Marine and Coastal

National Environmental Science Program

RESEARCH REPORT
Project 1.29c

Defining a pathway for the operational use of emerging technologies on Country

FINAL REPORT

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Catalogue data

This publication (and any material sourced from it) should be attributed as:

Justin Perry, Julia Perdevich, Erica McCreedy and Melina Pearse (2023) Project 1.29c: Defining a pathway for the operational use of emerging technologies on Country. Report to the National Environmental Science Program. NAILSMA (36 pp.).

ISBN

978-1-922640-15-4

This publication is available on the NESP Marine and Coastal Hub website:

www.nespmarinecoastal.edu.au

Acknowledgment

This work was undertaken for the Marine and Coastal Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Science Program (NESP). The NESP Marine and Coastal Hub is co-hosted by the Reef & Rainforest Research Centre and the University of Tasmania. This work was made possible through collaborations with Traditional Owner Land and Sea Organisations across northern Australia. We would like to acknowledge Aak Puul Ngantam, who led the on-ground activities that tested and iterated the turtle tracker methods. We would also like to acknowledge the project partners that led the research and software development, which underpinned the case studies presented in this report in particular Cathy Robinson (CSIRO).

Cover images

Front: A low-cost aerial photograph method using GO-PRO to collect high-resolution data at landscape scales. Credit – NAILSMA. Back: Seagrass along the intertidal edge in Yanyuwa Sea Country NT. Credit – TropWATER.

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Executive summary

In this report, we present some key principles for the design and use of technology with Indigenous land and sea managers in Northern Australia. We follow cybernetic approaches that focus on four design principles: human-centred design, adaptive systems design, context-aware technology design, and sociotechnical systems design. We identify a significant opportunity to support Traditional Owners and Indigenous land and sea managers to lead the collection and management of data and technology solutions. Establishing trusted and accessible technology solutions will enable the expansion of regionally and nationally consistent and trusted datasets that will dramatically increase the spatial and temporal scale of environmental data. This represents a latent opportunity that, with investment, could lead to a massive increase in consistent data collection across the nation and greatly reduce the requirement of individual researchers to conduct data collection that does not require specialist in-situ skills.

Firstly, we sought to identify factors of operational use that support local indigenous leadership in environmental management and monitoring. We identified that investment in appropriate infrastructure, including electricity, connectivity and access to common digital technology, is required. The provision of accessible, cost-effective solutions, appropriate skills and knowledge, understanding and accommodating cultural and social barriers and gender and age-differentiated opportunities need to be considered. Indigenous leadership can be supported through appropriate co-development of new technology solutions and ensuring that the associated methods are focused on local values and are embedded within cultural governance and decision-making processes.

Secondly, we used case studies and literature to define key factors that lead to uptake of new technology by Indigenous organisations in remote northern Australia. Here, we suggest that the use and utility of technological solutions will require the establishment of consistent Indigenous-led methods that enable the development of robust monitoring frameworks underpinned by automated human-centred data outputs that are locally relevant and useful for long-term monitoring, adaptive management strategies, and support research projects and longitudinal studies. Technology uptake by Indigenous organisations requires trust in the utility of the solution for meeting local objectives and supporting reporting requirements for external funders. Outputs should be relevant at local scales, and data should be owned or managed by Traditional Owners and not re-used by external organisations without permission. Another key factor determining scalable uptake is that software and hardware solutions should be resilient to rapid change, requiring maintenance and updates of equipment and software to be part of the ongoing support structures embedded within new methods. This requires either high-level external support or significant investment into the capability of Indigenous organisations so that there are internal skills to continuously update skills, equipment and software. We suggest that capable Indigenous organisations need to support internal capability in planning, data collection, data management, data analysis and summary and using data for decision-making.

Finally, we identify potential impactful research areas that address the knowledge and operational gaps we identify throughout the report. There are four areas of research that we suggest will support trust in new methods and rapid uptake of new technology, including development of trusted metrics that use new technology, development and testing of training and skills with associated verification, development of user-friendly software and hardware and explore governance models for the ownership and management of data and systems.

Introduction

Marine and coastal impacts in northern Australia occur overwhelmingly on Indigenous-managed land (Goolmeer et al., 2022; Grace & Holmes, 2022; Kennett et al., 2010; Wohling, 2009). Using tenure mapped according to Indigenous management categories derived by the Indigenous Carbon Industry Network (2022), 85% of the northern Australia coastline includes Indigenous interests in management. This is relatively similar between states, with 88.56% of Western Australian coastline, 86.73% of the Northern Territory coastline and 79.31% of the Queensland coastline subject to Indigenous rights and interests (Table 1). In the Northern Territory, 67% of the coastline is directly owned and managed by Indigenous people (Table 1) whereas in Western Australia (0.1%) and Queensland (9%) exclusive ownership is limited with co-management arrangements dominating these states.

Table 1. Indigenous management categories for the northern Australian coastline. Derived from Indigenous Carbon Industry Network (Grace & Holmes, 2022).

Indigenous management category	State	%
Indigenous co-managed	NT	0.001
Indigenous co-managed and subject to other special rights	NT	0.482
Indigenous managed	NT	0.012
Indigenous owned and Indigenous co-managed	NT	8.335
Indigenous owned and Indigenous managed	NT	67.609
Indigenous owned, Indigenous managed and subject to other special rights	NT	1.683
Subject to other special rights	NT	8.616
Non-Indigenous	**NT**	**13.261**
Indigenous co-managed	WA	0.014
Indigenous co-managed and subject to other special rights	WA	4.421
Indigenous managed	WA	4.338
Indigenous managed and subject to other special rights	WA	2.799

Indigenous owned and Indigenous managed	WA	0.100
Indigenous owned, Indigenous co-managed and subject to other special rights	WA	0.274
Indigenous owned, Indigenous managed and subject to other special rights	WA	38.990
Subject to other special rights	WA	37.625
Non-Indigenous	**WA**	**11.440**
Indigenous co-managed	QLD	2.757
Indigenous co-managed and subject to other special rights	QLD	1.540
Indigenous managed and subject to other special rights	QLD	1.122
Indigenous owned and Indigenous co-managed	QLD	4.345
Indigenous owned and Indigenous managed	QLD	9.057
Indigenous owned, Indigenous co-managed and subject to other special rights	QLD	12.135
Indigenous owned, Indigenous managed and subject to other special rights	QLD	30.316
Subject to other special rights	QLD	18.044
Non-Indigenous	**QLD**	**20.684**

Despite the significant Indigenous interests in the management of northern Australian coastal regions, the collection, analysis and use of data to support adaptive management of the threats to these important ecosystems are often undertaken by external organisations or non-Indigenous employees (Ens, Towler, et al., 2012; Thompson et al., 2020; Weiss et al., 2013; Wiseman & Bardsley, 2016). Where monitoring of environmental change does occur in remote Australia, it is typically characterised by systematic surveys using expert field observations (Butler et al., 2010; Finlayson et al., 2006; J. J. Perry et al., 2015). These methods sometimes include Indigenous participation but are generally designed and implemented by research institutions or groups. The methods that are used by researchers are inherently exclusionary, relying on specialised skills held by a few experienced individuals (e.g. taxonomic skills or management of specialised monitoring equipment).

These methods meet the needs of researchers who require robust data collected using consistent, repeatable and defendable methods that can be defended in peer-reviewed scientific literature (Elphick, 2008). Trusted data collection and reporting is legitimised through the use of individuals that have completed accepted training such as undergraduate or post-graduate degrees (Ens, Finlayson, et al., 2012).

The appropriate use of technology and associated training for Indigenous practitioners, coupled with software and hardware development, offers an alternative for Indigenous organisations, and funders to deliver improved environmental, social and cultural outcomes in northern Australia (e.g.https://nailsma.org.au/projects/smart-farms-managing-wild-herds-project). NAILSMA and its research and industry partners (CSIRO, CDU, Microsoft and Telstra) have been engaged in activities in partnership with Indigenous organisations that seek to develop ethical and inclusive technology solutions that enable Indigenous people to leverage new opportunities (CSIRO, 2023a, 2023b; Microsoft, 2021; NAILSMA, 2014, 2021). These initiatives aim to maximise Indigenous participation and leadership in activities that support the management of threats to ecosystems and cultural values across northern Australia. Using participatory planning and co-development approaches, we have produced operational technology solutions that match the aspirations and values of Indigenous organisations and developed training that meets the specific needs of the Indigenous land and sea management industry to enable the use of technology on Country for the benefit of local people. This approach is crucial for developing monitoring practices and indicators that reflect the management aspirations of Indigenous people (Izurieta et al., 2011).

While this approach has proved beneficial for local management, there is a gap when monitoring needs are considered at larger scales, including state, national, and international funding and reporting requirements (Weiss et al., 2013). For example, certain monitoring methods are rigidly defined by legislation, such as the carbon credits methodology (Australian Government 2018). This is an expanding field, with other forms of market-based environmental accounting currently under development in Australia (Australian Government, 2022). Data collection methods that underpin environmental and carbon accounting are becoming increasingly important for the accrual of untied revenue on Indigenous land. Developing new methods that meet the requirements of third-party verification for market-based environmental accounts should be a priority for future research activities that aim to support Indigenous people participate in these emerging markets.

Within the context of Indigenous-led monitoring and management, there is a gap in the development of monitoring solutions that meet the need for consistent and reliable data, shared metrics, and verifiable outputs that are common across northern Australia. This work needs to be done to inform strategic management decisions at regional and national scales at the same time as meeting the need to maintain cultural relevance and value within the context of local Indigenous land and sea management practices. This report seeks to provide a tangible link between these two scales and to situate this within the context of a field characterised by rapid developments in technology.

The rapid development of new technology has the potential to create transformative change for trusted remote data collection. However, rapid technological change also brings risks (Pasmore et al., 2019). New technological solutions often focus on increasing efficiency through automation with an explicit aim to reduce human input (Wimmer et al., 2010). In the context of developing solutions for ecological monitoring in remote northern Australia, an attribute of successful implementation of technology use is the demonstration of the capacity to collect trusted data on defined environmental values (e.g. how well does the solution measure change in environmental values such as positive or negative impacts on threatened species or ecosystem function) whilst being locally relevant for the social and cultural values defined by Traditional Owners. The objective of this report is to characterise the important technology attributes that maximise local Indigenous participation, produce positive environmental outcomes and generate economic returns for Indigenous organisations.

The challenge is to develop new technology that enables Traditional Owners and Indigenous land and sea management organisations to lead the collection and management of data. Clear environmental values must be defined that will enable the automation of human-centred data outputs that are locally relevant, useful for long-term monitoring, support adaptive management strategies, and support research projects and longitudinal studies.

The successful development of trusted and accessible technology will enable the expansion of regionally and nationally consistent datasets that will dramatically increase the spatial and temporal scale of environmental data sets. Currently, researchers and policymakers are confounded by a lack of temporal and spatial consistency in biological data sets. On a national scale, data analysis uses snapshot data that is spatially inconsistent, collected by multiple observers with very different skill sets, uses inconsistent variables and lacks temporal and seasonal consistency (Anderson et al., 2016; Guralnick et al., 2007).

The use of well-developed technology solutions, with consistent analytical and data management pathways, promises to substantially increase our national knowledge base. These activities can be led by Traditional Owners on their own country, across seasons and in very remote areas that are prohibitively expensive to visit for research organisations. For example, terrestrial vertebrate surveys using camera traps and freshwater and marine vertebrate surveys using underwater baited cameras are being conducted across northern Australia (Bond et al., 2022; Gillespie et al., 2015; Kutt et al., 2023; Stokeld et al., 2016). However, this work is generally being led by state and territory governments or research organisations through individual projects requiring independent bespoke data collection and analysis. If these data were being collected through a collaborative Indigenous-led and designed program, data sharing arrangements and consistency of methods could be applied to create a harmonised, consistent national data set for northern Australia. For this to be successful, it would need to be led by Indigenous organisations and include robust agreements and partnerships with external research or government institutions as required. Additionally, successful scaling of the uptake of new methods requires accessible, maintained software that can ingest, analyse and visualise data without requiring specialist analytical skills.

Despite the ubiquitous use of common technology, such as motion sensor cameras and video for modern-day surveys in research institutions, there is still no standardised operational solution that enables Indigenous land and sea managers to collect and use the data independently. This latent opportunity could lead to a massive increase in consistent data collection across the nation and greatly reduce the requirement of individual researchers to conduct data collection that does not require specialist in-situ skills.

For technology to augment existing trusted monitoring processes, we need to understand the characteristics of robust systems and define the criteria required to establish trust in data collected by non-specialist participants. We also need to understand where technology supports Indigenous leadership and where it becomes exclusive and displaces connection to country and local decision-making.

In this project, we will;

- Establish factors of operational technology use that support local Indigenous leadership and environmental management.
- Define the key elements enabling scalable uptake of new technology by Indigenous organisations in remote northern Australia. This will include the key elements of training that meet the Indigenous Land and Sea management industry requirements and constraints.
- Identify areas of research that are required to establish trust in current and emerging technology-driven monitoring processes that empower Indigenous organisations to deliver robust environmental data.

Methods

This project explores a scalable approach for training and use of technology on the northern Australian Indigenous-managed estate. We identify the constraints and opportunities for developing alternative monitoring and analytical methods that leverage the skills, knowledge and leadership of Indigenous people who own and manage their land and sea Country. We summarise critical elements of successful training, software and hardware development and implementation of management and monitoring approaches that leverage technology in an operational context. We do this using literature, reference to experience in operational settings and through case studies from ongoing partnerships with Indigenous organisations that are testing the use of technology for different environmental, economic and cultural outcomes to anchor the analysis within a contemporary operational context.

In this report, we leverage cybernetic theoretical framing to consider the development of technology in the context of Indigenous-led design and operational use for northern Australia's Indigenous land and sea management organisations. Cybernetics is a field of study that deals with control and communication in systems, including human-technology systems (Bell & Euchner, 2022; Rose, 2009).

In the context of technology design, some of the commonly accepted cybernetic approaches include:

- Human-centered design: This approach focuses on designing technology that considers the needs, abilities, and limitations of the people using it. The goal is to create technology that is intuitive, easy to use, and helps to enhance human capabilities (Giacomin, 2014).
- Adaptive systems: Adaptive systems are designed to change based on the user's actions and feedback. This allows the technology to adapt to the user's needs and preferences over time (Kardan et al., 2015).
- Context-aware technology: Context-aware technology considers the physical, social, and cultural context in which it is being used and adjusts accordingly (Ceri et al., 2007; Hwang et al., 2011).
- Sociotechnical systems design: This approach views technology and society as interconnected systems and designs technology that takes into account the social, cultural, and ethical implications of its use (Pasmore et al., 2019).

These approaches aim to create and interact with technology that is functional, enhances human well-being and improves the quality of life of end users and society. By incorporating cybernetic principles into the design process, technology that is more responsive to the needs and preferences of users can be created (Bell & Euchner, 2022; Norman, 1988; Verbeek, 2005).

Key features of technology supporting Indigenous leadership and participation in environmental management

When considering the development of new technology within the theoretical framework of a socio-technical system, we aim to extract the best elements of emerging technologies to address issues and challenges operating at different scales. We can't separate the ethical, social and cultural contexts of the challenges we are seeking to address (Pasmore et al., 2019). In this context, for emerging technologies to be adopted by Indigenous land and sea managers, they must support local values, be consistent with cultural expectations and governance, and function effectively in a remote context. Several factors can contribute to making technology more accessible and appropriate in remote Indigenous land and sea management organisations. Here, we contextualise technology use within the operational constraints and cultural context of remote Indigenous land and sea management organisations. This is distinct from the development of 'best available' technology, which usually involves untested experimental hardware, specialist software and specialist analytical skill sets.

The factors that optimise uptake and use of technology by Indigenous land and sea management organisations for a diverse workforce with variable access to infrastructure and inherent operational constraints include:

- **Infrastructure:** Infrastructure requirements can be viewed within the context-aware technology conceptual model (Hwang et al., 2011), where the physical and social constraints inherent in remote northern Australia are at the centre of the design challenge. For people to access technology, they need to have the necessary infrastructure in place, such as electricity, internet connectivity, and access to a variety of hardware. In many remote communities, these basic infrastructure needs are not always met (Henson et al., 2022), making it difficult for people to access technology and learn about it as part of their everyday lives. The development of technology solutions needs to be cognisant of the infrastructure gaps common in remote areas of northern Australia.
- **Cost:** The cost of technology can also be a barrier to access, particularly in low-income communities. To make technology more accessible, it may be necessary to provide financial assistance or subsidies to help individuals and families afford the necessary devices and connectivity. Understanding the digital divide between remote communities and urban centres is important when considering human-centred adaptive technology design in this context. Human-centered technology addresses the needs, abilities, and limitations of the people using it (Giacomin, 2014). In this context, the provision of software solutions that are available on low-cost devices (such as Android tablets or mobile phones), can run offline or using limited connectivity and have intuitive user interfaces that cater for variable numeracy or literacy skills will provide the greatest access to Indigenous people in remote areas (see section 6.1 that highlights the importance of accessible, robust hardware and software).
- **Skills and knowledge:** For people to effectively use technology, they need to have the necessary skills and knowledge. This will require providing training and education

programs to support the development of skills that can be used operationally. When designing training programs that aim to reduce the digital divide, we need to consider the social constraints in remote northern Australia for learning how to use new technology. For example, many contemporary training activities assume that participants have been using common productivity software (e.g. word processing, spreadsheets, file management) as part of their daily lives. In remote communities, access to computers and the internet at home can be limited to small mobile devices with very different user interfaces. Effective training programs need to identify cross-generational training opportunities to prepare students and end users in different age brackets.

- **Cultural barriers:** Using the sociotechnical systems design process (Pasmore et al., 2019) to develop context-aware technology is important when developing and testing new technology in cross-cultural settings. In some cases, cultural barriers may also prevent people from accessing and using technology or lead to unintended impacts on social structures. For example, Indigenous knowledge has traditionally been communicated and passed on from generation to generation through storytelling, governed by cultural protocols. Sacred knowledge is protected through identified roles and responsibilities with specific individuals responsible for the maintenance and protection of stories and places. The rapid development and uptake of technology are generally influenced by external organisations with commercial imperatives for development. This can target sectors of the community that are more likely to take on and promote its use to encourage rapid growth (Kastelle et al., 2018). For example, the CSIRO in Australia established a national business accelerator program that aimed to commercialise science. This program used lean methods that encouraged acceleration of research uptake with a commercial imperative (Kastelle et al., 2018). This approach is based on methods developed for rapid growth of technology businesses where methods favour economic value with limited focus on ethical or social value. However, methods have evolved rapidly to value public good outcomes (Qastharin, 2016).

  In remote northern Australia, the development and use of technology are more accessible to younger generations due to exposure at school. Without specific intervention, this skills inequity can displace traditional roles. Traditionally, older people are holders of knowledge and are the primary decision-makers (Henson et al., 2022). With technology use, this knowledge structure is reversed; young people hold the knowledge, and this can upset traditional decision-making protocols, particularly when this involves interactions with external organisations. The challenge here is not in the rapid uptake of technology but in how to effectively involve Indigenous people in the development and assessment of new approaches so that cultural values and protocols are embedded in solutions (Robinson et al., 2022).

- **Developing solutions that incorporate local values and priorities with well-understood impacts and threats to these values:** Context-aware design principals can support the development of technological solutions that support monitoring and reporting methods that clearly summarise and test the success of management interventions against identified environmental values and threats. Furthermore, adaptive technology principles can be applied so that the outputs provide feedback loops for management and report against the values that have been identified. Solution design needs to meet the expectations of the land and sea management organisation collecting the data whilst also meeting the expectations and needs of external organisations. For example, government funding programs require an assessment of their investment against the policy area they seek to influence. Consistent and targeted metrics can provide essential information that enables funding programs to be improved and modified. This can place a significant resource burden on projects to collect data that has limited local or national relevance. There is an opportunity to support the development of methods that leverage new technology to collect robust and consistent data without requiring specialised skills. These methods, with associated training and data management systems, could overcome some of the existing capability constraints that limit consistent reporting against environmental programs. However, existing approaches have used national or state-wide data input systems that are abstracted from the values held by Indigenous people and are not contextualised within the social and cultural contexts of the regions where the environmental management activities are being funded. Collaboratively designed systems could be equipped to report against the specific policy areas required by state and federal funding. Digital data collection and reporting programs require local customisations to ensure data outputs meet local needs as well as other end-user requirements.

- **Technology should be accessible:** There is a tendency to seek the best available technology when developing new solutions. This is usually exclusive to large government programs that can afford the capital outlay and support highly trained staff to utilise the equipment. Scaling the use of technology is best done with readily available technology that matches the limited resources and contexts of the organisations and end users. The challenge, therefore, is not to develop the best available technology but to develop new approaches that utilise available technology within an operational and local context. If new technology is used, it should incorporate hardware and software that is inexpensive, easy to access, and easy to use by variably skilled end users.
- **Data management:** Methods should not only support the collection of robust data but should also have accessible data management solutions. Method development should consider the inherent constraints of data collection and be cognisant of how data will be managed in the field. For example, a solution that leverages drone data collection should consider how photographs will be uploaded, analysed and stored. By following the cybernetic approaches above, a solution will assess all the elements of a suggested new technology approach and will be able to quantify the likely constraints within the context of remote use in northern Australia.

Identify important factors supporting scalable uptake of new technology by Indigenous organisations

Scaling the development and uptake of technology for use by Indigenous land and sea management organisations across northern Australia requires a dedicated and well-resourced program led by Indigenous practitioners. The development of new technologies should allow for rigorous testing of solutions within operational contexts and incorporate agile design processes to enable changes to be made in near real-time following feedback from end users. Desirable technology solutions will provide a solution to a problem identified by Indigenous land and sea managers and their partners, support the implementation and improvement of management and provide consistent and relevant information to multiple end users and funders.

Scaling the use of new technologies will require bespoke training programs that work within the inherent constraints of remote use for a diverse range of end users. Training should be adaptive and co-designed with the Indigenous land and sea management industry.

Uptake in the use of consistent methods, using similar hardware and software, has been slow in northern Australia due to incentives for development being centred on external organisations that aim to own and market a particular solution. These solutions are usually research grade, are specific to a narrow research field and require specialist input to maintain and manage elements of the solution. As such, when research projects conclude, the data collection and management system is no longer supported or maintained and rapidly deprecates.

Technology uptake

Technology uptake will be influenced by factors such as Traditional Owners' desire for uptake, use of Indigenous governance, the technology-driven monitoring is aligned to the strategic direction of an organisation, and Traditional Owners are supported to retain control of data. Specific factors that will support uptake include:

- **Robustness and trust in the methods***:* Methods need to respond to local environmental and cultural values using an appropriate, accessible and consistent methodology. Methods should be able to effectively measure change against defined values and be cognisant of the thresholds of trust for external reporting. For example, methods required by natural capital accounting often require third-party verification. Methods should address multiple outcomes and enable the aggregation of diverse values so that metrics are relevant to different end users.
- **Locally relevant metrics**: Landscape-scale approaches to monitoring are often too abstract to provide meaningful input back to Traditional Owners. We have learned that it is important to collect data on local values at sites where people have a stake in the outcomes. For example, when working with Traditional Owners to measure the success of a feral animal control program in northern Australia, collaboratively selected monitoring sites were areas used for hunting and fishing that were directly impacted by

feral animals (J. Perry et al., 2021; Robinson et al., 2022). In this context, it was straightforward to identify important values that could be measured to indicate management success. The Traditional Owners held a deep understanding of the impacts and regularly visited the sites across seasons, enabling constant assessment of the effectiveness of management interventions.

- **Data ownership**: Data ownership and access are important constraints to technology uptake by Indigenous organisations. There are many national and institutional data platforms that have been built to aggregate national data sets. For example, the Atlas of Living Australia (ALA) is a well-developed data management system for national biological data. This system is well-resourced and carefully curated, providing a stable archive for national data sets. Data systems such as the ALA are an important part of our national research infrastructure and are fit for the purpose for which they were designed. However, whilst useful for biological data sets, these platforms do not adequately address potential sensitivities regarding the storage and access of data from Indigenous lands and seas and due to their generality are difficult to repurpose for operational use.

  When considering data ownership and public access on Indigenous land and sea, it is important to understand how the data will be used and re-used. Data collected on Indigenous land can be sensitive, not only because of cultural implications but also because there are external interests seeking to use Indigenous land for economic benefits, and these external interests can access public data to undertake assessments without interacting with the Traditional Owners. In addition, external management of data can erode the rights of Indigenous decision-making protocols through regional planning processes and government policy development that utilise data in the absence of Traditional Owner input and cultural context.

Software and hardware that supports uptake

Software and hardware need to be fit for purpose, offer operational resilience to extreme conditions and be able to operate without connectivity in the field. The solutions also need to offer seamless integration between field and office use. Modern-day land and sea management operations complete a diverse range of activities using many different data inputs. Software needs to be able to integrate satellite data, sensors, drone data, and on-ground data, as well as aggregate and sort and display the data for easy interpretation.

The software needs to be resilient to rapid changes in technology. For the software to be resilient, long-term resourcing is required to update the software, account for the development of new hardware and have a team of skilled individuals that can keep up with the change and maintain the solution. Software maintenance needs to be resourced to keep up with new hardware, software and changes in connectivity. For example, remote connectivity has recently become available through low-level satellite solutions (https://www.starlink.com/). This has opened opportunities to change the way data is managed in the field and leverage the capabilities of cloud solutions that are maintained by large software companies such as Microsoft, Google and Amazon. This enables the development of technology solutions that are not required to maintain background software and hardware needs on the device, as remote servers are regularly updated and backed up, and new features are made available as part of subscription services.

On many occasions, projects invest in the development of bespoke data collection mobile applications. This requires specialist skills to develop high-quality applications. They are usually very good for the project period, but once a project is complete, there is no longer a budget to update the application, and the solutions quickly become deprecated. Another common technology failure is the use of bespoke project-based on-premises databases. Often, databases are held at institutions as part of project teams. When projects are completed and staff members move on, they are no longer maintained, and data can be difficult to access or are lost.

Institutional capability requirements

For technology solutions to be successfully embedded within land and sea management organisations, the organisations need to have appropriate and stable skill sets in-house (e.g., low turnover in staff). This includes experience in the use of various technology solutions, such as a common field filing system for data, the use and management of cloud servers and backups, and the management of consistent and high-speed internet connectivity. In the absence of these diverse and specialised skill sets, organisations require substantial external support that can be very expensive and not fit for purpose.

Scalable solutions should promote cumulative impact within an organisation through training that can be targeted at variably skilled staff. Training should offer a variety of opportunities, from very low-skill operations to highly technical jobs that can provide a pathway for workers to participate at all levels of data collection, management and development.

Successful training should lead to positive financial incentives for those individuals who become competent in more advanced technical skill sets. Currently, rangers are not generally awarded better rates of pay or given separate titles and responsibilities for advanced technical skills such as specialised equipment or software use. Indigenous land and sea management organisations need to train and incentivise staff to undertake a variety of roles in the collection, management and use of data using technology. The following is a suggestion for the various roles and responsibilities in an organisation:

- **The planner**: This role supports the development of values and metrics that underpin methods. This includes working with Traditional Owners and rangers to ensure the new methods meet local aspirations, meet operational constraints and fit in with governance and decision-making processes.
- **The data collector**: This role requires staff to be able to operate technology in the field to collect data. Staff need to understand the operational use of the technology and the limits of its effectiveness. They need to be able to troubleshoot issues in the field and prepare equipment for use before leaving the office.

- **The data manager**: Once the data has been collected, the data manager needs to transfer the data from the device into storage. This can be highly technical and require more advanced skill sets.
- **The data analyser and summariser**: This role uses the data to create summaries that take the raw data streams and convert them into metrics that can track changes over time. This role requires substantial training and experience.
- **The decision maker**: This person uses the data summaries to assess the effectiveness of their management actions and change methods to improve outcomes.

Fit-for-purpose training

For technology uptake to be successful, land and sea management organisations require bespoke training that meets industry needs. Current training focuses more on generic data management and technology use without identifying specific industry needs or commonly used methods. Micro-credentials offer a compelling approach in this context (Hunt et al., 2020). The development of micro-credentials is quick, easily updated and can be targeted to specific skills that are required by industry. This is particularly important for the use of technology, where rapid changes mean that fixed training programs such as certificate courses or diplomas can be quickly outdated due to the bureaucratic constraints for updating. NAILMSA and partners have recently trialled the development and implementation of unregulated micro-credential training that aimed to rapidly develop operational use of drones for Indigenous rangers to conduct environmental surveys (https://healthycountryai.org/). This training program was well received by the Indigenous organisations we worked with and exposed a potential pathway for rapid development and uptake of skills related to new environmental monitoring methods that leverage technology use.

Areas of research that establish trust in new environmental technology and empower Indigenous organisations

We have identified four areas of research that could support the establishment of trust and support scaling and uptake of useful technology in the context of Indigenous-led monitoring for environmental accounting on Country.

Trusted metrics

To be accepted by external parties, methods need to be rigorously tested and endorsed by trusted institutions. For example, artificial intelligence (AI) is being more commonly used to replace more traditional methods of data analysis, particularly for classification and prediction methods (VoPham et al., 2018). However, these new methods are not well described in literature and lack consistent and well-developed tests for accuracy (Schmidt et al., 2020). In an operational setting, the use of AI offers an accessible and rapid analytical approach;

however, to establish trust, it is important to develop methods that enable users to test the accuracy of results. Our experience using AI to detect turtle tracks from aerial photos (section 6.2 of this report) included linking predictions to the original photographs so that predicted values (turtle and predator tracks) could be assessed by the user before making a management decision. This is arguably more objective than traditional analytical methods, where data is based on observations, recorded in a spreadsheet and then summarised and aggregated without a means of checking the validity of the observations. An example is the observational data recorded in northern Australia on feral animal impacts on different wetlands types (J. Perry et al., 2021). In this case, researchers recorded feral animal impacts through observations around a wetland verge and assigned damage scores ranging between 1 – 5. The aggregation of these values established a feral animal damage index with an assumption that this accurately reflected the feral animal impacts and that these values are comparable between wetlands. If we consider the use of drones as an alternative survey method, we include a point of truth for observed values (the original photograph geo-referenced), the metadata and the collection organisation. An assessment of impact can then be assessed against the raw data used to derive the aggregated summary (J. Perry et al., 2021).

Technology (hardware and software) can rapidly evolve, requiring new methods to accurately define the equipment and software used to ensure that AI models and other automated processes remain valid. For example, digital cameras and motion sensor cameras are important data collection tools for land and sea managers. Digital camera resolution and light sensitivity have changed dramatically in the past ten years. The increase in image resolution has significant implications on the effectiveness of AI classification and object detection methods. It will be important to develop standardised methods to re-train and test predictive models as new equipment is introduced. Future analysis will need to develop methods to compare data from old cameras with new cameras, which will require constant maintenance of AI models (Vélez et al., 2023).

Trusted training and assessment of skills linked to operation use

An important research area is the development and testing of flexible training solutions that are linked back to common hardware and software solutions. Research that defines the training needs and objectively assesses the utility of training for helping organisations to support internal staff to manage new methods would be highly beneficial. An important element of building trust in the outputs of new methods will be ensuring that practitioners have access to appropriate training that objectively assesses their competency. See section 4.4 (above) for more details. Testing competency in various technical methods will be important to establish trust that data underpinning ecosystem service economies or fee for service opportunities (https://www.communitygrants.gov.au/) are robust. Currently, the primary means of establishing trust in training is through regulated training pathways (e.g. through TAFE-delivered certificate courses https://tafeqld.edu.au/course/17/17702/certificate-iii-in-conservation-and-ecosystem-management). For competence and trust in the use of technical equipment, other training pathways are likely to better meet the needs of Indigenous organisations and the organisations that are seeking to procure data collection services in remote areas (e.g. https://healthycountryai.org/).

Software and hardware development

Contemporary research often focuses on the development of new methods for measuring changes to particular values (e.g. feral animal impact on wetlands (J. Perry et al., 2021)). This work generally involves the development of bespoke analysis that utilises statistical software to complete one-off analysis and reporting. To enable Indigenous land and sea management organisations to collect robust data that is suitable for use in research projects and to add to national data sets, more robust universal operational software and hardware are required. Research projects are required to develop and test new methods that enable operational platforms to be developed that support ongoing, consistent data collection that can be done by Indigenous people as part of their day-to-day operations but are rigorous enough to be used by researchers and government agencies.

Community ownership of data and systems

The development and uptake of technology across northern Australia have been limited by mistrust in institutional and business interests (Carroll et al., 2019). There is an opportunity to build and test novel ways of developing and maintaining new methods that are linked to robust data management and storage protocols. Community ownership of solutions could be enabled through social enterprise approaches that support collective ownership by Indigenous organisations. Research projects that work with Indigenous organisations to conduct tests that establish trust in data collection and management systems are required (Kennett et al., 2010; Walter et al., 2021).

Case studies of technology use on Country

Case Study 1 – NAILSMA I-Tracker Program

The I-Tracker program was developed with a vision to create networks, tools, knowledge and skills that support and promote coordinated and collaborative Indigenous land management (Kennett et al., 2010). A key aspect of the program has been the establishment of the I-Tracker network of land and sea managers, who meet and communicate regularly to share ideas and knowledge, review current data collection and mapping tools, develop new ideas and tools together, and provide feedback on the program. The I-Tracker program also plays a key role in partnerships between ranger groups and external organisations. A significant aspect of developing sustainable Indigenous livelihoods is the capacity to enter into fee-for-service and other agreements with a range of government, non-government, and industry partners. Rangers across the I-Tracker network use I-Tracker applications to engage in work in partnership with other organisations on a wide range of issues, including control of weeds and feral animals, biosecurity surveillance, protection of cultural sites, patrolling of fisheries closures, and monitoring and removal of marine debris.

I-Tracker applications are designed to collect standardised data while allowing for customisation to reflect local and regional priorities. Partnerships with researchers and scientists inform best practice methodologies that meet the requirements of Indigenous rangers and data end users such as government or enforcement agencies. Incorporating community-based planning goals with external contractual requirements has been a major aim throughout the development of the applications.

Using I-Tracker applications, ranger groups can electronically document the process, effort and results of their patrols, making it easier to fulfil contractual obligations for organisations such as federal and state fisheries agencies. The applications also improve the transfer of data into mapmaking software and other data visualisation and analysis tools and create standardised reporting templates that rangers can use for numerous reporting and planning purposes.

By standardising data collection across north Australia, I-Tracker applications also enable data sharing for issues that occur across larger spatial scales (such as marine debris and national biosecurity issues). Data sharing can be a sensitive area, and NAILSMA staff have worked closely with Indigenous land and sea managers to develop agreements that protect their intellectual property rights while enabling the sharing of data to improve management outcomes, inform regional decision-making and promote the work being done in north Australia. The numerous partnerships formed through the I-Tracker network are central to the success of not only Indigenous natural and cultural resource management in north Australia but of wider conservation efforts in Australia as a whole.

The I-tracker program developed an integrated system for data collection, networking, training and support that was taken up across northern Australia by Indigenous land and sea managers. The rapid uptake and operational use of the I-tracker program provide a useful case study for understanding the elements of a successful Indigenous-led data collection and management program (Figure 1). However, the I-tracker platform was largely funded by the government, and when the grant funding was completed, critical elements of the program were lost. These included updating software and hardware to match the rapid change in mobile device use, regional connectivity and the emergence of cloud software. Additionally, support and training were no longer funded, so as new rangers were onboarded, there were limited opportunities to learn about the software, hardware and data collection methods. This highlights the need for a stable community-owned solution that can perpetually fund the maintenance and improvement of software, hardware, data management and method development.

Figure 1. Elements of the successful I-tracker program when it was operational and funded. A review of Cybertracker in 2018 highlighted the following factors that enabled the I-Tracker program to be successful when it was supported.

Single solution for data collection and management

The review highlighted that it was important that only one solution was required for data collection and management. The system included customisable and portable data capture functionality, the ability to download and store data on a personal computer, automated analysis and reporting in the format that suited funding agencies. The use of one system to manage all data collection and management meant that rangers only needed to learn how to use one system, and this was easier to manage from an operational context.

Efficient and simple reporting for external and internal stakeholders

Indigenous ranger organisations in northern Australia receive revenue and support from external organisations to conduct fee-for-service work (e.g. https://www.agriculture.gov.au/sites/default/files/documents/FINAL-BUDGET-FACTSHEET-Indigenous%20Rangers.pdf). The I-tracker review highlighted the importance of I-tracker for enabling rangers to collect robust data that met the needs of the external organisations. This enabled rapid uptake of fee-for-service opportunities in remote northern Australia. Some key features that supported external reporting included remote or real-time access to databases by internal or external stakeholders, customisable applications (with medium-low levels of technical specialisation), ability to incorporate icons and images in forms to ensure that rangers with low levels of literacy could still use the system and the ability to add or remove categories according to local monitoring priorities or external requirements. The system is designed so users can add aliases in data collection forms and change the language of field names, which enables complex technical language to be converted into forms that match local needs.

Integration of data from external sources

Indigenous land and sea management organisations indicated that the ability to derive and incorporate remote sensing and other topographic maps onto their devices was important. For example, to support fire management activities, fire scar data could be downloaded from the North Australian Fire Information site (https://www.firenorth.org.au/nafi3/) as a shape file or raster and imported into CyberTracker. This mapping is stored on the field collection device and therefore does not require internet connectivity. For more advanced users, GIS software, such as QGIS, could be used to build more complex maps that could be loaded back into CyberTracker, enabling bespoke mapping in the field.

Access to technical support and a peer network.

Peer support in the use of software and hardware was a critical factor in the use of CyberTracker. CyberTracker supported the community with updates and versioning and the cyber tracker team could be contacted to commission new features. NAILSMA was resourced to support Indigenous Land and Sea managers across northern Australia with their data collection and management activities using CyberTracker (https://nailsma.org.au/projects/i-tracker).

Offline capability and rugged hardware.

The hardware and software mix were specifically designed to operate in the extreme climatic conditions where rangers conduct their business and could be operated entirely offline. Additionally, the software had online capabilities and advanced features if there was capability within the organisations and a need to add more detailed reporting and data management approaches.

Case Study 2 – Turtle Trackers AI

The Turtle Trackers project was funded by the National Environmental Science Program (Project 2.5) and Microsoft AI for Earth (Microsoft, 2021). The project aimed to demonstrate the use of Artificial Intelligence to support an operational land and sea management program (J. Perry et al., 2021). In this project, we worked with Indigenous rangers and Traditional Owners from Aak Puul Ngantam on the west coast of Cape York Peninsula. The challenge was set to collect enough useful data to detect depredation events along a 100km beach with limited seasonal access and produce data summaries for rangers in near real-time that enabled them to make decisions, implement management and test the impacts of their decisions.

Turtle Trackers Version 1

For this survey method, rangers conducted five individual helicopter surveys (on different days), usually completed within seven days to reduce helicopter ferry costs. This enabled the recording of new nests each night and highlighted which of the new nests were depredated the following day/night. We identified the use of easily accessible, inexpensive action cameras attached to a helicopter, which required us to design and build a Civil Aviation Safety Authority (CASA)-approved camera rig. We worked with software engineers (Microsoft, 2021) to design a software architecture that could ingest the photographs, predict where turtle tracks and depredation of turtle nests were taking place and present the results on an interactive dashboard that would automatically update after each survey. We explicitly designed the solution to work in very remote areas with limited internet connectivity.

Turtle Trackers Version 1 successfully demonstrated the use of a locally-led data collection method and produced the first software solution that met the technical requirements outlined above. However, we identified some important constraints to operational use that were beyond the scope of the research project and further development was required to enable a production version of the software and method before it could be embedded into operational use.

Turtle Trackers Version 2: Building an operational solution

In phase one of the development, an issue was defined (turtle nest depredation), constraints for monitoring were identified (access challenges), a technological-based survey method was proposed and tested (aerial survey of nests), an analytical approach was identified (software architecture) and a management interface designed (interactive digital dashboard). This work was done with Aak Puul Ngantam and tested within existing feral pig management and turtle monitoring programs. Version one of Turtle Trackers was built with the support of Microsoft software engineers as a demonstration of the software possibilities but was not designed as production software.

In phase two of the development, we aimed to develop operational production software, hardware and methods. This required a far more rigorous approach to ensuring that software was stable and resilient to operational conditions (very limited connectivity) and that on-ground data collection methods were supported through training and documentation. Version two has been tested in an operational setting. This phase of development has led to an operationally stable software platform. As such, any similar data collection method can reuse most of the software solution. Please refer to Appendix 1 (Detailed description of operational data collection, management and analysis for automated detection of nests using AI) for a step-by-step approach that enabled the transition from a research-grade product (development) to an operational (production) ready solution.

Important lessons

The step-by-step summary of the operational solution developed for automating analysis of aerial photograph turtle track surveys (Appendix 1) demonstrates the attention to detail that is required to establish an operational solution as opposed to a research solution. The survey method and data collection steps need to be accurately defined and staff need appropriate and ongoing training. We identify the data management steps and provide software solutions that meet operational requirements and variable skill sets. We set up an analytical process that land and sea managers and Traditional Owners can participate in to increase job opportunities beyond data collection. We then link the whole solution back to an interactive report (digital dashboard) that is based on the decisions that rangers need to make and directly measures impacts rather than activities. The data is stored in a cloud-based solution that is managed by a login page linked to the ranger program, maintaining the highest standards of online security. This solution needs to be owned and maintained by an entity. We have built this solution progressively over time through philanthropic, government and industry support, and the codebase is freely available (https://github.com/microsoft/HealthyCountryAI). However, a stable and up-to-date solution will require an organisation to own and manage the solution and invest in the technical skill sets required to do this job.

Scaling the solution

We have established a production solution for monitoring turtle tracks and depredation of nests using off-the-shelf action cameras and a purpose-built Artificial Intelligence automated solution. This has included the development of training and documentation that helps to establish the skill sets required for each step of the solution.

For this to be a truly operational solution, we need to establish several new software features. This includes linking the solution to field data collection software and mobile applications. This allows the field data, such as turtle nest surveys and feral animal control data, to be stored and aggregated in the same database, greatly simplifying reporting. We are currently repurposing the software solution to enable other surveys to be conducted. This includes detecting ghost nets and marine debris and detecting and quantifying erosion gullies at landscape scales (Figure 2).

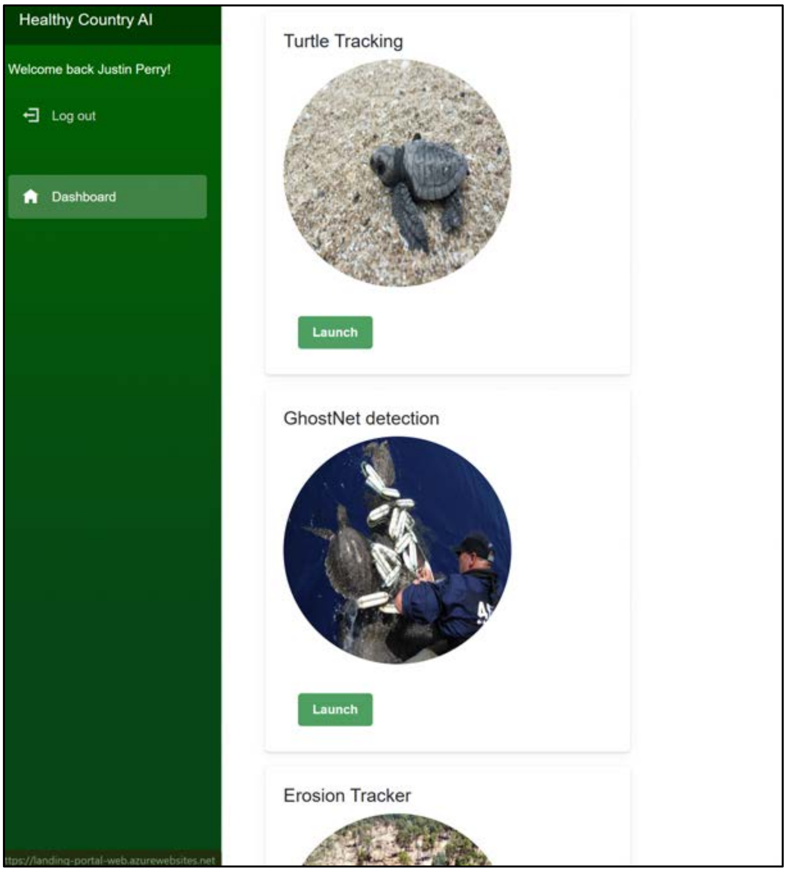

Figure 2. An example of the new interface where we have re-purposed data management and analysis software to identify ghost nets and erosion using the same software base.

Future-proofing software for new data collection hardware

We have developed the solution to work with the most appropriate hardware and survey methods (helicopter survey). Soon, long-range fixed-wing drones will become more commonly used in extensive systems. Once unmanned long-range drones are commonly owned and operated by Indigenous land and sea management organisations, the data management and storage requirements will exponentially increase. The software solution we developed is purposely built using inherently scalable cloud-based resources. Through the development of this method and associated software, we have identified the need to start identifying future costs that are currently not considered essential operational expenses. As the amount of data collected grows, so will the associated costs for storage and analysis. Organisations will need to be cognisant of a change in budgeting that will need to account for an increase in data management costs. This cost will replace the current expenditure on the critical operational expenditure of helicopters. This transition will require a cultural change in the way budgets are developed, which will also require the education of funders, who will have to learn that modern data management will become a significant cost for future operations.

Conclusions and recommendations

In this report, we have presented some key principles for the design of technology with Indigenous land and sea managers in Northern Australia. This includes following cybernetic approaches that focus on five principles for design: human-centred design, feedback-driven design, adaptive technology, context-aware technology, and sociotechnical systems design. When considering the case studies presented and the principles, we propose the following research priorities.

1. Testing technology solutions with peer review of the outcomes to quantify whether solutions are relevant and how they stack up against traditional methods (e.g. feral animal wetland impacts from on-ground surveys versus automated analysis using drone surveys).
2. Establish training programs with objective thresholds that can test training effectiveness and that enable technology use to be linked to a trust mechanism for appropriate and robust use. In the software development industry, the industry requires prospective staff to complete industry-developed micro-credentials that are very challenging to pass. The completion of the micro-credential generally requires a specific independent test against a common software development challenge that demonstrates to the industry that the staff member is competent. Developing similar micro-credential training for rangers, researchers, and consultants could offer trust in the use of methods. This could be linked to higher pay within organisations with increasing complexity of tasks. This will be very important for empowering Indigenous people to do fee-for-service tasks for research institutions or to establish trusted mechanisms for verifying environmental accounts.
3. Establish a research project that develops and tests multiple solutions within large-scale remote operational settings. This will enable the project to identify the elements that need more work, establish the true costs of conducting and maintaining the methods and assess capability and training requirements for staff.
4. Create a database of common research and monitoring methods applied by researchers across Australia and conduct a review of which elements are amenable to being replaced by technology solutions and automated analysis. This will require a detailed software and hardware architecture for each solution that is fully costed. To implement and test new solutions, it will be important to partner with technology companies to enable true costs to be attributed and have a realistic view of time, resources and ongoing maintenance required to manage new solutions.
5. Establish the real costs of building and managing new technology solutions and explore how methods can be maintained, constantly updated and improved. One potential solution is to develop a community ownership model where a not-for-profit company is established to build, maintain and support the use of new methods. Using this approach, data will be owned by Individual groups, but aggregation and analysis of data can be scaled as required.

6. Establish the benefits of technology use in the context of ecosystem service accounting. Demonstrate the external expenditure required to conduct contemporary biodiversity monitoring and ecosystem accounts. The high cost of external delivery of these services could be used to benefit indigenous organisations if trusted data collection, management and reporting systems are developed.

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Appendices

Appendix 1 – Detailed description of operational data collection, management and analysis for automated detection of nests using AI

Step 1. Prepare for the survey

Permissions and consultation

Work with Traditional Owners to ensure the survey is approved and is not impacting any important sites and is adhering to all agreed cultural protocols and local governance arrangements. Invite Traditional Owners to participate in the survey if they are interested and logistics allow.

Set up and test the camera

Use an action camera that has an inbuilt GP (for example, a GOPRO or a Garmin Virb). These cameras are easy to purchase from a wide range of electrical stores; they are not too expensive, have inbuilt stabilisation and are designed for operating in extreme conditions.

Settings vary depending on the brand and model of camera used; however, there are a few common settings that should be similar and are essential for consistent data collection.

- Use a high-speed micro-SD card (at least 64 GB).
- Set the camera to time-lapse (photo, not video) mode and set it to take a photo every 0.5 seconds.
- Set the resolution to the highest possible setting.
- Set the frame to linear or narrow (cameras usually default to wide as this is the best setting for sports photography and video).
- Ensure the device is set to collect GPS and that GPS is working (this is very important for automated analysis).
- Test that the settings are working by turning on the camera, trigger the timelapse, leave on for several seconds and check that it has taken at least six photos and that each photograph has a GPS reading embedded and the correct date and time (this can be done by checking the photo properties known as the EXIF data).

Attach the camera to the helicopter and test the mobile applications on land

Fit the approved camera mount to the helicopter (engineering approval required by CASA). Several off-the-shelf approved camera mounts are available online and in some specialty camera stores. The best mount we have found is a suction cap mount that is rated to >200 knots, which is much faster than a helicopter travels. Mount the camera with the lens facing directly down (not facing forward). Check that you can operate the camera using a mobile device and that the field of view is clear of helicopter parts.

Step 2. Conduct the survey

- Discuss the flight path and objectives with your pilot and identify these on a map.
- Fly to the start of your survey area and open the tablet application that controls your camera (e.g. GoPro Quick app).
- Ask the pilot to increase height whilst you are looking at the field of view of the camera on your tablet.
- Once the field of view encompasses the area of the beach you are interested in surveying, ask the pilot to note the height and maintain (this is important because although pilots have instrumentation, displayed heights are measured using pressure and therefore are dependent on take-off location and changes in ground height).
- Fly at a steady pace (around 50 knots) and trigger the time-lapse function on the camera using the tablet app. Fly along the beach for 100m, land the helicopter and use the app to see if photographs are overlapping. Identify if you need to increase or decrease speed (ensure that there is overlap in the photos). Depending on prevailing winds, we have found that surveys can be done at much faster speeds (70 – 80 knots), but this needs to be checked with the pilot and for the conditions on the day.
- Once you are happy with height and speed, ask the pilot to maintain these and proceed with the survey. Use a GPS or second mobile device to record GPS tracks as a backup.

Survey Considerations

Ensure photos encompass the area of interest and are high enough resolution to make out the object you are seeking to find. Make sure surveys are conducted at a time that limits shadows on the area of interest. For the west coast of Cape York, the best time of day is the afternoon. For the east coast, it is in the morning.

Useful backup items that enable troubleshooting in the field

Useful items to carry with you in the helicopter are three extra batteries for the camera, two fresh memory cards, a battery bank that is suitable for charging the tablet you are controlling the camera with and an extra tablet in case the primary tablet fails. In northern Australia, in the late dry season, temperatures can get very hot in the helicopter, which can cause tablets to overheat. There are portable cooling stations for mobile tablets that can be used, and some rugged tablets are designed to run on external power, thus removing overheating worries for lithium batteries.

Step 3. Data management and analysis

From camera to physical storage

After the survey is complete, remove the memory card from the action camera, replace it with a fresh microSD card and take the used SD card back to the ranger base. Use a microSD card reader to open the folders on the memory card. Copy the images into a folder on an external hard drive. We suggest the use of an external hard drive where internet speeds do not allow for a direct upload. Two external hard drives should be kept with the data sets backed up on each hard drive. Hard drives can then be sent to a location where the internet is fast enough to upload images to the cloud. For Aak Puul Ngantam, external hard drives were sent to Cairns via a weekly mail plane when the internet was not operational. We suggest the development of a standard field filing system that can manage the different types of data that are being collected. A field filing system has a logical file structure linked to activities and clearly separates dates and, in some cases, locations or sites. The field filing system does not need to differentiate between survey days as the software will automatically order the data; however, some land and sea managers find it easier to order files in a way in which they can easily manually search for images at a later date. In this case, the filing system would include location (APN), activity (turtle management), survey type (aerial survey), date (YYMMDD), and photo folders (copy and paste from microSD card).

From physical storage to cloud storage

There are several manual methods for uploading data from physical storage (hard drives or computers) to cloud storage. Through working with land and sea managers at Aak Puul Nangtam, we identified the need to develop a software solution that directly linked rangers to cloud storage through a simple user interface. This software solution reduced the technical skill sets required to manage the second phase of the data analytics process, opening up this job to a wider group. The user interface is entirely functional but will require collaborative design to build a more suitable operational platform (Figures 3 and 4).

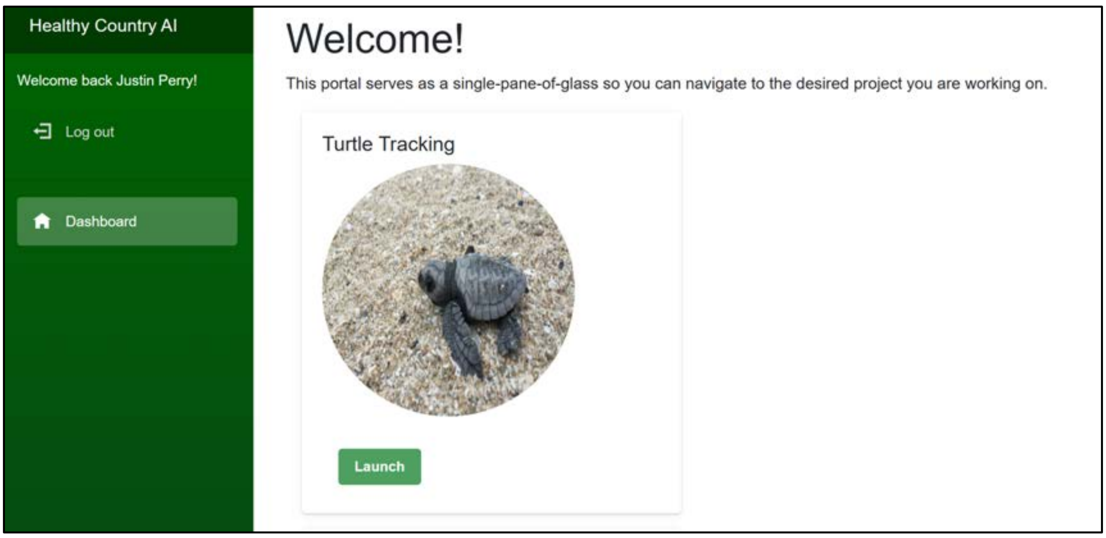


Figure 3. Landing page for the turtle trackers solution.

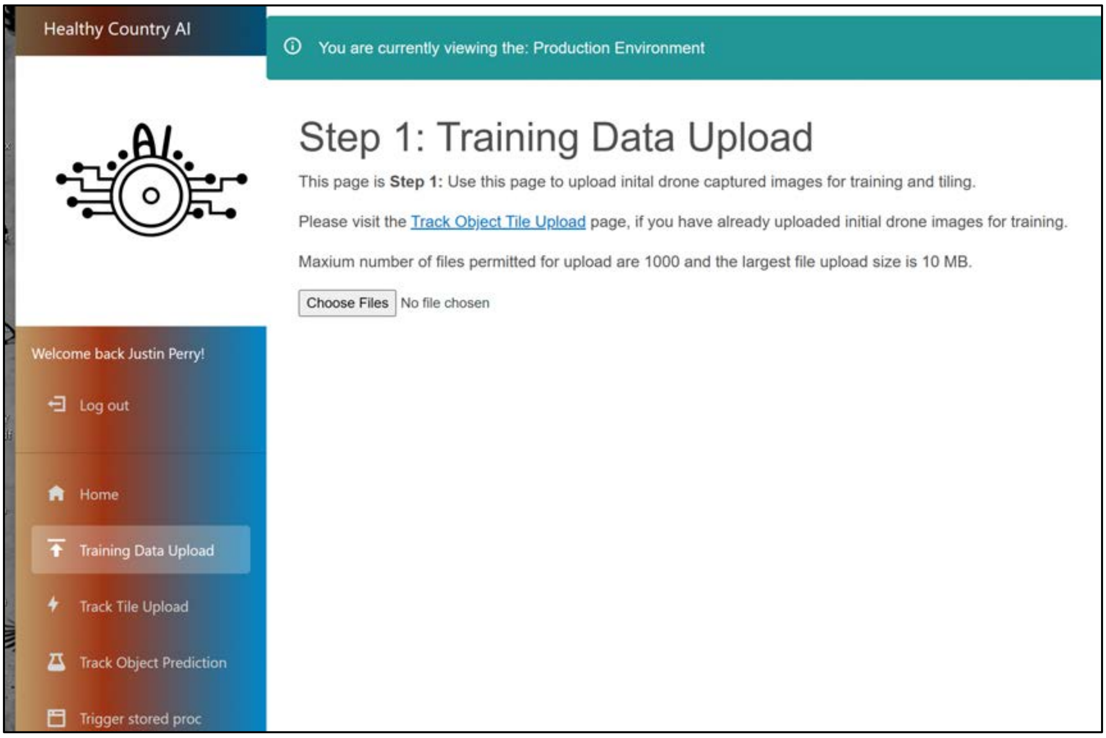


Figure 4. The data upload interface.

The user clicks on the Training Data Upload button and navigates to the latest images. Images are selected for upload, and this automatically sends the raw images to online storage (in this case, Azure blob storage), which triggers the automated analysis scripts. The raw images are renamed to provide a unique time/date base identifier (in case images from different devices, by some chance, have the same name). The renamed images are then broken up into smaller tiles (in this case, each image is broken into 121 smaller tiles). The tiles are uploaded to Microsoft cognitive services and surfaced in a Custom Vision project that can be accessed by staff who are going to train the AI models.

Train habitat model to filter out non-target regions

The first step of the analytical process is to create a classification model that can filter out tiles that are unlikely to contain turtle, predator or depredation objects (Figure 5). In this case, we classify images as beach (likely to contain objects of interest), vegetation and water (will not contain objects of interest).

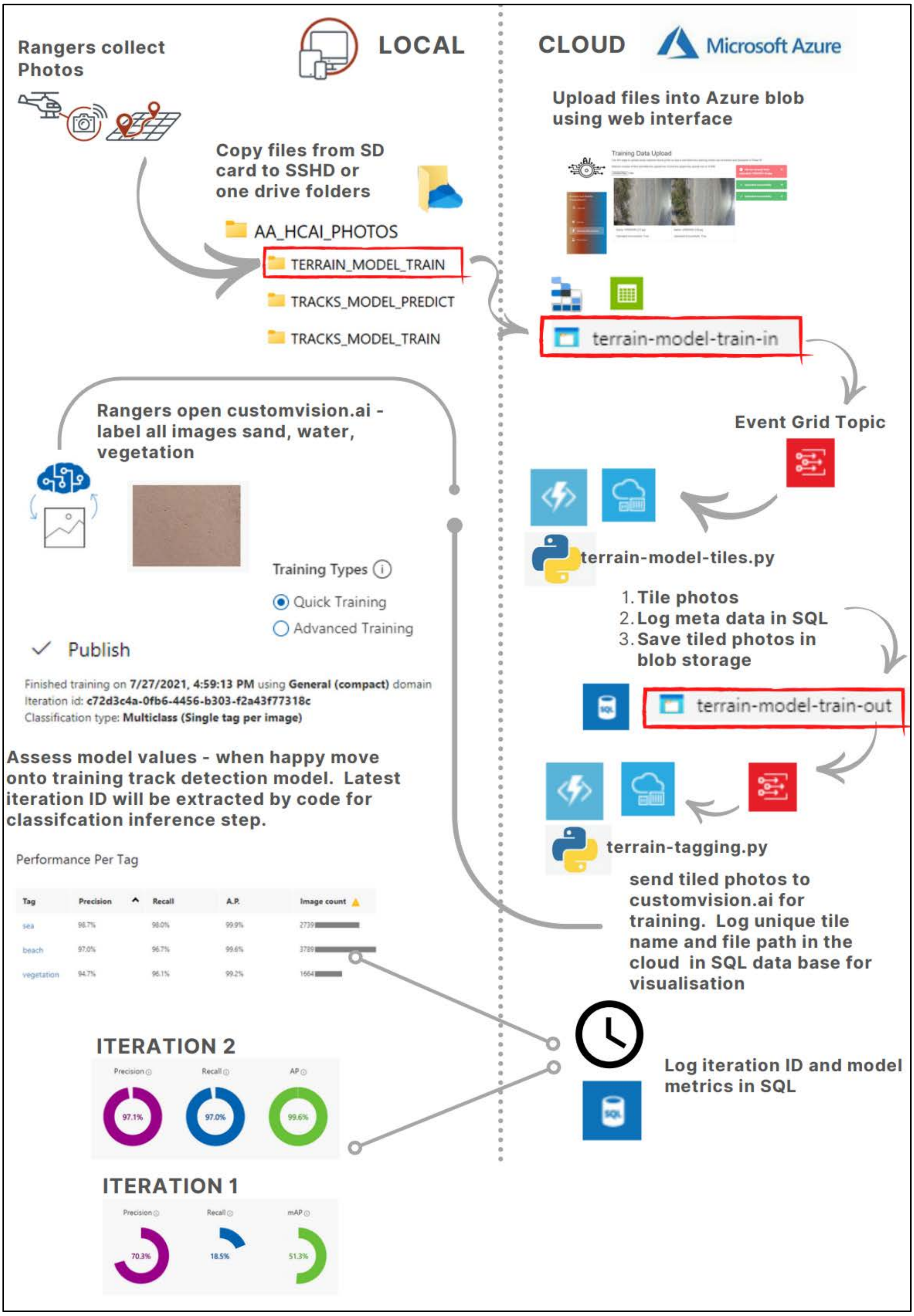


Figure 5. Software architecture for training habitat classification model.

Train the track model

Once the terrain model is trained and the end user is satisfied with the accuracy of the model, the next step in the solution is to train an object detection model. In this case, we identify several objects that are important for land management decision-making: predator tracks, depredation events and turtle tracks (Figure 6). We devise a software architecture that ingests the new photos, tiles the photos, uses the terrain model to filter out tiles that won't contain tracks and sends the remaining tiles to an object detection project in a custom vision, where an end user can label objects within each of the tiles (Figure 7).

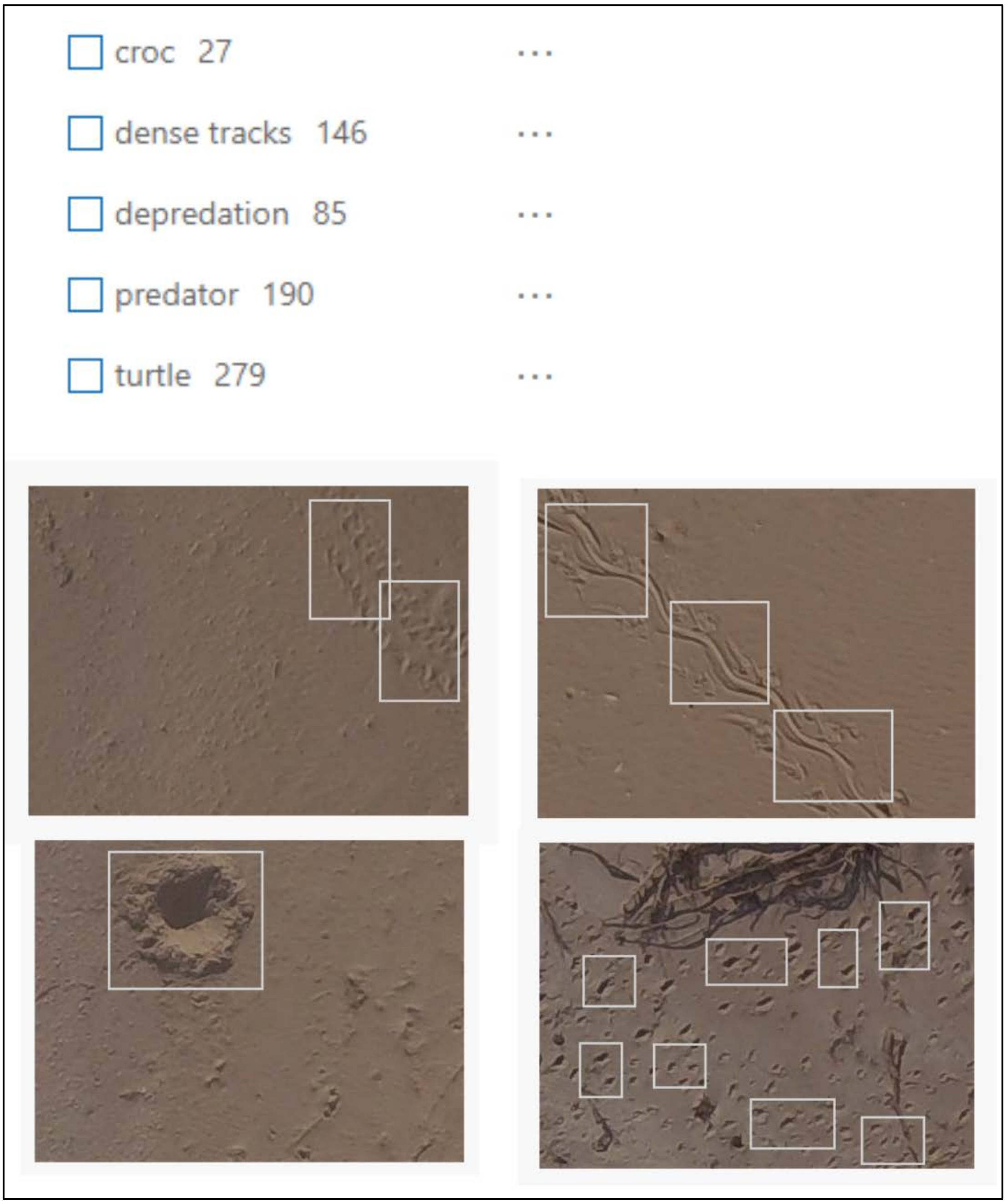


Figure 6. Example of object detection model categories.

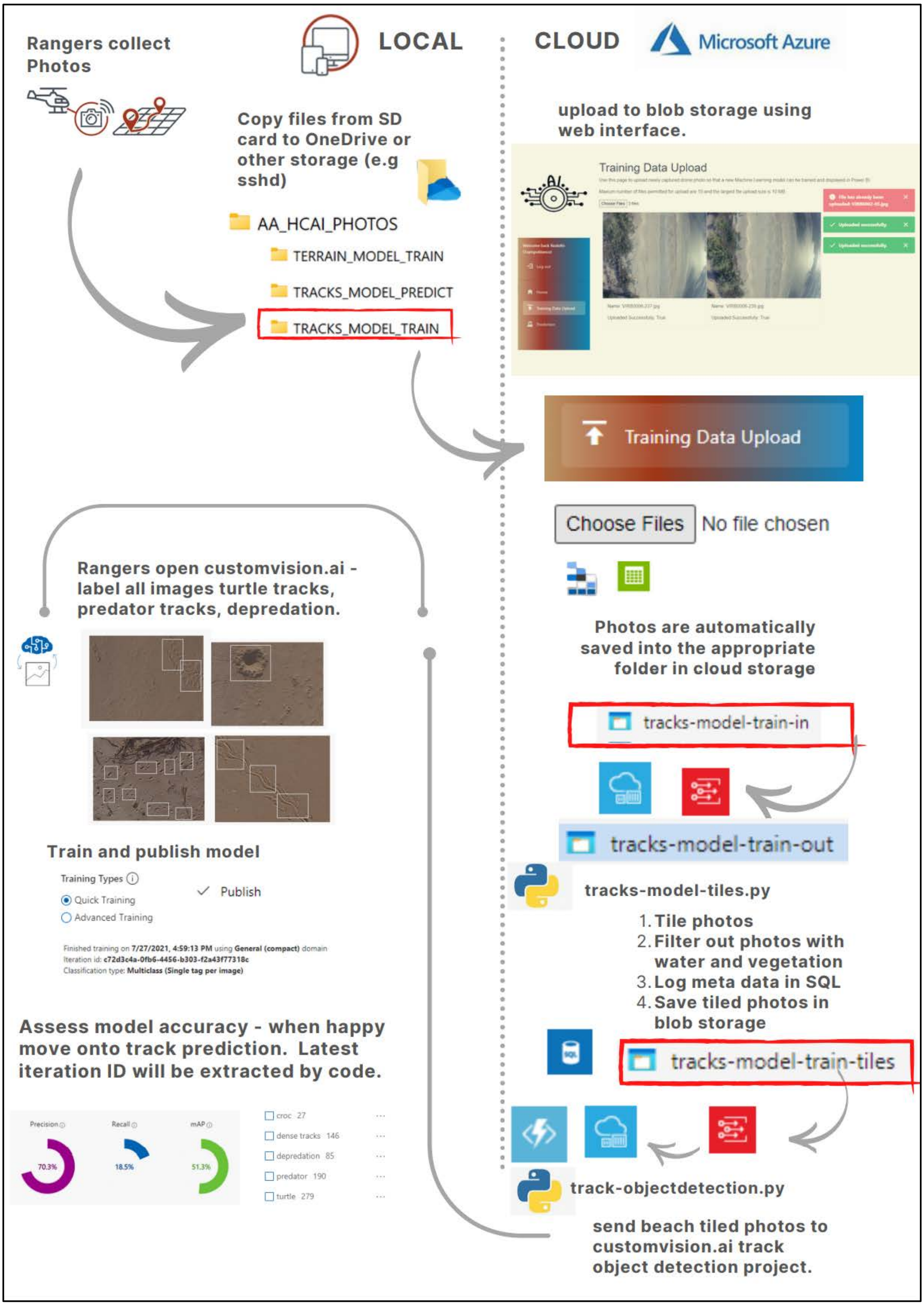


Figure 7. Software architecture for the object detection model.

Step 4. Using the models to identify important objects and visualise them in a dashboard

Once the object detection model is accurate, the final step of the solution does not require any more model training. The end user simply uploads the files and selects the predict button on the interface. The software automatically processes the tiles and uses the model to identify turtle tracks, predator tracks and depredation events and add the predictions to a database linked back to the original photograph with the pertinent metadata (date, time, latitude, longitude, group log-in). This database is exposed to Power BI, where rangers can interact with the data in a dashboard (Figure 8).

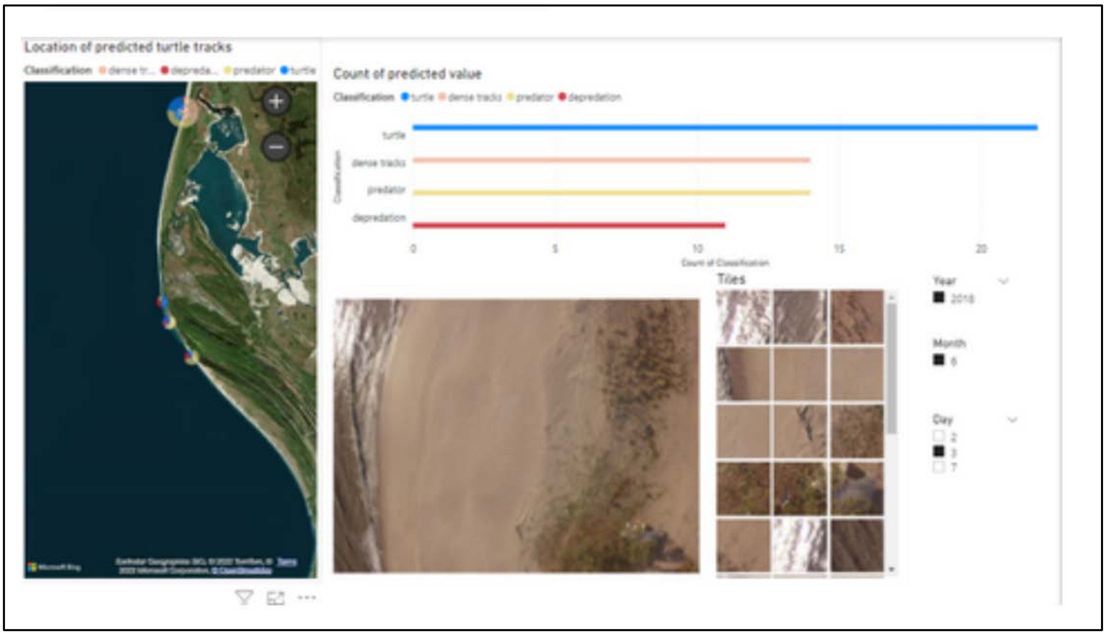
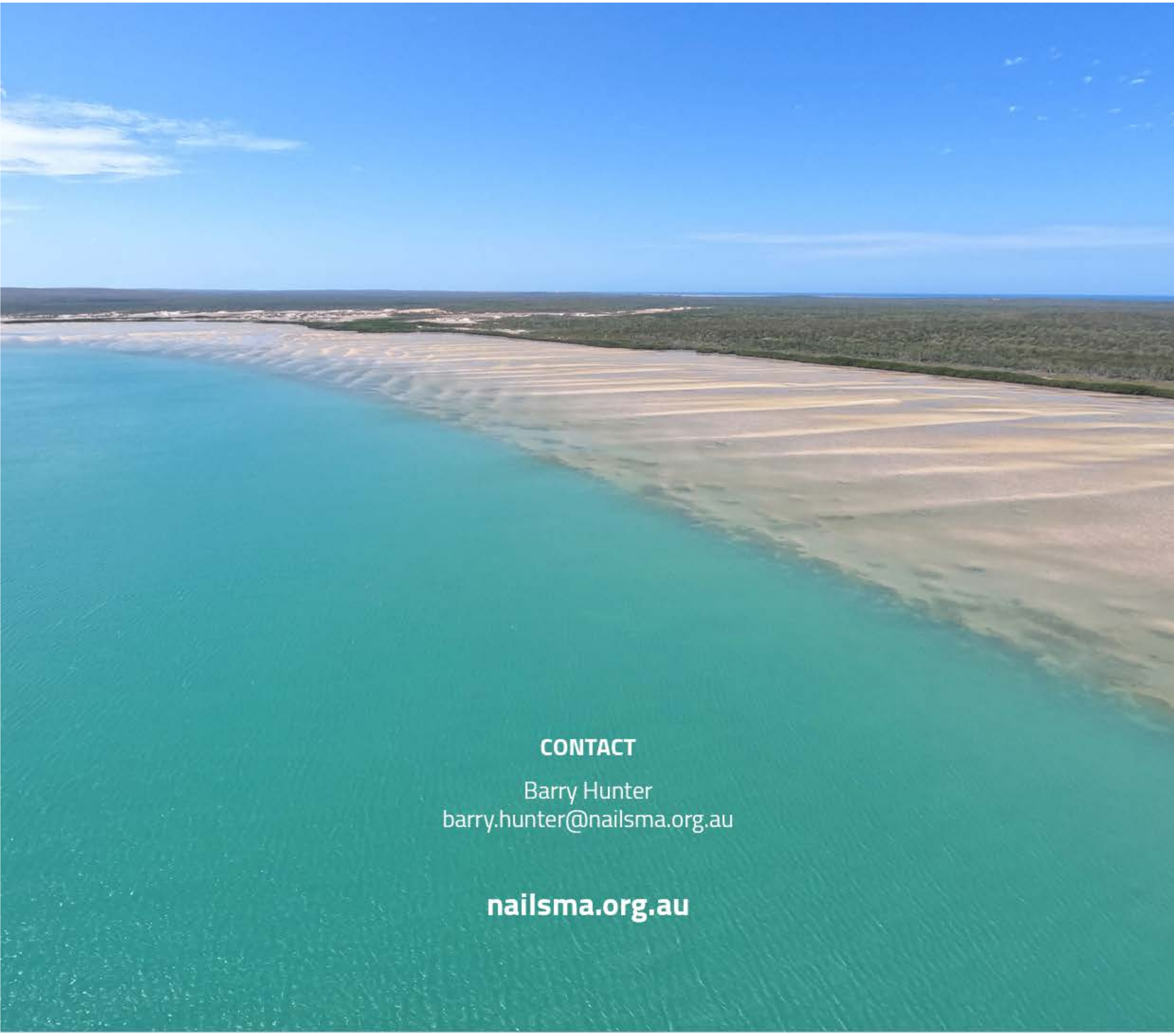


Figure 8. Dashboard example visualising the location and type of impact from the aerial surveys of turtle nesting.



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National Environmental Science Program

This project is supported with funding from the Australian Government under the National Environmental Science Program.