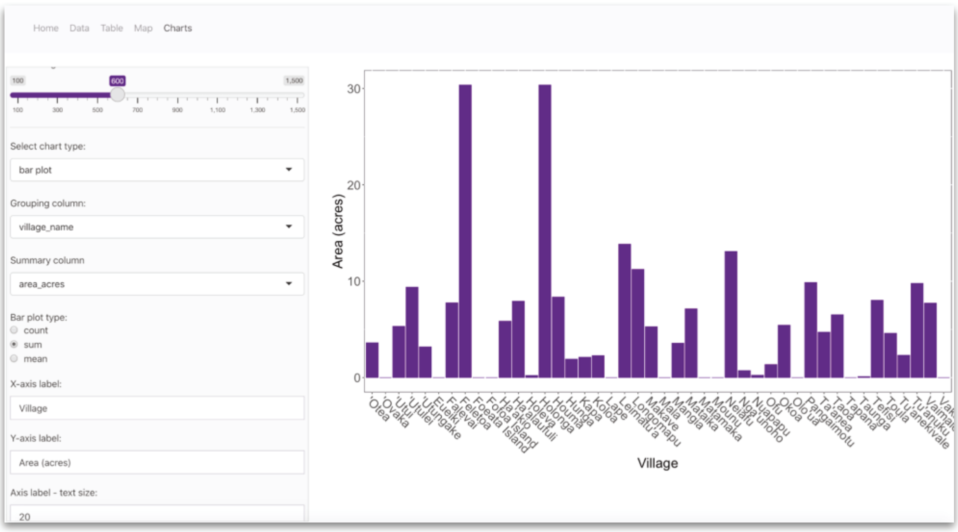

Figure 11: maplandscape charting interface.

maplandscape Applications

To date, maplandscape has become integral to MAFF, Tonga's daily operations and is now becoming the go-to platform for MoA, Fiji. Since full deployment, the platform has been used to conduct two full national crop surveys and support numerous bespoke data collection and disaster response initiatives across both nations. The following provides an overview of maplandscape applications:

Vanilla plantation survey Vava'u

In May and June of 2020, a team of MAFF, Tonga extension officers conducted a spatial survey of vanilla plantations using maplandscape on the island group of Vava'u. The purpose of the survey was to map the current extent of plantations and provide estimates of the numbers of plants, area under cultivation, and the proportion of plantations in neglect. In total, 140 plantations were surveyed with the resulting information used to support MAFF, Tonga's agricultural planning and decision making processes. Results highlighted that although vanilla is a key commercial crop for the agricultural economy of Vava'u, a large proportion of plantations were in a state of disrepair. Through the data collection and analysis workflow developed for MAFF, Tonga the organisation was able to gain a better understanding the challenges vanilla farmers faced and the result of these impacts on the system.

Tonga crop survey 2021

Each year, MAFF, Tonga conducts a national crop survey to record the area and number of individual crops planted across the Kingdom. The Ministry uses this information for reporting, informing policies and programs, and allocating government resources. Traditionally, this data was captured using paper based surveys by teams of extension officers, and manually typed into spread sheets before reporting. maplandscape has allowed for the automation of this process with the Kingdom's annual crop survey now collected digitally (Figure 12). By the end of 2021, over 50 MAFF, Tonga EOs had collected a database of over 12,000 spatial features with rich attribute information describing the landscape of agricultural production across each island group.

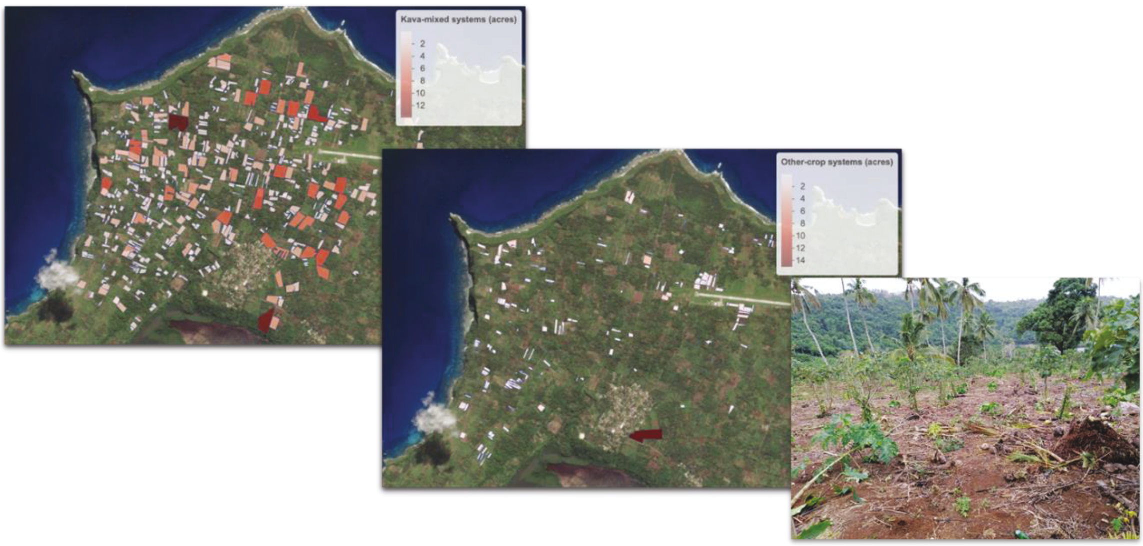

Figure 12: Example of 2021 crop survey data collected for Vava'u, Tonga.

Hunga Tonga-Hunga Ha'apia volcanic eruption

In January 2022 the Hunga Tonga-Hunga Ha'apai submarine volcano erupted resulting in an ash cloud and tsunami that damaged croplands across the Tongatapu and Ha'apai island groups (Figure 13). The Tonga Crop Survey, completed only a month prior, became an integral part of the response and recovery efforts. Directly after the eruption, the Tonga crop survey was used to perform an initial estimate of damage to the food supply. In the days and weeks that followed, maplandscape was used to map damaged agricultural lands and to conduct surveys for monitoring the deployment and use of government response and recovery resources. The event highlighted the adaptability of the maplandscape platform to support a broad range of landscape management solutions.

Figure 13: Ash laden field on Tongatapu, Tonga.

Tonga crop survey 2023

Late in 2022, MAFF, Tonga embarked on their second national crop survey. Again, large teams of extension officers survey farms across the Kingdom (Figure 13). Importantly, the post Hunga Tonga-Hunga Ha'apia volcanic eruption data collection initiative has allowed MAFF, Tonga to track recovery in tsunami and ash effected regions.

Fiji rice survey 2023

In July of 2023, MoA embarked on a survey of the nation's rice production landscapes. Here, maplandscape was used to collect information on the structure and status of rice production, rice farming systems, processing, and marketing. The initiative was a cross departmental undertaking, bringing together teams from MoA, Fiji''s Research, Crop Extension, Land Resource Planning and Development, and Economic Planning and Statistics Divisions. Over 1000 farms were surveyed providing a rich picture of the extent of Fiji's rice production across the island group.

Training

The project adhered to a 'learn by doing' training approach (Figure 14), providing an extensive educational program in Fiji and Tonga (Appendix 1). The project team provided consistent and frequent training sessions for stakeholder's across the life course of the project. During COVID related travel restrictions, the team continued to deliver training either entirely online or in conjunction with a local team members. Trainings focused on a range of topics from the general use of Geographic Information Systems (GIS) for landscape analysis, through to large scale geospatial data collection project setup and deployment. Training sessions focused on the following primary topics:

- Land-use/land-cover mapping
- QField mobile data capture project setup
- Geospatial data analysis using QGIS
- Ground truth data collection using QField
- Agricultural field data collection using QGIS
- Agricultural analytics using the maplandscape dashboard
- maplandscape stakeholder feedback sessions

Figure 14: ‘Learn by doing’ approach to training.

In total, >18 (~220 individuals) formal training sessions were delivered in Fiji with >20 (~250 individuals) in Tonga, each with a focus on maintaining gender balance. Trainings were generally delivered as ½ day interactive sessions including both classroom and field based instruction. In many instances, trainings were formalised to incentivise involvement and completion as well as instil a sense of accomplishment in participants (Figure 15). By building the local capacity of landscape stakeholders to use GIS applications to collect and analyse geospatial data to support decision making and management, we have helped ensure the sustainability of the project and the use of the maplandscape platform well into the future.

Figure 15: Formalised training session delivered at MAFF Tonga.

The project has also developed an extensive set of training materials that can be accessed through the project website. These include *Tutorials*, *Best Practice Guides* and useful *Reference* information. In addition, several workshops have been developed to demonstrate how satellite images, geospatial technologies, and socio-economic data can be combined to identify the fingerprint of climatic hazards in coastal regions across Oceania. The workshops, targeted at high school students, were based, in part, on findings from this project. To date more than 100 students across Australia have completed *More Than Maps* workshops. These additional training materials can be found here:

- Project Documentation and Tutorials - https://livelihoods-and-landscapes.com/docs/docs.html
- More Than Maps - https://morethanmaps.earth/#about

Gender Review

The Gender Review concluded that there was compelling evidence of gender participation in most project activities including trainings, individual stakeholder consultation, and workshop discussions. Gender training was delivered to team members at the beginning of the project with a focus on understanding gender dimensions influencing community level data collection methods and analysis. A balanced team of in-country research associates then led the continued data collection process using complimentary social tools including Participatory Resource Mapping, Stakeholder Mapping, Agricultural Timelines and Causal Loop Diagrams in order to better understand the information needs of community member's and landscape managers.

The Review concluded that gender and social inclusion had been efficiently implemented, as gender dimensions identified during the project were contextualised. Important, was the enhanced understanding of how women's cultural roles influence status and designations within communities, ownership and access to resources, and participation in the decision making processes; all of which can impact access to the internet and associated technologies. Strategies implemented to meet geographic information needs and prioritisation in the development of maplandscape were therefore inclusive of a range of social groups' needs.

The Review concluded the following:

- Project implementation was adapted to local contexts taking into account the different capacities and needs of different members of communities.
- Attempts were made to be inclusive of gender and other social groups' geographic information needs and were prioritisation in the development and use of geospatial tools.
- All interventions, like training and capacity building in geospatial mapping were gender inclusive.
- Geo-spatial mapping and participatory approaches allowed gender sensitive participation of community members in environmental decision making.

Recommendations for enhancing the role of gender in the ICT4D approach (with an emphasis on geospatial approaches) include the following:

- Geospatial information needs assessment and prioritisation must be inclusive of gender and other social groups' needs.
- Community data sovereignty should be considered as an early component of the project planning process and include gender needs and rights.
- Geospatial mapping platforms should contextualise tools and approaches that are relevant to women, youths and other marginalised groups at all levels of engagement.
- Gender differences should be incorporated into all levels of co-design.
- Collection of information should be sex-disaggregated and future dissemination of data, and data management and use, should be gender inclusive in approach, implementation and documentation.
- Standard gender Indicators should be developed to verify and measure gender progress in all work conducted on the ground.
- Development of gender mainstreaming and gender action plans should be considered as an outcome.

In conclusion, gender mapping and GIS applications demonstrate the potential for gender related information to be inscribed in wider multi-scalar geographical spaces, which may wield influence on development policy decision making into the future.

8 Impacts

8.1 Scientific impacts – now and in 5 years

This project has contributed to the development of a range of datasets relevant for monitoring agricultural landscapes, and their diversity and dynamics, in Fiji and Tonga. These datasets were generated using the maplandscape platform, in conjunction with other geospatial software applications. These datasets include:

- National scale maps of farming systems across Tonga's main island groups for two years (with a 2023 data collection campaign imminent). These datasets include maps of tens of thousands of fields and paddocks, their crop types and plant numbers, livestock and livestock management characteristics, and other farm variables.
- Spatial database of vanilla plantations and their management condition on the island group of Vava'u, Tonga.
- Spatial database of grower group's agricultural management and land utilisation on the island group of Vava'u, Tonga.
- Dataset of distribution of seedlings to women farmers after the Hunga Tonga-Hunga Ha'apai eruption.
- Dataset of recovery of agricultural lands following Hunga Tonga-Hunga Ha'apai eruption.
- National scale 10m spatial resolution land cover maps for Fiji for 2019, 2020, 2021, and 2022 (available on the Pacific Data Hub).
- Labelled ground truth dataset of over 13,000 points across Fiji to develop machine learning models for land cover classifications in Fiji (available on the Pacific Data Hub).
- Test dataset of points with land cover labels based on a nationally representative stratified sample across Fiji. This dataset is designed to permit assessment and comparison of land cover products over Fiji (available on the Pacific Data Hub).

The project has also resulted in a suite of scientific, capacity and community impacts. Six peer-reviewed scientific publications and two master's theses provide a foundation of impacts realised across the life course of the project (Section 10.2). Informing the development of maplandscape, the team systematically examined and published a review of ICT4D initiatives identifying factors for success to enhance the longevity of spatial decision support tools developed for this project (Haworth et al., 2018). The team published an overview of an idealised open-source mobile geospatial data collection and analysis platform for promoting climate-smart livelihood-landscape systems in the South Pacific (Davies et al., 2019).

Drawing from engagement with local communities and landscape managers, the project compiled local insights from managing multifunctional landscapes in the Pacific Island context (Duncan et al., 2020). Results highlighted that special consideration of the spatial footprint of landscape resources, and the institutional structures that facilitate resource access, are integral to landscape management and planning. Yet, the question still remained as to whether integrated landscape approaches moderate climate impacts on livelihoods?

To address this question, the team reviewed integrated landscape approaches (ILA) being utilised to address livelihood-climate interactions at the intersection of rural development and conservation (Duncan et al., 2021). Findings showed that identifying a reliable signal of climate resilience resulting from ILA is challenging with the majority of studies focusing on the plot or farm level as opposed to the spatial scales required for multi-functional landscape management. As such, landscape sustainability and climate change adaptation requires consideration of governance and institutional arrangements at various spatial levels if successful outcomes are to be achieved.

Finally, to enhance the use of geospatial information in landscape management, the maplandscape platform was developed as an open-source mobile geospatial tool for agricultural landscape mapping, monitoring and decisions making (Duncan et al., 2022). maplandscape also provides the analytic capabilities required for further scientific inquiry having been used to capture multiple years of detailed agricultural information across the entire Kingdom of Tonga. As such, it is now possible to examine the impact of integrated landscape management approaches and initiatives in order to support better decision making into the future.

8.2 Capacity impacts – now and in 5 years

Building capacity among the project's stakeholder group has been a priority throughout the life of the project and has been realised through a range of capacity building initiatives. First, employing a robust 'learn by doing' training approach, the project has provided extensive training in the use of Geographic Information Systems (GIS) for geospatial data collection, analysis, and communication. Delivering over 35 training workshops across Fiji, Tonga, and at regional user conferences such as the Pacific Geospatial Conference (Figure 16) the project has trained over 200 landscape stakeholders, many engaging in more than one session. Our trainings continued during COVID related travel restrictions, conducted either entirely online or in conjunction with a local team members (Figure 17).

Figure 16: maplandscape and QGIS data collection training, Pacific Geospatial Conference, USP, Suva, Fiji.

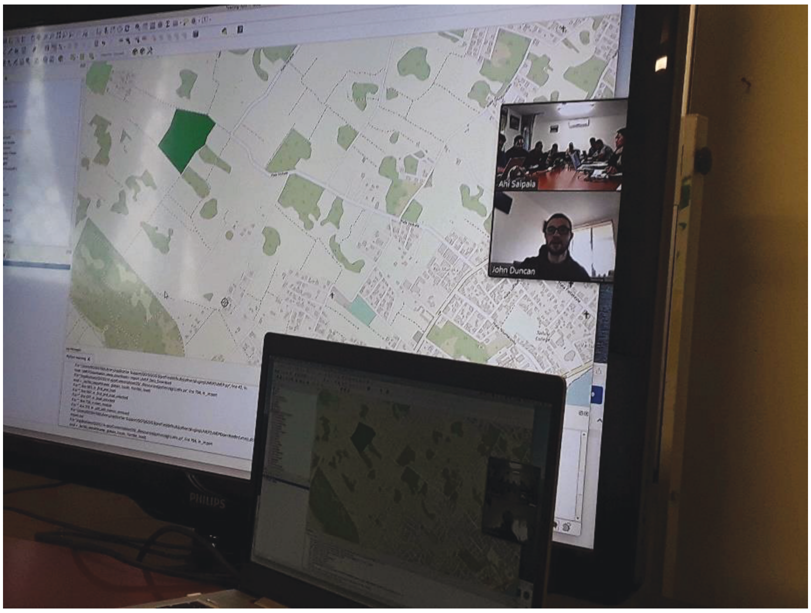

Figure 17: Online training delivered during COVID travel restrictions.

The annual Tongan Crop Survey has also provided a conduit for capacity building with over 40 EOs engaged in agricultural data collection and geospatial data analysis across the Kingdom. MAFF, Tonga provided additional training resources, delivering trainers to outer island groups recognising the benefit of a Kingdom wide workforce trained in the use of Geographic Information Systems (Figure 18). To enhance and maintain capacity to deliver the annual crop survey well into the future, MAFF, Tonga has provided a full-time position to our ACIAR project team member in Tonga to oversee future crop survey initiatives and maintain the organisations spatial analytic capabilities.

Figure 18: Tonga Crop Survey, in-field training.

In response to the Hunga Tonga-Hunga Ha'apai volcanic eruption, ACIAR provided funding to enhance the teams delivery of training in the use of geospatial technologies (in support of disaster response and recovery). Not only were additional trainings provided, additional ACIAR funds were used to provide much needed computing hardware in the form of laptops, tablets and protective housings (Figure 19).

Figure 19: Computing hardware delivered to MAFF, Tonga in support of disaster response and recover and future crop survey data collection initiatives.

Finally, to support the data needs of MoA, Fiji and build capacity in geospatial data development, the project team has worked with the organisation to develop a time series of land-use/land-cover data (2019, 2020, 2021 and 2022). During data development, the project team trained MoA, Fiji staff in approaches for collecting ground-truth data (using maplandscape) and land-use/land-cover image classification using Google Earth Engine. The results of this initiative are available via the Pacific Data Hub and can be access through the following link:

- Fiji Land Use Land Cover - https://pacificdata.org/data/organization/livelihoods-and-landscapes-project

8.3 Community impacts – now and in 5 years

Direct community impact from the project is difficult to measure as the project has focused on the delivery of resources to enhance the ability of EOs in managing agricultural landscapes. Better landscape management and decision making is ultimately realised at the community level and with MAFF, Tonga now possessing multiple years of crop survey information, the organisations ability to help individuals at the community level has been greatly enhanced particularly in monitoring the impact of agricultural landscape management initiatives.

8.4 Communication and dissemination activities

Web Material:

Project website and training material. (https://livelihoods-and-landscapes.com/).

High School Workshops. (http://morethanmaps.earth).

Data:

Project data is published on Pacific Data Hub. (https://pacificdata.org/data/organization/livelihoods-and-landscapes-project).

Software:

All applications and software developed through this project are open source and published to GitHub. (https://github.com/livelihoods-and-landscapes).

Presentations:

Bruce et al. (2018) - Earth observation for assessing environmental livelihood security in coastal mangrove communities. American Geophysical Union, Washington DC.

Davies et al. (2018) - Fiji Dynamic Land Use/Land Cover Mapping Workshop. University of the South Pacific, Suva.

Davies et al. (2018) - Tonga Dynamic Land Use/Land Cover Mapping Workshop. Ministry of Agriculture, Forestry and Fisheries, Tongatapu.

Davies and Wales (2018) - Mapping Landscape Diversity in the Ba Catchment: A Remote Sensing Approach using Google Earth Engine. Pacific GIS and Remote Sensing User Conference, Suva, Fiji.

Davies, K., and Wales, N. (2018). Mapping Landscape Diversity in the Ba Catchment: A Remote Sensing Approach using Google Earth Engine. Pacific GIS and Remote Sensing User Conference, Suva, Fiji.

Duncan and Wales (2019) - Climate-smart landscapes for promoting sustainability of Pacific Island agricultural systems. Monthly seminar series, Pacific Centre for Environment and Sustainable Development (PACE-SD), Suva, Fiji.

Duncan and Varea (2019) - An ICT4D approach to develop a geospatial platform for climate-smart landscape management in Fiji and Tonga. Pacific GIS and Remote Sensing User Conference, Suva, Fiji.

Biggs and Boruff (2019) - Using geospatial information and technologies for promoting climate-smart landscapes in Fiji and Tonga. Curtin University Seminar Series.

Boruff et al. (2019) - Understanding information needs and constraints in support of a mobile geospatial platform promoting climate-smart landscapes in Fiji and Tonga. Global Science Conference, Bali, Indonesia

Davies (2019) - Remote Sensing in the Cloud: Land cover mapping of Ba, Fiji using Google Earth Engine and Sentinel-2. Thinking Space Seminar Series, Sydney University.

Varea et al (2020) - Using the QField open-source mobile geospatial tool for promoting climate-smart livelihood-landscape systems in Fiji. FOSS4G Oceania - Suva Hub.

Duncan et al (2020) - Mapping Tongan farms with QField. FOSS4G Oceania - Perth Hub.

Davies et al (2020) - A Dynamic, Cloud-based LULC Mapping Methodology Using Sentinel-2 to Support Climate-Smart Landscape Management in Vulnerable Fijian Communities. American Geophysical Union Fall Meeting.

Varea and Duncan (2020) - QField Crop Survey - Training. Ministry of Agriculture, Fiji.

Duncan and Saipaia (2020) - QGIS and QField - mobile GIS data collection project set up. Ministry of Lands and Natural Resources, Tongatapu.

Duncan and Saipaia (2020) - Tonga Crop Survey - Training. Ministry of Agriculture, Food, Forests, and Fisheries, Vava'u.

Duncan and Saipaia (2020) - Tonga Crop Survey - Training. Ministry of Agriculture, Food, Forests, and Fisheries, Tongatapu.

Varea and Davies (2020) - Collecting Ground Truth Data. Ministry of Forests, Fiji.

Varea and Duncan (2020) - QGIS and QField - mobile GIS data collection project set up. Ministry of Forests, Fiji.

Varea and Duncan (2021) - QField, QFieldCloud, and maplandscape for data collection - Training. SPC, Fiji.

Duncan (2021) - QField - Workshop. FOSS4G 2021, Perth Hub.

Saipaia, Duncan, and Davies (2021) - FOSS4G 2021 - Buenos Aires, Online.

Varea and Duncan (2021) - QField Crop Survey - Training. Ministry of Agriculture, Fiji.

Varea, Duncan, and Davies (2022) CCAI geospatial data collection and analysis - workshop. Ministry of Agriculture, Suva, Fiji.

Duncan et al. (2022) - In-the-field data collection with QField and friends - workshop. Pacific Geospatial Conference, Suva, Fiji.

Varea et al. (2022) - Gender and geospatial technologies in the Pacific. Pacific Geospatial Conference, Suva, Fiji.

Saipaia et al. (2022) - Implementing and using an open source farm survey and mapping system. Pacific Geospatial Conference, Suva, Fiji.

Duncan et al. (2022) - Maplandscape - an open-source geospatial workflow for agricultural landscape monitoring. FOSS4G 2022, Firenze, Italy.

Davies and Duncan et al. (2022) - An Open-Source Mobile Geospatial Platform for Agricultural Landscape Mapping: A Case Study of Wall-to-Wall Farm Systems Mapping in Tonga. FOSS4G 2022, Firenze, Italy.

Varea and Duncan (2022) - QField, QFieldCloud, and maplandscape for data collection - Field workshop. SPC, Lautoka, Fiji.

Varea and Duncan (2022) CCAI geospatial data collection - workshop and field training. Ministry of Agriculture, Suva, Fiji.

Varea (2022) - QField and QFieldCloud for coconut surveys - Field training. SPC, Vanua Levu, Fiji.

Duncan (2022) - QField / OPENGIS.ch - seminar.

Other Media:

ACIAR Reach out: CALMING THE STORM - How multifunctional agricultural landscapes can be managed to make livelihoods in the South Pacific more sustainable and climate-resilient. (https://www.aciar.gov.au/media-search/blogs/calming-storm).

Mobile geospatial platform promoting climate-smart landscapes in Fiji and Tonga - The UWA Institute of Agriculture, December 2019.

(http://www.ioa.uwa.edu.au/__data/assets/pdf_file/0010/3440089/IOA-December-2019-Newsletter_.pdf).

Blog Post: QField Ecosystem Documentation: Ground Truth Data Collection Using QField for LULC Mapping in Fiji. (https://docs.qfield.org/success-stories/lulc-mapping-fiji/).

Blog Post: Vanilla Surveys using QField. (https://docs.qfield.org/success-stories/vanilla-survey/).

ACIAR News: Helping Tonga recover from Cyclone Harold. (https://www.aciar.gov.au/media-search/news/helping-tonga-recover-cyclone-harold).

9 Conclusions and recommendations

The maplandscape project is a robust example of how an adaptive ICT4D approach can provide the foundation for shaping a more resilient and sustainable future through the co-development of landscape management tools. The rigorous co-design process adopted here, has yielded a stack of open-source applications tailor-made for mapping and monitoring agricultural landscapes. These dynamic tools have not only provided enhanced spatial analytic capabilities for MAFF, Tonga but are also becoming widely used by MoA, Fiji, demonstrating their versatility and relevance.

At its core, maplandscape's innovative workflow streamlines geospatial and non-spatial data collection, supporting large-scale team collaborations, rapid disaster response, and ongoing monitoring initiatives. The platform's robust components, from QField's mobile data collection capabilities to QFieldCloud's efficient data management, and the bespoke data visualization and analytics tools powered by R Shiny, the project has developed an important toolkit for landscape management decision-making.

The impacts of the project are tangible, modernising the data collection and analysis approaches used by MAFF, Tonga and now those of MoA, Fiji as well. By developing a suite of open-source tools, fostering scientific research, building local capacities, and enhancing capabilities to manage landscapes at the community-level and beyond, the project has paved the way for a more informed approach to managing agricultural systems. With ongoing application in Tonga and growing adoption in Fiji, maplandscape is poised to shape smarter landscape decision making and promote sustainability agricultural practices across the Pacific.

Recommendations for the future application of maplandscape:

- Develop advanced training initiatives that provide for the evolving needs of stakeholders.
- Empower local experts to take ownership of training initiatives and capacity building to ensure a lasting impact.
- Encourage a feedback loop with users to gather insights on tool usability, features, and potential enhancements.
- Establish gender mainstreaming and develop a gender action plan to enhance future outcomes arising from the use of maplandscape.
- Expand the project's reach to other Pacific Islands to magnify its impacts and contribute to broader regional development efforts.
- To ensure further uptake by the geospatial community, invest in further public awareness and outreach initiatives.
- Support collaboration with educational institutions, and technical schools in the region, to integrate geospatial tools and training with relevant courses.

By implementing these recommendations, the maplandscape project can continue to build a user base and evolve to meet the current and future needs of the regions landscape managers and associated stakeholders.

10 References

10.1 References cited in report

Bon, A., Akkermans, H., and Gordijn, J., 2016. Developing ICT Services in a Low-Resource Development Context. Complex Systems Informatics and Modeling Quarterly, 9:84–109. https://doi.org/10.7250/csimq.2016-9.05.

Davies, K. P., Duncan, J., Wales, N., Varea, R., Shojaei, H., Bruce, E., Boruff, B., and Biggs, E., 2019. An open-source mobile geospatial platform for promoting climate-smart livelihood-landscape systems in Fiji and Tonga. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, VolXLII-4/W14: 31–36.

Duncan, J., Boruff, B., Biggs, E.M., Haworth, B.T., Wales, N., and Bruce, E., 2020. Managing multifunctional landscapes: local insights from a Pacific Island Country context. Journal of Environmental Management, 260. https://doi.org/10.1016/j.jenvman.2019.109692.

Duncan, J., Boruff, B., Biggs, E.M., Haworth, B.T., Wales, N., and Bruce, E., 2021. Do integrated landscape approaches moderate climate impacts on livelihoods? A review of the evidence from agricultural landscapes. Regional Environmental Change, 21(25): https://doi.org/10.1007/s10113-021-01754-6.

Duncan, J, Davies, K P, Saipai, A, Vainikolo, L, Wales, N, Varea, R., Bruce, E., and Boruff, B., 2022. An open-source mobile geospatial platform for agricultural landscape mapping: a case study of wall-to-wall farm systems mapping in Tonga. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences; GottingenVol.XLVIII-4/W1-2022, Gottingen: Copernicus GmbH. (2022): 119-126. DOI:10.5194/isprs-archives-XLVIII-4-W1-2022-119-2022.

Haworth, B.T., Biggs, E., Duncan, J., Wales, N., Boruff, B., and Bruce, E., 2018. Geographic Information and Communication Technologies for Supporting Smallholder Agriculture and Climate Resilience. Climate, 6(97): doi:10.3390/cli6040097.

Inam, A., Adamowski, J., Halbe, J., and Prasher, S., 2015. Using causal loop diagrams for the initialization of stakeholder engagement in soil salinity management in agricultural watersheds in developing countries: A case study in the Rechna Doab watershed, Pakistan. Journal of Environmental Management, 152: https://doi.org/10.1016/j.jenvman.2015.01.052.

Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management, Journal of Environmental Management, 90(5): 1933-1949. https://doi.org/10.1016/j.jenvman.2009.01.001.

Schreckenberg, K., Torres-Vitolas, C.A., Willcock, S., Shackleton, C., Harvey, C.A., and Kafumbata, D., 2016. Participatory Data Collection for Ecosystem Services Research. ESPA Working Paper Series.

10.2 List of research outputs produced by project

Publications:

Haworth, B.T., Biggs, E., Duncan, J., Wales, N., Boruff, B., and Bruce, E., 2018. Geographic Information and Communication Technologies for Supporting Smallholder Agriculture and Climate Resilience. Climate, 6(97): doi:10.3390/cli6040097.

Davies, K. P., Duncan, J., Wales, N., Varea, R., Shojaei, H., Bruce, E., Boruff, B., and Biggs, E., 2019. An open-source mobile geospatial platform for promoting climate-smart livelihood-landscape systems in Fiji and Tonga. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, VolXLII-4/W14: 31–36.

Shojaei, H., Biggs, E., 2019. Navigating the livelihood landscape in Tonga. Adrian: Newsletter of the Asian Development Research Institute, 1(2): 20-24.

Duncan, J., Boruff, B., Biggs, E.M., Haworth, B.T., Wales, N., and Bruce, E., 2020. Managing multifunctional landscapes: local insights from a Pacific Island Country context. Journal of Environmental Management, 260. https://doi.org/10.1016/j.jenvman.2019.109692.

Duncan, J., Boruff, B., Biggs, E.M., Haworth, B.T., Wales, N., and Bruce, E., 2021. Do integrated landscape approaches moderate climate impacts on livelihoods? A review of the evidence from agricultural landscapes. Regional Environmental Change, 21(25): https://doi.org/10.1007/s10113-021-01754-6.

Duncan, J, Davies, K P, Saipai, A, Vainikolo, L, Wales, N, Varea, R., Bruce, E., and Boruff, B., 2022. An open-source mobile geospatial platform for agricultural landscape mapping: a case study of wall-to-wall farm systems mapping in Tonga. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences; GottingenVol.XLVIII-4/W1-2022, Gottingen: Copernicus GmbH. (2022): 119-126. DOI:10.5194/isprs-archives-XLVIII-4-W1-2022-119-2022.

Masters Theses:

MacRae, L., 2019. Carbon Storage in Mangrove Ecosystems: Linking carbon storage distribution and local ecosystem service use. The University of Sydney.

Peyronnet, R., 2020. A multi-sensor machine learning approach to predict flood extent after Tropical Cyclone events. The University of Western Australia.

11 Appendixes

11.1 Appendix 1: Training

The project delivered extensive training in the use of Geographic Information Systems (GIS) for landscape analysis and data collection. Trainings involved both the use of GIS for data analysis and use of the maplandscape tool developed specifically for the project. Trainings were conducted with a range of Government and Nongovernment institutions across Fiji (>220 individuals) and Tonga (>250 individuals) as well as in conjunction with regional user's conferences.

Fiji

Land Use and Land Cover Mapping - USP and Fiji Government stakeholders, Fiji.

- November 2018.
- The University of the South Pacific, Lower Campus, Suva, Fiji.
- Instructor: Kevin Davies (KD).
- ~10 participants (Ministry of Lands & Mineral Resources, USP Researchers, Pacific Flying Labs).
- Half day introduction to land use and land cover mapping in Google Earth Engine.

QGIS and QField Mobile GIS data collection project setup - Ministry of Forestry, Fiji.

- November 2019.
- Forestry Training Centre, Colo-i-Suva, Fiji.
- Instructors: John Duncan (JD) and Renata Varea (RV).
- ~20 participants (all Ministry of Forestry, FRAC division).
- Day-long workshop of three sessions (mobile GIS project creation and database setup, collecting spatial data in the field using QField, and setting up complex projects). Workshop material designed in consultation with Ministry of Forestry including field demos.

Ground truth data collection workshop - Ministry of Forestry, Fiji.

- May 2020.
- Forestry Training Centre, Colo-i-Suva, Fiji.
- Instructors: RV, KD.
- ~10 participants (Ministry of Forestry).
- Half day workshop on collecting ground truth in QFIeld to support pilot land cover mapping as part of Forestry's Emissions Reduction Programme (ERPD/REDD+).

Ground truth data collection - Ministry of Forestry, Fiji.

- July 2020.
- Nalotawa Forestry Area, Ba, Fiji.
- Instructors: RV, KD.
- ~10 participants (Ministry of Forestry).

- Two full days collecting ground truth in QFIeld to support pilot land cover mapping as part of Forestry's Emissions Reduction Programme (ERPD/REDD+).

QGIS and QField Mobile GIS data collection - USP and Ministry of Agriculture, Fiji.

- November 2020.
- The University of the South Pacific, Lower Campus, Suva, Fiji.
- Instructors: RV and JD.
- ~15 participants (Ministry of Agriculture).
- Online follow-me style tutorial. Training covered introduction to QField and key concepts, data management best practice, opening QField on android device, opening QGS project, digitising spatial features using the map interface, entering non-spatial attribute information using a form interface, submitting a completed form online, downloading clean forms. Mock data collection activity on USP campus.

Data processing and visualisation map.landscape dashboard - USP and Ministry of Agriculture, Fiji.

- Nov 2020.
- ICT Professional Labs, The University of the South Pacific, Suva, Fiji.
- Instructors: RV and JD.
- ~15 participants (Ministry of Agriculture).
- Introduction, demo, and instruction of map.landscape dashboard for processing, summarising, and visualising crop survey data collected using QField.

QGIS and QField Mobile GIS data collection - USP and Ministry of Agriculture, Fiji.

- February 2021.
- The University of the South Pacific, Lower Campus, Suva, Fiji.
- Instructors: RV.
- ~15 participants (Ministry of Agriculture).
- Training covered introduction to QField and key concepts, data management best practice, opening QField on android device, opening QGS project, digitising spatial features using the map interface, entering non-spatial attribute information using a form interface, submitting a completed form online, downloading clean forms. Mock data collection activity on USP campus.

Data processing and visualisation maplandscape dashboard - USP and Ministry of Agriculture, Fiji.

- February 2021
- ICT Professional Labs, The University of the South Pacific, Suva, Fiji.
- Instructors: RV and JD.
- ~15 participants (Ministry of Agriculture).
- Introduction, demo, and instruction of maplandscape dashboard for processing, summarising, and visualising crop survey data collected using QField.

QField farm survey training / field trial - Ministry of Agriculture, Fiji (Rotuma).

- February 2021.

- Rotuma, Commercial Farms, Fiji.
- Instructor: RV.
- ~10 Participants, Ministry of Agriculture officials - Rotuma visit field team.
- Support Ministry of Agriculture using QField and server apps for mapping commercial farms on Rotuma.

Land Cover Mapping (Image Interpretation) - Ministry of Forestry, Fiji.

- April 2021.
- Forestry Training Centre, Colo-i-Suva, Fiji.
- Instructors: RV, Nathan Wales (NW), KD.
- ~8 Participants (Ministry of Forestry).
- Half-day workshop on image interpretation using Collect Earth Online to support pilot land cover mapping as part of Forestry's Emissions Reduction Programme (ERPD/REDD+).

Data Processing and Visualisation using the maplandscape dashboard - Land Resources Division, SPC.

- April 2021.
- Land Resources Division, SPC, Suva, Fiji.
- Instructor: RV.
- ~8 Participants (SPC).
- Introduction, demo, and instruction of maplandscape dashboard for processing, summarising, and visualising crop survey data collected using QField.

Online QField Training – Ministry of Agriculture.

- June 2021
- Conducted over Zoom
- Instructor: RV.
- ~15 participants - GIS officers and extension officers from the North, Eastern and Central Divisions of the Ministry of Agriculture.
- 2.5 hour session over the course of 3 days was conducted. This was an online follow-me style tutorial. The session provided lessons on QField and the maplandscape tool.

Fieldwork with Ministry of Agriculture – Fiji.

- April 2021.
- Fieldwork conducted by: RV.
- This activity took place in Naitasiri, Fiji.
- ~10 Participants - Ministry of Agriculture.
- Instruction on the use of QField to map farm areas that have been converted to road areas or cleared to build transmission towers for the Electricity of Fiji Limited.

Online Mobile Data Collection Training – Ministry of Agriculture, Suva, Fiji.

- June 2021.
- Conducted over Zoom.
- Instructors: RV.

- ~25 participants - GIS officers and extension officers from the North, Eastern and Central Divisions of the Ministry of Agriculture.
- Delivered over a 3 day period, instruction included creation of geographic information using QGIS, data collection using QField, and data analysis using the maplandscape dashboard.

Online Mobile Data Collection Training – SPC, Suva, Fiji.

- June 2021.
- Conducted over Zoom.
- Instructors: RV.
- ~25 participants - SPC.
- Delivered over a 3 day period, instruction included creation of geographic information using QGIS, data collection using QField, and data analysis using the maplandscape dashboard.

QField, QFieldCloud, and maplandscape for data collection - Lautoka, Fiji.

- June 2022.
- Conducted over Zoom and in person.
- Instructors: JD, RV
- ~20 participants from SPC.
- 2-day workshop. Day 1 was classroom based with online and in-person training on the use of QField, QFieldCloud, and the maplandscape dashboard for data collection and analysis. Day 2 was field-based training on farms.

In-the-field Data Collection with QField and Friends - Suva, Fiji.

- December 2022.
- The University of the South Pacific, Lower Campus, Suva, Fiji.
- Instructors: Bryan Boruff (BB), JD, RV, KD, Ahi Saipaia (AS).
- ~15 participants (delegates from the Pacific Geospatial Conference 2022).
- Workshop introducing mobile data collection workflow using QField and QFieldCloud.

Mobile Data Collection Training - Initial Damage Assessment – Ministry of Agriculture Suva, Fiji.

- December 2022.
- Ministry of Agriculture, Suva, Fiji.
- Instructors: JD, RV, KD.
- ~6 Participants (Land Use Division, Ministry of Agriculture).
- 2 days of training and workshops on generating cartographic outputs from LULC products using QGIS, using QField for mobile data collection (land cover ground truth demo), data syncing and project management using QField, and discussion of using QField for Initial Damage Assessment after flood events as part of a CCAI Innovation Grants project.

Tonga

Land Use and Land Cover Mapping – Ministry of Agriculture, Forestry and Fisheries (MAFF).

- November 2018.
- MAFF Head Office, Tongatapu, Tonga.

- Instructor: KD.
- ~25 participants (MAFF, Ministries of Lands & Natural Resources, Water, Fisheries, and Geological Services, MORDI, Nishi Trading).
- Half day introduction to land use and land cover mapping in Google Earth Engine.

QField Mobile Data Collection Training - MAFF, Tonga (Tongatapu)

- September 2020.
- MAFF Head Office, Tongatapu, Tonga.
- Instructors: JD, AS, and Leody Vainikolo (LV).
- ~30 participants (MORDI, MAFF admin, MAFF research, MAFF Eua, MAFF Forestry, MAFF Extension, MAFF Livestock, MAFF Ha'apai, and Ministry of Lands and Natural Resources).
- Online follow-me style tutorial. Training covered introduction to QField and key concepts, data management best practice, opening QField on android device, opening QGS project, digitising spatial features using QGIS, entering non-spatial attribute information using a form interface, submitting a completed form online, downloading clean forms.

QField farm survey training - MAFF, Tonga.

- September 2020.
- MAFF Head Office, Tongatapu, Tonga.
- Instructors: AS.
- ~30 participants (MORDI, MAFF admin, MAFF research, MAFF Eua, MAFF Forestry, MAFF Extension, MAFF Livestock, MAFF Ha'apai, and Ministry of Lands and Natural Resources).
- Brief recap on using QField. Introduction to Tonga crop survey form. Classroom and short field exercise testing crop survey form. Feedback on crop survey form structure and questions.

QField farm survey training (field) - Pumpkin Farms.

- September 2020.
- Pumpkin farms, Tongatapu, Tonga.
- Instructors: AS.
- ~30 participants (MORDI, MAFF admin, MAFF research, MAFF Eua, MAFF Forestry, MAFF Extension, MAFF Livestock, MAFF Ha'apai, and Ministry of Lands and Natural Resources).
- In- field training using QField to map farms and submit completed forms.

QGIS database, form, and project creation training - Ministry of Lands and Natural Resources.

- October 2020.
- Ministry of Lands and Natural Resources, Tongatapu, Tonga and Zoom.
- Instructors: JD and AS.
- ~10 participants (MORDI and MLR).
- Online follow-me tutorial. Open QGIS and connect to a basemap web map service (e.g. Open Street Map). Create spatial databases (GeoPackage) to store data collected using QField. Create and style form widgets to enter data

into spatial database. Create QGS project file. Configure project (ready to copy to QField for field data collection).

QGIS database, form and project creation training – MAFF.

- October 2020.
- MAFF Conference Room, Tongatapu, Tonga.
- Instructors: JD and AS.
- ~10 participants (MAFF and Ministry of Lands and Natural Resources Land Survey team).
- Online follow-me tutorial. Open QGIS and connect to a basemap web map service (e.g. Open Street Map). Create spatial database (GeoPackage) to store data collected using QField. Create and style form widgets to enter data into spatial database. Create QGS project file. Configure project (ready to copy to QField for field data collection).

Data processing and visualisation maplandscape dashboard – MAFF.

- October 2020.
- MAFF Conference Room, Tongatapu, Tonga.
- Instructors: JD and AS.
- ~10 participants (MAFF and Ministry of Lands and Natural Resources Land Survey team).
- Using maplandscape dashboard to sync data from completed crop survey forms from multiple mobile devices with a template / central database. Perform spatial join operations to join crop survey data with secondary geospatial layers (tax allotment boundaries). Perform group by and summarise operations (e.g. compute area of crops grown in tax allotment / village). Visualise crop survey data on web map.

Field training - various farms, Tonga (Tongatapu).

- October 2020.
- Various farms on Tongatapu, Tonga.
- Instructors: AS.
- ~30 participants (Survey teams from MAFF Tongatapu extension division staff).
- Supported use of QField to map farms on Tongatapu.

QGIS and QField Training - MAFF Vava’u and Ha’apai Extension Division, Tonga (Vava’u).

- October 2020.
- MAFF, Vava’u, Tonga and Zoom.
- Instructors: JD and AS.
- ~15 participants (MAFF Vava’u and Ha’apai Extension Division).
- Instruction on QField mobile GIS for collecting spatial data in the field, introduction to crop survey form, and instruction on submitting completed forms to the server via a webform.

Data processing and visualisation maplandscape dashboard - MAFF Vava’u and Ha’apai Extension Division, Tonga (Vava’u).

- October 2020.
- MAFF Vava'u and Zoom.
- Instructors: JD and AS.
- ~15 participants (MAFF Vava'u and Ha'apai Extension Division).
- Introduction and demo of maplandscape dashboard for processing, summarising, and visualising crop survey data collected using QField.

Field training - MAFF Ha'apai Extension Division (Vava'u).

- October 2020.
- Vava'u, Tonga (Leimatua Village).
- Instructors: AS.
- ~5 participants (MAFF Ha'apai Extension Officers).
- MAFF Ha'apai team travelled to Vava'u to shadow Vava'u extension team working collecting crop survey data, join training sessions, and receive in-the-field instruction from AS.

Data processing and visualisation maplandscape dashboard - MAFF Vava'u, Eua, Tongatapu, and Ha'apai Extension DivisionVava'u).

- November 2020.
- Zoom training across Tonga - Vava'u, Tongatapu, and Eua.
- Instructors: AS.
- ~5 participants (nominated data analyst "trainer of trainer" from MAFF extension teams on each island group).
- Introduction and demo of maplandscape using Vava'u vanilla survey data. Instruction on data processing, summarising, and web map visualisation of data collected using QField.

Data processing and visualisation maplandscape dashboard - MAFF.

- November 2020.
- Conducted over Zoom.
- Instructors: JD.
- 1 participant (nominated data analyst "trainer of trainer" from MAFF extension team on Tongatapu).
- Instruction on use of maplandscape dashboard for processing, summarising, and visualising crop survey data collected using QField.

Introduction to project and geospatial apps for collecting landscape / seascape data - Ministry of Fisheries, Vava'u, Tonga.

- February 2021.
- Ministry of Fisheries Office, Vava'u, Tonga and Zoom.
- Instructors: AS and JD.
- 1 participant - Ministry of Fisheries, Vava'u, officer.
- Introduction to geospatial apps developed and used for mapping farms on Vava'u. Discussion regarding Ministry of Fisheries data collection. Q and A about geospatial apps.

Data processing and visualisation maplandscape dashboard - MAFF.

- March 2021.
- Conducted on Zoom.
- Instructors: JD.
- ~3 participants (nominated data analysts “trainer of trainers” from MAFF extension team on Tongatapu).
- Instruction on use of maplandscape dashboard for processing, summarising, and visualising crop survey data collected using QField.

Data processing and visualisation maplandscape dashboard - MAFF.

- March 2021.
- Conducted on Zoom.
- Instructors: JD.
- 1 participant (nominated data analysts “trainer of trainers” from MAFF extension team on Tongatapu).
- Instruction on use of maplandscape dashboard for processing, summarising, and visualising crop survey data collected using QField.

Feedback on crop survey results to Leimatu’a Village, Vava’u - MAFF.

- June 2021.
- Vava’u, Tonga (Leimatua Village).
- Instructors: LV and AS.
- 23 participants (farmers and Town Officer from Leimatu’a Village, MAFF Tongatapu IT, and MAFF Vava’u).
- Hard-copy report on crop area, crop number, and cropping systems generated using data collected through the crop survey given to participants. Presentation on state of cropping systems in Leimatu’a. Visualisation of cropping system data in Leimatu’a using dashboard. Discussion about how to share crop survey information with farmers and town officers.

MAFF Vava’u Meeting - MAFF Vava’u.

- July 2021.
- MAFF Office Vava’u, Tonga.
- Instructors: AS.
- ~10 participants (MAFF staff Vava’u, Tonga).
- Powerpoint presentation on crop survey results for villages across Vava’u.

MAFF GIS Training – MAFF Tongatapu.

- September 2022.
- MAFF Head Office, Tongatapu, Tonga and Zoom.
- Instructors: JD, AS, NW.
- 14 participants (MAFF staff from various divisions, Tongatapu, Tonga).
- 3 day online and in-person training session on an introduction to GIS using QGIS, creating geospatial data collection projects using QGIS, mobile data collection using QField and QFieldCloud, cartography and data visualisation using QGIS, and data analysis using the maplandscape dashboard.

Data Analysis Training - MAFF Tongatapu.

- January 2023.
- In-person. MAFF Office Tongatapu.
- Instructors: AS.
- 5 participants (MAFF staff from ‘Eua, Ha’apai, and Tongatapu).
- Training on crop survey data analysis for MAFF ‘Eua and Ha’apai using the maplandscape dashboard.

11.2 Appendix 2: maplandscape project info graphic