Northern Australia Environmental Resources Hub

National Environmental Science Programme

# Remote environmental monitoring in northern Australia: Scoping key research needs

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This report should be cited as:
King A.J, Novak P, Marshall J, Ward D, Gillespie G and Burrows D. (2016). *Remote environmental monitoring in northern Australia: Scoping key research needs*. Charles Darwin University

Cover photographs
Front cover: Fixed-wing drone. *Photo: ERISS.*
Back cover: Miniature boat monitors aspects of water quality. *Photo: ERISS.*

This report is available for download from the NESP Northern Australia Environmental Resources Hub website: www.nespnorthern.edu.au

The Northern Australia Environmental Resources Hub is supported through funding from the Australian Government's National Environmental Science Programme. The NESP NAER Hub is hosted by Charles Darwin University.

ISBN 978-1-925167-64-1

June 2016

Printed by Uniprint

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# Acronyms

| | |
|---|---|
| AIR | active infrared |
| ALOS | Advanced Land Observing Satellite |
| ARU | Autonomous Recording Units |
| AU | Australian |
| AUVs | automated Underwater Vehicles |
| BACI | before-after-control-impact |
| BRUV | Baited remote underwater video camera |
| CASA | Civil Aviation Safety Authority |
| CASR | Civil Aviation Safety Regulation |
| CDU | Charles Darwin University |
| CPUE | catch per unit effort |
| DGPS | Differential Global Positioning System |
| DIDSON | dual-frequency, identification sonar |
| DISTIA | Department of Science, Information Technology and Innovation |
| DLRM | Department of Land Resource Management |
| DNA | deoxyribonucleic acid |
| DNRM | Department of Natural Resources and Mines |
| DOE | Department of the Environment |
| eDNA | environmental DNA |
| EHP | Environment and Heritage Protection |
| EODC | Earth Observation Data Centre |
| EO | earth observation |
| EPBC Act | Environment Protection and Biodiversity Conservation Act |
| ERISS | environmental research institute of the supervising scientist |
| ESA | European Space Agency |
| FLIR | Forward Looking InfraRed |
| GDE | groundwater dependent ecosystem |
| GEE | Google Earth Engine |
| GPCPs | ground control points |
| GPS | Global Positioning System |
| GU | Griffith University |
| IUCN | International Union for Conservation of Nature and Natural Resources |
| JCU | James Cook University |
| KLC | Kimberley Land Council |
| LiDAR | Light Detection and Ranging |
| MDB | Murray Darling Basin |
| MODIS | Moderate Resolution Imaging Spectro-Radiometer |
| MVS | Multi-View Stereo |
| NAER | Northern Australia Environmental Resources Hub |
| NESP | National Environmental Science Programme |
| NFIS | Northern Fire Information System |
| NGO | non-governmental organisation |
| NLC | Northern Land Council |
| NRM | Natural Resource Management |
| NRT | near real-time |
| NS | no sample |
| NT | Northern Territory |
| OH&S | Occupational Health and Safety |
| PIR | passive infrared |
| POM | Particulate Organic Matter |
| QA/QC | Quality Assurance / Quality Control |
| QLD | Queensland |
| ReOC | remotely piloted aircraft operator's certificate |
| RePL | remote pilot's license |
| RGB | Red-Green-Blue |
| RNA | Ribonucleic acid |
| RPAS | remotely piloted aircraft systems |
| SAR | Synthetic Apature Radar |
| SAV | submerged Aquatic Vegetation |
| SCUBA | self-contained underwater breathing apparatus |
| SD | Secure Digital |
| SfM | Structure from Motion |
| SWIR | Short Wave Infrared |
| UOC | Unmanned Operating Craft |
| USGS | United States Geological Survey |
| VTOL | Vertical Take-Off and Landing |
| DPAW | Department of Parks and Wildlife |
| WA | Western Australia |
| WOfS | Water Observations from Space |

# Abbreviations

| | |
|---|---|
| et al. | and others |
| e.g. | for example |
| etc | etcetera |
| Gov't | Government |

# Acknowledgements

We wish to thank a number of experts (listed within the document) who contributed their expertise and knowledge to the desktop reviews and presented at the workshop on the new and emerging environmental monitoring techniques. We also gratefully acknowledge the large number of Natural Resource Management research users across northern Australia who contributed their time, opinions and experience into this project.

Human ethics clearance was obtained from the Charles Darwin University Human Ethics Committee (permit number H15098), to complete both the research users survey and workshop questionnaires presented in this report.

# Executive summary

Northern Australia is a vast an environmentally significant region at a global level. Whilst the region is in very good environmental condition, there are still significant threats to its biodiversity values, including climate change influences, altered fire regimes, land use and river flow changes and incursions of non-native species. Accurate, cost-effective and well-designed environmental monitoring of the region is therefore critical to its future. However, environmental monitoring in northern Australia is significantly challenged by many resource and logistical constraints. A number of emerging technologies are thought to be able to mitigate these constraints, and may provide an opportunity to improve and increase the effectiveness of monitoring programs. However, their utility, appropriate sampling design, limitations, and their cost-effectiveness relative to other conventional techniques in northern Australian conditions have not been adequately considered.

This project aims to determine the priority research needs in the development and refinement of emerging environmental monitoring technologies and techniques that could be useful in a northern Australian context. The project was conducted in three stages:

- Stage 1: Survey of research users to understand the specific drivers, requirements and limitations of environmental monitoring, and also to establish which emerging environmental monitoring tools and technologies research users thought had potential application in a northern Australian context.
- Stage 2. Desktop review of emerging monitoring techniques to explore their potential utility and limitations for use in environmental monitoring in a northern Australian context.
- Stage 3. A workshop to determine the utility of various emerging technologies, their limitations and developing research needs for their development and refinement for potential use in environmental monitoring of northern Australia.

The survey was conducted online, with 48 responses received from a range of organisations involved in environmental monitoring activities. A wide range of environmental monitoring activities are being conducted across northern Australia, although the majority are focused on monitoring biodiversity and ecosystem change. Most environmental monitoring is conducted at local or catchment scales, and is conducted by in-house Government employees; although a number of respondents highlighted the increasing involvement of Indigenous rangers in monitoring activities. Importantly, the survey highlighted that the majority of research users thought that monitoring was significantly limited by a resource and environmental constraints; and they were unsatisfied or unsure about how well their monitoring activities met their monitoring objectives. All respondents however, were positive about the possibility of new techniques improving their monitoring outcomes.

The desktop review provides background information about a number of emerging technologies and techniques that could be suitable for application in environmental monitoring activities of northern Australia. These reviews were completed by identified experts in the field. The information contained in each of the reviews described the technology, its applicability to monitoring in northern Australia, discusses the current known limitations and presents some areas of future research. Viewed in isolation these reviews are an important source of information to interested parties on these techniques and technologies.

A workshop was held in May 2016, which gathered key researchers and research users to (i) review a range of emerging environmental monitoring technologies and explore their potential utility, limitations, biases & cost-effectiveness and suitability for northern Australia, and to (ii) determine the priority research needs required to develop and refine the emerging monitoring techniques and technologies for widespread adoption in northern Australia. Workshop participants were presented with information on the techniques by relevant experts, and then asked to:

(i) evaluate the relevance of each technology for a range of monitoring activities,

(ii) evaluate the amount of research required to develop each technique before it could be utilised for environmental monitoring in northern Australia, and

(iii) develop priority research questions required for each technique.

Whilst the project was principally targeted at informing the development of potential research projects within NESP NAER Hub, the outcomes of the project are much broader and could inform both the use and applicability of these techniques for environmental monitoring in northern Australia, and the development of future research supported by a variety of different funders.

# 1. Introduction

Northern Australia is a region of global environmental significance. Spanning an area of approximately 1.28 million $km^2$ (Ward et al. 2011), the region has a very low population density, and limited intensive land use including industrial and agricultural developments. Environmentally, the region hosts significant concentrations of free-flowing rivers, uncleared tropical savannahs and rainforest, highly productive marine and coastal environments. The land, water and biodiversity of the region also holds strong cultural values to Indigenous people, with 30% of the land mass owned by Aboriginal people (Jackson et al. 2011), and is also important for non-Indigenous people (King et al. 2015).

Whilst the region is largely in very good condition, there are still significant threats to its biodiversity values, including changing fire regimes, sea level rise and climatic changes, weed and feral animal incursions and infestations, and habitat loss and modification, including changing flow regimes in aquatic systems. Environmental monitoring targeted at detecting these threats and understanding their impact is critical in the conservation and management of the northern Australian environment. A large number of government and non-government organisations undertake environmental monitoring across the region to ensure its unique values are preserved and this monitoring is essential to evaluate and improve management of northern Australia's environmental resources. Undertaking environmental monitoring in such a large, sparsely populated region, however, is particularly challenging.

Environmental monitoring in northern Australia is challenged by many resource and logistical constraints, including the large spatial scale, limited and variable site access (e.g. limited all-weather roads and associated infrastructure, wet season inaccessibility), environmental hazards to field-based studies (including crocodiles, cyclones and harsh climate), very low population density and limitations on technical capability and skills (Townsend et al. 2012). These constraints unfortunately can often lead to restricted sampling designs, with limited sample sizes, reduced spatial coverage, and poor power to both accurately identify patterns across the landscape and track environmental change, particularly in timeframes suitable for managers. Furthermore, environmental monitoring in northern Australia is additionally constrained by limited funding and significant operating costs required to undertake the monitoring.

Irrespective of the location and type of environmental monitoring being conducted, there are a number of rapidly developing, new technological advances that offer the potential to refine current monitoring techniques or even to develop new ones (Turner 2014). For example, recent technological advances in capturing, storing and analysing big datasets have provided significant improvements in remote sensing capabilities (Dafforn et al. 2015). Similarly, new techniques have improved the collection of robust data that is able to be collected by scientists and community groups (Newman et al. 2012; Laut et al. 2014), using in situ sensing devices such as automated cameras, environmental detection systems and audio listening devices for biodiversity monitoring (Kalan et al. 2015; Leach et al. 2016). However, there are also many new potential techniques that could be developed for specific environmental monitoring applications, but are still in the research and development phase.

A number of new remote sampling or surveillance technologies have emerged in recent years that may assist environmental monitoring in northern Australia. These techniques include:

- Use of environmental DNA (eDNA) for detection of rare or invasive species, and increasingly studies on biomass and distribution of biota (see Rees et al. 2014 for review);
- Camera-based field detection techniques for terrestrial (see Gillespie et al, 2015) and aquatic species (see review by Ebner and Morgan 2013);
- Remote stations for detecting and identifying audio calls of birds and frogs;
- Remote sensing techniques for monitoring landscape-scale changes (e.g. satellite imagery of key drivers) and finer resolution data and imagery collection by unmanned aerial systems imagery (e.g. water quality, vegetation mapping and condition monitoring);
- Underwater sonar-based imagery of fish numbers and habitats (see for example Petreman et al. 2014);
- A variety of telemetry approaches for tracking animal movements of rapidly increasing sophistication and capability;
- Collection of detailed qualitative or quantitative environmental data by Indigenous rangers (e.g. iTracker; http://www.nailsma.org.au/hub/programs/i-tracker);
- Collection of observational or other types of data by citizens (e.g. Atlas of Living Australia (http://sightings.ala.org.au/recent), Birds Australia atlas data or data from social media (see for example Keeler et al. 2015))

These technologies have the potential capacity to mitigate the resource and logistical constraints and increase the effectiveness of monitoring programs. While these techniques may be applicable for some monitoring requirements in northern Australia; their utility, appropriate sampling design, limitations, and their cost-effectiveness relative to other conventional techniques in northern Australian conditions requires further attention.

## 1.1 Project aims

This project aims to determine the priority research needs in the development and refinement of emerging environmental monitoring technologies and techniques that could be useful in a northern Australian context. The project brought together relevant experts and natural resource managers or research users, to explore each of the main technologies, and develop the key research needs.

The purpose of this project was to inform the development of potential research projects within NESP NAER Hub. However, we believe the findings could also be used to help justify further research and funding support to other research funding organisations.

## 1.2 Approach

The project was conducted in three stages:

**Stage 1: Survey of research users**

The purpose of this survey was to understand the specific drivers, requirements and limitations of environmental monitoring, and also to establish which emerging environmental monitoring tools and technologies research users thought had potential application in a northern Australian context. The survey focussed on research users who were undertaking environmental monitoring in northern Australia.

**Stage 2. Desktop review of emerging monitoring techniques**

Relevant experts (i.e. researchers) of each targeted emerging technique were asked to complete a review of identified existing and emerging techniques in their discipline/research area, and explore their potential utility and limitations for use in environmental monitoring in a northern Australian context.

**Stage 3. Workshop to determine research needs in emerging environmental monitoring techniques**

A workshop was held to determine the utility of various emerging technologies, their limitations and developing research needs for their development and refinement for potential use in environmental monitoring of northern Australia. Importantly, the workshop brought together key research users and researchers, to work together and develop a common understanding of research requirements.

Throughout this report the term *research user* is used to represent the organisations or groups that currently undertake environmental monitoring in northern Australia and thus would be the users of any new monitoring technologies and techniques developed from future research and development.


A workshop involving some of Australia's top experts in environmental monitoring. *Photo: Briena Barrett.*

# 2. Survey of research users

## 2.1 Survey aims and methods

An online survey of research users was conducted to (a) establish the drivers, requirements and limitations of current environmental monitoring activities in northern Australia, and (b) to describe, as a first step, what types of emerging environmental monitoring tools and technologies are both being currently used, and could be used in the future.

To meet these aims, a link to an online survey was sent to 154 research users operating across northern Australia. The survey consisted of 12 questions, where the first eight questions were designed to target aim (a) (see above). The final questions were designed to address aim (b), by ascertaining the current level of use of new and innovative technologies across northern Australia; and also determine the likelihood of respondents to use the techniques in the future. Respondents were also asked whether there were any restrictions to them fully adopting the new techniques.

The prospective participants of the survey were selected from a range of organisations operating across the region, and were nominated by members of the research team and members of the NESP NAER Hub. These organisations included: State/Territory Government departments (Western Australia, Northern Territory, and Queensland), Federal Government, natural resource management organisations, environmental consultancies, and Indigenous corporations. The survey was created on the online survey software Survey Monkey and distributed to prospective participants via an email link. All prospective participants were contacted three times to ensure maximum response rates. A text version of the survey is presented in Appendix 1.

Dr Niels Munksgaards demonstrates a portable instrument used for field-based analysis of stable isotopes in environmental samples. *Photo: Briena Barrett.*

## 2.2 Results

### 2.2.1 Number of respondents

A 31% response rate to the survey was achieved (48 respondents from 154 contacts). Respondents were from a broad spectrum of organisations including State/Territory Government agencies, Federal Government agencies, Indigenous groups, natural resource management groups and environmental consulting groups. The greatest number of respondents were employed by State or Territory Government agencies (Figure 1). This high number of respondents from State/Territory Government is not surprising, as State/Territory Government agencies comprised the largest group of prospective participants across the three jurisdictions (WA, NT, Qld) (25/46 respondents, 2 respondents skipped this question). However, the response from Federal government participants was low (4 out of 48 respondents) (Figure 1).

A fairly even number of respondents had backgrounds or experience in aquatic or terrestrial monitoring (12 and 13 respectively) (Figure 2). However, there was some disparity at the State/Territory level, with few Qld Government terrestrial experienced respondents, and few WA Government aquatic experienced respondents. There were also a higher number of WA Government terrestrial experienced respondents (Figure 2).

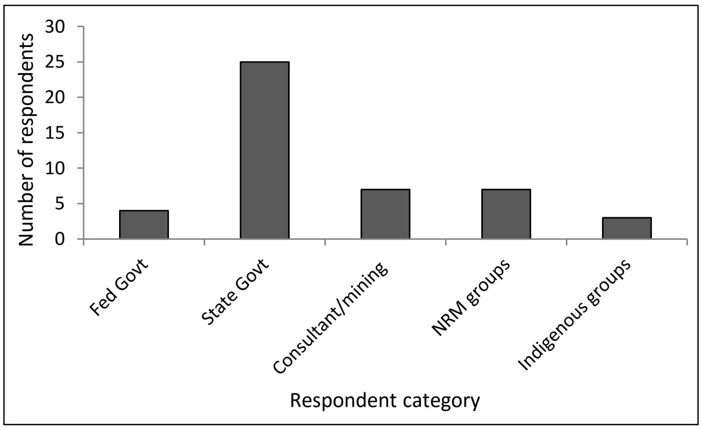



**Figure 1.** Number of respondents in each respective category (total n = 48)

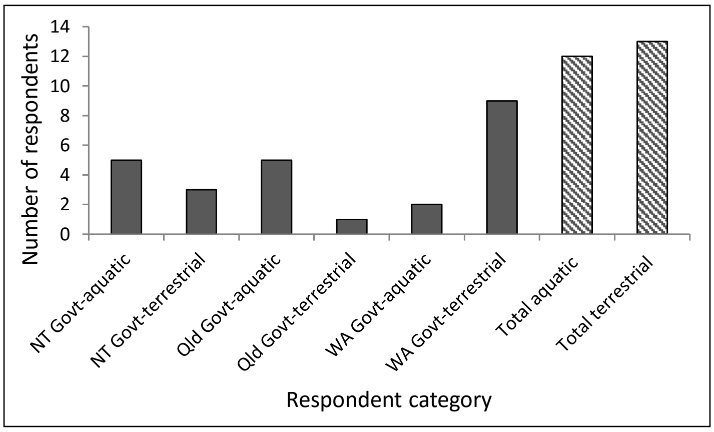



**Figure 2.** State government respondents broken down into respective states and working in either aquatic or terrestrial fields.

## 2.2.2 Primary monitoring activities

The questionnaire listed 23 (plus an "Other" option) monitoring activities and asked respondents to select the main activities that they were involved with (number selected not limited) (n=250 responses); with "ecosystem condition" the most commonly chosen category (Figure 3). For simplicity, these activities were condensed into seven broad categories (Figure 4). The number of selections across the categories was fairly consistent across five categories, with pollution monitoring (soil, water and sediments contaminants, ecotoxicology) receiving about half of the other categories, and broad changes in ecological condition (landscape change, ecosystem condition and health, climate, social ecological) receiving nearly double of the number of selections as the other categories.

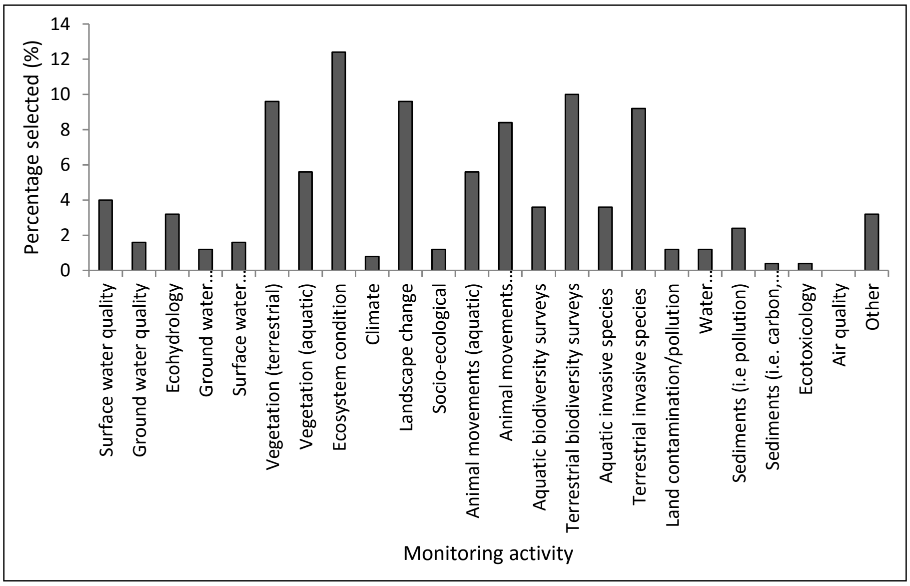



**Figure 3.** The monitoring activities selected by survey participants.

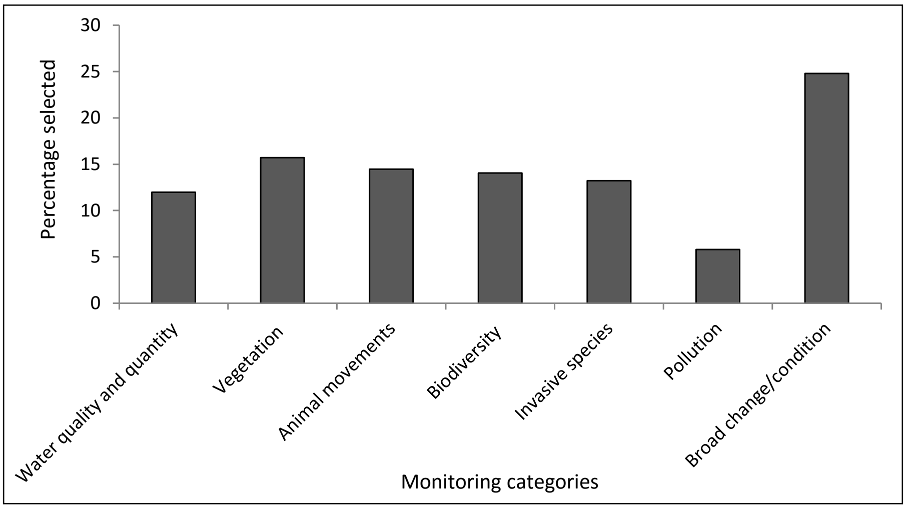



**Figure 4.** The broad monitoring categories

### 2.2.3 Purpose of monitoring

Respondents were asked to identify the main purpose for their monitoring activity. The dominant monitoring activities (54%) were associated with biodiversity conservation, assessment of environmental condition and weed control. Rehabilitation was the least commonly selected purpose for monitoring. This may reflect the low numbers of environmental consultants who responded to the survey (7/48 respondents). Responses to “Other” were generally associated with statutory requirements under respective state government water acts. Adaptive management was also discussed as a monitoring purpose under the “Other” category.

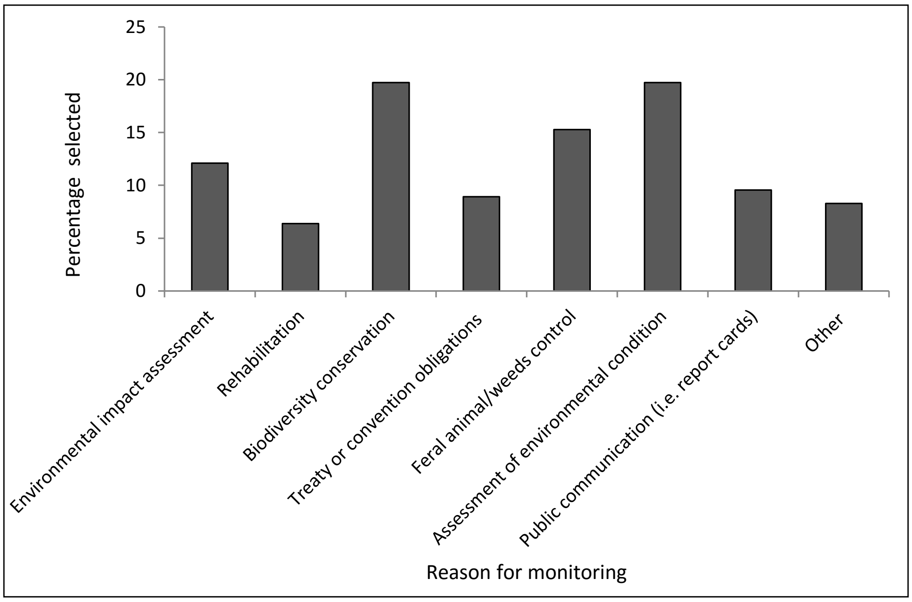



**Figure 5.** The purpose for undertaking the monitoring activity and the percentage of time they were selected by the respondents.

### 2.2.4 Scale of monitoring

The survey revealed that very little monitoring is conducted by a single agency across all of northern Australia (3%) (Figure 6). The majority of monitoring occurs at a local and catchment scale (53%). In the “Other” category, respondents gave specific locations or regions of monitoring rather than a scale different to that offered in the question.

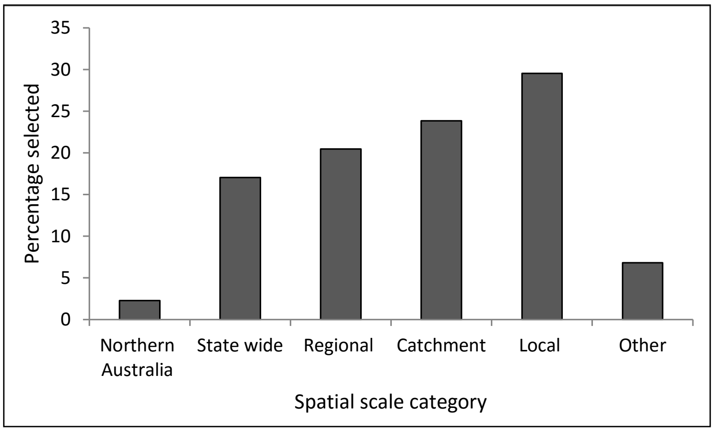



**Figure 6.** The scale over which the monitoring activities are conducted and the frequency of selection.

### 2.2.5 Organisational responsibility for monitoring

Most environmental monitoring in northern Australia is conducted by in-house government agency staff (38%) (Figure 7). A substantial percentage of respondents selected "Other" (19%), and listed Indigenous ranger or community groups as also undertaking monitoring.

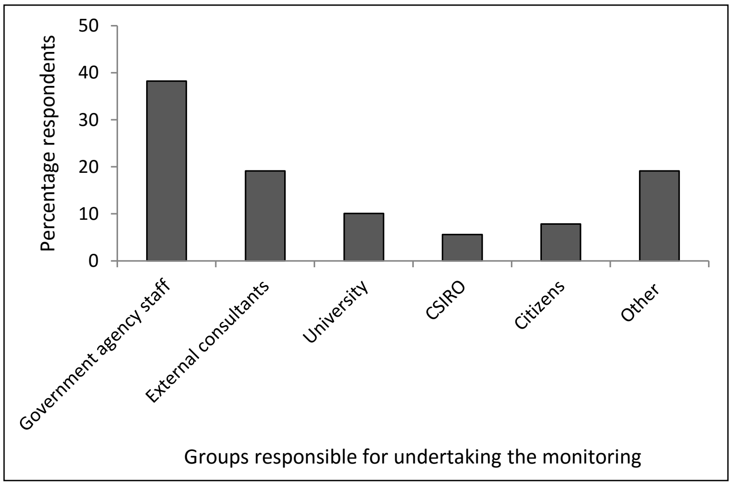



**Figure 7.** Monitoring personnel organisation associations.

### 2.2.6 Limitations and satisfaction with current monitoring

Most respondents (70%) felt that financial and logistical constraints were the biggest limitations to current environmental monitoring efforts (Figure 8). This question attracted a substantial body of comments (31 comments). These comments focused on a range of issues including (but not limited to): general skill shortage (e.g. invertebrate identification, piloting of Unmanned Airborne Systems, GIS, sampling design), monitoring methods, the development of appropriate sampling and analysis frameworks, and appropriate engagement of landholders in order to gain access. Other comments specified various funding, OH&S or logistical constraints including climate, crocodiles, lack of funding and the geographic size of monitoring areas.

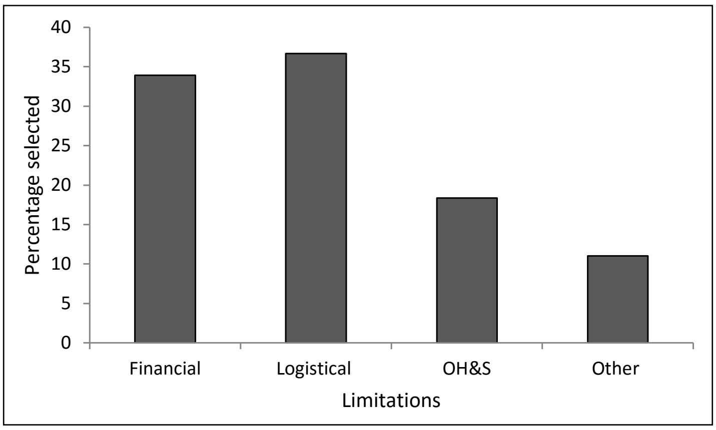



**Figure 8.** The limitations to current monitoring activities

When asked about how well their current monitoring met existing needs, most (56%) respondents were either unsure or negative (Table 1). Ten comments were received on this question and generally stated that the respondents felt their monitoring activities were not adequate and often were severely limited in spatial and temporal replication. Others stated they felt some of these issues were being addressed by advances in technology.

**Table 1.** Current feeling toward how well existing monitoring activities meet their agency needs.

| **How well does your current monitoring meet your needs?** | | | | |
|---|---|---|---|---|
| Very poorly (low confidence) | Poorly | Not sure | Well | Very well (high confidence) |
| 1 | 16 | 10 | 20 | 1 |

All respondents were positive about the possibility of new techniques and technologies improving monitoring outcomes (Table 2). No comments were received on this question.

**Table 2.** Expectation of the ability of new technologies to improve monitoring outcomes

| **Could new monitoring techniques or technologies improve monitoring outcomes?** | | | | |
|---|---|---|---|---|
| No/unlikely | Possibly | Yes | Yes, we are actively seeking or trialling new techniques/technologies | N/A |
| 0 | 8 | 18 | 22 | 0 |

### 2.2.7 Use of emerging technologies – current and future

Questions 9 and 10 asked respondents to select new technologies and techniques that they currently use or have trialled (question 9) and the new techniques and technologies they consider to have great future utility in environmental monitoring. Respondents could select as many categories as they wished in each question. Consequently, the number of selections for current use or trialled is lower (n = 177) than possible future utility (n = 289). The data is presented as the number of selections rather than a relative percentage as this gives the best impression of current use versus possible future use (Figure 9).

Camera-based tracking and detection work in terrestrial environments, and coarse-scale satellite remote sensing technologies were the technologies that had the greatest use currently. Drones (aerial and boats) and fine-scale aerial photography were the two most highly selected technologies that respondents thought would have the most utility in the future. The discrepancy between current use and future use for each technology is of interest, as technologies with great future use and little current use presents a guide to the future tools respondents consider are the most important for developing and researching. The technologies with the largest discrepancies favouring future use included: drones, fine-scale aerial photography and image analysis, camera-based aquatic (and image analysis), underwater sonar-fish detection, remote listening stations and genetic techniques. Those technologies with the lowest discrepancy between current and potential future use included: camera-based terrestrial, coarse-scale satellite and remote sensing, stable isotopes for water source detection.

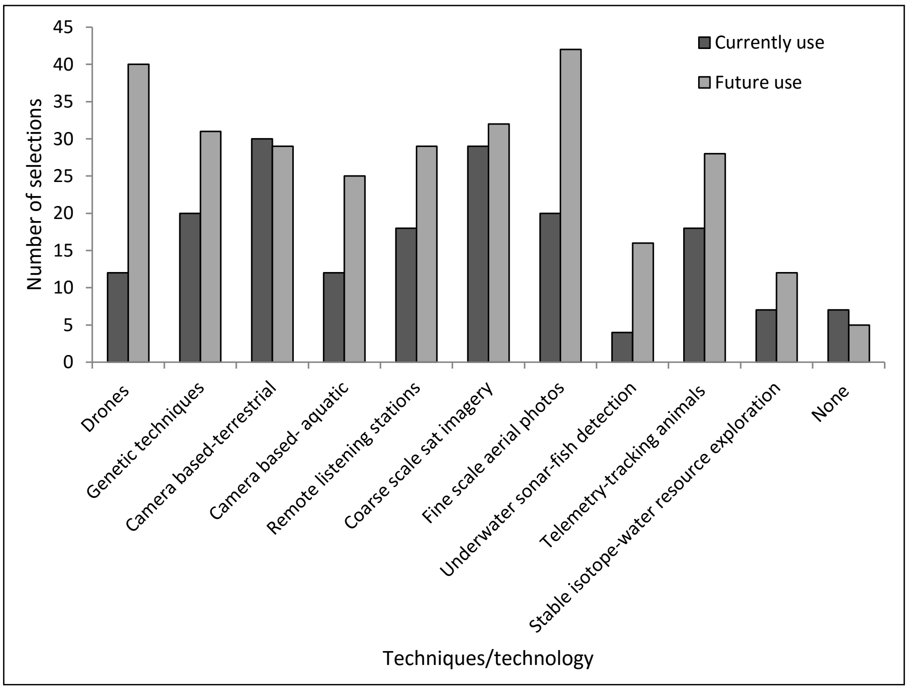



**Figure 9.** A comparison between current use and proposed future use of proposed technologies and techniques

### 2.2.8 Identified development areas of techniques where currently used or trialled

Survey participants were asked to provide a comment about the benefits and limitations of the new technologies and techniques if they have been using them, with 31 comments being received. The majority of these comments provided a discussion on the current limitations of these new techniques, and provide a valuable insight into the future possible utility of these techniques (Table 3). The comments also provide a possible direction on the developments that need to occur before they can be truly effective in remote environmental monitoring in northern Australia. There were few comments on the benefits of the new techniques apart from general statements affirming the successful trial of some techniques.

Some comments, not specific to a particular technique were:

- *Overall problems for most lie in the costs of initiating their use (capital and skills training/trials), identifying collaborators with the skills, costs in implementation and costs and skills in interpreting the resulting data.*
- *Analytical issues in regards to generating robust estimates of density/abundance (fauna surveys) with many remote techniques (cameras, listening stations etc).*

**Table 3.** The list of new monitoring techniques and technologies and limitations identified (verbatim) by survey participants.

| **Technique** | **Limitations** |
|---|---|
| Drones | – RPASs are yet to be tested fully - while potentially useful in a range of scenarios, the processing time and capability for data is yet to be resolved<br>– Limited appropriately skilled and certified operators, with relevant experience; CASA licensing requirements to be a legal operator have time delays and cost may be limiting to some people<br>– Appropriate sensors to cope with environmental conditions in northern Australia (the majority of sensors have not been tested in conditions such as those found in the Top End)<br>– Data processing (software and hardware requirements to process very large datasets); limited extent (spatial scale) due to battery duration. |
| Genetic techniques | – Genetic techniques are costly |
| Camera-based – Terrestrial | – Camera sensor designs not optimised for small animals (currently designed by game hunters, not ecologists). Unit cost is very high. Currently no automated photo ID software capability, resulting in large labour costs from manual photo ID<br>– Large volume of data (images) collected by camera traps<br>– We have intensified camera use recently, and need to learn more about how to use them strategically for determining population densities and other purposes<br>– Camera traps are useful but have limitations around abundance measures and identification of some species<br>– Problems with reliable power and automatic identification of species |
| Camera-based – Aquatic | – BRUV - take a long time in the office to process videos<br>– Has worked, but odious processing time in office, turbid sites are not well sampled |
| Remote listening stations | – Costs in getting sound processing software specific for the species you are trying to detect when using remote listening stations - otherwise costly and time-consuming to sit and listen<br>– Current limitations are cost and the time required to analyse the data (and lack of knowledge about sound recognition programs that could assist with analysis). |

| Technique | Limitations |
|---|---|
| Coarse-scale satellite imagery | – Both coarse and fine-scale imagery do not have sufficient accuracy to provide a 'fact', only likelihood or inference.<br>– Both coarse and fine-scale imagery fail at low weed density<br>– The time involved in image acquisition, processing and interpretation exceeds that of simply sending a weed officer or local expert to the location<br>– Costs of obtaining images are decreasing all the time but getting high-res imagery is still costly for monitoring programs<br>– Satellite imagery is very limited in terms of getting cloud-free and/or smoke-free imagery in the Top End which limits the ability to undertake quantitative remote sensing analysis<br>– Some issues with cloud cover<br>– There is a general failure by the drone/imagery/remote sensing industry to understand and address the functional requirements of those in the weed management/land management industry (outside of the agriculture/cropping sector) |
| Fine-scale aerial photography | – Both coarse and fine-scale imagery do not have sufficient accuracy to provide a 'fact', only likelihood or inference.<br>– Both coarse and fine-scale imagery fail at low weed density<br>– The time involved in image acquisition, processing and interpretation exceeds that of simply sending a weed officer or local expert to the location<br>– We would like to improve capacity to analyse images with software, as manual handling and analysis of images is very time-consuming |
| Underwater sonar-fish detection | *No comments received* |
| Telemetry-fauna tracking | – Although weight and size is reducing, this is a still a limitation for very small animals<br>– Still costly and difficult to get equipment for some purposes and lengths of time (ie small batteries equal small battery life; longer life batteries equal larger size and unusable for some species).<br>– Reliability of some telemetry collars |
| Stable isotope – water source determination | *No comments received* |

## 2.3 Discussion and conclusions

The aim of the survey was to both describe the drivers and limitations of current monitoring activities in northern Australia, and also to describe the current, and potential future use, of emerging environmental monitoring technologies and techniques. The survey received 48 respondents from a range of agencies across northern Australia; however, there were a limited number of respondents from Federal Government agencies. We do not believe this created any significant bias, although it may have influenced the spatial coverage responses of environmental monitoring (Section 2.2.4), with few respondents monitoring across all of northern Australia which is likely to be conducted only at a Federal level.

Respondents were found to be engaged in a wide range of environmental monitoring activities, although the specific focus tended to be on monitoring ecosystem change and condition. Most monitoring was conducted for biodiversity conservation, assessment of environmental condition and weed control. Unfortunately, statutory requirements as a driver for monitoring was not included as a specific monitoring purpose in the survey; however, a number of number of respondents commented that it was a particularly important driver for undertaking monitoring. More than half of all monitoring occurred at the local or catchment scale, and is conducted by in-house Government employees. This may reflect the high number of State/Territory Government respondents to the survey. A large proportion of monitoring was also conducted by Indigenous ranger groups. This suggests that appropriate training in the use of these new technologies will need to be considered for Indigenous ranger groups if the techniques are to be widely adopted and utilised across northern Australia.

The majority of respondents considered that current environmental monitoring in northern Australia is significantly limited by (in order) funding, skills shortages, large geographic ranges and climate. These limitations gave rise to a generally negative consensus regarding the ability of current monitoring to adequately meet reporting requirements. However, all respondents were positive about the possibility of new technologies and techniques to address these limitations, and improve environmental monitoring outcomes in a safe and cost-effective manner.

Unmanned vehicles (drones) and fine-scale aerial photography were highly favoured as being useful emerging environmental monitoring techniques in the future. A number of techniques were also identified that respondents considered had strong potential for use in the future, but were rarely being utilised currently. These included: drones, fine-scale aerial photography and image analysis, camera-based aquatic (and image analysis), underwater sonar-fish detection, remote listening stations and genetic techniques. Some emerging techniques were already being trialled by respondents, and in some cases they are already very well developed (including terrestrial camera trapping, and acoustic and radio telemetry). Some respondents also had direct experience in the emerging technologies, and commented on their limitations in northern Australia, such as: software requirements, expense, technical refinements and lack of skilled users. These limitations and the work required to overcome them will be further discussed in the desktop review (Section 3) of the technologies and also in the workshop (Section 4).

Terrestrial camera trapping is one of the emerging environmental monitoring techniques already being trialled by respondents in the survey. *Photo: Michael Lawrence Taylor.*

# 3. Desktop literature review

This section of the report is a desktop review of relevant literature for each of the new and emerging technologies identified by the project team and in the previous survey as potentially requiring further research and also applicable for environmental monitoring. A notable exclusion from this list is radio and acoustic telemetry to monitor animal movements. These techniques are heavily researched and developed and are currently being used in northern Australia, and the project team considered their use to be more research focussed and having limited monitoring applicability.

A number of researchers who are experts in their fields took the lead in conducting these reviews (note authorship of each section below), and we gratefully acknowledge their input and contribution.

## 3.1 Using satellite and airborne remote sensing techniques in environmental monitoring

**Component author:** Doug Ward (Griffith University)

Emerging trends in remote sensing are occurring largely in four broad areas:

(i) increase in spatial resolution (the size of the pixel),
(ii) increase in spectral resolution (the number of spectral bands),
(iii) computer vision and photogrammetry, and
(iv) advances in software processing techniques.

For both satellite and airborne sensors, multispectral systems measure fewer than 10 bands, but increasingly hyper spectral systems now cover > 10 bands. There are an increasing number of high spatial resolution satellites with pixel sizes < 1 m. Computer vision and photogrammetry have advanced rapidly with the ability to capture terrain features (elevation, tree height etc.) at fine spatial resolution < 1 m. Online sources of image archives (e.g. ~ 30-yr Landsat archive) are now available with good software interfaces for the analysis of image time series. Software processing methods have made significant advances, particularly object-based image processing techniques and online processing options such as the Google Earth Engine and the Earth Observation Data Centre (EODC; https://www.eodc.eu). Because the spatial resolution of the sensor, along with the size of features in an environment, controls the level of detail and size of features able to be mapped, this review will cover two broad areas:

1. Landscape-scale (satellite imagery)
2. Fine-scale (airborne and satellite imagery)

### 3.1.1 Landscape-scale (satellite imagery)

At a landscape scale, with satellite sensors with pixel resolutions >1 m, some significant emerging techniques are: 1) image processing and analysis methods, 2) the use of long time series of archival imagery, and 3) Landscape-scale satellite systems.

**Image processing and analysis methods**

**Description of technique**

Major advances in image processing and analysis methods are being made largely centring around parallel processing capabilities. A number of cloud-based computing platforms have arisen aimed at hosting satellite data and extensive cloud-based processing power. For example, Google Earth Engine (https://earthengine.google.com) and EODC are two such systems. These systems hold extensive archives of imagery and other earth observation data with advances in image processing techniques such as object-based feature extraction, and computer learning algorithms.

Google Earth Engine provides access to a large warehouse of satellite imagery and the computational power needed to analyse those images. The data catalogue includes a complete archive of scenes from Landsat 4, 5, 7, and 8 that have been processed by the United States Geological Survey (USGS), a wide variety of Moderate Resolution Imaging Spectro-Radiometer (MODIS) data products as global composites, and many other remotely-sensed and ancillary image data products. All data are pre-processed, georeferenced, and ready for use.

The EODC hosts its activities using very powerful processing engines. EODC operates a virtualised, distributed earth observation data centre, providing collaborative IT infrastructure for archiving, processing, and distributing earth observation data. EODC focus ranges from scientific research to operational services in the areas of water resources and land monitoring, agricultural applications, and humanitarian aid and civil security. In particular, the EODC receives sentinel data from European Space Agency's data hub, applies pre-processing rules (e.g. format conversion, compression, quality control, etc.) and redistributes the data through an archive. EODC can process and distribute data products in near real-time (NRT) for specific applications and provide NRT data access to meteorological forecasts and other NRT satellite data.

**Current application in environmental monitoring**

Applications of the Google Earth Engine have included mapping the forests of Mexico, identifying water in the Congo basin, and detecting deforestation in the Amazon. Other applications of Earth Engine have included production of Google's cloud-free, 15 m base map of Earth, global-scale multi-decadal time-lapse animations, numerous large and small analyses by scientists from a range of academic, government, and non-governmental institutions, and focused studies for detecting deforestation, classifying land cover and land cover change, estimating biomass, urban mapping, and species habitat modelling.

Data products developed at the EODC include the most complete and consistent global soil moisture data record based on active and passive microwave sensors. The remote sensing research group at the Vienna University of Technology is implementing a near real-time (NRT) processor for surface soil moisture on a 500 x 500 $m^2$ grid based on Sentinel-1 (S-1) data. Processing includes orthorectification, radiometric calibration and geocoding using ESA's Sentinel toolbox. Service provider GeoVille is using EODC to establish an operational wetland monitoring service, dedicated to and fully exploiting the capabilities of the Sentinel-1 mission.

This wetland mapping service will be accessible through web-based interfaces, enabled via the EODC framework.

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

By bringing together a range of satellite imagery over time frames in the order of many decades the GEE and the EODC provide powerful tools to measure environmental drivers, pressures, stressors or responses in northern Australia. For example changes in vegetation cover, extent and composition can be monitored. Similarly, the historical patterns of fire scars can be mapped and collated to give a historic perspective of fire in the landscape (e.g. NFIS). Water quality characteristics such as turbidity and macrophyte cover can be extracted using from the GEE image archive to identify seasonal and inter-annual changes in water quality.

The GEE and the EODC could be applied to a wide range of environmental monitoring in northern Australia. This could include vegetation and land cover change, water body and flood mapping, monitoring water quality, or fire monitoring (although this is already available via the Northern Fire Information System).

See https://earthenginepartners.appspot.com/science-2013-global-forest for example of global forest cover change.

See https://www.eodc.eu/esa-soil-moisture-climate-change-initiative/ for the EODC Soil Moisture Climate Change Initiative.

**Benefits and constraints**

The benefits of the GEE and the EODC in northern Australia comes from the facility to cover large areas without the need to mosaic and calibrate large numbers of images required to cover the vast area. The Earth Engine and EODC Catalogues provide users with a variety of raw and processed data products derived largely from the Sentinel, Landsat, MODIS and other high-resolution archives. A technical constraint on the use of the GEE is that it requires knowledge of either Java or Python scripting to run the image analysis and consequently limits the number of potential users to those with computer scripting skills.

**Possible research questions and areas for future development**

See workshop, section 4.

### 3.1.2 The use of long time series of archival satellite imagery

**Description of technique**

An emerging landscape-scale technique for Australia that utilises archival satellite imagery is the Water Observations from Space (WOfS) developed by GeoScience Australia (http://www.ga.gov.au/flood-study-web/#/water-observations). WOfS uses Australia-wide Landsat 5 and Landsat 7 satellite imagery archive to display detected surface water. For all of Australia for the period 1987 to present, WOfS is a web service displaying historical surface water observations derived from satellite imagery. The WOfS displays surface water inundation frequency as a proportion of the number of observations of water, relative to the total number of observations for a pixel (Mueller et al. 2016).

**Current application in environmental monitoring**

WOfS provides large-scale, regional information on surface water inundation characteristics. Satellites capture spectral information which helps to distinguish water from land, and to understand water quality. WOfS can help to identify areas at risk of flooding by comparing water observed during floods in an area, with the amount of water that is usually observed for that area. It can also be used to detect changes in the landscape that alter the way water moves, such as levees and dams.

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

WOfS can identify the inundation frequency of waterbodies across northern Australia, and as such provides information on the perenniality (the degree of permanence) of the waterbody. During the dry season across Northern Australia, the aquatic systems contract and the connectivity between riverine and the surrounding lacustrine and palustrine systems is significantly reduced. This is a period of limited resources for biota. Isolated perennial waterholes in the river channels and on floodplains play an important refugial role and become critical for sustaining aquatic biota during the dry season. The WOfS data set is useful for identifying the degree of permanence of waterbodies which is an important trait of waterbodies in northern Australia.

In northern Australia, the WOfS data can be used to identify and map perennial waterbodies that act as aquatic refuges at the end of the dry season. Refuge areas play a key ecological role for the persistence of freshwater biodiversity in northern Australia. In northern Australia, these systems regularly experience dry periods, which constrain the availability of suitable habitats. Current and future threats (e.g. water extraction and climate change) can exacerbate the negative effects of drying conditions on key refugia. This could compromise the persistence freshwater biodiversity, so the identification and protection of refuges is important.

**Benefits and constraints**

Satellite surface water mapping provides large-scale, regional information on water. Understanding how past floods have behaved improves our ability to predict future behaviour. This product is also useful for understanding related processes in the landscape such as groundwater recharge and the way vegetation responds to different water conditions.

Observation of earth by the satellites used for this service depends on clear skies. However, the Landsat satellites, which are the basis of WOfS, view the same area of Australia only once every 16 days. The observations show only what was visible on the day of the satellite pass. Therefore, a significant limitation of WOfS is that not all historical surface water inundation will have been observed by satellite.

**Possible research questions and areas for future development**

See workshop, section 4.

### 3.1.3 Landscape-scale satellite systems

**Description of technique**

The most recent emerging satellite system suitable for landscape-scale environmental monitoring is the Sentinel systems of satellites (http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4). The Sentinel system of satellites comprises a system of six satellite systems, each with specific functions such as all-weather, day and night radar imaging, high-resolution optical imaging for land services (e.g. imagery of vegetation, soil and water cover, inland waterways and coastal areas), ocean and global land monitoring services, and atmospheric monitoring. The satellites most suitable as an emerging platform for environmental monitoring in terrestrial and aquatic environments in northern Australia are the Sentinel-1 and the Sentinel-2A Satellite Sensors. Sentinel-1 (https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/sentinel-1) is a two-satellite constellation with the prime objectives of Land and Ocean monitoring. The goal of the mission is to provide all-weather C-Band Synthetic Apature Radar (SAR) data. The Sentinel-2A (https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/sentinel-2) mission is a land monitoring constellation of two satellites that provide high-resolution multispectral optical imagery. Other sensors useful for environmental monitoring include the ALOS satellite which captures multispectral as well as SAR (L-band SAR).

**Current application in environmental monitoring**

The Sentinel-1 C-band SAR sensor offers medium and high-resolution imaging in all weather conditions. Balzter et al. (2015) use the C-band SAR to report large-scale land cover change with a minimum mapping unit of 5 ha every six years which is usually operationally mapped using optical multispectral imagery by the European Environment Agency. De Grandi et al. (2015) use Sentinel-1 C-band SAR backscatter to characterise degraded forest in Cameroon based on forest structure derived from the Sentinel SAR data.

The Sentinel-2A Satellite Sensor mission is dedicated to the full and systematic coverage of land surface (Spoto et al. 2012, Fernandez et al. 2013). Sentinel-2A satellite image data supports generic land cover, land use and change detection maps. Other applications include maps of geophysical variables for leaf area index, leaf chlorophyll content, leaf water content (Team 2015).

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

The Sentinel-1 C-band SAR sensor has spatial resolutions ranging from 5 m to 100 m with a return interval of 12 days and single and multi-polarisation. The Sentinel-1 C-band SAR sensor is useful for detecting vegetation structure. This may be useful for monitoring weed spread as well as other changes in vegetation structure in northern Australia. The Sentinel-1 C-band SAR data may also useful for wetland ecosystem mapping (Henderson and Lewis 2008).

The Sentinel 2A optical multispectral sensor has 13 spectral bands, from the visible and the near-infrared to the shortwave infrared at different spatial resolutions ranging from 10 to 60 m on the ground, makes it an ideal landscape-scale sensor for monitoring habitat removal or disturbance, real-time flood monitoring, introduced weeds species, water quality, and thermal characteristics.

While Sentinel 1 and 2 have relatively coarse spatial resolution (10 m–100 m pixels), it is better than other free sources of imagery with repeat image captures such as the Landsat series. These satellites are capable of a range of environmental monitoring including vegetation health and landcover monitoring, waterbody and flood extent mapping, water turbidity and weed cover monitoring.

**Benefits and constraints**

Sentinel 1 has spatial resolutions ranging from 5 m to 100 m and provides a range of benefits for northern Australia. These include high return interval (12 days) C-band SAR data for land monitoring of forests, agriculture, soil and wetlands (Henderson and Lewis 2008). The benefits for northern Australia of Sentinel 2A is systematic coverage of land surfaces revisiting every 5 days under the same viewing angles with spatial resolution of 10 m, 20 m and 60 m. The spatial resolution with four spectral bands at 10 m has consistent coverage of the earth's surface. As with all optical sensors, cloud cover can be a major limitation to capturing useable imagery. The Sentinel satellite system is operated by the European Space Agency (ESA) and has the benefit of open access to data.

A limitation of the Sentinel system of satellites is that the sensors have only had a short period of image capture and consequently only limited archival analysis is available.

**Possible research questions and areas for future development**

See workshop outcomes, Section 4.

### 3.1.4 Fine-scale (airborne and satellite imagery)

At a fine scale, i.e. with sensors with spatial resolutions < 1 m, significant emerging techniques are: 1) High spatial resolution satellite sensors, 2) Manned aircraft sensors, and 3) Helicopter video surveys.

### 3.1.5 High spatial resolution satellite sensors

**Description of technique**

A large number of high spatial resolution (pixel < 1 m) have been launched in the last five years. These include Worldview-3 (0.31 m), GeoEye-1 (0.41 m), Pleiades-1A (0.5 m) or SkySat-2 (0.9 m). See http://www.satimagingcorp.com/satellite-sensors/ for details of design specifications and spatial and spectral resolutions. Most of these high-resolution satellites have spectral characteristics that incorporate Panchromatic, Multispectral, and SWIR. One of the only high-resolution satellites that have a SAR sensor is the TerraSAR-X Radar satellite (Abdullahi et al. 2016, Lei et al. 2016).

**Current application in environmental monitoring**

These high-resolution satellites are used for a wide variety of environmental monitoring programs such as generic land cover, land use and change detection mapping as well as water body delineation and water quality mapping. For example, Wang et al. (2016) explored the effectiveness of textural and differential spectral features in mapping mangrove intertidal species obtained from WorldView-3 high-spatial-resolution imagery for mangrove species in Hong Kong. Hunt et al. (2016) explored the feasibility of estimating leaf water content using spectral indices from WorldView-3's near-infrared and shortwave infrared bands. Li et al. (2014) reviewed the remote sensing of ecosystem health using high spatial resolution satellite sensors.

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

At spatial resolutions < 1 m these high-resolution satellites could be used for weed mapping, forest dieback, fire mapping, or riparian vegetation change. With very high resolution imagery, animal detection such as animal movements, tracks and nesting sites in northern Australia could be undertaken. For example, Yang et al. (2014) use GeoEye-1 for spotting east African mammals in open savannah. Robinson et al. (2016) test the discrimination and detection limits of WorldView-2 imagery on invasive plant targets. Malahlela et al. (2015) map the occurrence of an invasive species in subtropical forest gaps using environmental and high-resolution WorldView-2 data.

With suitable spatial and spectral resolution, high-resolution satellites could be applied to map weed infestations in northern Australia. This would need to be done in conjunction with field sampling for image training. High-resolution satellites could be applied to map damage from feral animals in northern Australia such as pig and buffalo damage. Whiteside and Bartolo (2015) map aquatic vegetation in a tropical wetland in northern Australia using high spatial resolution WorldView-2 imagery.

**Benefits and constraints**

The < 1 m spatial resolution greatly enhances the capacity of satellite imagery to delineate features on the surface of the earth that coarser resolution satellites cannot achieve. For example, individual tree crowns and their associated biophysical variables such as leaf area index can be obtained. Despite their beneficial features, these satellites have a number of constraints for application in northern Australia. Most high-resolution satellites do not have regular repeat captures over the same areas and require specific tasking of the satellite to capture a temporal series of images over an area. This limits their functionality for environmental monitoring. Data captured by these satellites also tends to be expensive.

A further limitation is that standard per-pixel based classifiers are often not applicable, depending on the features to be mapped. In a number of applications, the image objects to be mapped can be made up of multiple features with varying spectral reflectance signatures. Hence, the assumptions of per-pixel classification and subpixel mixing cannot be met. However, object-oriented approaches which sample the underlying textural and spectral characteristics of the features under study to build complex aggregate signatures can overcome this problem.

**Possible research questions and areas for future development**

See workshop outcomes, Section 4.

### 3.1.6 Manned aircraft sensors

**Description of technique**

Historically, aerial photography has provided the finest-scale imagery and is usually scanned and orthorectified for applications. More recently, a range of digital cameras have increasingly been used with aircraft. A particular airborne sensor application that has found recent wide application in environmental monitoring is the capture of Light Detection and Ranging (LiDAR) data (Froidevaux et al. 2016, Lin and Hyyppa 2016, Sander et al. 2016). Airborne LiDAR is when a laser scanner, while attached to a plane during flight, creates a 3-D point cloud model of the landscape. LiDAR data provides detailed (< 1 m spatial resolution) method of creating digital elevation models.

Despite the success of LiDAR at capturing 3-D representations of the earth's surface, recent changes in computer vision have provided emerging technologies that will supersede LiDAR-type technologies. The emergence of Structure from Motion (SfM) with Multi-View Stereo (MVS) in recent years has revolutionised 3-D topographic surveys. SfM-MVS originates from the fields of computer vision and photogrammetry, requires minimal expensive equipment or specialist expertise and, under certain conditions, can produce point clouds of comparable quality to existing survey methods (e.g. LiDAR). SfM-MVS is about feature matching, which allows common points in imagery taken from different positions to be identified, so that the geometry of the camera and the features themselves can be calculated. This is computationally intensive, so much of the work has been in making the use of this technology more computationally efficient.

**Current application in environmental monitoring**

Current applications of 3-D representations of the earth's surface include fine-scale hydrologic modelling, geomorphology and vegetation change detection. Froidevaux et al. (2016) investigated the relationship between the activity of bats and forest structure and compared the performance of airborne 3-D topographic data and terrestrial field surveys for measuring habitat features in a representative sample of mixed and deciduous forests in the Swiss lowlands. Lin and Hyyppa (2016) developed an efficient framework of proposing and validating feature parameters from airborne 3-D data for tree species classification. Sander et al. (2016) used 3-D topographic data to investigate coastal landforms and the Holocene evolution of the Island of Samso, Denmark.

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

Digital elevation models derived from 3-D topographic data have found a range of environmental monitoring applications. High-resolution digital elevation models can facilitate detailed hydrological modelling that can be applied to assess the potential impacts of sea level rise. Canopy heights, biomass measurements, and leaf area can all be studied using airborne 3-D image capture systems. 3-D topographic data can be used to detect topographic features such as river terraces and river channel banks and to measure the land-surface elevation beneath the vegetation canopy. Repeat captures of 3-D topographic data can be used to monitor soil erosion processes such as the volume of soil lost from gully erosion (A Brooks, unpublished data.).

3-D topographic data derived digital elevation models facilitate hydrologic modelling of sea level rise using rainfall runoff models with tidal and storm surge as inputs (e.g. Kakadu floodplains) (Bayliss et al. 2016). Using time series of LiDAR data estimates of the volume of soil lost from gully erosion can be estimated in northern Australia (A Brooks, unpublished data).

**Benefits and constraints**

The benefits of 3-D topographic products are many and varied, but are constrained by the cost of image capture over large areas of northern Australia. Because of the detail data captured in a point cloud, data processing overheads are high and require specialised software.

**Possible research questions and areas for future development**

See workshop outcomes, Section 4.

### 3.1.7 Helicopter video surveys

**Description of technique**

Video imagery collected from a helicopter provides a means of capturing high-resolution data at a relatively low height above the ground, and slower speeds than fixed-wing aircraft. Video imagery can be collected from a low-flying helicopter flying transects at heights of 30–50 m at speeds between 50 and 100 km/hr. The video camera is positioned perpendicular to the direction of travel and video imagery is collected with a concurrent GPS track to provide spatial reference to the imagery (Nelson et al. 2003, Reusen et al. 2008). Voice recording of the observers on the helicopter can be taken in conjunction with the video to add additional observer information (http://eatlas.org.au/nerp-te/ts-jcu-mangrove-freshwater-status-torres-strait-islands-2-2).

**Current application in environmental monitoring**

Current applications include coastal erosion monitoring, weed infestation surveys (Rebbeck et al. 2015) (http://www.abc.net.au/landline/content/2015/s4267598.htm), riparian vegetation condition surveys, and fauna counting surveys such as sea mammal research and bird studies (Dawson and Miller 2008).

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

Weeds are a particular problem in northern Australia and helicopter video surveys are potentially useful for mapping the extent of weed infestations. Coastal and terrestrial erosion such as gully erosion can also be captured using and helicopter video surveys.

Current applications in northern Australia include the identification of rubber vine infestations in the Kimberley and helicopter shoreline mangrove surveys of Torres Strait investigating the health of shoreline mangrove communities. Other application for environmental monitoring in northern Australia could include identifying weed infestations, assessment of soil erosion, riparian vegetation condition, and large-bodied fauna surveys.

**Benefits and constraints**

The benefits of helicopter video surveys is they provide high-resolution spatial coverage often in conjunction with observer information. The resolution is usually better than aircraft surveys due to the slower speed of the helicopter. Helicopter surveys also have the advantage of being able the fly under cloud. The major constraint is the cost of helicopter surveys to cover large areas and the significant amount of post-processing and validation of the captured and interpreted imagery.

**Possible research questions and areas for future development**

See workshop outcomes, Section 4.

## 3.2 Using remotely piloted aircraft systems (RPAS) (or unmanned vehicles, drones) as platforms in environmental monitoring

**Component authors:** Renee Bartolo (ERISS), Doug Ward (Griffith University)

### 3.2.1 Description of technique

Remotely piloted aircraft systems (RPAS) potentially fill the data gap between satellites, manned aircraft and ground surveying, and offer a generally low-cost, ultra high-resolution image capture capability. They can also function as real-time monitoring mechanisms and they are able to fly at lower altitudes, collecting more precise information than manned aircraft or satellites.

They can fly below clouds making them advantageous in tropical areas such as northern Australia where clouds can often impede satellite image collection. RPASs can capture imagery at fine spatial scales (typically < 10 cm spatial resolution) flying at altitudes of 100–200 m. A particular advantage of RPASs is they have the capacity to fly semi or fully autonomously due to sensors and an on-board computer. The two main physical types of RPAS configurations are: (1) fixed-wing platforms, (2) rotor-based copter systems (Figure 10). Within these two RPAS types they can be further classified broadly into three classes based on range: close-range, short-range and endurance which determine the flight time, weight, speed and altitude (Table 4).

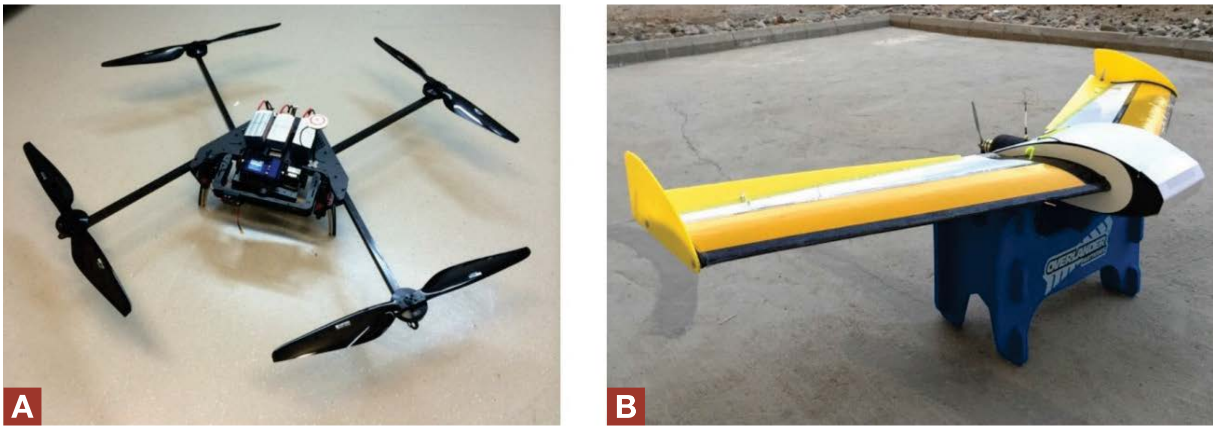



**Figure 10.** Rotor-based copter system (A), and fixed-wing platform (B)

**Table 4.** Classification of RPASs based on range capabilities.

| Characteristic | Close-range | Short-range | Endurance |
|---|---|---|---|
| Range | ~50 km | ~200 km | > 200 km |
| Flight time | 30 min–2 hrs | 8 hrs–10 hrs | > 24 hrs |
| Weight | < 5 kg | < 5,000 kg | < 105 t |
| Speed | ~60 km/hr | < 485 km/hr | < 730 km/hr |
| Altitude | < 6 km | < 16 km | < 20 km |

Source: http://na.unep.net/geas/getuneppagewitharticleidscript.php?article_id=100

**Table 5.** The resolution (grain) and extent (area) of possible images that can be obtained with a range of platforms

| | Grain | Extent |
|---|---|---|
| Multi-rotor < 7 kg | < 1 cm–20 cm | 10 ha |
| Multi-rotor > 7 kg | < 1 cm–20 cm | 10 ha |
| Fixed-wing < 1 hr | 3–20 cm | 200–300 ha |
| Fixed-wing > 1 hr | 3–20 cm | > 300 ha |

Fixed-wing RPASs are best when an extended flight time over a long distance is required. Fixed-wing RPASs can have wingspans from 0.5 m to more than 35 m and have a multitude of launch and retrieval mechanisms (e.g. bungee launch systems). RPASs can fly as low as a few hundred metres and some as high as 6,000 m. A multi-copter (Figure 10a), which can remain stationary, is best to use if small areas are being mapped (Niethammer et al. 2012). Small RPASs can be run with a ground operator and a laptop, but larger RPASs may require equipment mounted in vehicles or trailers (Watts et al. 2012). Launching tends to rely on bungee propulsion, whereas landing is usually accomplished through a controlled glide onto soft ground or parachute.

RPASs can carry a range of sensors depending on the payload. Most RPASs carry a digital camera and a multispectral sensor but a range of other types or sensors are increasingly being developed for RPASs. The resolution and extent of images is governed by the type of platform used (Table 5). Sensors include thermal infrared radiometres, hyperspectral radiometres, Light Detecting and Ranging (LiDAR) instruments and Synthetic Aperture Radars (SAR) (Rango and Laliberte 2010). RPASs equipped with video cameras can allow scientists to do monitoring in real time.

### 3.2.2 Current application in environmental monitoring

RPASs are beginning to be used for a wide range of environmental monitoring applications, such as coastal wetland mapping, water quality, LiDAR terrain capture, flood, soil erosion assessment, wildfire surveillance and species and habitat monitoring. For example, Hodgson et al. (2013) successfully used RPASs to survey dugongs in Shark Bay, western Australia. Casado et al. (2015) presents a RPAS-based framework for the identification of hydromorphological features from high-resolution RGB aerial imagery. Gamba et al. (2015) used RPASs to classify lands according to their soil water content. There is also a growing class of RPASs that are based on small biometric designs. These small biometric RPASs studies provide insights into animal behaviour in environments where human observers and larger RPASs would otherwise disturb the subject organism (Anderson and Gaston 2013). A fixed-wing RPAS and a helicopter in tandem have been used to locate weeds in remote rangelands and spray them with herbicide (Marris 2013). RPASs have also been used to map wetlands and survey estuaries for hazardous algal blooms (Anderson and Gaston 2013). Multispectral RPAS imagery has been applied to monitor the vegetation success of a rehabilitated mine site in northern Australia (http://www.ntspatial.com/uploads/6/6/3/1/6631203/201508_twhitesidde.pdf).

An application currently under development is the linking of RPAS-derived imagery to the data collected under the AusPlots program. The aim of this work is to determine which ecological attributes collected through AusPlots sampling can be directly measured through ultra high-resolution remote sensing data.

A range of other applications can be found at: http://conf2016.uas4rs.org.au/proceedings/

### 3.2.3 Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia

RPASs offer a promising route to responsive, timely, and cost-effective environmental monitoring at spatial and temporal resolutions that are appropriate to the scales of many ecologically relevant variables. Because RPASs are increasingly able to carry many of the sensors that are utilised by manned airborne and satellite sensors, RPASs can measure a similar array of environmental drivers, pressures, and stressors as satellite sensors, but at a lower cost and greater spatial resolution. These include habitat removal or disturbance, real-time flood monitoring, introduced weeds species, water quality, and thermal characteristics.

With the ability to fly low and slow, RPASs offer scientists new opportunities to study of individual organisms and their spatiotemporal dynamics at close range. Thermal imaging systems on RPASs show great promise for monitoring the distribution and abundance of organisms and the spatiotemporal monitoring of population and behavioural dynamics. Thermal imaging from RPASs can provide a useful indicator of the water status of vegetation. One of the most widespread applications of RPASs has been in monitoring and mapping the extent, biomass, and health of vegetation cover, including tidal wetlands, forests, and agricultural crops (Klemas 2015).

Because of northern Australia's remoteness, difficulty of access, and potential safety risk factors such as crocodiles, RPASs are potentially useful for environmental monitoring in the region. Further to this, extensive areas of flooded floodplain covered in macrophytes that limits conventional propeller-driven boats makes RPASs a viable option for monitoring in these types of environments. Given that RPASs are able to carry an increasing range of different sensors, RPASs are potentially applicable to a range of applications in northern Australia. These include a number of existing uses of RPASs for monitoring the mine site rehabilitation (including revegetation efforts and erosion) and turbidity of billabongs. Thermal infrared sensors could be used to locate and track wildlife. RPASs with hyperspectral sensors could be used to assess riparian vegetation condition and assess contamination resulting from different land uses. The costs of acquiring LiDAR data to assess gully erosion could be significantly reduced by using LiDAR sensors on a RPAS.

### 3.2.4 Benefits and constraints

Time-series data of species abundance and distribution is often required in both pure and applied population ecology studies. RPASs can provide an effective means of obtaining such information because of the potential for suitable resurvey periods and removal of observer bias from population counts can be automated (see Abd-Elrahman *et al*. 2005). RPASs may offer advantages as platforms for performing marine ecological surveys, particularly when species have large ranges and are typically surveyed using manned aircraft, for example dugongs (Hodgson *et al.* 2013). RPAS wildlife surveys have been shown to be comparable to ground-based methods for waterbird colonies and nest counts (Chabot *et al.* 2015)

The primary advantages of using lightweight RPASs for research into vegetation dynamics is that individual plants can be spatially resolved if flight paths are at sufficiently low altitude (Getzin et al. 2012) and revisit times can be optimised to the phenological cycle of target species. The ability of RPASs to capture imagery concurrent with field observations solves a common remote-sensing problem resulting from differences in the acquisition of ground and remotely sensed data. RPASs are particularly useful when manned aircraft deployment would be potentially unsafe or inefficient, for instance in real-time monitoring of the spread of forest fires.

One of the major benefits of using RPAS in northern Australia is flexibility in obtaining data when conditions may otherwise be unsuitable for manned airborne data collection or satellite imagery. With a dry season dominated by active fires that affect atmospheric conditions, and ubiquitous cloud in the wet season, RPAS provide the ability to fly below cloud and smoke.

Constraints in the use of RPASs include limited flight time depending on RPAS platform and size. The use of RPASs is limited by wind speeds and gusts depending on the size and type of RPAS. The very high temperatures found across northern Australia can affect the reliability of sensors. Due to small image footprint, numerous images must be captured resulting in intensive data processing requirements and capability to produce ortho-mosaics with minimal geographic reference errors (that can be used to undertake quantitative remote sensing). The particular technical challenges associated with RPASs relate to the radiometric and geometric quality of the data. The use of down-welling light sensors (irradiance sensors) on platforms, on-ground calibration panels, and on-ground control points (GPCPs) that have DGPS positioning can overcome some of these technical challenges.

The use of RPAS in Australia is governed by regulations administered by the Civil Aviation Safety Authority (CASA). The relevant regulation that affects the operation of RPAS in Australia is the Civil Aviation Safety Regulation (CASR) Part 101 and is one of the most developed regulations in the world. New rules for RPA operations will be incorporated in the CASR Part 1 as of 29 September 2016 and are designed to ensure appropriate safety standards in line with the different risks associated with different RPA, whilst reducing costs and processes for operators. The major change to the regulation is that operators of RPA in the < 2 kg commercial category will be allowed to fly commercially without holding a ReOC (remotely piloted aircraft operator's certificate) or RePL (remote pilot's license); however there are still limitations to operations and insurance may be difficult to obtain without a ReOC or RePL. For current UOC/ReOC holders, the new rules will provide for additional privileges such as licenses allowing operation of an RPA up to 25 kg and the ability to apply for exemptions to the regulations (e.g. flight beyond visual line of sight).

The rate of technological development in the RPAS field is phenomenal with new sensors and platforms being commercially developed on a monthly basis. As a result, without specialist knowledge it can be difficult to determine what sensor and platform best suits your application or needs. Large advances will occur with improved battery technology and the further development of VTOL (Vertical Take-Off and Landing) RPA. Users are also able to build their own sensors and platforms with components purchased cheaply from the internet. There is an unprecedented number of custom-built systems and the technology continues to grow.

### 3.2.5 Possible research questions and areas for future development

Can an operational turnkey RPAS be developed to survey and monitor weeds in northern Australia?

## 3.3 Using forensic DNA detection of aquatic species and profiling of entire biological communities (environmental DNA (eDNA)) in environmental monitoring

**Component author:** Dean Jerry (James Cook University)

### 3.3.1 Description of technique

As animals go about their activites, they all shed cells containing DNA. This DNA persists in the environment for only short periods of time from days to a few weeks (termed environmental DNA, or eDNA) and if assayed can be used as a sensitive indicator of the occurrence in the area of a particular species. The use of eDNA sampling methodologies are revolutionising how environmental scientists can detect and monitor the occurrence of a species or even whole communities, as the technique allows for rapid assessment of a water body for the presence of a species, even if it is rare and/or cryptic. Studies are showing that eDNA has a reliable detectability for aquatic species, and may be more sensitive than traditional sampling approaches like electrofishing and netting for surveys interested in species occurrence only.

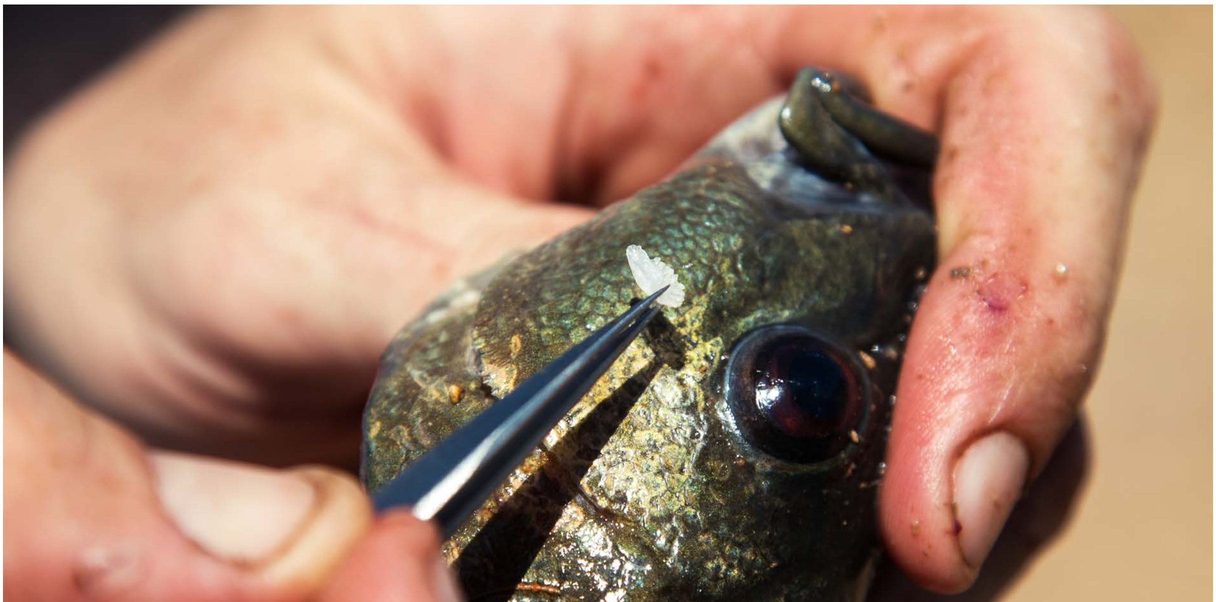
A further major benefit of eDNA is that it allows for quick and widespread sampling to occur even in remote or hard-to-access locations, as all that is required is for a water sample to be collected and bought back to the laboratory for analysis. Use of eDNA techniques are proving to have a wide range of applications in both marine and freshwater systems from biodiversity monitoring, early detection of invasive species, to animal diet assessment. eDNA also has applicability in terrestrial systems to detect microorganisms in soil samples, dietary analyses of scats and waterhole use by terrestrial species. Once refined, the eDNA approach can be used to detect a variety of taxonomic groups such as bacteria, viruses, fungi, plants, crustaceans, molluscs, invertebrates, fish, amphibians, birds and mammals.

Currently there are two major eDNA approaches:

(i) single species detection, or

(ii) metabarcoding.

Single species eDNA detection relies on the targeting of DNA using DNA probes (=primers) that will only amplify in the presence of DNA from the target species (i.e. relies on species-specific DNA primers). Most eDNA assays currently target single species and have been highly effective at detecting rare (e.g. sawfish; Simpendorfer et al. 2016) or invasive (e.g. tilapia; Robson et al. 2016) aquatic species in Australian tropical ecosystems.



Fish sampling. *Photo: Michael Douglas.*

Metabarcoding eDNA is a rapidly developing approach which is showing promise to be able to sample whole biological communities and is based around high-throughput next-generation sequencing methodologies. With metabarcoding, a taxonomic group-specific (i.e. teleost) universal primer is used to amplify DNA from all DNA in the water sample and then this DNA is mass-sequenced and computer algorithms used to probe sequence data against known species sequences in databases.

For a great review on eDNA see:

Rees, H. C., Maddison, B. C., Middleditch, D. J., Patmore, J. R., & Gough, K. C. (2014). REVIEW: The detection of aquatic animal species using environmental DNA–a review of eDNA as a survey tool in ecology. *Journal of Applied Ecology*, *51*(5), 1450-1459.

### 3.3.2 Current application in environmental monitoring

eDNA approaches are being used for many ecological investigations. These include detection of rare, endangered, cryptic and/or invasive species (including sawfish, amphibians, invertebrates), distribution of aquatic species, metazoan community biodiversity, microbial community biodiversity, community structure time-series analyses, changes in biological communities due to disturbances, and potentially biomass estimation. The eDNA methodology is applicable to any questions relating to the occurrence (and suggestively biomass) of aquatic organisms. It is also an effective tool to help prioritise field effort in remote and hard-to-reach locations.

Most eDNA studies to date have been in aquatic systems; however, they also can be applied to address environmental questions in terrestrial systems, particularly related to changes in microbial communities due to land practices, dietary analyses of grazing and predacious species, and access to waterbodies by land mammals. As an example, waterbody metabarcoding analyses at James Cook University regularly pick up genetic signatures of bovines, pigs, dingos and humans, along with aquatic species.

### 3.3.3 Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia

The eDNA/metabarcoding approach has broad applicability in northern Australia to determine the effect of various stressors (whether climate or anthropogenic) on aquatic and to a lesser extent, terrestrial communities. Metabarcoding for instance can be applied to survey changes in aquatic community biodiversity as a result of mining activities, introduction of new barriers to migration due to land changes, introduction of invasive pests/diseases (their spread and synergistic changes in impacted biodiversity), climate perturbations, etc. The species-specific eDNA approach can be used to more minutely examine habitat access and impeded migration of catadromous species as a result of changed land use.

### 3.3.4 Benefits and constraints

The benefit of the eDNA/metametabarcoding approach is that it is a relatively rapid and reliable technique to detect specific species or profile aquatic communities. It allows for rapid, remote, and wide-scale sampling to occur, as all that has to be collected is a water sample which is bought back to the lab. It also can help focus more in-depth field sampling using traditional approaches, as once a species is detected by eDNA there is confidence that the species will be present for further surveys. For example, this may help focus where to net for freshwater sawfish surveys.

The current constraints to the widespread use of eDNA are as follows.

a) Currently there have been limited DNA primer sets designed and proofed for Australian tropical species, particularly for invertebrates. To design species-specific primers for Australian aquatic organisms, sequence information is required from a large number of fauna to ensure that primer sets only amplify the target species.
b) Metabarcoding eDNA is similarly constrained by a lack of sequence information for the northern Australian aquatic fauna. The metabarcoding approach relies heavily on there being species sequences for the target genes in DNA databases. Without this large database, sequences that are returned from water samples will not be able to be matched to a particular species.
c) Preservation and transport of water samples from remote regions requires further investigation. Currently, DNA is either preserved by filtering in the field which increases effort and the likelihood of DNA contamination, or transport of 2 L water samples on ice to a lab with 48 hrs. Further knowledge needs to be generated on how long DNA will persist in shipped water samples before it degrades,

field-based preservation, along with the refinement of field-based filtering methodologies that make the process more efficient, particularly for turbid water systems

### 3.3.5 Possible research questions and areas for future development

a) Genetic audit of aquatic fauna at different taxonomic levels across northern Australia. A research project would focus on sampling and generating DNA sequence data for several key genes which then forms the bases for subsequent DNA primer design and metabarcoding.

b) Development of research methodologies for land animals and soil analyses.

c) Refinement of field preservation and sampling methodologies.

d) Can eDNA be used to estimate effective population sizes?

## 3.4 Using DNA-based methods for indirect estimation of population size and individual body condition in environmental monitoring

**Component authors:** Daniel Schmidt (Griffith University), Ryan Woods (Qld Government – DSITI)

### 3.4.1 Monitoring effective population size

**Description of technique**

Effective population size ($N_e$) is a key parameter for monitoring the genetic health of wildlife populations because it reflects a population's recent demographic history and future evolutionary potential. Traditional measures of population abundance such as counts may not represent the underlying effective size due to historical population fluctuations (e.g. bottlenecks) and reproductive variance which can reduce $N_e$ to a small fraction of census population size. Molecular estimates of $N_e$ can be used to compare demographic trends, either within populations (i.e. temporal monitoring), or between populations (i.e. spatial monitoring). Applications include temporal monitoring of threatened taxa for conservation management, temporal monitoring of harvested populations to assess sustainability, and spatial $N_e$ comparison of multiple populations for conservation planning.

Techniques involved in monitoring effective population size include genetic profiling of population samples using highly polymorphic genetic markers. A population sample consists of preserved tissue samples (or whole organisms) from ~30–100 individuals of the target species from the geographic area of interest. Larval stages or young-of-year fish are a good choice if available because sampling a single cohort reduces assumptions used in calculating $N_e$. Genetic profiling requires a molecular biology laboratory with skilled technicians. Statistical analysis and interpretation of results require collaboration with an experienced molecular ecologist.

Where the population sample consists of individuals of similar age, the data can be used to estimate the number of breeders ($N_b$) contributing to that cohort. This may be the most useful metric for monitoring contemporary demographic trends in a population of interest. Where the sample consists of individuals belonging to overlapping generations, estimation of $N_e$ may require additional information on individual sex and age that are less practical to collect in remote monitoring situations.

Emerging areas of new development include access to larger numbers of polymorphic genetic markers via Next-Generation DNA sequencing (NGS) methods.

**Current application in environmental monitoring**

Information on $N_e$ or $N_b$ is often incorporated into conservation management programs for endangered species. For example the well-known '50/500 rule' adopted by the IUCN Red list is based on the idea that threshold population sizes required to prevent inbreeding depression and retain evolutionary potential are 50 and 500 respectively.

Monitoring of $N_e$ or $N_b$ across successive years or generations can be used to assess trends in population growth or decline in a target species. One example is a 25-year study of grizzly bears in Yellowstone National Park which documented population growth since the 1980s (Kamath et al. 2015).

More commonly, assessment of $N_e$ or $N_b$ is incorporated into studies of spatial population genetic structure across the range of a given species. When combined with information on spatial variation in environmental variables, this information can be used to examine environmental correlates of recruitment success. We are using this approach at Griffith University to study spatial variation and environmental drivers of recruitment in a long-lived species, the Australian lungfish (*Neoceratodus forsteri*).

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

Any environmental driver/pressure/stressor that influences the demographic characteristics of a population or species could potentially be examined by monitoring $N_e$ or $N_b$. This technique is probably best suited to situations where there are particular focal taxa of interest. A species may be of interest due to conservation concern, or because of its economic importance, or because it is a sensitive indicator species.

**Benefits and constraints**

The benefit of monitoring population size using molecular markers is that it's an indirect approach that requires a DNA sample. Assessment of variation using DNA markers provides information on demographic quantities such as breeding population size that are difficult to obtain by direct observation.

The main constraint of this approach is that it requires a good quality DNA sample (i.e. fresh tissue sample) from a relatively large number of individuals (~30–100) to provide a reliable estimate of $N_e$ or $N_b$. For this reason, it is probably not an ideal method for remote monitoring in northern Australia. However, if there is a requirement to monitor demographic trends in particular focal species that are subject to targeted sampling, then this approach is probably a good one.

**Possible research questions and areas for future development**

Technical and analytical approaches are reasonably well established already, but continually refined in the literature.

Can eDNA be used to estimate effective population sizes? We are reasonably sure this has never been attempted because the molecular markers used in eDNA are different to those used for monitoring $N_e$ or $N_b$. However, we wonder if some sort of target-capture approach could be developed to extract suitable polymorphic markers from a water sample

## 3.4.2 Assessing individual body condition using RNA:DNA

**Description of technique**

Fish condition is often assessed to determine the well-being or robustness of individuals, populations and cohorts. Traditionally, estimates of condition have been measured by comparing morphometric measures, that are not effected by starvation against those that are, such as length–weight relationships (e.g. Fulton's K). The underlying theory behind morphometric measures is that for a given length, fish that weigh more have larger energetic reserves, as a result of resource-rich environments, and are thus in better condition than those that have a lower biomass. In addition, morphometric indices have been correlated to growth rate, muscle protein and lipid content, suggesting they are also an indicator of nutritional status. However, these indices are generally indicative of the environmental conditions spanning a timeframe of weeks rather than potentially critical but shorter time periods (Suthers 1998). This latency creates difficulties in making the link between fish condition (response) and the current state of the environment at the time of sampling (stressor).

An alternative to morphometric indices that value bigger, fatter fish are biochemical indices of the nutritional status of consumers, such as the ratio of RNA to DNA (Wagner et al. 2013). This technique measures changes in an individual's metabolic rate and thus its growth. The underlying premise is that faster-growing fish will have better survival potential than bigger fish alone, as it is the faster growth rate that has allowed them to become bigger successfully, and ultimately contribute proportionally more to recruitment (Suthers 1998). In essence, the RNA:DNA becomes an estimate for survival probabilities and thus an early predictor of recruitment success. This biochemical ratio reflects variations in instantaneous growth and nutritional condition because RNA concentration fluctuates with current food intake and protein requirements, whereas the somatic content of DNA remains constant (Chicharo and Chicharo 2008). Unlike the slow responsiveness of morphometric measures, metabolic activity can change within hours (Buckley et al. 1999), allowing change in the nutritional condition to be detected over much shorter timeframes and therefore allowing inferences to be made between the conditions at the time of sampling and fish health. Linking current environmental conditions (stressor), such as limited primary production, to the nutritional status of consumers (response) can provide evidence of the effect that human-induced impacts (pressures), such as flow alteration can have on the physiology, life-history, behaviour and recruitment success of individuals.

**Current application in environmental monitoring**

Numerous studies have used nutritional indicators of condition in ecological assessments of various pressures and stressors. An applied example of using RNA:DNA within a pressure-stressor-response framework is Woods (2012), that demonstrated a link between the extent of riparian cover and the nutritional status of two freshwater fish from Cooper Creek in Lake Eyre Basin. Increased riparian cover resulted in an increase in the condition of golden perch (*Macquaria ambigua ambigua*), that have been shown to consume lipid-rich terrestrial insects, while bony bream (*Nematalosa erebi*), that rely on algae for the bulk of their diets, showed decreased nutritional condition in response to the increased shading from high canopy cover. The approach has subsequently been applied to examine the changes in the condition of consumers in the Lower Balonne River (Murray–Darling Basin) in response to flow alteration (Woods et al. 2012). Other uses of the technique to monitor specific pressure, stressors and responses include:

- Condition assessments of barramundi (*Lates calcarifer)* health to monitor contaminant levels in North Queensland (Humphrey et al. 2007),
- Effect of catchment deforestation and urbanisation on the intensity and frequency of summer flooding and the subsequent impacts on Atlantic salmon larvae health (Arndt et al. 2002),
- Utilising the more sensitive larval fish RNA:DNA to determine quality nursery habitats for protection along an environmental gradient, where traditional estimates of condition (Fulton's K) had failed to detect differences (De Raedemaecker et al. 2012), and
- Determining the importance of the floodplain inundation in Kakadu National Park for energy acquisition in the diamond mullet (*Liza alata*), and the importance of the transfer of this energy back to waterhole environments to be utilised for reproduction (Villamarín et al. 2016).

**Measurement of environmental drivers, pressures, stressors or responses in northern Australia**

Monitoring RNA:DNA in fish or other consumers (e.g. invertebrates) in northern Australia provides a cost-effective, relative index to quantify the immediate response of regionally specific stressors and pressures at various spatial and temporal scales. For example, changes to the natural flow regime for water use may alter the flux of nutrients between floodplains and waterholes, thus resulting in reduced growth of individuals and ultimately lower recruitment success of cohorts. This method can provide insights into impacts from such changes long before impacts would be detected in coarser estimates like species abundance. The index also provides a rigorous measure of ecosystem condition to monitor health through time as part of routine monitoring programs. The information from routine monitoring can be used detect change and to predict impacts from future changes to various stressors. For example, primary production may be suppressed following increases in suspended sediments following large flooding events leading to a reduction in growth of larvae. The response of RNA:DNA in individual fish can be used to predict likely impacts from pressures that may also increase turbidity, such as land clearing. In addition, the index is also suitable to test hypotheses in relation to localised impacts, such as pollution or contamination. The application of this index is best suited to test the specific effect that high-risk, regionally specific pressures and stressors have on the growth and survival of individuals and thus cohort success.

**Benefits and constraints**

The main benefits of the technique are the sensitivity and timeframe in measuring an ecological response to an environmental change. This provides a tangible cause-and-effect relationship that is often missing in monitoring approaches. The processing of tissue sampling in the field requires little training and can be readily added to traditional fish sampling protocols with very limited increases to time or cost. Laboratory methods are now well researched and documented, and specific protocols are easily acquired and performed by trained molecular ecologists at very low prices (< $2 a sample). Constraints of the approach relate to issues surrounding sample size (variability in the response metric), size dependency (larvae–adult), sex and reproductive state, temperature dependence, baseline species-specific validation (e.g. when is starvation causing detrimental impacts) and minimum and maximum thresholds of concern (Chicharo and Chicharo 2008). These issues would be ideal targets for future research, but would not hamper the methods immediate and effective application.

**Possible research questions and areas for future development**

Although the use of RNA:DNA has become widespread, several issues still require further development:

- Size dependency: can the index be applied to all size classes or should it be restricted to larvae?
- Test and reference site approach to test conceptual understanding of responses from various stressors.
- Wild-caught vs. lab-reared fish: laboratory calibration under different stressors and starvation gradients to determine minimum and maximum values and inferences from wild-caught fish.
- Multi-index calibration: combining RNA:DNA measures with estimates of growth from otolith edge estimates of growth.
- Heritability: some evidence suggests RNA:DNA maybe inherited from parents and therefore genetically controlled, i.e. higher ratio in parents results in faster growing offspring (Domingos et al. 2014).

## 3.5 Use of biochronology for measuring fish production in environmental monitoring

**Component author:** John Morrongiello (University of Melbourne)

### 3.5.1 Description of technique

Fishes have important social, cultural and economic value to the peoples of northern Australia, and they also fulfil essential roles in both marine and freshwater ecosystems. Environmental, biological and anthropogenic factors all affect fish population dynamics and life history characteristics such as growth, recruitment and age and size at maturity. We need to understand how these key biological metrics are tracking and how they are affected by environmental change if we are to adequately manage our valuable aquatic environments. To do this, we need long-term monitoring data. Monitoring the status of fish populations can, however, be difficult, labour-intensive and expensive because of the relative inaccessibility of aquatic habitats and the intractability of working with often large, long-lived animals.

The unique age and growth information naturally archived in fish otoliths ('ear bones') offers an opportunity to quickly develop biological time series (a biochronology) for species and locations that we otherwise know little about. Analogous to tree rings, otoliths contain increments that can be used to recreate an individual's growth history over many years as well as estimate year-to-year variation in fish recruitment (Morrongiello et al. 2012). Fisheries scientists routinely use otolith-derived information to determine fish age and overall growth rate for inputs into their fisheries assessment models. A similar approach could prove useful for monitoring the status of key fish species in northern rivers, estuaries, and marine environments. This would require the periodic (e.g. every few years) collection of fish samples from a location and the subsequent generation of growth and recruitment time series. These data can then readily be used to predict the response of fish to broader environmental change such as river flow variation and commercial or recreational fishing (e.g. Morrongiello et al. 2014, Morrongiello and Thresher 2015). The information encoded in annual growth increments in otoliths remains an under-utilised and potentially powerful monitoring tool to extract detailed information on temporal and spatial effects on fish ecology and the factors that affect their populations.

Recruitment and growth are key determinants of animal population productivity and both are sensitive to changes in the environment. When conditions are good, fish will grow faster and more fish will successfully survive the larval phase and join the adult population, a process known as recruitment. Understanding what 'good conditions' are for a species is, however, a difficult process. It requires detailed observations or experiments that may not be feasible for a given species or location context. Otoliths provide a unique archive of an individual's growth across its lifetime as well as its age, two pieces of information that can be used to understand what conditions promote population productivity. As a fish grows, material is deposited onto the otolith at a rate proportional to somatic growth (Campana 1990). These age-dependent growth estimates can be combined using models (Morrongiello and Thresher 2015) to recreate time series of population growth that can be related to environmental drivers (Morrongiello et al. 2012). Likewise, the age information naturally archived in fish otoliths can be used to recreate population age structures and, in conjunction with known date of capture, estimate an individual's year class. This information allows for the quantification of year class strength, i.e. whether a given year was good or bad for recruitment (Staunton-Smith et al. 2004, Morrongiello et al. 2014, Jenkins et al. 2015).

Growth and recruitment time series can be easily developed using the same otolith sample and the required data collected at the same time. These techniques require the periodic collection of fish from the environment and their otoliths prepared (mounted in resin, sectioned using special saw) for viewing under a microscope. An image is taken of the otolith and the number of increments counted (gives estimate of fish age) and their widths measured (gives estimate of age-dependent growth rate). New samples can be combined with existing archived otolith collections to extend the temporal extent of biological time series.

### 3.5.2 Current application in environmental monitoring

The growth and recruitment techniques proposed here are rarely used for explicit environmental monitoring, although their use in such a format has been advocated (Morrongiello et al. 2012, Izzo et al. 2016). Rather, these techniques are used primarily in an ecological sense whereby researchers once-off develop a growth or recruitment time series and explore their relationship to environmental drivers. Growth and recruitment time series can, however, be regularly updated with new data to improve biology–environment model predictions and also provide an explicit measure of the process in question (i.e. population productivity). Indeed, otolith-based age information for fished populations is regularly collected and integrated into fisheries assessment models where it helps resource managers to accurately estimate current and future stock biomass and in turn, set fisheries catches (e.g. Flood et al. 2014). The utility of the growth and recruitment time series techniques proposed here are not restricted to just fish otoliths. Many marine and freshwater organisms regularly deposit material in carbonate or siliceous 'hard parts' and similar growth and recruitment techniques have been applied to good effect on these animals (reviewed in Morrongiello et al. 2012), including studies spanning aquatic and terrestrial environments in northern Australia (Ong et al. 2016).

### 3.5.3 Measurement of environmental drivers, pressures, stressors or responses in northern Australia

Growth and recruitment are key biological parameters that underpin population productivity and provide a readily interpretable, temporally resolved, metric of a fish's response to a range of pressures. Variability in growth and recruitment can be driven by one or many pressures and thus they can be seen as integrators of the effects of environmental change. Statistical models relating these responses to environmental variables (Morrongiello et al. 2014, Morrongiello and Thresher 2015) can be used to identify key drivers (e.g. climate variability) and pressures (e.g. reduced stream flow) that can be monitored independently. Once biology–environment relationships are developed, fish growth and recruitment could be used as proxies for hard-to-measure pressures such as changes in habitat quality (Izzo et al. 2016).

The development of biological time series for key species can be used as indicators of overall ecosystem health. For example, detailed food web analyses could initially be used to parameterise relationships among predators and their prey and subsequently the growth of the predator as inferred from otolith analysis would provide information on the status of prey populations.

### 3.5.4 Benefits and constraints

The relative inaccessibility of much of northern Australia means that monitoring techniques are ideally operated remotely or can be quickly and efficiently performed on-ground. A key benefit is that the samples required to develop otolith-based growth and recruitment time series can be quickly collected from a location, and these sampling events can be conducted every few years to even a decade (although ability to rapidly detect change is diminished with longer timeframes). The proposed techniques can then 'infill' data for the times when no physical samples were collected because the otoliths themselves are continually recording biological responses to environmental conditions. Another benefit is that growth and recruitment time series provide biologically relevant metrics for important species that we might not know a great deal about or have difficulty surveying using other field techniques, from an environment (underwater) that is notoriously hard to monitor. Growth and recruitment time series for co-occurring species can be generated and compared to assess commonalities and differences in response to environmental conditions. Further, the biology–environment models that can be developed from analysing time series can be used to provide much-needed biological context to purely physical parameters that might also be monitored (i.e. provides a tangible impact for changes in river flow, temperature or habitat extent).

Potential drawbacks of the proposed otolith-based approaches include: the processing time/cost of samples in the laboratory, coarse detectability resolution if sampling events are spread out through time whereby evidence for a biological change might be found years after the change occurred, and the destructive nature of sampling (fish is killed) which might not be appropriate for species of conservation concern.

### 3.5.5 Possible research questions and areas for future development

- How do proposed dams or water extractions affect the productivity of barramundi and mud-crab fisheries?
- What is the current demographic status of key species of conservation concern, and is this changing through time?
- How are estuarine fishes responding to changes in sea level and consequent saltwater inundation of mangroves and coastal wetlands?
- Is commercial and recreational fishing impacting on the viability of targeted species?
- Can we develop metrics to rapidly assess the current status of data-poor fished species?
- Does temperature change affect fish growth, and what does this mean for populations under future warming scenarios?

### 3.5.6 Using field-based stable isotope techniques for tracing water sources and greenhouse gases in Environmental Monitoring

**Component author:** Dr Niels Munksgaard, Charles Darwin University

### 3.5.7 Description of technique

The stable isotope ratios $^{2}H/^{1}H$, $^{18}O/^{16}O$, $^{13}C/^{12}C$, and $^{15}N/^{14}N$ have long been used to trace the sources, transport and reactions of liquid water, water vapour, carbon dioxide, methane and nitrous oxide in the environment. However, recent technological advances have enabled isotope data to be collected in the field at high spatial and temporal resolution at minimal cost. The new generation of instruments are portable, have low power requirements, can be mounted in cars, boats and planes and, when linked to Global Positioning Systems, can map gas emissions in unprecedented detail.

Environmental applications include: (i) tracing the hydrological cycle: moisture sources, precipitation, groundwater recharge and river runoff (Munksgaard et al. 2011 and Munksgaard et al. 2012); (ii) hydrograph separation: sources of river flows (Tweed et al. 2015); (iii) agricultural water management: separating soil evaporation and plant transpiration (Williams et al. 2014); (iv) tracing the carbon cycle: landscape management (Munksgaard et al. 2013); (v) greenhouse gas accounting: tracing environmental and anthropogenic (e.g. coal seam gas) sources of carbon dioxide and methane (Maher et al. 2014); and (vi) cycling and removal of nitrogen in waste water treatment plants (Munksgaard 2015).

### 3.5.8 Current application in environmental monitoring

See for example: http://www.picarro.com/technology/stable_isotopes and

http://www.lgrinc.com/analyzers/isotope/

Water isotopes:

1. Identifying the source of water.
2. Tracking food to its point of production and revealing adulteration.
3. Identifying growth condition of plant systems.
4. Exploring climate history by analysing ice cores.
5. Understanding the flow of ocean waters.

Carbon isotopes:

1. Understanding how carbon is exchanged between the atmosphere and ecosystems, such as oceans, soil and plants.
2. Monitoring carbon geo-sequestration sites.
3. Verifying food origin and authenticity.
4. Substantiating supply chain integrity.
5. Determining the carbon source in dissolved carbonates.
6. Identifying and partitioning the sources of fugitive methane gas emissions.

Nitrogen isotopes:

1. Distinguishing $N_2O$ production sources from nitrification and de-nitrification on the basis of isotopomer abundances.
2. Identifying and partitioning $N_2O$ emission sources.
3. Understanding how nitrogen is exchanged between the atmosphere and ecosystems, such as oceans, soil and plants.
4. Understanding dissolved nitrogen in aquatic systems.

### 3.5.9 Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia

- Identifying water sources and loss.
- Greenhouse gas accounting.
- Waste water monitoring.
- Groundwater source and quality monitoring.

### 3.5.10 Benefits and constraints

Benefits include:

1. Stable isotopes provide a 'fingerprint' of molecules, allows for tracking of sources and transport/reaction history,
2. New generation of IRIS instruments are portable allowing field deployment and therefore the capture of unprecedented spatial and temporal detail, and
3. Cost of data collection is a small fraction of previous techniques which required discrete sampling in the field followed by later costly laboratory bound analysis.

Constraints include the need for reliable power sources and security of equipment if left in the field, potential for reliability issues with new technology.

### 3.5.11 Possible research questions and areas for future development

1. Oxygen and hydrogen isotopes: Apportioning of source water for river flow and groundwater (e.g. Daly River).
2. Carbon isotopes: Mapping and monitoring of gas emissions (carbon dioxide and methane) from potential coal seam gas/shale gas developments in the NT, including baseline mapping.
3. Nitrogen isotopes: Optimisation of waste water treatment plants.

# 3.6 Using animal audio for species detection in environmental monitoring

**Component author:** Lin Schwarzkopf (James Cook University)

## 3.6.1 Description of technique

While there is some information on the geographic locations of various vertebrate species available in databases, there are a variety of reasons why we may require more. Detailed studies of species or assemblages may require information on presence, absence, or activity, for a variety of purposes, such as determining the influence of anthropogenic or natural disturbances (e.g. land use change, grazing, fire, urbanisation, logging, climate change), or we may require information on threatened or rare species, for which such information is scare.

Traditional fauna monitoring is typically conducted using traps and active searching for fauna, using a crew of two or more individuals trained to identify fauna. Traditional audio surveying is typically done by 'point count' in which a trained observer stands at a single point and records all fauna (typically birds or frogs) seen or heard, for a defined period, typically 20–30 minutes. Fauna monitoring using trapping or listening and observing is highly effective, but is limited primarily by the time observers spend at the field site. Seasonal fluctuations in species activity can decrease detection of some species at some times, and similarly, rarity may make it less likely that species will be detected during traditional fauna surveys.

Autonomous Recording Units (ARUs) provide an opportunity to record the presence or absence of vocal species over very long periods of time (up to a year, at the moment) (e.g. Acevedo & Villanueva-Rivera 2006). Once recordings have been made, data on species and time of calling can be obtained from recordings in a variety of ways. First, someone trained in audio recognition of target species can listen to the recordings, and determine which species were calling when. This is effective, but prohibitively time-consuming, as the entire recording must be processed in real time by a trained observer. Alternatively, there are a variety of computer-based techniques that can be used to increase the probability of detecting calls in the recorded data. These can be used to narrow down the range of material that must be processed by listening to detect calls, or they can be used to detect the calls themselves. Computer-based 'recognisers' use algorithms of various types that detect patterns in the data that are likely to be the calls of various species.

## 3.6.2 Current application in environmental monitoring

Comparisons of traditional audio surveys with ARUs suggest that during the 20–30 minutes of a traditional point count, a human observer present at that location is more effective at detecting species (i.e. detects more species), first because humans may see individuals that are not calling, but also because the observer may distinguish distant or indistinct calls better in person than from a recording. If a computer-based recogniser is used to detect calls, the success of call recognition is influenced by environmental noise, and the distance between the calling individual and the recorder, further reducing success at detection in any 20–30 minute period. On the other hand, over long periods of time, and at times of seasonal change, ARUs with call recognisers detect more species than humans conducting multiple point counts over time (Klingbeil & Willig 2015).

The success of computer-based recogniser algorithms varies greatly dependent on the characteristics of call the algorithm is designed to detect (i.e. whether the call includes distinctive patterns or frequencies), and its distinctiveness from background noise. In addition, recognisers can be optimised to work well in one environment, but may not work well in an area with different levels or types of background sound. At present, the best results for recogniser algorithm use are obtained from iterative processes in which a human is used to 'tag' or identify a large number of sounds in a recording, a neural network recogniser is developed to distinguish calls, and then a human checks the success of the identifications, and the algorithm is improved (Wimmer et al 2013).

#### Bioacoustics versus ecoacoustics

Surveys and ARUs can be used, as described above, to describe the presence, absence or activity of individual species, and the results from different species, e.g. from a series of different recognisers, or from human data processing, or both, can be compiled to describe the activity of groups of species, or assemblages. Such approaches are often referred to as 'bioacoustics' studies (Sueur & Farina 2015). However, a different approach is to examine entire soundscapes, and avoid attempting to identify species. Such approaches are typically referred to as 'ecoacoustics' studies (Sueur & Farina 2015). Ecoacoustics or soundscape studies examine and classify acoustic signatures of whole ecosystems.

Typically, such studies use either one or several acoustic indices, which provide some measure of aspects of the soundscape relevant to biodiversity, such as indices of complexity or activity, signal-to-noise ratios, spectral diversity, duration of acoustic events, etc. (summarised in Sueur et al 2014, and assessed in Towsey et al. 2014).

There is some evidence that ecoacoustics can be used effectively to distinguish among similar ecosystems, for example among woodlands in Greece (Bormpoudakis et al. 2013). In addition, this technique has been used to examine the impact of anthropogenic sounds (anthropophony) on animal acoustic activity (biophony). Acoustic indices tend to be lower in areas with large amounts of anthropogenic sound, consistent with our expectations that humans have a negative impact on biodiversity, and suggesting such indices can be useful to measure impacts (Tucker et al. 2014).

While such approaches have promise, they do not focus on species recognition and identification or evaluation.

**Bringing bioacoustics and ecoacoustics together**

Importantly, however, acoustic indices can be used to narrow down the search for biologically relevant sound in very long recordings. Towsey, Wimmer et al. (2014) used acoustic indices to narrow down the search for relevant sounds, and greatly increased the success of call identification and descriptions of an avian assemblage over random sampling small segments.

Techniques to visualise and search through large amounts of data are continually being developed and improved, and this is an area of great research activity at this time (Towsey, Zhang et al., 2014).

### 3.6.3 Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia

Acoustic monitoring has great potential for measurement of environmental drivers, pressures, stressors or responses in northern Australia, for a variety of reasons. Firstly, ARUs can deployed in remote areas (including much of northern Australia), and used to record vocal species for long periods, providing a rich data set on species activity, presence, and absence, unobtainable in any other fashion. Secondly, the data collected can be correlated with environmental data obtained in various ways (by local monitoring or other monitoring, such as that conducted by the Bureau of Meteorology) to determine the environmental drivers of biological patterns, such as breeding phenology. Comparing the results from recording locations with more or less anthropogenic impact can be used to detect anthropogenic pressures or stressors. One interesting project of this nature would involve adding acoustic monitoring to existing experiments, for example feral animal (pig) exclusion experiments occurring in northern Australia. By comparing the acoustic environment in replicate pig-access and pig-exclusion areas, it may be possible to determine the influence of pigs on frogs, and possibly small birds. Similarly, acoustic monitoring could be used to detect rare but habitat-associated species, such as purple-crowned fairy wrens, by placing ARUs in their preferred habitat and 'listening' for them.

### 3.6.4 Benefits and constraints

This method has many benefits, because ARUs can be placed in a single location and allowed to remain there for long periods, limiting the number of visits required to remote areas (including nearly all of northern Australia). ARUs are non-invasive, relatively inexpensive devices that can typically store a large amount of data. A disadvantage of ARUs is that they are restricted to detecting the presence of vocal species only, which includes birds, frogs, insects, some reptiles, and some mammals (and fish and aquatic invertebrates if deployed aquatically), but does not include some mammals and many reptiles. Another, perhaps surprising, disadvantage of ARUs is that the analysis of sound has lagged greatly behind the ability to collect it, so analysing the data collected by ARUs can be challenging.

### 3.6.5 Possible research questions and areas for future development

I have already discussed several concrete examples in which ARUs could be deployed to conduct research projects, for example in the case of monitoring the impacts of feral pigs, and in the case of detecting purple-crowned fairy wrens. We are hoping to deploy them to detect southern black-throated finches. The possible uses of ARUs and the recordings obtained are very broad. They could, for example be used to monitor the effects on wildlife of agricultural intensification in the north, by recording in impacted areas, and pristine areas, and comparing them, or by conducting BACI (before-after-control-impact) designs to compare sites before and after development with control sites.

**Future development**

One method that can be used to increase call detection, which has not to my knowledge been used before in acoustic detection research, is call playback. Many species will answer a recorded call if played to them (e.g. Catchpole & Slater 1995; Gerhardt & Huber 2002) and therefore, it may be possible to elicit the calls of rare or cryptic species by playing a call, then listening for it shortly after the playback. There is a great need for research and development into this technique, to determine if it can be used effectively to increase detection of desired species in long-term recordings.

Similarly, a great deal more research is required to develop methods to store, retrieve, and process the data collected using this technique. The sheer size of the data sets makes them unwieldy, and the enormous amount of information in them requires specialised techniques for data processing. Visualisation of large data sets is a difficult problem that needs development of approaches.

In general, this is a nascent technique with great potential as a monitoring tool for remote areas.

## 3.7 Using terrestrial-based cameras in environmental monitoring

**Component author:** Graeme Gillespie (Department of Land and Resource Management, NT Government)

### 3.7.1 Description of technique

Automated cameras, known as 'camera traps' or 'remote cameras', collect still photos or video to verify the presence of species at a particular point in space and time. There are three types of camera traps currently used for sampling wildlife. Most are triggered by infrared sensors. These fall into two categories: passive infrared (PIR) and active infrared (AIR). PIR sensors detect moving objects within the sensor's detection zone that are a different temperature to that of the background environment. PIR systems have a single sensor component and in most camera units, the sensor is integrated into the camera housing. PIR camera traps take still images but some models can also take video. AIR systems are activated when an object breaks an invisible narrow beam of infrared light that extends between a transmitter and a receiver. The transmitter and receiver units of an AIR system must be properly aligned for the unit to function correctly. In AIR camera systems, the transmitter and receiver units are separate from the camera and connected by an electrical cable. AIR systems can be set up to take still images or for video (see Meek et al. 2014; Gillespie et al. 2015). The third type of camera trap does not rely on sensors but automatically takes still photos at set time intervals (autonomous cameras). Some commercially available PIR camera traps can also be programmed to do this.

PIR camera traps are the most widely used and readily available type of camera trap. They detect animals moving within a zone of detection radiating outwards in front of the sensor. Autonomous cameras have a similarly defined detection zone but automatically take photos irrespective of the presence or movement of animals. Time and date-stamped images are stored on SD cards that can be downloaded into a computer (see Gillespie et al. 2015). Data collection volume is only limited by memory card capacity and battery life. Depending on the circumstances, cameras can be successfully deployed and operated for several months at a time. Some camera traps can be hooked up to solar battery chargers for longer deployments.

The majority of camera traps that are currently commercially available comprise a compact digital camera activated by PIR sensors. The main advantage of PIR-triggered cameras is their ease of use by a single operator with minimal training and experience. Commercially available camera traps are compact and lightweight, and have a wide range of features. These include but are not limited to: either white light or infrared flashes; continuous (i.e. 24-hour) or day or night only operation; a range of delays between successive photographs, and sensitivity settings that allow the sensitivity of the sensor to be adjusted so as to minimise false-triggering (see Meek et al. 2015). Numerous PIR camera trap models are commercially available, ranging from under AU$200 to around $1000. Like most things, you get what you pay for (Meek et al. 2015), and the top-of-the-range camera traps are currently the most amenable for ecological and environmental applications.

For most applications, one or more cameras are deployed concurrently at a set of sampling sites for a defined sampling period (days, weeks or months) (Rovero et al. 2013). Depending upon the question and objectives, cameras can be set up in conjunction with lures or baits, or in specific habitat locations, to increase probability of detecting target species. A wide range of deployment set-up methods have been developed to increase detection of various species of interest (Meek et al. 2014, 2015; Gillespie et al. 2015). Camera traps can also be deployed in conjunction with other sampling devices and data loggers to record concurrent temporal environmental variability.

### 3.7.2 Current application in environmental monitoring

Camera traps are currently being used worldwide for a wide range of applications (Meek et al. 2014; Gillespie et al. 2015).

- General biodiversity inventory surveys: camera traps are used in conjunction with other standardised sampling methods, such as conventional traps or visual encounter censuses, to systematically document spatial patterns of vertebrate biodiversity, including species richness and composition.

- Targeted wildlife surveys: camera traps are used, either exclusively or in conjunction with other sampling methods, to determine the spatial distribution of species that are amenable to camera trapping.
- Population density estimation: an array of cameras is used to identify the population density or spatial distribution of individuals of a species.
- Monitoring, in order to document changes in occurrence and distribution of individual species or a suite of species over time.
- Management evaluation, in order to document changes in species occurrence or species composition through time and space, in response to specific environmental management interventions, such as pest management or fire management.

### 3.7.3 Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia

PIR camera traps are already being used extensively across northern Australia to collect data on a wide range of species for a variety of purposes in a wide range of environmental settings. These include: surveys, ecological studies, and monitoring and evaluation of fauna in general, threatened species and invasive species. The following examples demonstrate the potential of camera trap technology to augment existing methods of monitoring and evaluating responses of fauna to environmental drivers, pressures and management across northern Australia.

Diete et al. (2016a) used camera traps in conjunction with other mammal sampling methods to determine the current distribution and conservation status of the northern hopping mouse (*Notomys aquilo*) on Groote Eylandt. Camera traps proved to be the most sensitive method for detecting this species, and are currently being used on Groote to investigate potential relationships between threatened mammal distribution, feral cat occurrence and fire regimes (NT Department of Land Resource Management unpublished data).

Camera trapping methods have been developed and deployed in the Kimberley and on Groote Eylandt to monitor northern quoll *(Dasyurus hallucatus*) population densities and survivorship. Photo identification of unique spot patterns on coats of the quolls enables individual animal recognition and application of robust mark–recapture population estimation methods (Hohnen et al. 2013, Diete et al. 2016b).

Feral cats have been identified as one of the major threats to vertebrate biodiversity in northern Australia, but until recently their low population densities, cryptic nature and avoidance of traps has greatly limited investigations of their ecology, distribution or monitoring their populations. McGregor et al. (2015) used camera trap arrays to estimate feral cat densities and evaluate factors influencing their density in the Kimberley. Stokeld et al. (2015) developed camera trapping methods to greatly improve sensitivity of detection of feral cats for survey and monitoring programs in the Top End of the NT.

Camera traps have been used to evaluate the influence of fire regimes and feral herbivores on native mammal species at Fish River Station in Top End of the NT (Risler et al. unpublished data). A National Environmental Science Programme project has recently commenced in Kakadu National Park that will principally use camera traps to monitor the responses of native mammals and other threatened species to integrated enhanced fire and feral herbivore management and suppression (http://www.nespnorthern.edu.au).

The NT government, in conjunction with Kakadu National Park, has established a network of long-term fauna monitoring sites across Kakadu, Litchfield and Nitmiluk National Parks. Data from this monitoring program continue to be the principle source of evidence of the marked decline of northern Australian mammals (Ziembicki et al. 2015). Recent camera trapping trials in the NT have demonstrated that detection probabilities of many mammal species derived using camera traps far exceed those from conventional sampling methods, demonstrating that camera traps are likely to be powerful tools for detecting future changes in mammal populations. This monitoring program is currently being revised and expanded to additional protected areas, incorporating camera trapping in the sampling regime (NT unpublished data).

Other land management organisations, including conservation NGOs, Indigenous Protected Areas and other Indigenous ranger groups, are also incorporating camera trapping into their methods for monitoring and evaluating their land management activities and biodiversity. Camera trap technology and methods are constantly evolving. With some refinements, it is likely that in the future camera traps of various kinds will become integral tools of trade for most forms terrestrial fauna monitoring and evaluation.

### 3.7.4 Benefits and constraints

**Benefits**

Sampling sensitivity and high detection probability are the currency of effective environmental and biodiversity monitoring programs. One's ability to detect change is directly contingent on the sensitivity of the measuring devices used to detect the thing(s) one wishes to measure. Because many organisms move or are otherwise not always detectable, all sampling methods have imperfect detection, meaning that there is invariably a probability of the species not being detected when it is actually present at a sampling site. The lower the detection probability (for a given sampling method), the weaker the ability to detect changes in state, and therefore the weaker the monitoring program design. This is a particular problem for rare or otherwise cryptic species, or those that require a lot of sampling effort to detect. For many terrestrial mammal species, native and invasive, and some bird species, detection probabilities are much higher with camera traps than those achievable with any other sampling methods. This is not only the case for many rare or cryptic species but also many common and widespread species. Camera traps therefore enable a much greater sampling sensitivity for a wider arrange of species than was previously possible.

As for any fauna sampling method, detection probabilities of species are sensitive to deployment methods and potentially observer/user bias. Like many wildlife sampling methods, the effectiveness of camera traps and consistency of data acquisition are sensitive to subtle variation in set-ups and deployment methods. However, because the actual data collected are stored images, the characteristics and consistency of camera deployments can be evaluated objectively and accounted for in analysis and interpretation. This is more difficult and rarely undertaken with other wildlife sampling methods.

A workable set of 50 decent PIR camera traps and associated equipment needed to operate a basic fauna monitoring program will cost about AU$55,000. Whilst this up-front cost may appear high compared with that of other conventional sampling methods, this is offset by considerable savings in personnel and field-based time. Several cameras can be deployed at a site in less than one hour, and at several sites in a day. Sites only need to be revisited once to recover the cameras. There are some additional personal time costs associated with image processing; however, considering the sampling effort in order to achieve similar detection probabilities, conventional sampling methods are more expensive. Camera traps also have the advantage of efficient continuous data collection at remote locations for long periods of time (weeks or months).

In contrast to many other wildlife sampling techniques, camera traps are relatively non-invasive, as animals don't need to be physically captured or handled as part of the survey. From an ethical and animal welfare point of view, remote camera surveys are only minimally intrusive, with impacts on animals limited to minor disturbances caused by flashes and camera noise, and behavioural responses to baits and minor habitat disturbance. For these reasons, animal ethics committee approvals and wildlife research permits are still required for implementing remote camera surveys in all jurisdictions (Gillespie et al. 2015). Nevertheless, camera traps are a much more accessible tool for a wide range of practitioners to collect wildlife information, including park managers and rangers, Indigenous land management groups, environmental consultants and students and naturalists.

Several projects have demonstrated that camera traps are highly accessible and engaging for Indigenous rangers and traditional land owners. With appropriate training, Indigenous rangers are able to deploy, recover and download data from camera traps, either in collaboration with other partners, or as part of their programs (Stevens and Mahney 2016; Risler et al. unpublished data).

**Constraints**

Current PIR camera trap technology is mostly amenable to sampling mammals, and birds to a lesser extent, due to their thermal signatures. To date PIR cameras have been relatively ineffective at sampling reptiles and amphibians, as their body temperatures are similar to that of background environments in northern Australia and do not readily trigger PIR sensors. More sensitive sensors and better sensor configurations may improve this situation in the future. Autonomous cameras also have potential to improve detection rates for reptiles; however, this has yet to be properly trialled in northern Australia.

For PIR camera traps, there is marked variability in detection sensitivities amongst different mammal species due to behaviour and size differences. In particular, PIR camera traps are poorer at detecting small mammals (e.g. mice or small dasyurids) compared with large rats, bandicoots or possums. Small mammals have a small thermal signature which is less detectable against relative warm background environments in the tropics. Different deployment methods are required to maximise detection of a wide range of species. To date, very small mammals, such as planigales, have not been detected on camera traps in the tropics. Improved sensor configurations may be necessary to achieve this.

Some groups of mammals such as rodents and small dasyurids can be difficult to identify from photographs alone. Identification could be improved with better camera optics and higher resolution images. However, some species can only be confidently identified from examination in the hand, and it is likely that in the future some taxa will only be able to be confidently assigned to a species with a tissue sample for genetic analysis. For broad-scale fauna monitoring programs, this is not a major limitation; however, if more detailed information is required on animals, such as genetic material, body condition and health metrics, then other sampling methods will be necessary.

Northern Australian environments place significant constraints on the application of current camera trap technology. In hot places or during warm seasons and times of day, the temperature differential between endotherms and the background environments inadequate to trigger camera traps. For some animal groups, the temperature differentials across northern Australia may never be adequate for PIR camera traps.

Fire is a frequent event in dry season fieldwork in northern Australia. Steps can be taken to minimise the impact of fire on camera trap monitoring, but some loss of data and equipment is almost inevitable in large-scale dry-season sampling. In northern Australia, camera traps are frequently attacked by some mammal species or infested with ants, often resulting in damage to components and data loss.

Virtually all of the camera traps currently commercially available have been designed to detect large mammals for recreational or security purposes, not for ecological research or monitoring. Many of the problems and limitations outlined above could be addressed by developing a camera trap that was specifically designed to deal with ecological requirements and built to withstand some of the harsh conditions in northern Australia. Several review studies have suggested optimal camera designs for wildlife ecological studies (Meek and Petit 2012; Glen et al. 2013).

### 3.7.5 Possible research questions and areas for future development

**Methodological developments**

- Development of methods for increasing detection of small mammals and reptiles.
- Evaluation of the effectiveness of autonomous camera traps for reptiles, and their potential complimentary use with PIR sensor cameras.
- Evaluation and development of standardised deployment and equipment methods across northern Australian ecosystems.

**Technological developments**

- Development of robust web-based camera photo database systems that streamline data transfer from camera to analytical platforms, and are accessible to a wide range of users with different needs.
- Development of species recognition software for automated species detection and recording from images.
- Development of camera traps more suited for wildlife ecology, such as improved sensor designs and optics.
- Development of cost-effective, compact motion-only AIR camera traps.

## 3.8 Using aquatic-based cameras, audio and sonar in environmental monitoring

**Component author:** Brendan Ebner (TropWater, James Cook University)

### 3.8.1 Underwater camera

**Description of technique**

Camera-based techniques involve collected images via still photography or in the form of moving picture (video) to verify the presence and, in some cases, absence of taxa. Cameras can be manually or remotely activated and these techniques are integral to fauna studies in deep ocean environments including at depths beyond safe and practical limits for SCUBA diving (Priede and Merrett 1996). Video-based ecological studies are also increasingly prominent in shallow-water marine, estuarine and freshwater environments (Murphy and Jenkins 2010, Ebner *et al.* 2014, Mallet and Pelletier 2014). Interesting areas of new development include monitoring relative abundance of taxa and/or their behaviour in response to long-term shifts in environmental variables (e.g. Boom *et al.* 2014, Beyan *et al.* 2015), and combining underwater video with other techniques such as large-scale habitat mapping or animal telemetry (Murphy and Jenkins 2010). The increase in affordability of underwater video cameras has led to its widespread use (Harvey *et al.* 2007).

Species richness is measured as a surrogate for biodiversity. Underwater video provides and affordable means of estimating species richness or contributing to multiple-survey-method based assessments of macro-faunal assemblages. In this regard, cameras can sometimes provide evidence of species that elude conventional techniques. Single images or video provide lasting records of aquatic fauna (and flora and habitats) that can be manually or automatically screened and processed for data collection. In some instances where rapid assessments are conducted, baits are used to attract fauna to cameras.

**Current application in environmental monitoring**

Underwater video is being used widely in marine environments, notably on tropical coral reefs and temperate reefs to assess species richness of mobile and sessile fauna including in relation to marine parks and human activity based on manual and remotely deployed cameras (Malcolm *et al.* 2007). Video and still imagery is being used to monitor the dispersal, growth and behaviour of individuals and populations including high-profile species (Arzoumanian *et al.* 2005). Fixed continuous cameras are being used on coral reefs (Boon *et al.* 2014, Beyan *et al.* 2015) and in abyssal depths (Berta *et al.* 1995, Vardaro *et al.* 2007). In freshwater systems,video-based applications are arguably less central to environmental monitoring, though success has been had with monitoring pest and threatened species populations (e.g. Weyl *et al.* 2013).

Black catfish. *Credit CDU & ERISS.*

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

Underwater video can be used to measure macrofauna assemblages in terms of species composition, relative abundance, body size and behavioural interactions. Two of its primary strengths are visual identification of species and providing observational records of biotic and biotic–abiotic interactions. This affords a flexibility for interpreting complex scenarios where multiple drivers, pressures and responses play out. For instance, a shift in the fauna and flora associated with increased urbanisation and the associated pet/aquarium/pond releases, garden nurseries, etc., can be detected in terms of newly recorded species and changes in their interaction with endemic biota, through to scenarios of species loss. Long-term photographic (or video) records also provide capacity for reconstructing changes in abiotic context (e.g. benthos condition, riparian bank condition, water clarity), though these would require consideration of scale and repeatability including above and below-water image capture (including mobile video).

**Benefits and constraints**

The advantages and disadvantages of using underwater video to detect fishes and crustaceans in Australian waters, including in tropical rivers, received detailed attention in a recent review (Ebner *et al.* 2014). Underwater video is a visual tool advantageous in identifying large-bodied fauna and enabling quantification and interpretation of biotic and abiotic interactions with the potential for minimal observer effect and without human fatigue associated with direct underwater observation (Ebner *et al.* 2009, Ebner *et al.* 2014). It is particularly useful for studying certain aquatic threatened species including at sensitive times in the life cycle (Butler and Rowland 2009, Ebner *et al.* 2009, Ebner *et al.* 2014).

In northern Australia where riverine and estuarine ecology researchers frequently work in remote locations, underwater video provides a safe alternative to working in the vicinity of crocodiles and other harmful creatures, and with flexible deployment prospects (e.g. setting nets and electrofishing (Ebner and Morgan 2013, Ebner *et al.*, 2014, 2015). Underwater video has the capacity to communicate aquatic ecology to the greater public (Ebner *et al.* 2014).

Major disadvantages are a) the small field of view, b) limitations of visibility including unfavourable water clarity and night vision, c) identification of small-bodied species or life stages, and d) the costs and expertise associated with manually processing film for data (Ebner *et al.* 2009, Ebner and Morgan 2013, Ebner *et al.* 2014). Standardisation of baiting techniques is a subsidiary problem of conducting baited remote underwater video (Ebner *et al.* 2014).

**Possible research questions and areas for future development**

How do we effectively and affordably resource remote biotic and abiotic monitoring stations that incorporate physical–chemical sensors and video–audio data collection at key northern river sites, from a technical and environmental management perspective?

### 3.8.2 Underwater audio

**Description of technique**

Sound recording (audio) involves detecting the noises generated by fauna. These noises include vocalisations or behavioural artefacts such as that of fish grazing on hard substratum. Audio recording has been used to identify and locate spawning aggregations of fish and establish daily behavioural rhythms (e.g. Mann and Grothues 2009). Marques *et al.* (2013) provide a sound account of the niche for passive acoustic detection of species in estimating population density where visual detection is compromised.

Automated audio monitoring of aquatic species and the composition of assemblages and communities, in relation to environmental variables, is a promising are for development. This technique has the advantages of not being compromised by poor or variable visibility environments including low light (e.g. night). Detecting aquatic species with audio involves recording sound with a hydrophone.

**Current application in environmental monitoring**

Audio recording of semi-aquatic and terrestrial species is standard practice for some taxa including frogs and birds. Frog calls are used to monitor stream riparian habitat condition. Audio recording of aquatic fauna is also standard practice for several cetaceans. The noises of other aquatic species including fishes are recorded in research projects but are not widely used in environmental monitoring. Large-scale mapping of sound production by fishes has been demonstrated with automated gliders and it has been argued this could be used as the basis for fisheries management of particular commercial fisheries species (Wall *et al.* 2012).

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

Similar to underwater cameras, audio records can provide measures of shift in aquatic animal presence and behaviour. Audio methods have an advantage over video in being able to detect species at larger scales (video field of view is highly restrictive to a few metres). However, one of the relative disadvantages of audio is that the behaviours and species it can record are highly contingent on species making discernible and uniquely attributable noise. Nevertheless, there is scope for using the soundscape to record stasis or change in assemblages. Notable examples include detecting crustacean relative abundance and activity, since these species commonly use stridulation for communication, and monitoring spawning behaviour of fishes.

**Benefits and constraints**

Audio is compromised by high background noise conditions (e.g. in riffles and cascades) but has (Wysocki et al. 2007) superior detection range to video under optimal conditions (e.g. low or no flow, deep water) and arguably has comparable detection range to sonar under most conditions. Audio also has good potential for automated processing capacity for audible animals, and remote hydrophones have moderate cost and minimal powering and maintenance restraints. A major restriction of audio methods for detecting aquatic fauna is that a subset of species do not make distinctive noises or do not make distinctive noises at regular enough intervals to be detected at effective spatial or temporal scale (Wall *et al.* 2014).

**Possible research questions and areas for future development**

How do we effectively assemble and fund an early (image-based) detection system for alien species invasion in vulnerable small–high value aquatic ecosystems?

### 3.8.3 Underwater sonar

**Description of technique**

Sonar involves mechanically emitting sound pulses and measuring the reflection of these pulses. Sonar technology is not exclusively a human technology. For instance, cetaceans and bats use sonar in locating aquatic prey (e.g. Miller et al. 2004, Weinbeer and Kalko 2007). Sonar is used to monitor depth and benthic structure, fauna and especially schooling fish in the water column, and the functioning of fishing gear (Misund 1997, Murphy and Jenkins 2010). It provides real-time feedback (Murphy and Jenkins 2010). Increasingly sophisticated technology has seen progress in the visual imaging of fauna by sonar (e.g. dual-frequency, identification sonar or DIDSON) with benefits over video in low-visibility environments (e.g. Holmes et al. 2006, Murphy and Jenkins 2010 and references therein).

Whilst sonar provides poor taxonomic resolution of biotic presence in many circumstances, it is advantageous in providing real-time feedback of aggregations of aquatic fauna. It has the capacity to enhance the detection of species by informing spatial and temporal allocation of more costly survey methods that have high taxonomic resolution, including in poor or variable visibility environments (e.g. tropical rivers and estuaries).

**Current application in environmental monitoring**

Sonar plays a major role in real-time targeting of fishery resources and the independent monitoring of oceanic and to a lesser extent, coastal fisheries (Misund 1997). Sonar is sometimes used in monitoring freshwater biota including fish (Matveev and Steven 2014 and references therein). It provides a rapid means of surveying pelagic species in large rivers and lakes. It facilitates simultaneous data collection of benthic topology, structure and biota distribution at a landscape, riverscape or lake scale (cf. Murphy and Jenkins 2010).

**Potential for measuring environmental drivers, pressures, stressors or responses in northern Australia**

Sonar has considerable potential for application in tropical Australian river systems and estuaries, especially because it functions in high and variable turbidity and because it provides excellent topographic information (e.g. benthic mapping) (Murphy and Jenkins 2010). However, it provides poor taxonomic resolution of fauna, though this can be overcome to some extent if coupled with directed and replicated conventional sampling (e.g. netting) (Misund 1997, Marques *et al.* 2013). Automated or replicated manual applications of sonar should prove useful in determining large-scale shifts in the composition of large mobile pelagic and to a lesser extent, benthic fauna and where major erosional, scouring and depositional processes are anticipated in large river–estuary ecosystems.

**Benefits and constraints**

Arguably, sonar is most useful in large, expansive, open waters. DIDSON has the advantage of providing imagery under conditions that impair or compromise video but lacks the visual resolution of video. Standard sonar surveys can be optimised temporally and spatially by factoring in optimal times when fauna are distributed in the water column thereby improving accurate estimation of biomass (Matveev and Stevens 2014). Clearly in small-scale applications, there is scope for combining DIDSON and video at sites to maximise information gain under variable visibility scenarios, and specifically at instream barriers and fishways. These sites provide ideal conditions for monitoring directional assemblage and even community-level movement and provide an alternative or complement to telemetry studies based on tagged individuals and species. DIDSON units are expensive.

**Possible research questions and areas for future development**

A priority for sonar and audio research is testing its applicability to mapping fauna and likely schooling fishes in large rivers and estuaries at scale via mobile methods (based on drone-craft and boat mounted applications).

# 4. Workshop and research questions

## 4.1 Method

A research user workshop was held at the Mercure Darwin Airport Resort on May 9th and 10th 2016. The aims of the workshop were to:

1. Review emerging environmental monitoring technologies and explore their:
   - Potential utility,
   - Limitations, biases & cost-effectiveness,
   - Suitability for northern Australia, and
   - Opportunities for capacity building for Indigenous people.
2. Determine priority research needs for their development and refinement for potential use in northern Australia.

Invitations to the workshop were sent to 75 people from a wide range of Government and non-Government organisations. Forty people attended the workshop from a range of organisations (see Table 6).

**Table 6.** Organisations represented at emerging techniques workshop.

| University | State Government agencies | Federal Government | Indigenous organisations | NRM | NGO |
|---|---|---|---|---|---|
| Charles Darwin University | NT Department of Land Resource Management | Department of Environment (Supervising Scientist) | NLC | Territory NRM | World Wildlife Fund |
| James Cook University | NT Parks & Wildlife | Department of Environment (Kakadu National Park) | Balkanu | | |
| Griffith University | NT Department of Primary Industries and Fisheries | | KLC | | |
| University of Melbourne | QLD DISTIA | | | | |
| | QLD EHP | | | | |
| | QLD DNRM | | | | |
| | WA DPAW | | | | |
| | WA Museum | | | | |
| | WA Fisheries | | | | |

Presentations on each of the nine key emerging technologies were conducted in the morning of the first day, followed by two break-out/discussion sessions (see Table 7 for summary agenda). Topic presentations are available on the project's webpage under the Publications heading on the NESP NAER website (http://www.nespnorthern.edu.au/projects/nesp/remote-environmental-monitoring-techniques).

**Table 7.** Summary workshop agenda.

| **Day 1** | **Who** | **Organisation** |
|---|---|---|
| Arrival and register | | |
| Welcome, project introduction, workshop purpose | Alison King | CDU |
| Results of research user survey | Peter Novak | CDU |
| Satellite and airborne remote sensing techniques | Doug Ward | GU |
| Unmanned vehicles (drones) as platforms | Renee Bartolo | ERISS |
| Environmental DNA – Forensic DNA detection of aquatic species and profiling of entire biological communities | Dean Jerry | JCU |
| DNA-based methods for indirect estimation of population size and individual body condition | Dan Schmidt & Ryan Wood | GU, QLD DSITI |
| Using biochronology for measuring fish production | John Morrongiello | Uni Melb |
| Tracing water sources and greenhouse gases using field-based stable isotope techniques | Niels Munksgard | CDU |
| Using animal audio for species detection | Lin Schwazkopf | JCU |
| Terrestrial camera trapping | Graeme Gillespie | NT DLRM |
| Aquatic camera trapping | Brendan Ebner | JCU |
| Discussion of breakout groups and tasks | Alison King | CDU |
| Group discussions around relevance & research effort required for each technique | ALL (rotate every 30 min) | |
| **Day 2** | | |
| Recap of Day 1. Purpose of Day 2 | Alison King | CDU |
| Groups: Limitations of technique & research questions | ALL (rotate every 40 min) | |
| Groups: Developing research questions | ALL (rotate every 40 min) | |
| Group Report back | 10 min each group | |
| Close. Where to from here? | Alison King | CDU |

## 4.2 Relevance of each technique and research effort required

### 4.2.1 Approach and methodology

We were interested in determining what research users thought was the:

(i) relevance of each technique to specific monitoring activities, and

(ii) research effort required for each emerging technique to specific monitoring activities.

To do this, we asked all participants at the workshop to individually score two matrices on the relevance and research effort required for each technique/monitoring activity combination. Participants were informed that the survey was voluntary, and had received human ethics approval. Participants were instructed to fill out only cells in the matrix that they considered they had knowledge about.

The 'relevance' matrix was scored as:

0 - Not relevant

1 - Possibly relevant (some uncertainty)

2 - Sometimes relevant (relevant for some specific applications),

3 - Highly relevant

The 'research effort required' matrix was scored as:

0 - No research required, already being used successfully in monitoring

1 - Already being used in northern Australia monitoring, but some refinements/specific research required

2 - Already being used in monitoring, but not in northern Australia (research required)

3 - Demonstrated in research, but has not been applied to monitoring (therefore significant research required)

Scores for technique were collated and averaged across the total number of participants for that technique/monitoring activity within each matrix. Technique/monitoring activity cells with less than three participant scores were not averaged and designated as NS (no sample) in the matrix. Results for each matrix are reported and discussed separately, and then multiplied to highlight techniques with high relevance and high and moderate research efforts required.

### 4.2.2 Matrix results

The analysis of workshop participant responses to the relevance and research requirements for each emerging technique revealed some interesting patterns (Table 8 and Table 9). Workshop participants felt that a number of the emerging techniques were highly relevant to specific monitoring activities (Table 8). For example, satellite technology was highly relevant for vegetation mapping and landscape change, while RPASs were seen to be highly relevant for assessing both of these and aquatic vegetation and ecosystem condition. eDNA techniques were highly relevant for aquatic-based biodiversity surveys including biosecurity and not surprisingly, audio detectors and terrestrial cameras were noted as being highly relevant for terrestrial biodiversity surveys. Other emerging techniques were considered to have lesser levels of relevance for all monitoring activities.

There were a high number of cells in the 'research required' matrix that contained fewer than three respondents, i.e. no sample (Table 9); however, some patterns did emerge. Respondents considered that eDNA, genetics-based techniques, biochronology and audio detection techniques all required a high amount of research required before they would reach their full potential in monitoring activities in northern Australia.

Seven of the nine techniques had monitoring aspects where it was deemed that they were both highly relevant and required a significant amount of research effort for widespread use in monitoring (Table 10). These cells could be used as focus of research prioritisation, or it could be viewed that those with high relevance but little research required should be the focus of future research efforts.

**Table 8.** Average scoring of the relevance of each emerging technique for each monitoring activity.

Average score is generated by averaging across scores from all workshop participants, where 0 = not relevant, **1 = possible relevance** (some uncertainty), **2 = sometimes relevant** (for some specific applications), and **3 = highly relevant**.

| | Satellie & airborne remote sensing techniques | Unmanned vehicles (drones) as platforms | eDNA & meta-barcoding | DNA-based methods for estimating pop'n size & individual body condition | Using biochronology for measuring fish production | Tracing water sources & greenhouse gases using stable isotope techniques | Using animal audio for species detection | Terrestrial camera trapping | Aquatic camera trapping |
|---|---|---|---|---|---|---|---|---|---|
| Surface water quality | 1 | 2 | 1 | 1 | 1 | 2 | 1 | 0 | 1 |
| Ground water quality | 0 | 0 | 1 | 1 | 1 | 2 | 0 | 0 | 0 |
| Ecohydrology | 2 | 2 | 1 | 2 | 2 | 2 | 1 | 0 | 1 |
| Ecosystem condition/status/health | 2 | 3 | 2 | 2 | 1 | 1 | 2 | 1 | 2 |
| Groundwater quantity/hydrology | 1 | 1 | 1 | 1 | 1 | 2 | 0 | 0 | 1 |
| Surface water quantity/hydrology | 2 | 2 | 1 | 1 | 1 | 2 | 0 | 0 | 1 |
| Vegetation (terrestrial) | 3 | 3 | 1 | 1 | 0 | 1 | 1 | 0 | 0 |
| Vegetation (aquatic) | 2 | 3 | 2 | 1 | 1 | 1 | 0 | 0 | 1 |
| Climate | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 |
| Socio-ecological | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Animal movements (aquatic) | 1 | 1 | 2 | 2 | 2 | 0 | 1 | 0 | 2 |
| Animal movements (terrestrial) | 1 | 2 | 2 | 1 | 0 | 0 | 2 | 2 | 0 |
| Landscape change | 3 | 3 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| Aquatic biodiversity surveys | 1 | 2 | 3 | 1 | 1 | 0 | 1 | 0 | 2 |
| Terrestrial biodiversity surveys | 1 | 2 | 2 | 1 | 0 | 0 | 3 | 3 | 0 |
| Aquatic non-native animal/plant detection & spread monitoring | 2 | 2 | 3 | 1 | 1 | 0 | 1 | 1 | 2 |
| Terrestrial non-native animal/plant detection & spread modelling | 2 | 2 | 2 | 1 | 0 | 0 | 2 | 2 | 0 |
| Population abundance estimates (species management) | 1 | 2 | 2 | 2 | 1 | 0 | 2 | 2 | 2 |
| Land contamination/pollution | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| Water contamination/pollution (i.e. spill events, ghost nets) | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 | 1 |
| Sediments (i.e. contamination/pollution) | 1 | 1 | 1 | 2 | 0 | 2 | 0 | 0 | 1 |
| Sediments (i.e. carbon storage/emission, nutrients) | 1 | 1 | 1 | 1 | 0 | 2 | 0 | 0 | 0 |
| Air quality | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |

**Table 9.** Average scoring of the research effort required for each emerging technique for each monitoring activity. Average score is generated by averaging across scores from all workshop participants, where 0 = no research required, already being used successfully in monitoring, **1 = already being used in northern Australia monitoring**, but some refinements/specific research required, **2 = already being used in monitoring, but not in northern Australia** (research required), and **3 = demonstrated in research, but has not been applied to monitoring** (therefore significant research required).

| | Satellite & airborne remote sensing techniques | Unmanned vehicles (drones) as platforms | eDNA & meta-barcoding | DNA-based methods for estimating pop'n size & individual body condition | Using biochronology for measuring fish production | Tracing water sources & greenhouse gases using stable isotope techniques | Using animal audio for species detection | Terrestrial camera trapping | Aquatic camera trapping |
|---|---|---|---|---|---|---|---|---|---|
| Surface water quality | 1 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Ground water quality | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Ecohydrology | 1 | 2 | 3 | 3 | 2 | 2 | 0 | 0 | 0 |
| Ecosystem condition/status/health | 1 | 2 | 3 | 3 | 2 | 1 | 2 | 2 | 2 |
| Groundwater quantity/hydrology | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Surface water quantity/hydrology | 1 | 2 | 0 | 2 | 0 | 1 | 0 | 0 | 0 |
| Vegetation (terrestrial) | 1 | 2 | 2 | 3 | 0 | 2 | 0 | 0 | 0 |
| Vegetation (aquatic) | 1 | 2 | 2 | 2 | 0 | 0 | 0 | 0 | 0 |
| Climate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Socio-ecological | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Animal movements (aquatic) | 0 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 2 |
| Animal movements (terrestrial) | 0 | 2 | 2 | 0 | 0 | 0 | 3 | 1 | 0 |
| Landscape change | 1 | 2 | 0 | 2 | 0 | 0 | 3 | 2 | 0 |
| Aquatic biodiversity surveys | 0 | 1 | 2 | 0 | 2 | 0 | 2 | 0 | 1 |
| Terrestrial biodiversity surveys | 0 | 2 | 2 | 0 | 0 | 0 | 2 | 1 | 0 |
| Aquatic non-native animal/plant detection & spread monitoring | 1 | 1 | 2 | 2 | 0 | 0 | 2 | 0 | 1 |
| Terrestrial non-native animal/plant detection & spread modelling | 1 | 2 | 2 | 3 | 0 | 0 | 2 | 1 | 0 |
| Population abundance estimates (species management) | 2 | 2 | 3 | 0 | 3 | 0 | 3 | 1 | 2 |
| Land contamination/pollution | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water contamination/pollution (i.e. spill events, ghost nets) | 1 | 1 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| Sediments (i.e. contamination/pollution) | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sediments (i.e. carbon storage/emission, nutrients) | 2 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| Air quality | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table 10.** Combined matrix of relevance:research effort required for each emerging technique for each monitoring activity.

Scores from each of relevance and research effort matrices multiplied (Table 8 and Table 9). 0 = no sample, as number of participants was < 3 for research effort, **score 2–3 = moderate relevance : research effort**, and **score > 3 = high relevance : research effort**.

| | Satellie & airborne remote sensing techniques | Unmanned vehicles (drones) as platforms | eDNA & meta-barcoding | DNA-based methods for estimat-ing pop'n size & individual body condition | Using biochro-nology for measuring fish production | Tracing water sources & green-house gases us-ing stable isotope techniques | Using animal audio for species detection | Terrestrial camera trapping | Aquatic camera trapping |
|---|---|---|---|---|---|---|---|---|---|
| Surface water quality | 2 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Groundwater quality | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| Ecohydrology | 2 | 3 | 3 | 5 | 3 | 3 | 0 | 0 | 0 |
| Ecosystem condition/status/health | 3 | 4 | 5 | 4 | 3 | 2 | 5 | 2 | 2 |
| Groundwater quantity/hydrology | 0 | 2 | 0 | 0 | 0 | 3 | 0 | 0 | 0 |
| Surface water quantity/hydrology | 3 | 4 | 0 | 1 | 0 | 3 | 0 | 0 | 0 |
| Vegetation (terrestrial) | 4 | 5 | 3 | 2 | 0 | 2 | 0 | 0 | 0 |
| Vegetation (aquatic) | 3 | 4 | 4 | 3 | 0 | 0 | 0 | 0 | 0 |
| Climate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Socio-ecological | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Animal movements (aquatic) | 0 | 3 | 4 | 0 | 4 | 0 | 0 | 0 | 5 |
| Animal movements (terrestrial) | 0 | 3 | 3 | 0 | 0 | 0 | 4 | 3 | 0 |
| Landscape change | 3 | 5 | 0 | 2 | 0 | 0 | 3 | 2 | 0 |
| Aquatic biodiversity surveys | 0 | 2 | 6 | 0 | 1 | 0 | 2 | 0 | 3 |
| Terrestrial biodiversity surveys | 0 | 3 | 3 | 0 | 0 | 0 | 5 | 3 | 0 |
| Aquatic non-native animal/plant detection & spread monitoring | 2 | 3 | 6 | 2 | 0 | 0 | 2 | 0 | 3 |
| Terrestrial non-native animal/plant detection & spread modelling | 3 | 4 | 4 | 3 | 0 | 0 | 4 | 2 | 0 |
| Population abundance estimates (species management) | 2 | 4 | 4 | 0 | 3 | 0 | 5 | 3 | 5 |
| Land contamination/pollution | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Water contamination/pollution (i.e. spill events, ghost nets) | 1 | 2 | 0 | 5 | 0 | 0 | 0 | 0 | 0 |
| Sediments (i.e. contamination/pollution) | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sediments (i.e. carbon storage/emission, nutrients) | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| Air quality | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## 4.3 Key monitoring activities, limitations and research questions

### 4.3.1 Using satellite and airborne remote sensing techniques in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- Vegetation mapping

*Limitations*

- Spatial resolution
- Only some weeds can be detected (including gamba and mimosa)
  - A weed signature database could be beneficial
- There is a high skill level required to apply technology
- Technology required to implement techniques
- Data handling logistics
  - Download speeds
  - Massive (cloud computing required)
- High level of ground truthing
  - Expensive
- Data sharing and IP

*Research questions or future directions*

- How to map weed infestations
  - To research validation
- Mangrove clearing and change
- Terrestrial clearing
  - Agriculture and development
- Seagrass loss
  - Terrestrial runoff
- Key habitats
  - Riparian
- Repeated snapshots over time
  - Monitoring
- Corrections between Landsat and MODIS
  - Fire mapping (POM sharpening)
- How to see through the canopy
  - Critical research question!
- Can we monitoring rapidly enough to monitor change
  - Depends on temporal scale of change
- Feral animal damage
- Combine fine-scale and coarse-scale images

*Other comments*

- Emerging remoting sensing is much more in the applied setting
  - How to map key habitats and stressors such as weeds, mangroves and seagrasses

### 4.3.2 Using unmanned vehicles (drones, RPAS) as platforms in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- Ecosystem condition and health
- Surface water quantity/hydrology
- Aquatic and terrestrial vegetation monitoring
- Landscape change
- Non-native animal and plant detection and monitoring
- Population abundance estimates

*Limitations*

- Data processing, information extraction, management
- Standards for data collection
- Cost of RPAS
  - $20K to get RPAS and CASA licensing (entry level), ~$100K for suitably qualified person
- Staff retention, training, maintaining capacity
  - ReOc is tied to individuals not organisation, although issued to the organisation.
- Rapid pace of change in technology for entry-level
- Scale of current research
  - Research limited by researchers using multi-rotors because of cost (10 ha)
- Areal coverage limited to 300 ha (fixed-wing) and 10 ha (multi-rotor)
- FLIR (Forward Looking InfraRed)
  - Ambient temperature (differential between target and land)
  - Calibration of temperature and sensitivity
- Savannah canopy – issues in data processing
- Water applications – glint, glitter, sea states

*Research questions or future directions*

- What are the optimal parameters/conditions for capturing RPAS data for waterbodies? (e.g. time of day, angle, flying height?)
- What parameters can be directly measured from RPAS for vegetation monitoring?
- Can we detect myrtle rust using RPAS imagery?
- How can we process and analyse RPAS data to measure turtle tracks on nesting beaches?
- How do we use RPAS to monitor stressors and pressures (fire, weeds, ferals)?
- Where do RPAS fit in integrated spatio-temporal monitoring framework and links with other technology?
- Monitoring SAV (Submerged Aquatic Vegetation) using AUVs (Automated Underwater Vehicles) or remote-piloted boats
- How can we detect and monitor contaminants using hyperspectural RPAS-derived data? (Also scaling between airborne hyperspectural and RPAS derived data)
- What sensors can be used for fauna surveys? E.g. dependent on turbidity for aquatic fauna?
- Can we use RPAS to monitor erosion and exposure of tree roots in rainforests? (Erosion driven by external pressures) would require using RPAS under canopy
- GDE mapping?
- Could RPAS be used to map aquatic habitat distribution in wetlands and rivers?

*Other comments*

Need for centralised collaboration, (maybe centralised in NT Government?) to pool resources and expertise when required.

Could be used to monitor monsoonal vine thickets on Dampier Peninsula, fish kills, fire spotting, vegetation mapping validation, river mapping, aquatic biodiversity surveys in dense vegetation, large sedges and wooded wetlands.

### 4.3.3 Using forensic DNA detection of aquatic species and profiling of entire biological communities (environmental DNA (eDNA)) in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- Ecosystem condition and health
- Aquatic vegetation
- Aquatic animal movements
- Aquatic biodiversity surveys
- Aquatic and terrestrial non-native animal and plant detection
- Population abundance estimates

*Limitations*

- Lack of DNA sequence database for aquatic fauna (particularly invertebrates)
- Lack of DNA sequence database for terrestrial fauna (particularly invertebrates)
- Link to QA/QC taxonomy – voucher specimens – DNA links
- Field methods around limiting contamination
    - Best method to preserve samples in the field
    - How to deal with turbidity
- Benchmark efficiency against other traditional methods in Australian context
- Design universal primer sets to target a broad range of species
- Ideal for presence/absence but not effective at estimating abundance
- Extending the approach to population genetics to understand genetic diversity
- Cryptic species/hybrids – nDNA (nuclear DNA at some time in the future)
- Has not been tested on plants

*Research questions or future directions*

- Create genetics resources and customise eDNA methods to northern Australia
    - DNA database linked to voucher specimens (fish, turtles, macro invertebrates)
    - Refine the field methods – set up a standard kit
    - Benchmark project

*Other comments*

- End user needs - detection of rare species (aquatic and terrestrial)
    - Create distribution maps/abundance
    - Invasive species surveillance and biosecurity (e.g. cane toads and red claw)
    - Determining effects of land use change and community structure changes
    - Changes within and between catchments
    - Biological monitoring surveys – direct effects
    - Can do 16s bacterial metabarcoding as a surrogate of ecological processes

### 4.3.4 Using DNA-based methods for indirect estimation of population size and individual body condition in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- Ecohydrology
- Ecosystem condition and health
- Water contamination and pollution

*Limitations*

- Methods are single-species approaches and so it is vital to target the right species
- Sample sizes are low for threatened taxa
- Have to understand the link between the stressor and the response, what does the RNA:DNA result mean? Need conceptual model.

*Research questions or future directions*

- Scale of the monitoring program
  - Genetics can inform this but currently not well understood
- Thresholds for species
  - 50/500 rule – is this a relevant viability threshold?
- Pilots to identify variability and inform monitoring
- DNA database for northern Australia
  - Currently non existent
  - Share samples
  - Project to co-ordinate genetic data collection
- Testing RNA:DNA stressors relevant to northern Australia

*Other comments*

- Proof of concept RNA:DNA/Nb
  - Field monitoring include test/reference populations for northern Australia stressors and threats
  - Lab test specific stressor and response
  - For example; fish condition in response to specific stressors/events i.e. Archer River – feral pigs and Mitchell River – flood plain inundation.
- Need to research the sample size limitations
  - For example; genome wide heterozygosity based on n=1
- Develop and maintain a long-term, population level tissue archive – genetic techniques will advance in the future thus could do new analysis on collected tissues

### 4.3.5 Use of biochronology for measuring fish production in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- Aquatic animal movements

*Limitations*

- Species life history, particularly age and longevity an issue for use in monitoring (species selection will be key)
- Temporal resolution of growth needs to be validated, seasonal/annual/daily
- Otolith collections required over many years, or species with reasonable longevity to be used
- Resolution and accuracy of environmental data that are to be linked to growth. In particular, flow data limited across northern Australia
- Technical expertise required in collection, sample preparation, reading and analysis
- Need to be aware of uncertainty in ageing and predictions

*Research questions or future directions*

- What species are the best to use? And under what circumstances?
- Can you link growth to movement and habitat use?
- What other taxa could be used? What is the utility of turtle shells, dugong tusks, crocodile teeth or osteoderms?
- Utility of using multi-species approach and across different systems (marine, freshwater, terrestrial). Does this extend data or make inference harder?
- Ensure agencies are collecting suitable number of otoliths from key regions, and that collections are archived and maintained in a database.
- Is it possible to begin collecting hardparts from other taxa - Indigenous community collaborations?

*Other comments*

Most likely application is on effects of water extraction on fish production?

### 4.3.6 Using field-based stable isotope techniques for tracing water sources and greenhouse gases in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- No activities were identified in the matrix (Table 9)

**Carbon dioxide**

*Limitations*

- Access issues
- Timely monitoring
- Integration of isotope analysis with GPS
- Power sources

*Research questions or future directions*

- Accounting for fire $CO_2$ in northern Australia (relatively small percentage?)
- Carbon capture and storage monitoring
- Coal seam gas monitoring ($CH_4$)

**Blue Carbon monitoring**

*Limitations*

- Underwater monitoring is limited
- Need to develop a sampler

*Research questions or future directions*

- Blue carbon monitoring (gain or loss of C)
- Storage in mangrove forests and seagrass beds?

**River/creek water monitoring**

*Limitations*

- Need for a long-term secure site
- Safe and reliable power source

*Research questions or future directions*

- Tracing sources of moisture
  - Rainfall
  - Central Australia

- Tracing river water sources over time
  - Surface
  - Soil water
  - Groundwater
  - Hydrographic separation of water sources (i.e. which parts of the hydrograph come from groundwater/rainfall runoff)
- Plant water sources and usage (surface water or deeper water, partitioning of evapo-transpiration)
- Food verification
  - Verify the origin of food based on food water stable isotope ratios (H, O and C)
- Animal migration/movement
  - i.e. feather isotopes: pin point geographic locations of majority of growth
  - feral pigs?

### 4.3.7 Using animal audio for species detection in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- Ecosystem condition and health
- Terrestrial animal movements
- Terrestrial biodiversity surveys
- Terrestrial non-native animal and plant detection
- Population abundance estimates

*Limitations*

- We have a biased knowledge of species presence/absence. There has been lots of planning based on this 'knowledge' – need more accurate records, especially for rare or little-known species
- Right now we can collect a very, very large amount of sound data
- Analysis methods have not kept up with ability to collect and store sound
- At present most methods require an ecologist to recognise and identify species and 'tag' calls in recordings
- For some species (e.g. insects) we may need to refine sound database

*Research questions or future directions*

- What are the expected outcomes from different kinds of disturbances to design monitoring to detect specific effects to predict when influences are having an effect?
- This technique could provide an effective method to assess damage by feral animals; however:
  - Experimental work required – compare sounds in impacted, non-impacted sites
  - Skill and time to process data and get the best outcomes from data
  - Develop recogniser for many sounds – particular frog species (or birds; whatever the target/indicator taxa may be)
  - Soundscapes – more research on how to describe and compare them
  - Environmental data to explain variations
- Better ways to detect rare and threatened species or quiet and difficult-to-detect species
- Better understanding of when animals call
- Develop caller/listener devices to better detect cryptic, rare or threatened species by eliciting calls
- Efficient and cheap data collection on many species simultaneously with good unbiased sampling in many land uses, specifically targeting good systematic sampling of different habitats and land uses
- Combine sound and image data

### 4.3.8 Using terrestrial-based cameras in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- No activities were identified in the matrix (Table 9)

*Limitations*

- Current cameras have been designed for use in hunting activities. No fit-for-purpose design for ecological studies (although there is starting to be interest in this)
  - Current cameras use motion and thermal detection to trigger photo. Therefore thermally sensitive and movement only
  - Also need to consider camera specifications e.g. focal length
- No methodological consistency. Cameras are widely used in fauna surveys, especially in northern Australia, but there is no standard approaches to placement, data collection, processing or analysis
- Taxonomic resolution problematic and variable among species groups
- Generates a large number of images, therefore data capture, storage and management is difficult and problematic
  - Ideally information should be available to end-users

*Research questions or future directions*

- Development of ecologically specific cameras
- Develop and trial camera placement designs and metrics to obtain reliable estimates of relative abundance
- Review and recommend standards or protocol for implementation of cameras into monitoring programs to ensure standardisation of outcomes and calibration across systems
- Development of suitable data management systems
  - Trial automated approaches
  - Particularly to ensure timeliness and access for management
- Conduct short-term trials on methodological developments and refinements

*Other comments*

Method is widely employed across northern Australia, but is not fully utilised to its full potential. This is mainly due to a low number of skilled users than can manage images, accurately identify fauna, and manage data outputs. Storage of large datasets also problematic.

### 4.3.9 Using aquatic-based cameras in environmental monitoring

*Highly suitable monitoring activities where research is still required*

- Aquatic animal movements
- Population abundance estimates

*Limitations*

- No national standards or protocol for implementation into monitoring programs
- Taxonomic resolution problematic and variable among species groups
- Variable environmental factors (e.g. water clarity) altering species detection and effective CPUE may make standardisation of effort difficult
- Post-processing of video footage time-consuming

*Research questions or future directions*

- Determine influence of environmental factors on species detection and effectiveness of standard CPUE across range of environmental conditions
- Determine precision and accuracy of identification of aquatic species using camera-based sampling in northern Australian systems
  - E.g. trials of different footage types with taxonomic experts
- Do baited underwater cameras increase species detection and are they worth the risk?

- What are the most appropriate metrics to be used in collecting CPUE from the videos? MaxN, time at first arrival etc?
- How accurate are cameras for relative abundance measurements? And what is the variability in different conditions?
- Recommend standards or protocol for implementation of cameras into monitoring programs to ensure standardisation of outcomes and calibration across systems (e.g. Sustainable River Audit protocol for fish sampling using electrofishing in the MDB is now widely used). To include:
    - Recommended sampling design (minimum number, placement etc) under various conditions to maximise species detection
    - Camera set ups inc. camera setup, placement
    - Consideration as a complimentary sampling technique, potentially decision rules for implementation of methods
- Determine if there are appropriate post-processing efficiencies that can be applied e.g. shape detection/automatic reading of video, sub-sampling of video, appropriate metrics

*Other comments*

- A key issue discussed was underwater video is an excellent public communication device of "what's under the water?". Public appreciation and support for aquatic management initiatives could be enhanced if people could see them easier
- Could be used to test behavioural responses of aquatic fauna to a management intervention (e.g. exotic species control, flow manipulation, environmental watering). Group not aware of any studies, but would be important to explore community interactions
    - For e.g. Use underwater cameras to assess the changes in fish behaviour in tilapia-excluded and control sites
- Cameras could also be used to monitor the effectiveness of fish passage constructions

## 4.4 Other emerging technologies or techniques not discussed at the workshop

Workshop attendees also contributed to a discussion of other techniques that they would like to understand more about, but which weren't presented at this workshop. Those identified were:

- Fire mapping
  - Comparison of available satellites (rMODIS and LANDSAT)
  - Can different satellite imagery be integrated?
  - Can pan sharpening occur?
- Telemetry of animals
  - Movement of small animals
  - E.g. of novel applications
- Blue Carbon measurements (seagrass and mangroves)
- Sensory networks
  - Can we fully integrate different sensors into one large network ('enviromesh')
  - Also possibility of public platform for some data to increase availability
- Passive samplers for water chemistry
  - Time integrated, mostly metals and nutrients
- Big data constraints
  - Methods, storage and techniques to manage big datasets
- Air chemistry/pollution monitoring
- Are there novel probes for continuous monitoring of air, soil, water etc?
- Advances in sampling methods and design
  - Statistical design
  - Working towards a standard or consistencies in method usage
- New ways to measure management effectiveness
- New ways to conduct large-scale feral animal surveys
- Novel methods for monitoring effectives of social/human geography
- Public engagement with animal cameras or audio identification
  - Online collaborative network?
- Advances in camera trapping
  - Integrated camera network, that communicate with each other

# Conclusions

This report describes and presents:

- the current knowledge base of a range of emerging technologies and techniques applicable to environmental monitoring in northern Australia for this project, and to a wide range of research users across northern Australia (Sections 2 and 3)
- the current use of emerging environmental monitoring technologies in northern Australia (Sections 2 and 4; Tables 8, 9 and 10)
- the potential for their use, including positive attributes and limitations (Sections 2, 3 and 4)
- a list of research areas that are needed to more fully utilise these techniques in environmental monitoring (Section 4; Tables 8, 9 and 10; subsection 4.3).

The desktop survey provided a useful snapshot of research users' perceptions of their current monitoring activities, and the potential usefulness of emerging technologies. The information provided in the desktop review and presented at the workshop by each of our research collaborators on the emerging techniques provides a useful description, summary and limitations of each technique. We also highlighted a number of potential research requirements for developing these emerging techniques, and have developed a range of potential research questions and focus for future research proposals.

Finally, whilst the project was principally targeted at informing the development of potential research projects within the NESP NAER Hub, the outcomes of the project are much broader and could inform both the use and applicability of these techniques for environmental monitoring across northern Australia, and the development of future research supported by a variety of different funders.

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# Appendix 1: Research users survey

This section aims to determine the type of monitoring activities you are responsible for within your organisation.

1. **What organisation and branch do you work for?**

2. **What sort of monitoring activities do you undertake or are responsible for?**

   ☐ Surface water quality
   ☐ Groundwater quality
   ☐ Ecohydrology
   ☐ Ecosystem condition/status/health
   ☐ Groundwater quantity/hydrology
   ☐ Surface water quantity/hydrology
   ☐ Vegetation (terrestrial)
   ☐ Vegetation (aquatic)
   ☐ Climate
   ☐ Air quality
   ☐ Socio-ecological
   ☐ Animal movements (aquatic)
   ☐ Animal movements (terrestrial)
   ☐ Landscape change
   ☐ Aquatic biodiversity surveys
   ☐ Terrestrial biodiversity surveys
   ☐ Aquatic non-native animal/plant detection and spread monitoring
   ☐ Terrestrial non-native animal/plant detection and spread modeling
   ☐ Land contamination/pollution
   ☐ Water contamination/pollution (i.e spill events, ghost nets)
   ☐ Sediments (i.e. contamination/pollution)
   ☐ Sediments (i.e. carbon storage/emission, nutrients)
   ☐ Ecotoxicology
   ☐ Other (please specify)

3. **Why are the monitoring activities being undertaken? What are the policy or management drivers for this monitoring activity?**

   ☐ Environmental impact assessment
   ☐ Rehabilitation
   ☐ Biodiversity conservation
   ☐ International treaty or convention obligations (i.e. UNESCO, Ramsar) nationally listed protected ecosystems or species obligations (EPBC Act, State Government Acts)
   ☐ Feral animal/weeds control
   ☐ Assessment of environmental condition/status/health and how this changes over time e.g. water quality, ecosystem condition
   ☐ Public communication (i.e. report cards)
   ☐ Other (please specify)

4. **Where, and at what spatial scale, is the monitoring undertaken?**
   ☐ Northern Australia (across all three states)
   ☐ State-wide
   ☐ Regional (i.e Top End of the NT, Far North Queensland, North East Kimberley)
   ☐ Catchment (i.e Daly River, Mitchell River, Burdekin River, Ord River)
   ☐ Local (i.e. mining lease, state forest allotment, national park)
   ☐ Other (please specify)

5. **Who undertakes the monitoring?**
   ☐ Government agency staff
   ☐ External consultants
   ☐ University
   ☐ CSIRO
   ☐ Citizens
   ☐ Other (please specify)

This section is aimed at determining if there are any limitations or issues with the current monitoring activities you are undertaking.

6. **How well do your current monitoring techniques meet your reporting requirements? I.e. Ranging from "very poorly" = methods are not ideal, sampling frequency constrained; to "very well" = sampling meets expectations, little room for improvement.**
   ☐ Very poorly (low confidence)
   ☐ Poorly
   ☐ Not sure
   ☐ Well
   ☐ Very well (high confidence)

7. **Are there any known limitations to the monitoring you currently undertake, or that could affect the monitoring you undertake in the future? Please provide short summary of limitations in the comment box.**
   ☐ Financial
   ☐ Logistical (i.e. available field staff, remoteness, appropriate gear availability)
   ☐ OH&S (i.e. dangerous animals (esp. crocodiles), heat, remoteness)
   ☐ Other (please described in comment box)
   ☐ Comments

8. **In regard to the limitations you described above, do you think that new environmental monitoring technologies or techniques such as those discussed in the introduction to the survey could improve this monitoring?**
   ☐ No/unlikely
   ☐ Possibly
   ☐ Yes
   ☐ Yes, we are actively seeking/trialling new techniques/technologies
   ☐ N/A

This section seeks to determine if you are currently using new technologies or would be interested in using them in the future.

**9. Does your organisation currently use any of the emerging technologies, listed below, in its monitoring activities? If you are, please provide a short summary of the techniques' usefulness, problems or other limitations you have found.**

- ☐ Remotely operated vehicles (e.g. airborne drones and wireless boats), as a platform for cameras, sensors (water or air quality) and other tracking equipment
- ☐ Genetic techniques such as: environmental DNA (e.g. eDNA) for detecting rare or invasive species, metabarcoding to determine biomass and distribution of biota, techniques to determine effective population sizes and individual health
- ☐ Camera-based field detection techniques for terrestrial species
- ☐ Camera-based field detection techniques for aquatic species
- ☐ Remote listening stations for detecting and identifying audio calls of animals, e.g. birds and frogs
- ☐ Coarse-scale satellite remote sensing techniques for monitoring landscape-scale changes using satellite imagery
- ☐ Fine-scale (high-resolution aerial photos/drone imagery) for monitoring local-scale landscape change, animal populations
- ☐ Underwater sonar-based imagery of fish and habitats
- ☐ Telemetry approaches for tracking animal movements of rapidly increasing sophistication and capability
- ☐ Stable isotope techniques for water source exploration
- ☐ None of the above techniques
- ☐ If you selected any of the above techniques can you please provide details of how they are currently being used and any problems or limitations experienced. Or, provide details of other techniques you are using.

**10. Do you think any of the emerging technologies listed below could be useful to your organisation? If there are technologies or tools you see as being important but are not listed below, please provide details.**

- ☐ None of the techniques below will be used
- ☐ Remotely operated vehicles (e.g. airborne drones and wireless boats), as a platform for cameras, sensors (water or air quality) and other tracking equipment
- ☐ Genetic techniques such as: environmental DNA (e.g. eDNA) for detecting rare or invasive species, metabarcoding to determine biomass and distribution of biota, techniques to determine effective population sizes and individual health
- ☐ Camera-based field detection techniques for terrestrial species
- ☐ Camera-based field detection techniques for aquatic species
- ☐ Remote listening stations for detecting and identifying audio calls of animals, e.g. birds and frogs
- ☐ Coarse-scale satellite remote sensing techniques for monitoring landscape-scale changes using satellite imagery
- ☐ Fine-scale (high-resolution aerial photos/drone imagery) for monitoring local-scale landscape change, animal populations
- ☐ Underwater sonar-based imagery of fish and habitats
- ☐ Telemetry approaches for tracking animal movements of rapidly increasing sophistication and capability
- ☐ Stable isotope techniques for water source exploration
- ☐ Other (please elaborate in the comments box)
- ☐ Comments

11. **Are there any impediments to using or adopting any of these new technologies or techniques in the future?**
    - ☐ Cost
    - ☐ Confidence in the technique or technology
    - ☐ Confidence in its applicability in northern Australia
    - ☐ Hasn't been developed yet
    - ☐ Lack of technical expertise or competence in the technique
    - ☐ Other (please specify)

12. **Are there any other people from your organisation or other organisations that you would like to invite to participate in this survey?**

13. **Optional - Please provide your contact details. This will be separated from your responses and used for record-keeping purposes. We will also use these details to contact potential participants for the workshop to be held early in 2016.**
    - ☐ Name
    - ☐ State/Province
    - ☐ Email Address

Northern Australia Environmental Resources Hub

National Environmental Science Programme

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This project is supported through funding from the Australian Government's National Environmental Science Programme.