PCPA CHAMP

Port Curtis and Port Alma Coastal Habitat Archive and Monitoring Program

2015-2016 Annual Report

CA14000114: Monitoring the survival and recovery of shorelines, specifically Tidal Wetlands (Mangroves/Saltmarsh/Saltpans)

Norman C Duke, Jock Mackenzie, John Kovacs, Duncan Hill, Franz Eilert, Ian Atkinson and Steven van der Valk

Report No. 16/52

14 September 2016

PORT CURTIS AND PORT ALMA COASTAL HABITAT ARCHIVE AND MONITORING PROGRAM

2015-2016 Annual Report
for the
Environmental Research and Monitoring Program Advisory Panel
as part of the
Gladstone Ports Corporation's
Ecosystem Research and Monitoring Program

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This report has been produced for the Ecosystem Research and Monitoring Program Advisory Panel as part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program. The study was undertaken through a Consultancy Agreement (CA14000114) between Gladstone Ports Corporation (GPC) and James Cook University (JCU) to monitor the condition, survival and recovery of shorelines, specifically tidal wetlands (Mangroves/Saltmarsh/Saltpans) in the Port Curtis and Port Alma region; in field surveys conducted by researchers, traditional owner rangers and community members.

This publication has been compiled by the Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), JCU.

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EXECUTIVE SUMMARY

1) This 2016 Annual Report documents the status and key current findings from the program of works for 2015-2016 (commencing in mid November 2014) directed by Dr Norm Duke and Jock Mackenzie from James Cook University (JCU) with key project partners: Prof John Kovacs of Nipissing University in Canada, Rangers of the Gidarjil Development Corporation, and Prof Ian Atkinson with the eResearch Centre at JCU.

2) Project Components 1 & 2 - High Resolution Mapping and Change Detection and Ecological Condition Mapping. Working with Prof Kovacs, the team has sourced preliminary satellite imagery from which they have mapped the 2010 condition of tidal wetlands. The vegetation classifications made are being compared and checked with field observations, and the validations show differences from existing map units. This applies to upstream estuarine stands, and along landward margins throughout the study area.

3) Project Component 3 - Aerial shoreline surveys. The first aerial surveys were flown in 5 flights during 26-28 August 2015. Shorelines of the entire study area from Fitzroy River mouth to Rodds Bay were filmed, providing the essential first baseline observations for this project. The shoreline length filmed was around 1,600 km. In addition, these surveys provide the first observations and information about 17 processes influencing mangrove tidal wetlands both in the vicinity of Port operational areas and neighbouring comparative areas north and south.

4) Project Component 4 - Boat-based shoreline surveys and field studies. Boat-based surveys were done in 5 days during 28 August to 3 September 2015 (Fig. 1). Shorelines of selected parts of the study area were filmed, providing further essential first baseline observations for this project. The shoreline length filmed from boats was around 150 km. These surveys have contributed significant new measures of the presence, extent and severity of around 12 drivers of change.

5) Project Component 5 - Public access open data archive. Progress has been achieved but work was delayed in part with the need to restructure the data management and storage systems. Prof Atkinson and his group at JCU are planning to complete the key works later in the year – and, to give a demonstration of the prototype at the next scheduled ERMP meeting in August.

6) Additional promotional & relevant contributions. Presentation by Dr Duke about the PCPA CHAMP projects at the 2016 Australian Mangrove and Saltmarsh Network Conference in Darwin, 3-6 May 2016.

7) Additional promotional & relevant contributions. Production of two short documentary films about the PCPA CHAMP projects, the partnership between scientists and indigenous rangers supported by industry.

8) Additional promotional & relevant contributions. Publication of a research article (Mackenzie et al., 2016) describing the shoreline survey method used in this program.

9) Additional promotional & relevant contributions. In April-May 2016, the launch of a new project, the Southern GBR CHAMP funded by the National Environmental Science Program, in Burnett Heads. This project is being conducted in compliment to the PCPA CHAMP, extending the study area to the complete TUMRA area of the local traditional owners. The project continues the collaboration and partnership between Gidarjil

rangers and TropWATER Centre scientists – along with key participation of two NRM groups, the Burnett Mary Regional Group and the Fitzroy Basin Association. The Gladstone Ports Corporation are important endusers and participants in this extended work program.

Figure 1. Gidarjil rangers on survey with the PCPA CHAMP project with TropWATER scientists.

ACRONYMS USED IN THIS REPORT

ALOS – Advanced Land Observation Satellite
AUIG – ALOS User Interface Gateway
AVNIR – Advanced visible and near infrared
BMRG – Burnett Mary Regional Group
CHAMP – Coastal Habitat Archive and Monitoring Program
ERMP – Ecosystem Research and Management Program
FBA – Fitzroy Basin Association
GBR – Great Barrier Reef
GDC – Gidarjil Development Corporation
GPS – Global Positioning System
HD – high definition
JAXA – Japan Aerospace Exploration Agency
JCU – James Cook University
NDVI – normalized difference vegetation index
NIR – near infrared
NRM – Natural Resource Management
PCI Geomatica – a remote sensing desktop package for processing earth observation data
PCPA – Port Curtis Port Alma
QCIF – Queensland Cyber Infrastructure Foundation
TropWATER – Centre for Tropical Water and Aquatic Ecosystem Research
TUMRA – Traditional Use of Marine Resources Agreement

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1 INTRODUCTION

This is the 2015-2016 Annual Report of the Port Curtis Port Alma (PCPA) Coastal Habitat Archive and Monitoring Program (CHAMP) lead by scientists from James Cook University (JCU) TropWATER Centre. The work program includes monitoring the condition, survival and recovery of shorelines, specifically tidal wetlands, as outlined in the scope of works for tender CA14000114.

As noted in the 2014-2015 Annual Report, this project forms part of Gladstone Ports Corporation's (GPC) Ecosystem Research and Monitoring Program (ERMP) - a compliance requirement under GPC's approval for the Western Basin Dredging and Disposal Project, Stage 1A of which was completed in Septemeber 2013. The PCPA CHAMP project commenced around mid November 2014.

This second annual report, plus appendices, describes current project achievements, with their status in this six year program of assessment and monitoring of mangrove tidal wetlands of the Port Curtis and Port Alma area, including Port Curtis and Rodds Bay (see Fig. 2). Over the project period, 2014-2020, the plan is to generate essential baseline data, including comparisons with historical information, as the basis for on-going evaluations of environmental condition and change in the region.

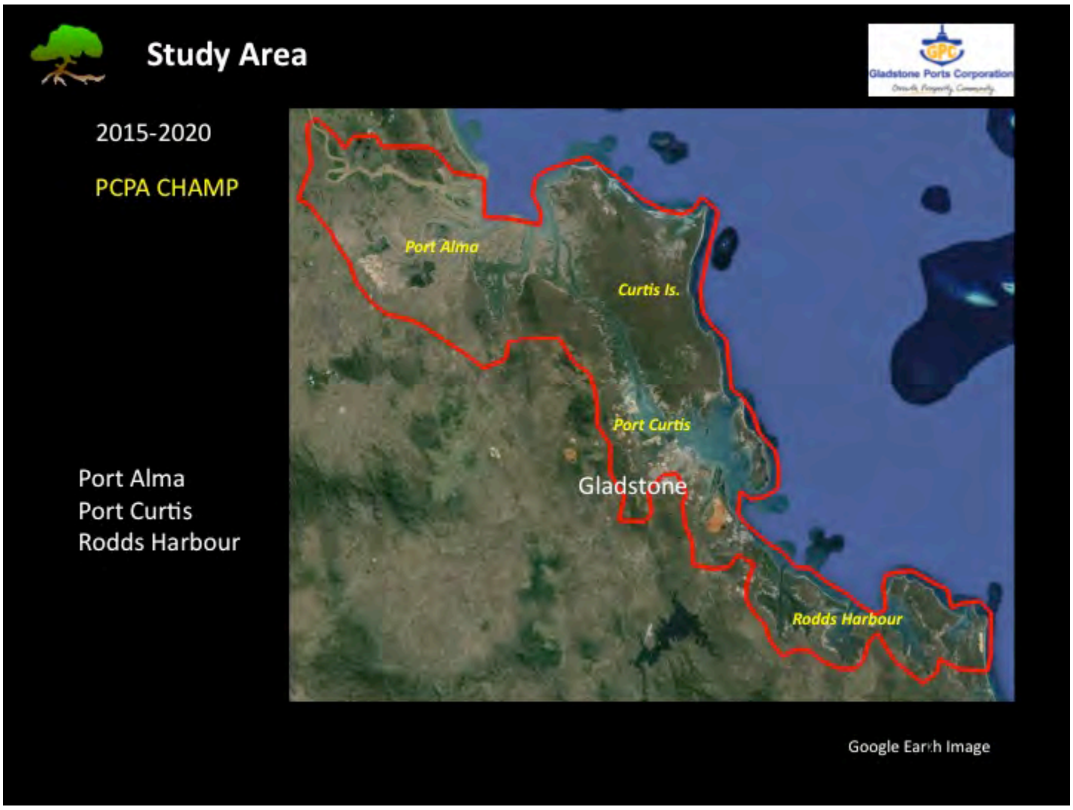

Figure 2. Map of the study area for the PCPA CHAMP projects showing the key study areas north and south of Port Curtis, Port Alma and Rodds Bay.

The information presented in this second report describes the on-going project logistics, planning, ranger engagement and training, plus project results to date. The five component tasks continue to be fundamental to meeting the objectives of this program.

Current data presented are the result of project findings that further extend on prior project achievements. Surveys and mapping have been most beneficial in our on-going establishment of baseline information, noting that we are now getting the benefit of prior efforts in the establishment of organisational facilities, like the Gladstone office, and with the training and familiarisation workshops with our partner rangers.

As previously noted, the program commitment is to undertake and complete the five components listed in the project scope of works for the Port Curtis and Port Alma area, as:

1. High resolution maps of tidal wetlands, plus historical assessment (change detection);
2. Normalised Difference Vegetation Index (NDVI) mapping of tidal wetlands;
3. Shoreline condition monitoring using oblique aerial image data acquisition;
4. Shoreline condition monitoring using boat based video image data acquisition and community volunteers; and
5. Public access and data entry portal for display of current and past mapping.

The integration of these components is fundamental to the success of the whole program. All efforts continue to be made to ensure each component is connected with each other component. The methodologies applied to the mapping, the aerial surveys, the field works, and the public outreach are all linked to the future central archive database now in advanced development.

As noted previously, the program is chiefly lead by science specialists in tidal wetlands, who are characterising shoreline environmental values for the Port Curtis and Port Alma area. This is being achieved through the mapping and evaluation of natural tidal wetland resources using the Shoreline Video Assessment Method (S-VAM) and all linked to the integrated monitoring and archiving program, bringing together partners in field research, remote sensing, IT and teaching skills.

While JCU TropWATER is the lead agent for the purposes of contracting with GPC, we are collaborating with partner organisations through individual sub-contracting/partnership arrangements, as appropriate:

a. Gidarjil Development Corporation indigenous Sea Rangers along with community volunteers in the Gladstone region, are assisting in the monitoring and assessment of coastal tidal wetland habitats (Component 4 chiefly, plus 3);
b. Collaboration with Prof John Kovacs of Nipissing University, Canada, for dedicated remote sensing assessments and mapping of tidal wetland habitats in the region (Components 1 & 2 primarily, plus using 4 for opportunities in ground truth and data validation);
c. Partnership with Queensland Cyber Infrastructure Foundation and the JCU e-Research Centre for the development and implementation of the planned online facility (Component 5 primarily, plus all other components eventually).

This project is considered an important opportunity to achieve world best practice for compilation and dissemination of data and expert advice gathered from field surveys and meetings with key stakeholders from industry, government, universities and with indigenous rangers and community volunteers. These works build on prior surveys like Duke et al. (2003; 2005).

The program is planned to raise awareness amongst communities about the values and threats to coastal tidal wetlands. In addition, by encouraging people in monitoring these fragile ecosystems, human communities can contribute to the preservation of coastal nursery habitat and coastal shoreline buffering from erosion and deposition, and the protection of neighbouring coastal habitats, like seagrass meadows and coral reefs.

2 BACKGROUND

While the program is an integrated package, it is being delivered as five Project Components with sometimes quite different contributing, specialist partners applying specific methods to address the particular objectives of each part.

2.1 Project Component 1. High resolution mapping and change detection

Criteria:	Generate high resolution maps of tidal wetlands with historical change detection to identify areas of net loss and gain in key habitat components (mangroves, saltmarsh and saltpans)
Project Lead:	Dr Norm Duke, JCU TropWATER
Partners:	Prof. John Kovacs, Nipissing University, Canada

Specific Tasks
Suitably fine-scaled Image data will be acquired from a number of sources starting with the remote sensing archives spatial imagery housed by the Queensland Herbarium and the Remote Sensing Centres with Queensland Department of Science, Information Technology and Innovation (DSITIA), and the Queensland Department of Natural Resources and Mines (DNRM). These and other spatial data, like that held by the Fitzroy Basin Association (FBA), will be identified and sought for use with this project prior to the project team making purchases to meet listed project objectives.

The key methodology being employed is:

1. Identify and collect source imagery based on a combination of high definition satellite imagery (0.5-1.0m) and aerial photographs.
2. Ensure adequate historical cover is captured by using imagery back to 2000.
3. Create the mapping using the tools for difference and record, notable occurrences of vegetation dieback and expansion and overall changes to habitat condition (health) reflected in canopy condition.
4. These outcomes will provide guidance for Components 3 and 4.
5. The maps will be uploaded and displayed on the dedicated, online public access website and data entry portal under Component 5, combining historical and current information on the condition of mangrove and tidal wetland vegetative communities in the region.

2.2 PROJECT COMPONENT 2. Ecological condition mapping

Criteria:	Normalised Difference Vegetation Index (NDVI) mapping of tidal wetland with historical change detection to identify areas of net loss and gain in key habitat components (mangroves, saltmarsh and saltpans);
Project Lead:	Dr Norm Duke, JCU TropWATER
Partners:	Prof. John Kovacs, Nipissing University, Canada

Specific Tasks
Suitably fine-scaled, multispectral Image data will be acquired as described for Component 1. It

is expected that the key imagery will be suitable for both components.

The methodology that will be employed is:

1. Identify and collect source imagery based on a combination of high definition satellite imagery (0.5-1.0 m) of suitable multispectral bands for NDVI analyses and mapping detection of sublethal change in canopy condition. Corrections and classifications will be made to image data based on field measures of *in situ* Leaf Area Index (LAI) measured during field surveys described in Component 4.
2. Ensure adequate cover is captured by using imagery specifically dated in at least two time periods each around 2014 and 2018. Additional time periods will be assessed where image availability and funding permits. The choice of suitable image data will be determined by availability, suitably high definition, and lack of cloud cover.
3. Create mapping using tools for difference and record, notable occurrences of zonal margins of vegetation dieback or expansion and overall changes to habitat condition (health) reflected in canopy condition.
4. These outcomes will provide guidance for Components 3 and 4.
5. The maps will be uploaded and displayed on the dedicated, online public access website and data entry portal under Component 5, combining historical and current information on the condition of mangrove and tidal wetland vegetative communities in the region.

2.3 PROJECT COMPONENT 3. Aerial shoreline surveys

Criteria:	Shoreline condition monitoring using oblique aerial image data acquisition and current assessment criteria for quantification of key ecological processes
Project Lead:	Dr Norm Duke, JCU TropWATER Jock Mackenzie, JCU TropWATER
Partners:	Gidarjii Development Corporation Land and Sea Rangers

Specific Tasks

The methods used in these surveys are geo-referenced videography. All imagery is processed and used both to visually describe coastlines, and to be used to make ecological assessments of shoreline composition, status and condition.

The methodology that will be employed is:

1. Collect source video and still imagery taken obliquely from aircraft flown at around 150 m altitude, covering entire shorelines of estuarine areas and embayments. The extent of shorelines filmed will comprise continuous coverage of most mainland and island shorelines (as chiefly mangrove seaward margins, but not restricted to them) in the study area.
2. Ensure adequate temporal cover is captured by using imagery taken in at least two time periods around 2014, and 2018. Additional time periods will be assessed if funding permits. The choice of days for flying surveys will be determined by the suitable weather conditions, time of day, coupled with periods of relatively low tide.
3. Records will initially be made of baseline conditions, followed by difference records in subsequent surveys. Records will note occurrences of habitat type, condition and change. Specifically, these include key processes of change, like shoreline retreat,

erosion, dieback of vegetation, encroachment of vegetation, and other indicators/evidence of changes to the shoreline.
4. These outcomes will provide guidance for site selections made in Component 4.
5. The information will be mapped based on background maps developed in Components 1 and 2. These will be uploaded and displayed on the dedicated, online public access website and data entry portal under Component 5, combining historical and current information on the condition of mangrove and tidal wetland vegetative communities in the region.

2.4 Project Component 4. Boat-based shoreline surveys and field plots

Criteria:	Shoreline condition monitoring using boat based video image data acquisition and community volunteers**.**
Project Lead:	Dr Norm Duke, JCU TropWATER Jock Mackenzie, JCU TropWATER
Partners:	Gidarjii Development Corporation Land and Sea Rangers MangroveWatch Ltd Gladstone MangroveWatch Community Volunteers

Specific Tasks

The methods used in these surveys are geo-referenced videography. All imagery is collected by either indigenous rangers or by community volunteers. All participants are trained by the project team. In the study area, the indigenous rangers are already trained and operationally ready to conduct surveys in the study area. Processing of image data collected by community members is assessed by the project team at the Mangrove Hub at JCU TropWATER. Data taken from imagery and from survey diaries are used to visualise and describe coastlines, to make ecological assessments of shoreline composition, status and condition.

The methodology that will be employed is:

1. Collect source video and still imagery taken laterally from small boats around 50 m distance to shoreward margins. Filming will be undertaken such that it covers continuous shorelines of specific sections of estuarine areas and embayments. The intent of the project team is to cover all seaward margins in the study area, but limitations of funding dictate that only about 200 km of shoreline will be filmed and assessed. Ideally, the extent of shorelines filmed will include continuous coverage of most mainland and island shorelines (as mangrove seaward margins mostly, but not restricted to them) in the study area. Attention will be made of specific sections of the coastline as will be determined in meetings with the GPCL, the project team and the Gidarjil Rangers.
2. Training has been given to the Gidarjil Rangers by the MangroveWatch project team in 2012-13 to specifically develop their skill base for the effective, independant gathering of imagery and other data for development of shoreline profiles relevant to this scope of work.
3. The project team would prefer to make annual temporal coverages, but the extent of work will be determined fully, as soon as possible after commencement of the project. There is sufficient funding support in the budget proposed to make at least 3 surveys during the 6 project years working with the Gidarjil Rangers with surveys in at least

three time periods around 2014, 2016 and 2018. To fill the gaps and enhance the existing program, a number of strategies will be employed: 1) additional funds will be sought with appropriate grant applications to further employ Gidarjil Rangers; and 2) community volunteers will be enlisted and trained. In this way, additional time periods will be assessed, depending on the level of interest shown by community volunteers for additional shoreline coverage and filling time gaps (notably years 2015, 2017, 2019 and 2020). Community volunteer engagement will be facilitated by our budgeted support of a community coordinator position for one day per week each year until 2020.

4. The choice of days for boat surveys will be determined by the suitability of weather conditions, the time of day, coupled with periods of relatively low to mid tide.
5. Initial records will represent baseline conditions. Subsequent records will provide the means to measure differences from baseline. Project observations will describe occurrences of habitat type, condition and change; specifically noting: specific vegetative conditions, like species type, biomass, dieback condition, presence of plant mutations, notable erosion, root/bank exposure, sediment deposition, presence of seedlings, and seasonal changes along with verified combinations of species present in each habitat assemblage.
6. As part of this component, field surveys will be conducted in early 2015 and early 2017 to provide specific ground truth to support the mapping and remote sensing (Components 1 and 2), plus each of the videographic surveys (this Component and Component 3). Information gathered will include confirmation of habitat structure, biodiversity, condition, presence of fauna, and soil character.
7. The information from video tracks and sites will be mapped based on background maps developed in Components 1 and 2. These will be uploaded and displayed on the dedicated, online public access website and data entry portal under Component 5, combining historical and current information on the condition of mangrove and tidal wetland vegetative communities in the region.
8. The community coordinator position and office location in Gladstone is considered an important role for the delivery of this component outcomes. The position will be funded from the project at one day per week. The positions work role will be to coordinate community engagement in all MangroveWatch activities combining contributions from the Gidarjil Rangers along with community volunteers and school students. With this, the Gidarjil Rangers are working with the Boyne Island Environmental Education Centre (BIEEC) for collaboration in MangroveWatch surveys. This involves boat support used with project surveys. An additional role of the Coordinator will be to organize community workshops, training sessions, plus outreach activities, like annual Ecofest, The Boyne Tannum Hook-up event, and MangroveWatch art gallery shows.

2.5 PROJECT COMPONENT 5. Public access open data archive

Criteria: Public access and data entry portal for display of current and past mapping.
Project Lead: Prof. Ian Atkinson, JCU eResearch
Dr Norm Duke from JCU TropWATER
Partners: Queensland Cyber Infrastructure Foundation (QCIF)
MangroveWatch Ltd

Specific Tasks

The JCU eResearch Centre, in consultation with Dr Duke, is developing a highly engaging and effective, interactive public access website featuring contributor links, along with assessments of risk and vulnerability of the study area shoreline - including estuaries, channels and islands. This system will be able to store, display, organise and archive the data sets and outputs from components 1 to 4 above and provide a single source interface to the programs activities.

This facility is to be an online Digital Asset Management system (DAM) containing all of the digital observations and products developed in components 1-4. This includes the map data with the facility to add/upload future mapping from Component 1 and shoreline profiles (Component 3 & 4). As well, it will permit the combining of historical and current information on the condition of mangrove and tidal wetland vegetative communities, including any significant impacts of episodic change during the study period to be displayed. The website will have the facility for ready access and uploading of data for the display of the data and imagery from Component 1-4.

The public-access website will be available by the end of 2016, and functionality will be added across the first two years in direct response to user feedback and emerging requirements. All data, video and other assets will be managed and securely stored in the DAM and relevant metadata will be uploaded to the national Research Data Australia (RDA) repository to enable discovery of the raw and processed data by public search engines such as Google. The website will be updated and reviewed biannually. This component will be developed in 2015-2016 and will continue throughout the periods of Components 1-4.

The products generated by the proposed project offer tangible long-term benefits, include:

1) A constantly renewed and expanding archive of geo-referenced maps and imagery, available online with assessments of past and current condition of coastal and estuarine habitats, aided by the ShoreView platform (see http://shoreview.jcu.io/) with notable contributions from the community science partnership program (see Component 4) MangroveWatch (see: www.mangrovewatch.org.au);
2) A specific stakeholder network supporting industry, government and community initiatives for improved environmental management of coastal and estuarine habitats, with awareness raising, public workshops and targeted publications and training manuals;
3) A robust, best practice, standardized program, methodology and reporting framework for the systematic assessment and monitoring of the condition and health of coastal and estuarine habitats, involving community volunteers and indigenous rangers.

3 2015-2016 RESULTS

3.1 Project Components 1 & 2. High Resolution Mapping, Change Detection & Ecological Condition Mapping

Prof. Kovacs has worked with Dr Duke in their on-going collaboration to meet the mapping commitments with this project. The focus is on depicting tidal wetlands including mangroves, saltmarsh plus saltpans being the zone/niche that roughly extends between mean sea level and the highest astronomical tides.

The strategy developed for this project has been to source suitable image data and to prepare a staged series of vegetation maps showing tidal wetlands. The aim is to accurately define the location and extent of these vegetation units, and then to describe how they have changed (historical) and how they continue to change. This will quantify lethal changes on the basis of changes in presence and absence between one date and another. Sublethal changes and variations in canopy condition will also be investigated in an effort to gauge measures of on-going health and well being of mangrove areas across the region. The principle behind this approach is two fold – one is to recognise any sublethal pressures on these habitats, and the other is to evaluate whether any intervention might prevent further canopy deterioration.

Figure 3. The three insets cover the study area and depict the primary maps developed for this project from 2010 ALOS satellite imagery. See Figs. 4 to 6.

It is fully acknowledged that a number of mapping projects are available, including those done by the Queensland government (http://wetlandinfo.ehp.qld.gov.au/wetlands/facts-maps/tile-100k-gladstone/). The plan is to enhance these prior mapping efforts further by improving the scale of detection, by improving the discrimination of vegetation types, and/or by more tightly classifying imagery for specific year dates, as far as possible. The value in making these refinements is immense, as it will allow the easier use of change detection across the entire study area by reference to an accurate and reliable baseline from which all change, both retrospective and future change, can be determined with confidence.

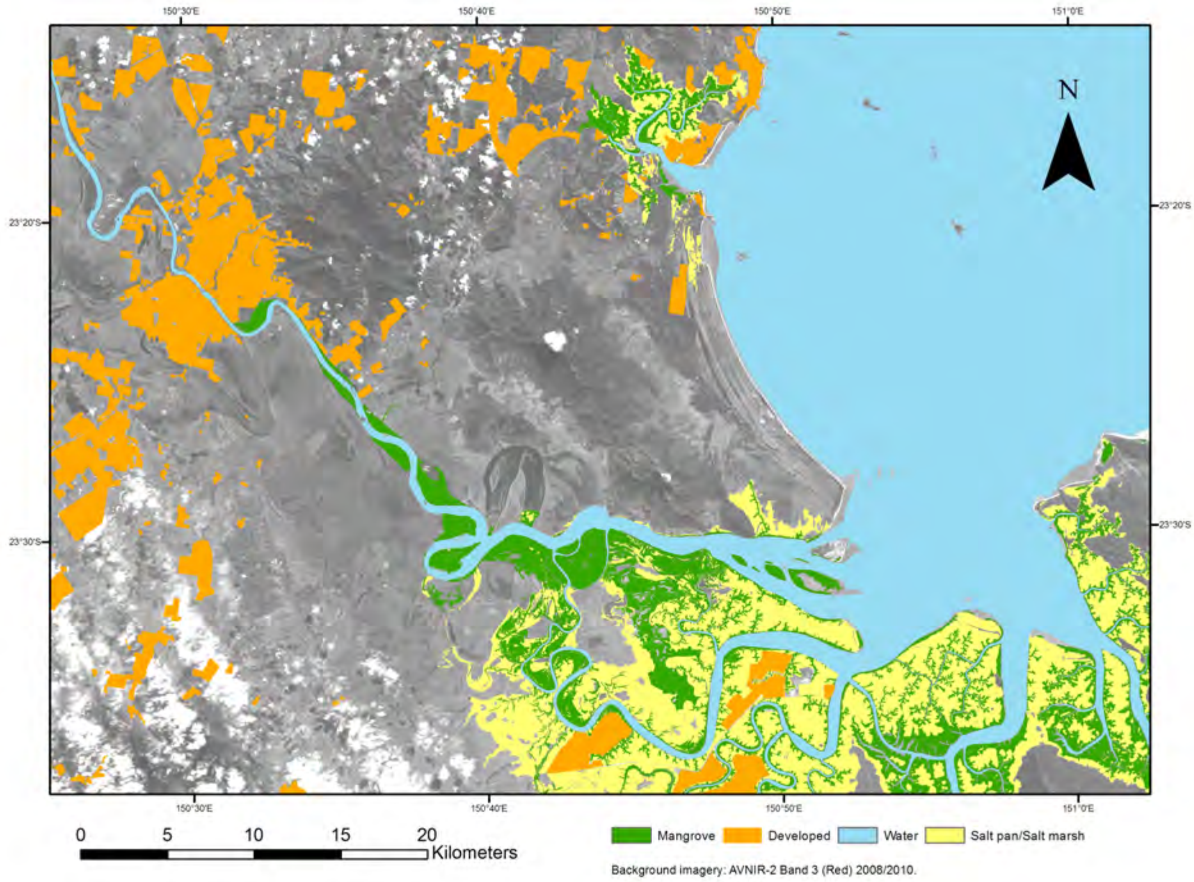

Figure 4. The 2010 map of Fitzroy River and Port Alma showing the extent of tidal wetlands (mangroves, saltmarsh and saltpans) and the presence of developed areas.

This has been achieved by the Queensland Government in recently released mapping of Moreton Bay tidal wetlands showing changes in extent between 1955, 1997 and 2012 (http://wetlandinfo.ehp.qld.gov.au/wetlands/ecology/components/flora/mangroves/mangrove-moreton.html).

Our current project aims to emulate such improvements in tidal wetland habitat mapping for the Port Curtis region.

Primary maps have been drafted (Fig. 3) showing baseline condition for 2010, and helping us redefine the actual limits of mangrove distributions at a number of hard to determine locations. One is the distribution of mangroves upstream in estuarine systems. Mangrove stands in these locations are difficult to discriminate in low (coarse) resolution imagery because trees are often small in size, and they occur in very narrow zones, sometimes just a few trees wide. In other locations, mangroves at the landward fringes are sometimes hard to distinguish where they border certain kinds of supratidal rainforest vegetation.

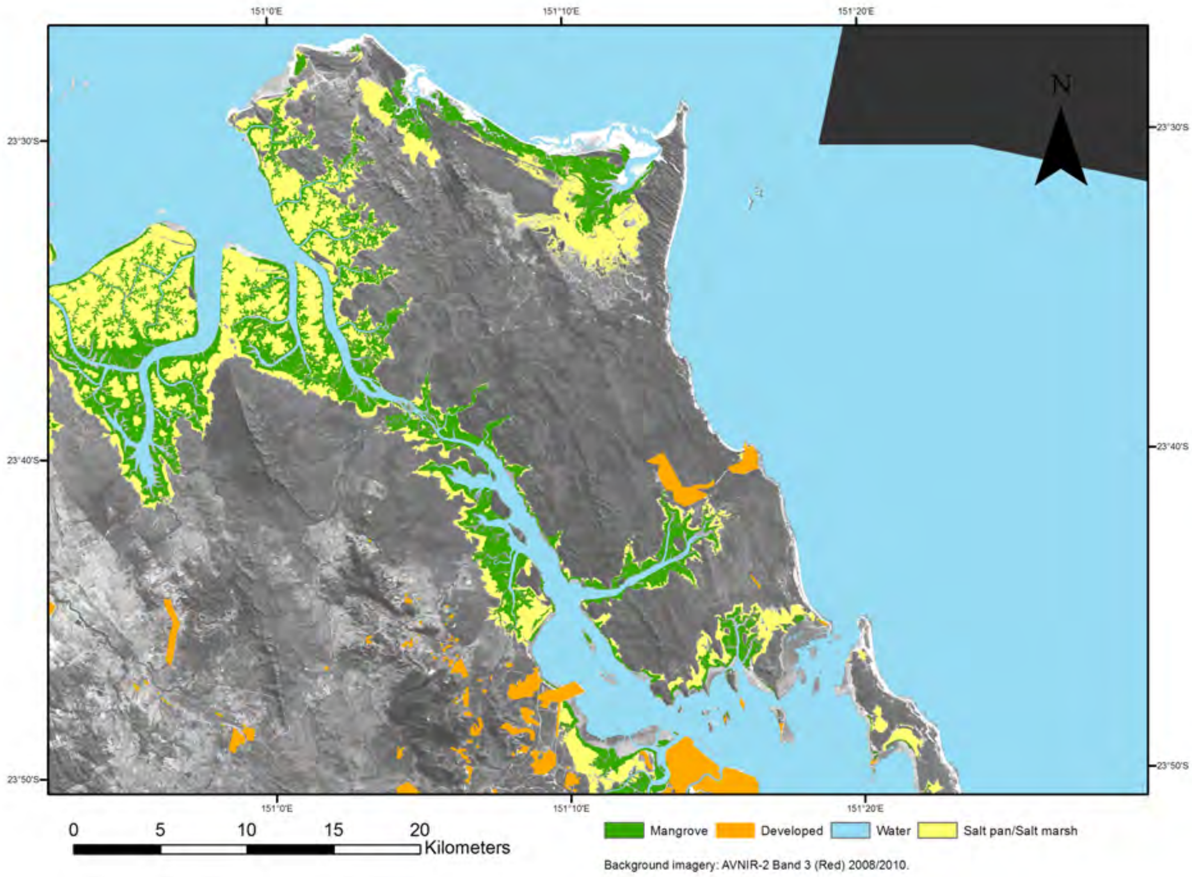

Figure 5. The 2010 map of Curtis Island and northern Port Curtis showing the extent of tidal wetlands (mangroves, saltmarsh and saltpans) and the presence of developed areas.

Data collection and image pre-processing methods

Six Japanese ALOS AVNIR-2 satellite images were acquired from the JAXA AUIG2 online system to cover the PCPA study area (Table 1). Each image contains four spectral bands (blue, green, red, near-infrared) at 10 meters spatial resolution and 8 bit radiometric resolution.

Table 1. ALOS AVNIR-2 Satellite Images used for the PCPA mangrove and saltpan mapping.

Scene ID	Date of Acquisition	Path Number	Frame Number
ALAV2A230464080	2010-05-23	21	4080
ALAV2A134774070	2008-08-05	23	4070
ALAV2A232944070	2010-06-09	22	4070
ALAV2A232944080	2010-06-09	22	4080
ALAV2A234694080	2010-06-21	20	4080
ALAV2A234694090	2010-06-21	20	4090

Each image scene was processed to surface reflectance using *PCI Geomatica's ATCOR* module in order to correct for atmospheric attenuation. All scenes were projected and resampled to WGS84 UTM Zone 56. The radiometrically corrected scenes taken from the same adjacent swath (path number) were then mosaicked together using *PCI Geomatica's OrthoEngine* module.

Image classification

Classification of the mangrove and saltpan/saltmarsh areas was achieved using an iterative per-pixel unsupervised classification approach. For example, to extract the mangrove areas each individual scene or mosaic of scenes was first classified using an ISODATA algorithm based on the four spectral bands to identify vegetated and non-vegetated areas. A second unsupervised classification was then applied to the previously classified vegetated areas only in order to best extract the mangrove areas from the spectral data. Using ancillary data (e.g., *Google Earth*) on screen manual editing was then performed to remove any erroneously classified mangrove pixels. The same iterative unsupervised classification process was used to map the saltpan/saltmarsh areas. Surface water was classified using a simple thresholding technique based on the near infrared spectral band and the developed areas were identified using the Queensland Government's *Queensland Spatial Catalogue- QSpatial*. Finally, the classifications from each of the individual scenes or mosaics were merged into one dataset covering the entire PCPA study area. For convenience and display in this report, this mapping has been divided across 3 figures (Figs. 4-6).

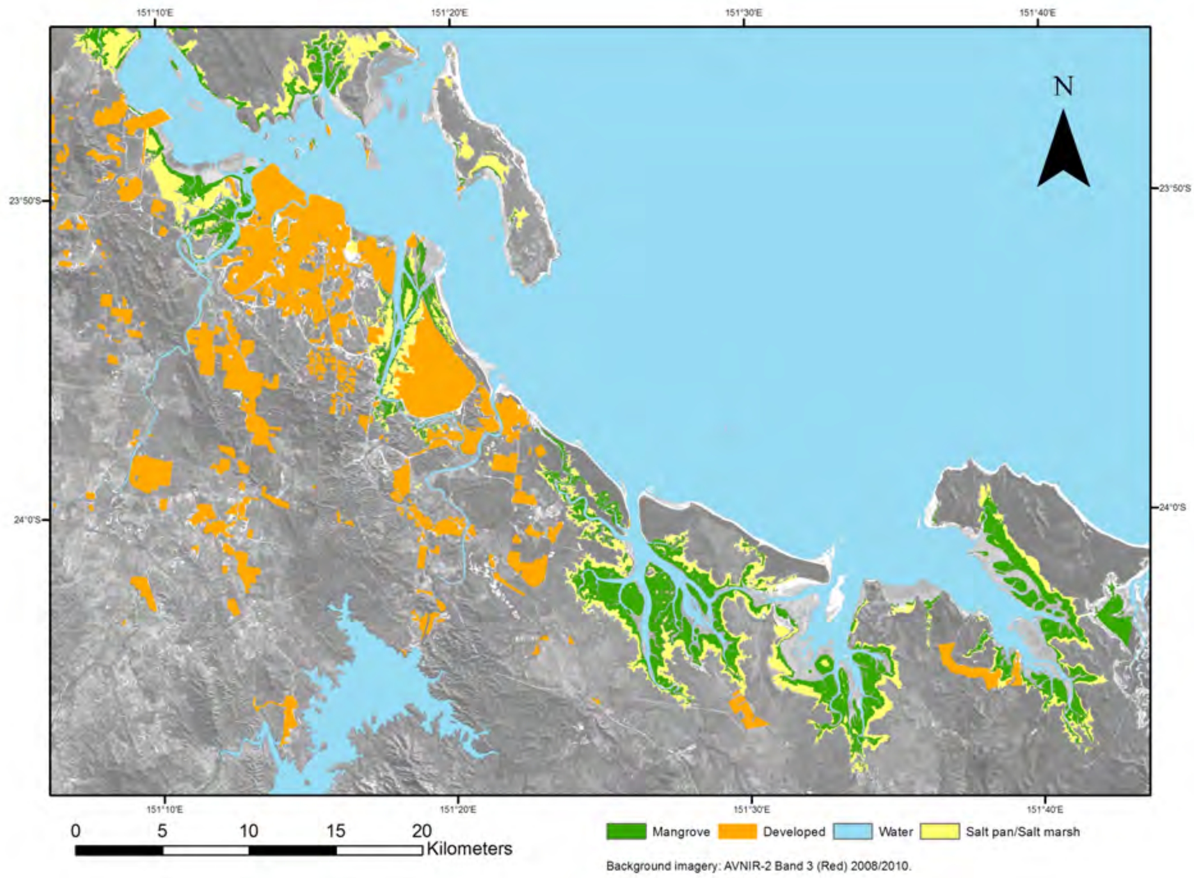

Figure 6. The 2010 map of Port Curtis and Rodds Bay showing the extent of tidal wetlands (mangroves, saltmarsh and saltpans) and the presence of developed areas.

Future image processing

Higher spatial resolution imagery, likely *SPOT-7*, will be acquired for either 2014 or 2015. Once collected, these data will first be radiometrically and, if necessary, geometrically corrected. Since several swaths of imagery are likely to be needed to cover the entire PCPA study area, the many surface reflectance images may also be mosaicked. The NDVI will then be produced from each surface reflectance mosaic. NDVI is calculated using the following formula: NDVI = *(*NIR − Red*)(*NIR *+* Red). The NDVI images can then be used to monitor changes in the health of the vegetation by comparing them with future NDVI images collected of the same locations. Finally, using more recent ancillary data (e.g., Gidarjil field surveys), an updated per pixel classification procedure will be applied to the newly acquired imagery in order to map the most recent areas of mangrove and saltpan/saltmarsh land cover.

3.2 Project Component 3. Aerial shoreline surveys

Aerial surveys were conducted over 3 days during 26-28 August 2015. These surveys used a Robinson 44 helicopter (Fig. 7), flying 5 separate missions: one morning and one afternoon on each of 26th and 27th August, and a morning flight on 28th August. In all missions, the timing of flights was made to maximise favourable light conditions in conjunction with the mid day period of low tides. The goal was to photograph and observe exposed tidal wetlands and their vegetation at low tide.

Figure 7. Aerial surveys filmed tidal wetland shorelines throughout the PCPA study area.

The survey crew consisted of Dr Duke and Jock Mackenzie on all flights, plus a third survey member on rotation amongst 5 of the Gidarjil rangers. The survey crew operated 5 cameras in total amongst themselves along with a portable GPS device to record the flight track. All cameras were synchronised for time reference, and with their internal GPS recording.

The 5 cameras and hand-held GPS device used included:

- Large format Nikon D800E with Nikkor 50mm 1:1.4G lens & GPS, 2 sec. time lapse
- Canon Dslr EOS 450D with 17-85 lens & GPS
- HD Sony video HDR-PJ430 with GPS
- Sony Cyber-shot DSC-HX50V with GPS
- Sony Cyber-shot DSC-HX5 with GPS
- Garmin GPSmap 62s loaded with local satellite imagery

DAILY SCHEDULE for Aerial Surveys – 26-28 August

Wednesday 26/8. Aerial Survey Day 1
Low tide is at 1208.
Objective: To conduct aerial research surveys using S-VAM from a helicopter – aerial survey day 1 of 3.

Participants: Norm & Jock plus one Ranger. Helicopter arrived at the airport launch site around 0800 with pilot, Ben, from Reid Heliworks (the same operator used by the seagrass project with their surveys starting on Saturday and going for 3 more days).
AM: Meet Gladstone Airport: 07:45. Flight Crew 1: 0830-1130. ND, JM, Symeon
PM**:** Flight Crew 2: 1230-1530. ND, JM, Jayme
Survey Locations:
AM- East facing shoreline from Gladstone south to Rodds Bay & tidal wetland/terrestrial ecotone.
PM- West facing shoreline of Inner Hummock Hill Island and Turkey Bay, estuaries & mangrove/ saltmarsh ecotone from Rodds Bay to Gladstone.
The Plan: Norm, Jock & one Ranger (as above) conducted 2 helicopter flights of around 2-3 hours each, during the mid day period. The first flight was between 0830-1130. And the second between 1230-1530. These flights involved 3 survey crew filming shorelines using up to 5 hand-held cameras. Over the 3 days, 26-28 August the plan was to survey the study area from Rodds Bay to Fitzroy River estuary. On the first day, the survey crew concentrated on the southern sector from Port Curtis Narrows to Rodds Bay.

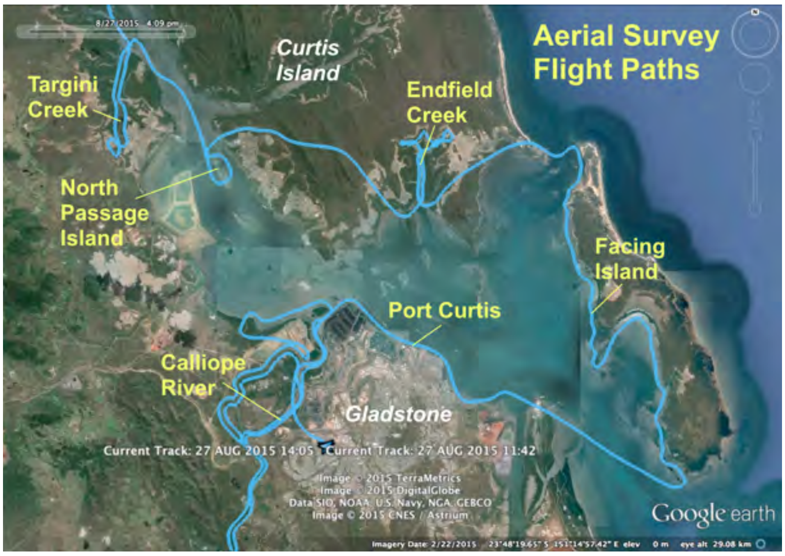

Figure 8. Track of helicopter flight path (blue lines) showing part of the aerial coverage of S-VAM surveys conducted during afternoon flight on the 27 August 2015 around Port Curtis.

Thursday 27/8. Aerial Survey Day 2
Low tide is at 1306.
Objective: To conduct aerial research surveys using S-VAM from a helicopter – aerial survey day 2 of 3.
Participants: Norm & Jock plus one other.
AM: Meet Gladstone Airport: 08:45. Flight crew 1: 0930-1230. ND, JM, William
PM: Flight crew 2: 1330-1630. ND, JM, Peter
Survey Locations:
AM- East facing shoreline from Gladstone north to Fitzroy River & tidal wetland/terrestrial ecotone & the northern Curtis Island shoreline.
PM- West facing shoreline of Facing & Curtis Islands, estuaries & mangrove/saltmarsh ecotone from Fitzroy to Gladstone (Fig. 8).
The Plan: Norm, Jock & one other (see above) conducted 2 helicopter flights of around 2-3

hours each, during the mid day period. The first was between 0930-1230. And the second between 1330-1630. These flights involved 3 survey crew filming using up to 5 hand-held cameras. For this second aerial survey day, we filmed the southern sector from Port Curtis Narrows to Fitzroy River estuary.

Friday 28/8. Aerial Survey Day 3
Low tide is at 1400.
Objective: This day was used to film documentary scenes about aerial surveys. This involved helicopter filming in the morning.
Participants: Norm, Jock, and 2 others Brent and Mark, specifically for extra camera work.
Flight Crew 1:
AM: 0930-1230. ND, JM, 2x Rangers, Brent, Mark
Survey Locations:
AM- Helicopter surveys were made around Calliope River mouth, Auckland Creek, Barnie Point & southern Port Curtis Island.

Figure 8. Track of helicopter flight path (yellow lines) showing total aerial coverage of S-VAM surveys conducted during 26-28 August 2015. To see the study area, see Fig. 2.

Aerial surveys were used to film mangrove shorelines throughout the study area (Fig. 8). The filming and the observations made will assist our on-going efforts to more effectively validate mapping units and features identified in Components 1 & 2.

The total distance flown and filmed for these late 2015 aerial surveys was 1,597 km.

Specific aerial survey program tasks achieved include:

- completed surveys of the entire study area in August 2015.

Key features and indicators observed

A preliminary result from these aerial surveys was the types of features and indicators observed. Some were indicative of processes of change taking place. The more-or-less full diversity of indicators that identify drivers of change in tidal wetlands were described by Duke (2014). These range from human related drivers like altered hydrology, cattle damage, vehicle access and reclamation, to the more indirect or natural drivers, like drought effects, floods and erosion. One additional feature was the presence of the seasonally deciduous mangrove, *Xylocarpus mollucensis*, the Cedar Mangrove, which was reddening and losing its leaves at the time of the surveys.

Table 3. Features and issues affecting tidal wetlands across the PCPA study area during both aerial and boat-based surveys during August-Sept 2015.

Issues & Features	**Aerial S-VAM**	**Boat-based S-VAM**
Direct damage – reclamation, landfill	+	+
Direct damage – surface sand extraction	+	
Direct damage – boat ramps	+	+
Direct damage – vehicle tracks	+	
Direct damage – cattle tracks	+	+
Direct damage – flood damage	+	+
Direct damage – boat prop scars	+	
Altered hydrology - impoundment	+	
Green mudbanks – eutrophication	+	+
Species specific effect – harmful agricultural chemicals	+	+
Upland shift/retreat – sea level rise	+	+
Eroding banks – dynamic hydrologies	+	+
Depositional gain – runoff sediments	+	+
Burial dieback – shifting sediments	+	+
Light gaps – lightning strike damage	+	+
Ecotone shift – drought effect	+	+
Deciduous trees – natural seasonal defoliation	+	+

During the aerial surveys, we observed at least 17 different features and issues. These are listed in Table 3. Six of the more notable issues are shown in Fig. 10. These include flood damage, upland retreat, drought effects, vehicle tracks, cattle trampling and prop wash scars. When our assessments are completed, we will be able to compare the frequency of these features with our measures of mangrove canopy condition, to learn if they correlate with mangrove health. Additional features, including boat-based observations are shown Fig. 11.

A more detailed assessment is underway and due to be completed in the next 6 months.

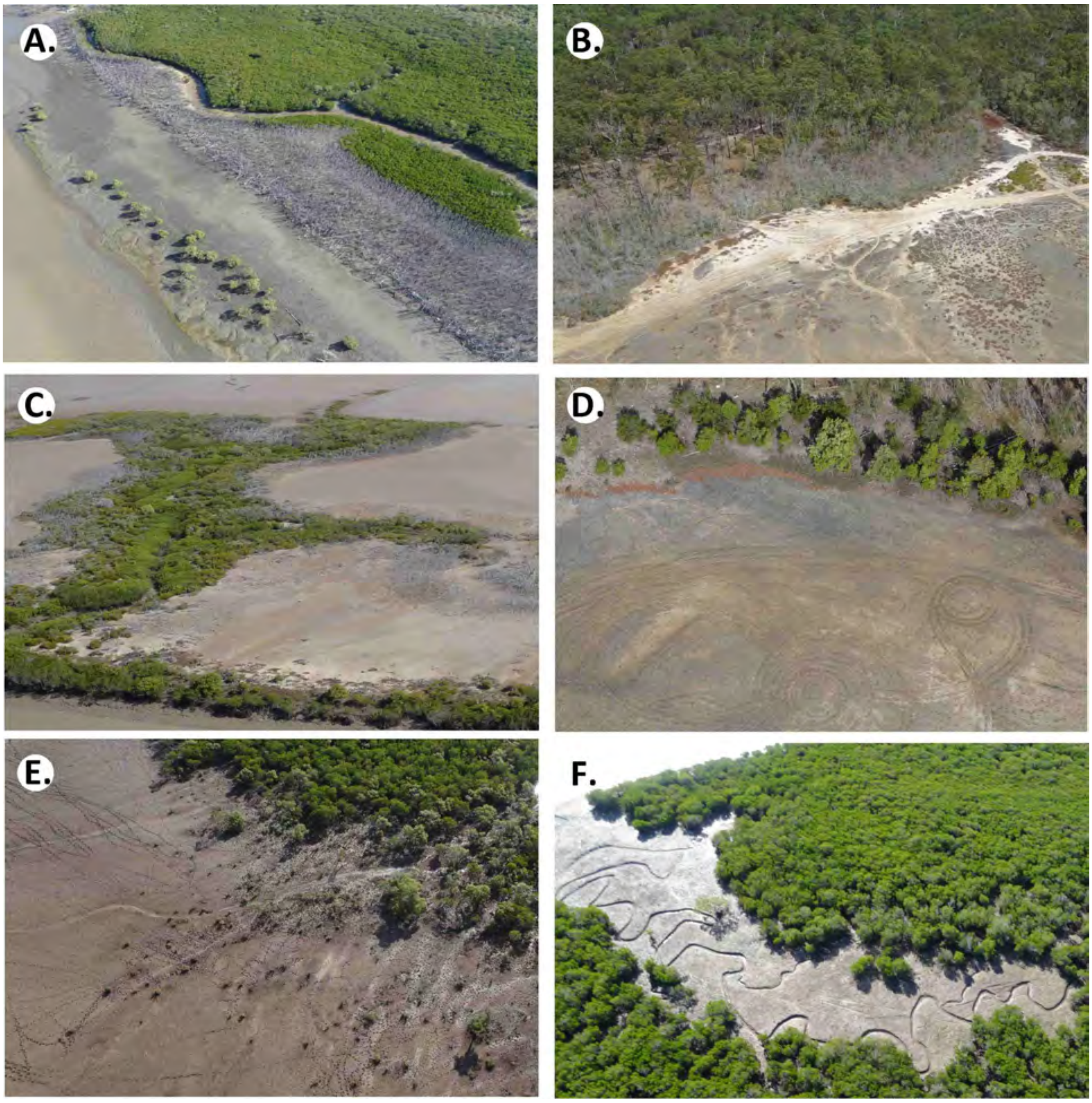

Figure 10. Six indicators and features observed during the 2015 aerial surveys across the entire study area, including: A. flood damaged foreshore mangroves; B. upland retreat from saline incursion; C. drought affected ecotone shift; D. direct damage from vehicle access; E. direct damage from cattle grazing; and F. propeller wash damage.

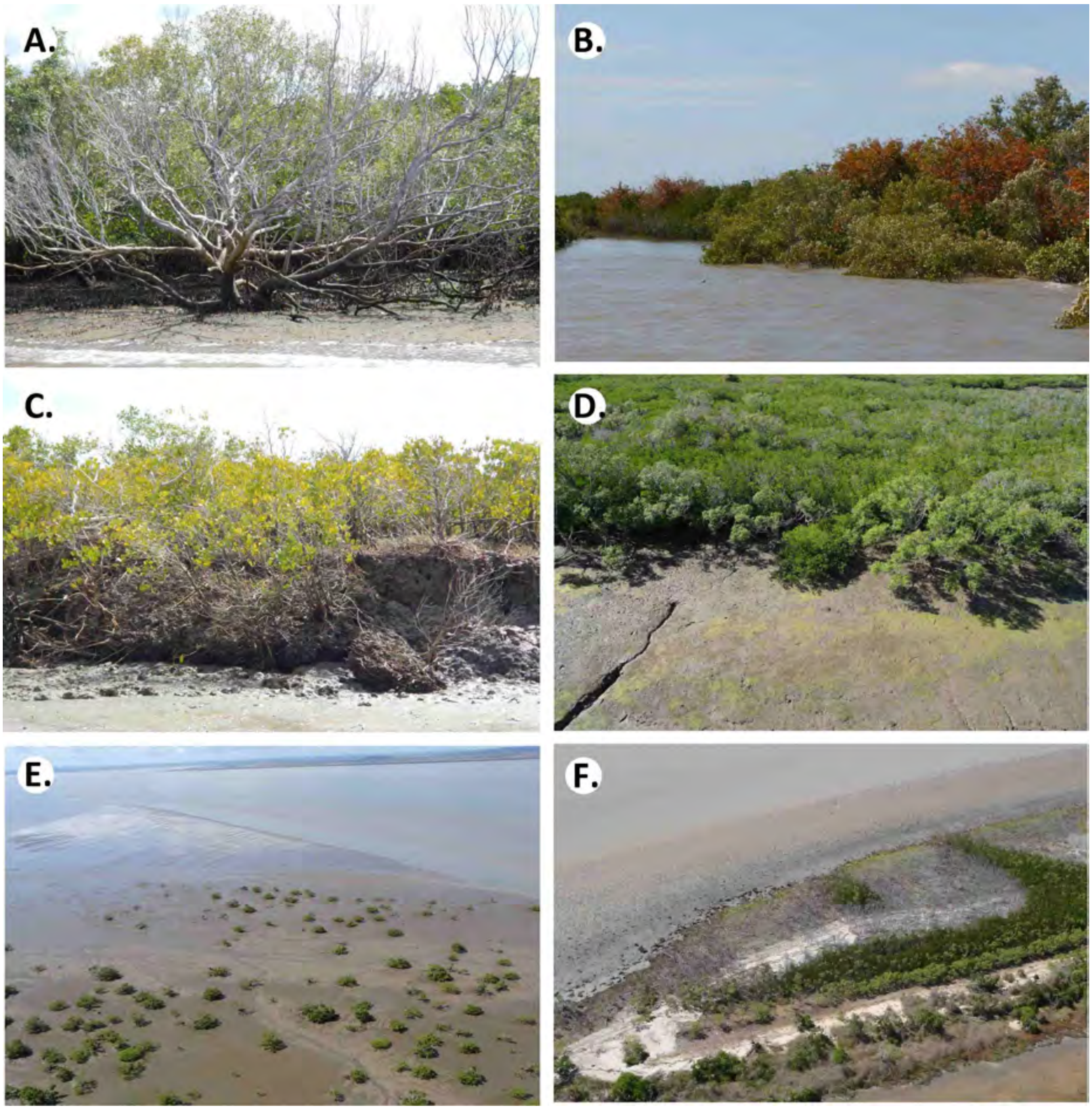

Figure 11. Six more indicators and features observed during the 2015 aerial and boat-based surveys within the study area, including: A. species specific dieback of *Avicennia*; B. seasonally red deciduous *Xylocarpus*; C. eroding bank with *Ceriops*; D. green algal cover on the mud flats fronting mangroves; E. depositional gain mangrove expansion; and F. root burial dieback with shifting sediments.

Historical comparisons with current imagery

This project will also draw comparisons with historical data and images where possible. Two images taken during the August-September aerial surveys are compared with images from 1924 and 1947 (Fig. 12). This is a part of the port area that is well known to have changed with notable foreshore development and port expansion.

Figure 12. Views of Auckland Hill, Gladstone, from the 2015 aerial survey compared with earlier images (Duke et al. 2003). This is an area of substantive change with port and shoreline development affecting tidal wetlands along Auckland Creek.

3.3 Project Component 4. Boat-based shoreline surveys and field plots

There have been three different types of boat-based S-VAM surveys including those by the JCU team with Rangers and community volunteers, and those lead by the Rangers. The first two while being working surveys, they were also essential training exercises for the rangers and community volunteers.

Boat-based surveys lead by the JCU team were conducted over 5 days during 28 August to 3 September 2015. These surveys used small open vessels (Figs. 13 and 14). The survey crew consisted of either Dr Duke or Jock Mackenzie with all filming, accompanied by 3-4 others as either Gidarjil rangers or community volunteers.

The timing of boat surveys was made to maximise favourable light conditions in conjunction with the mid day period of mean tides. The goal was to photograph and observe exposed tidal wetlands and their vegetation at low tide while being able to navigate safely.

The survey crews operated 3 cameras in total amongst themselves along with a portable GPS device to record the flight track. All cameras were synchronised for time reference, and with their internal GPS recording.

The 3 cameras and hand-held GPS device used included:

- HD Sony video HDR-PJ430 with GPS
- Sony Cyber-shot DSC-HX50V with GPS
- Sony Cyber-shot DSC-HX5 with GPS
- Garmin GPSmap 62s loaded with local satellite imagery

Figure 13. S-VAM surveys lead by the JCU team off Port Alma in Sept 2015.

Figure 14. Community volunteers filming the Boyne River in Sept 2015.

DAILY SCHEDULE for Field boat-based Surveys –28 August to 3 September 2015

Friday 28/8. Boat survey 1
Low tide is at 1400.
Objective: This afternoon is for boat-based filming of S-VAM with community volunteers. This starts with helicopter filming in the morning, then in the afternoon, is for getting interviews with as many project participants as possible, and to start with some S-VAM filming to be done by the rangers and community volunteers. With the interviews, we expect that there will be representatives of the Port, and other stakeholders in the project. Please check with Norm, and consider inviting additional people you think need also to be included. We will have a schedule so we coordinate who is doing what. We are hoping GDC will be keen to show off at least one of the documentaries amongst your contacts and staff.
Participants: Norm, Jock, Brent, Mark, Gidarjil Rangers and a community volunteer.
PM: Meet Boat Ramp around 1245.
Boat Team 1 (RV *Avicennia* - 7m Punt): 1330-1630. ND, JM, 2 x Gidarjil, 1 x Community (Kat), Brent, Mark. Boat Pax: 11 in Smooth waters (Max 7 in partially smooth & for comfort). Boat Driver: Symeon.
Survey Locations:
PM - Locations around Gladstone (Boyne River)
The Plan : In brief, we are working on 2 documentaries over the Friday and Saturday – one doco being a short 3-4 minute one about port industry and environmental monitoring using scientists and rangers, and another training video for S-VAM. At all times, we took opportunities to get interviews with participants and stakeholders. During the afternoon, we conducted the boat-based doco work with the Rangers and volunteers.

Figure 15. Tracks (yellow lines) of boat-based S-VAM surveys made by the JCU team with Gidarjil rangers during 29 August to 3 September 2015. Note surveys are focused on Port Alma, Balaclava Island in the north, Port Curtis in the central area, plus Boyne River and Rodds Bay in the south.

Saturday 29/8. Boat survey 2

High Tide is at 0842 (3.9m), and low tide is at 1448 (0.3m).

Objective: This was a filming day for documentary about boat-based S-VAM surveys in the morning, plus additional stakeholder interviews. This started with boat-based filming in the morning.

Participants: Norm (ND), Jock (JM), Brent, Mark, Arthur, Richard, and a small number of community volunteers and rangers.

AM: 0930-1330

Boat Team (2x polycraft vessels pax 4 each):

Boat 1: JM, 3xCommunity

Boat 2: ND, Brent, Mark, 1xCommunity (community to rotate)

Survey Locations: Gladstone vicinity, Port Curtis

AM - Meet Tannum Sands Boat Ramp - Wild Cattle Ck 09:00.

The Plan : All morning we used the boat and for taking filming of rangers and volunteers actually applying S-VAM, using video cameras, using GPS, using the laser distance measure, and generally conducting surveys. We will us all S-VAM data and film for the monitoring surveys, but a key aim was to make sure the film crew got the material they needed. During this time, the film crew also took the opportunity to get interviews with participants. In the afternoon, we continued the survey work.

Sunday 30/8. Regroup and rest day

High tide is at 0926 (4m), and low tide is at 1534 (0.2m).

Monday 31/8. Field surveys 1

High tide is at 1011 (4.1m), and low tide is at 1619 (0.2m).

Objective: Boat-based field survey, day 1 of 4 days. Field surveys applying S-VAM for selected comparative areas, plus data collection of mangrove shoot counts of waterside Rhizophoras. On ground field investigation of a landing site in Rodds Bay to evaluate upland edge conditions,

and status of upper intertidal vegetation.
Participants: Norm, Jock, 5 GDC Rangers, 1X community volunteer.
AM: 1000-1700 (Rtn Gladstone 1800)
Field Team (RV Avicennia - 7m Punt pax 11):
ND, JM, Community x 1, Rangers x 5
Survey Locations: Rodds Bay to Port Curtis
AM: Meet TBA - Rodds Bay 0930
The Plan : The condition of the tides was best around midday for conducting the on-ground field surveys. The morning was spent preparing equipment and conducting further training of Rangers and volunteers. Surveys using S-VAM were made across the study area, plus the landing site investigation.

Tuesday 1/9. Field surveys 2
High tide is at 1057 (4.1m), and low tide is at 1704 (0.4m).
Objective: Boat-based field survey, day 2 of 4 days. Field survey of mangrove shorelines as the day before. Sites were established and sampled close to Port Alma in the morning, and north towards the Fitzroy River mouth in the afternoon.
Participants: Norm, Jock, 2 X GDC Rangers.
AM: 0800-1700. Meet 0730
Field Team (RV Guyala - JCU Boat pax 4)
ND, JM, Community x 1, Rangers x 2
Survey Locations: Port Alma to Fitzroy River mouth
The Plan : We conducted S-VAM surveys around the port area, and surrounding comparative areas. We conducted a land survey on Balaclava Island.

Wednesday 2/9. Field surveys 3
Low tide is at 0535 (0.4m), high tide is at 1146 (4m), and low tide is at 1751 (0.7m).
Objective: Boat-based field survey, day 3 of 4 days. Field survey of mangrove shorelines as the day before. Sites were established and sampled in northern Port Curtis in the morning, and along southern Curtis Island in the afternoon.
Participants: Norm, Jock, 2 X GDC Rangers.
AM: 0800-1700
Field Team (Guyala - JCU Boat pax 4)
ND, JM, Rangers x 2
Survey Locations: Port Curtis northern areas and the Narrows
Meet TBA - 0730
The Plan : We conducted S-VAM surveys around the northern port area, and surrounding comparative areas.

Thursday 3/9. Field surveys 4, final
Low tide is at 0619 (0.6m), high tide is at 1238 (3.8m), and low tide is at 1841 (1m).
Objective: Boat-based field survey, day 4 of 4 days. Field survey of mangrove shorelines as the day before. Sites were established and sampled towards the Fitzroy River mouth.
Participants: Norm, Jock, 2 X GDC Rangers.
AM: 0800-1700
Field Team (RV Guyala - JCU Boat pax 4)
ND, JM, Rangers x 2
Survey Locations: Port Alma and Balaclava Island

Meet TBA - 0730
The Plan : We conducted S-VAM surveys around the northern port area, and comparative areas.

The 153 km of survey tracks for these late 2015 boat-based S-VAM surveys are shown in Fig. 15.

Ranger lead surveys commenced

During the first week of June 2016, the Gidarjil rangers conducted an independent S-VAM survey of the Boyne River estuary (Fig. 16). The rangers involved were: Arthur Dahl, Noah Saumalu Johnson, Jayme Cook and William Waia (an EQIP work experience student).

The vessel was a 4.5 m inflatable vessel hired from the BIEEC. The filming of shorelines was made along 26 km of the estuary – filming both sides up to the bridge. The mangroves appeared quite stressed still since the floods, having debris, plus branches and twigs, caught up in them.

The mullet were running, they recorded two turtles - one large, one small. The small turtle (about 40 cm carapace length) was at the mouth of the Boyne River at high tide. And, the larger turtle (about 100 cm carapace length) was seen at about 10 km upstream on the incoming tide. These were both understood to be Green turtles.

Figure 16. Gidarjil rangers filming the Boyne River in June 2016 (Photo: A. Dahl).

Linked scheduling with the NESP Southern Great Barrier Reef project

We report on the recently awarded collaborative monitoring program, starting in January 2016. This new program enhances the work being undertaken by the PCPA CHAMP project partners, JCU TropWATER Centre and Gidarjil Development Corporation. This is a 2 year program funded by the National Environmental Science Programme (NESP) Tropical Water Quality Hub to monitor the wider area of the Port Curtis Coral Coast TUMRA, and eight of its larger estuarine systems between Rockhampton and Hervey Bay; namely the Fitzroy to the Burnett River (Fig. 17). These extended works will facilitate the significant further improvement and better management of southern Great Barrier Reef (GBR) estuarine mangrove wetlands.

Both projects employ the same monitoring strategies and methods, like the Shoreline Video Assessment Method combined with walkabout cultural evaluations for the identification of practical shoreline rehabilitation works. One additional outcome will be the develop of a regional Mangrove Management Plan (MMP) in collaboration with the two local Natural Resource Management groups, the Burnett Mary Regional Group (BMRG), and the Fitzroy Basin Association (FBA). The MMP will provide a strategic framework for estuarine repair activities that maximize water quality outcomes in the southern GBR region.

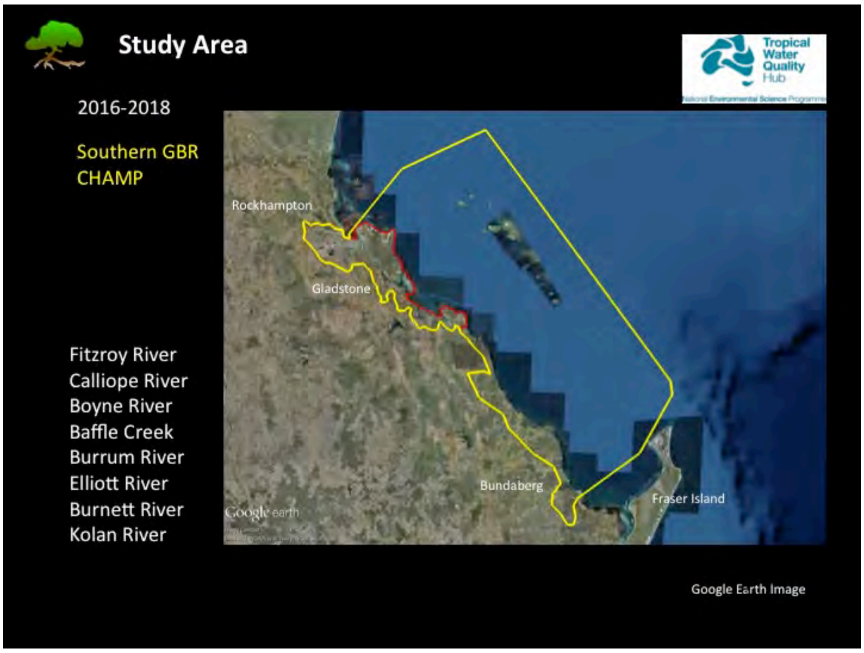

Figure 17. Map of the study area (yellow outline) for the NESP Southern GBR CHAMP projects including the eight key estuaries from Rockhampton to Bundaberg and Fraser Island. The PCPA CHAMP study is shown at the northern part (red outline).

Both projects are focused on building human capacity and skills amongst Gidarjil rangers and local community volunteers for the conduct of scientifically-rigorous, ecological monitoring, assessment and rehabilitation works. Such management and mitigation strategies are needed to bolster efforts to effectively protect estuarine sea country resources as well as build lasting partnerships between community, scientists, industry, managers and NRM agencies in the region.

In summary, further mangrove tidal wetland shorelines across the expanded southern GBR study area are being surveyed and monitored with this additional NESP support for the PCPA CHAMP.

It has been important to recognise that while the study areas overlap, the work schedules differ between each program (Table 4). The PCPA area is focused on overall shoreline surveys, and in comparing areas of greater port activity with neighbouring areas of less activity. By contrast, the Southern GBR project will focus on monitoring and managing the health of major estuarine systems for improving and maintaining coastal water quality. The latter is to be achieved by our assessment of 8 major estuarine systems, including: the Fitzroy; Calliope; Boyne; Baffle; Kolan; Burnett; Elliot and Burrum.

Table 4. Schedule of areas surveyed prior to, and during, the PCPA CHAMP project. Repeated area surveys provide opportunities for measuring change, like flood recovery. Note that systems surveyed to date include both boat-based (green & orange shading) and aerial surveys (blue shaded). All will be repeated in subsequent surveys, as proposed in the schedule.

GIDARJIL Shoreline Video Assessment Surveys

PCPA CHAMP project study sites | COMPLETED | [illegible] | JCU team | Gidarjil rangers | STUDY AREAS: PCPA CHAMP, SGBR CHAMP

#	NRM region	PCCC System	2012-2013	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018	2018-2019	2019-2020	ERMP	NESP
1	FBA	Fitzroy River mouth				[illegible]	5			[illegible]	ERMP	NESP
2	FBA	[illegible] Island			[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	ERMP	NESP
3	FBA	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	ERMP	NESP
4	FBA	Maria Inlet				[illegible]				[illegible]	ERMP	NESP
5	FBA	Barker Ck				[illegible]				[illegible]	ERMP	NESP
6	FBA	Mosquito Ck				[illegible]				[illegible]	ERMP	NESP
7	FBA	Deception Ck				[illegible]				[illegible]	ERMP	NESP
8	FBA	Badger Ck				[illegible]				[illegible]	ERMP	NESP
9	FBA	Monte Christo Ck				[illegible]				[illegible]	ERMP	NESP
10	FBA	Middle Ck				[illegible]				[illegible]	ERMP	NESP
11	FBA	The Narrows Ck				[illegible]				[illegible]	ERMP	NESP
12	FBA	Black Swan				[illegible]				[illegible]	ERMP	NESP
13	FBA	[illegible]				[illegible]	[illegible]		[illegible]	[illegible]	ERMP	NESP
14	FBA	[illegible]			[illegible]	[illegible]		[illegible]		[illegible]	ERMP	NESP
15	FBA	[illegible]				[illegible]	[illegible]		[illegible]	[illegible]	ERMP	NESP
16	FBA	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	ERMP	NESP
17	FBA	[illegible] (Upper +Lower)			[illegible]	[illegible]	5	[illegible]	[illegible]	[illegible]	ERMP	NESP
18	FBA	[illegible]				[illegible]	[illegible]			[illegible]	ERMP	NESP
19	FBA	[illegible] Island				[illegible]	[illegible]		[illegible]	[illegible]	ERMP	NESP
20	FBA	[illegible]		2		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	ERMP	NESP
21	FBA	[illegible]		3	[illegible]	[illegible]	5	[illegible]		[illegible]	ERMP	NESP
22	BMRG	Wild Cattle Ck				[illegible]				[illegible]	ERMP	NESP
23	BMRG	Pancake Ck				[illegible]				[illegible]	ERMP	NESP
24	BMRG	[illegible]			[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	ERMP	NESP
25	BMRG	Eurimbula										NESP
26	BMRG	Round Hill Ck										NESP
27	BMRG	Deepwater										NESP
28	BMRG	Baffle					5					NESP
29	BMRG	Littabella										NESP
30	BMRG	Kolan	1			5	5					NESP
31	BMRG	Burnett	1			5	5					NESP
32	BMRG	Elliott	1			5	5					NESP
33	BMRG	Coonarr										NESP
34	BMRG	Theodolite										NESP
35	BMRG	Burrum	1			5	5					NESP
36	BMRG	Gregory/Burrum				5						NESP
37	BMRG	Isis/Burrum				5						NESP
38	BMRG	Cherwell/Burrum										NESP
		TOTAL [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

Legend - survey teams

1	JCU BMRG	Boat
2	JCU C-4-C	Boat
3	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]
5	GDC SGBR CHAMP NESP	Boat

Given the potential for overlaps and confusion in work programs, it has been useful to compile a combined schedule of works, as shown in Table 4. Note that the eight estuarine systems are delineated with boxes in black and white. By contrast, the three types of surveys used in the PCPA CHAMP work program have been colour shaded (green, blue, orange). Also included in the table are earlier surveys funded from other sources (no shading). All such surveys have great value since the condition of these estuaries has changed dramatically over the period with severe flooding experienced in most if not all these estuarine systems.

With this report, we describe the successful accomplishment of primary and planned tasks (specifically the S-VAM surveys), training workshops and now a number of temporal surveys (i.e., changes from baseline). In the next report, we plan to present on-going assessments of the completed surveys, and with the addition of further work as the Gidarjil rangers gain confidence and independence.

Figure 18. Community volunteers filming Boyne River.

Specific boat-based field work program tasks achieved include:

- JCU lead boat-based surveys completed in all key strategic sets of coastline – Port Alma and comparative area; Port Curtis and comparative area; and Rodds Bay.

- JCU lead boat-based surveys with community volunteers (Fig. 18) completed the Boyne River estuary.

- Field surveys recording leaf counts as proxy measures of foliage canopy density at all key sites.

- Gidarjil ranger lead boat-based surveys completed in key strategic estuarine systems building on those completed earlier Targinie Creek and lower Narrows (12 km), Calliope (34 km) and now the Boyne River (16 km).

- Walkabout field investigations of upland high intertidal margins in an evaluation of indicators of shoreline change.

Reporting in News Media

The Observer, Gladstone. Posted 25th August 2015 5:00 AM.
http://www.gladstoneobserver.com.au/news/mudlarks-sought-as-mangrove-monitors/2751423/

Volunteers wanted to help monitor mangroves

IF YOU love fishing and are interested in the marine environment, a group of marine scientists wants your help - but be warned that you will get muddy.

Intensive mangrove monitoring is about to begin in Gladstone Harbour to assess the health of the fish habitat as part of the Port Curtis-Port Alma Coastal Habitat Archive and Monitoring Program.
Tomorrow scientists from James Cook University's TropWATER Centre and traditional owner rangers from Gidarjil Development Corporation will begin 10 days of shoreline environmental monitoring that includes tidal saltmarsh and need your help with mangrove field surveys.
The surveys will be done next week between Monday, August 31, and Thursday, September 3.
The monitoring work forms part of Gladstone Ports Corporation's Ecosystem Research and Monitoring Program .

The CHAMP project will incorporate Sea Country ranger knowledge, understanding and passion for the importance and beauty of the valuable coastal zone, with that of expert JCU mangrove scientists.

The plan is to report back to the community with annual reports and relevant observations.
Project leader Dr Norman Duke said interested people could get involved in the six-year program that would help protect the critical natural coastal resources of the Gladstone region.

"This is a chance for interested locals to get involved, to learn about the health of their tidal wetlands, and to help gather valuable scientific data about one of our most undervalued natural ecosystems: mangroves," he said.
http://inread-experience.teads.tv/

To get involved in the project contact Richard or Arthur at Gidarjil Development Corporation on 4972 1881, ormangrovewatch@gmail.com.

3.4 Project Component 5. Public access and data entry portal for display of current and past mapping and S-VAM surveys

This project component involves collaboration between the James Cook University (JCU) TropWATER project coordinators along with the JCU eResearch Centre and QCIF.

The key goal has been the innovative creation and development of an online public database for uploading, managing, processing and displaying imagery and other data collected and produced in Components 1-4 of the PCPA CHAMP project.

ShoreView Prototype Facilities

The Shoreview prototype (Fig. 19) is undergoing redevelopment due to a major review of its requirements and functionality by the project team. Whilst a previous version was working, the loading and management of the data became quite arduous and impractical for public use. A major internal structure redesign process has been undertaken and the system has been rebuilt around a more simplified storage plan. The plan is to give a working demonstration of this advanced ShoreView prototype at the next ERMP meeting in August 2016.

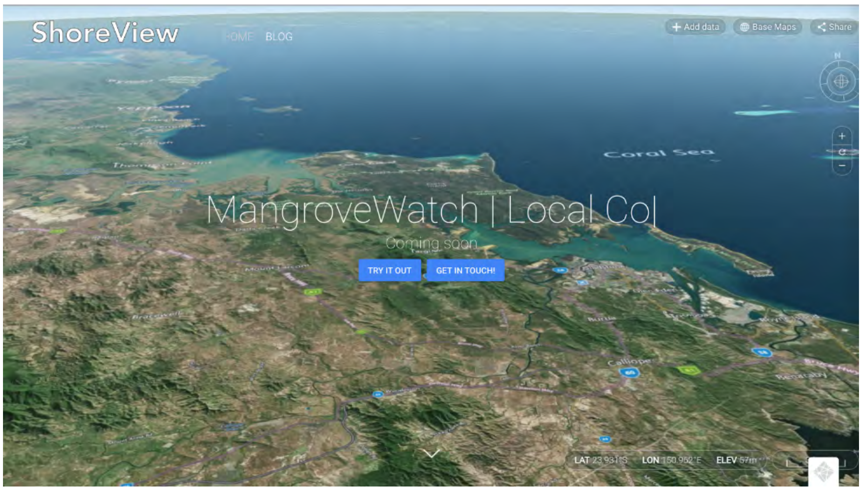

Figure 19. The ShoreView landing page.

Image & Data Visualisation Facility

As noted before, the initial conceptualisation and development of the prototype for the image and data visualisation facility was made in 2009-2010 (Duke et al. 2010). The url for the prototype for the Montara oil spill project with QCIF is: http://shoreview.jcu.io/

This site displays all image data collected for the shorelines from Darwin to Broome. Its relevance to the current project is in its use as both a tangible vision, as well as a technical prototype. The key functions lacking in this prototype facility include: the lack of a means for the upload of additional imagery – a data entry portal; the lack of a data assessment portal; and the lack of a capacity to compare shoreline locations/monitoring over different survey dates.

These added functions will be integral to the further development planned with this PCPA CHAMP project.

System requirements: user Authentication and Authorisation

One of the key issues with Shoreview is to ensure that the correct people have the correct sort of access. In the new version, the access control is defined by the diagram shown below (Fig. 20). This methodological structure will ensure that only the appropriate users are given special access. For the most part, the public users will only have view access rights.

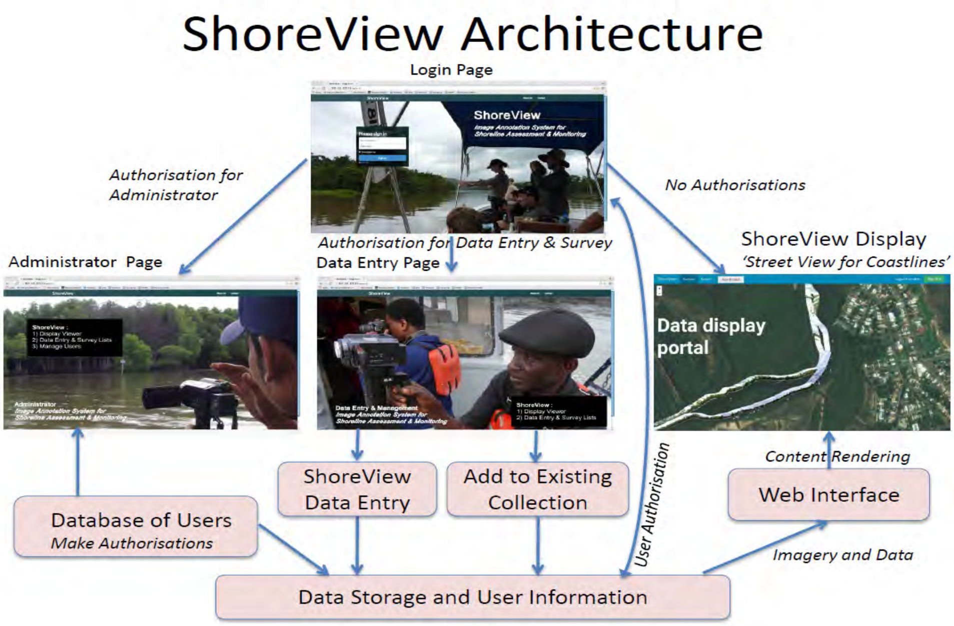

Figure 20. The structural layout of the ShoreView components and their inter-connectivity.

User Services

Once a user has authenticated themselves then the following rules will apply at a campaign level. Each series set of survey data represents an individual campaign. Public users, as the default situation, will only have access for viewing data.

The planned additional services include the following features.

- Contributors of audit and access. Manage access to the data, and who annotates these data.
- Automated classification of selected sets of coastline images would be 'pink-flagged'. And, once they are classified or verified they then will be changed to 'green-flagged'.
- Use a trial set of mangrove assessments to judge the capability of any assessor and then apply to the dataset they have assessed.
- Access at the data set level.

The data can be loaded and identified by the particular data collection campaign details.

The Data Input Portal part of ShoreView (Fig. 21) is needed for the upload, management, assessment and storage of digital data plus images. It requires rapid searching and retrieval by multiple users, as expected with a public online facility (Fig. 22 & Fig. 23).

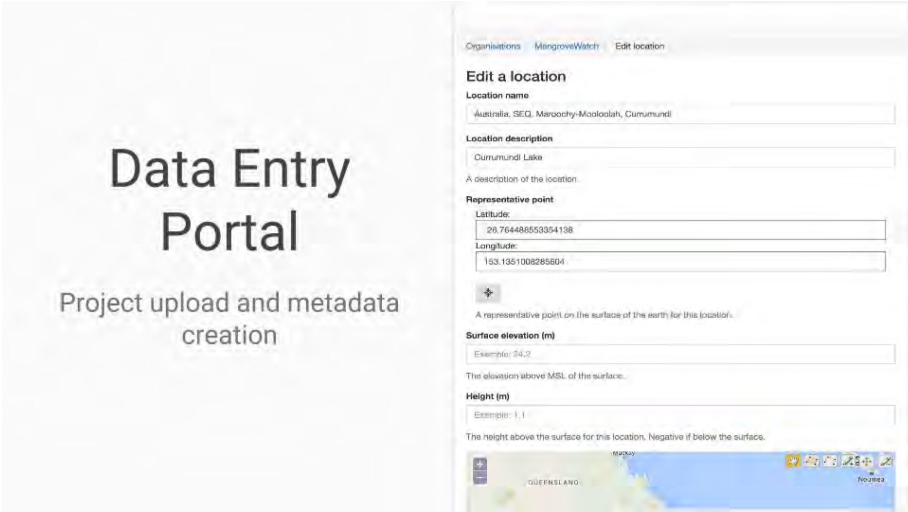

Figure 21. ShoreView data entry portal – the EnviroCOMS prototype for the online data upload and input facility.

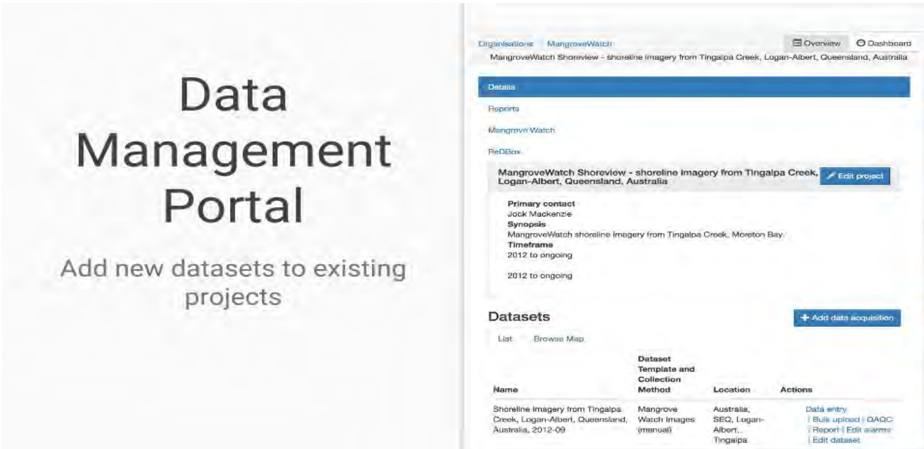

Figure 22. ShoreView data management portal – the EnviroCOMS prototype for the online data upload and input facility. New data needs to be added to existing projects.

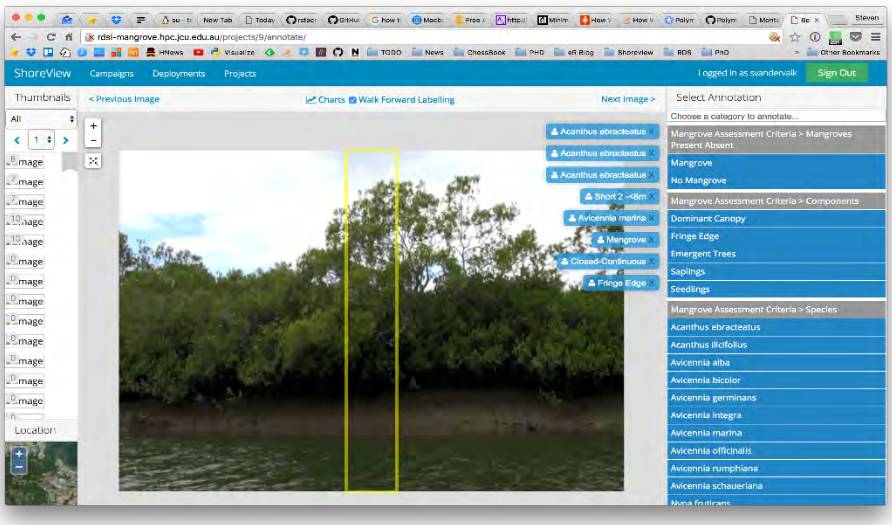

Figure 23. ShoreView data assessment portal – the EnviroCOMS prototype for the online data upload and input facility. The classifying staff can also classify each image in the tool.

Public Interface

The public interface will have an improved look and feel but still have the underlying 'Streetview'-like feel and functionality (Fig. 24).

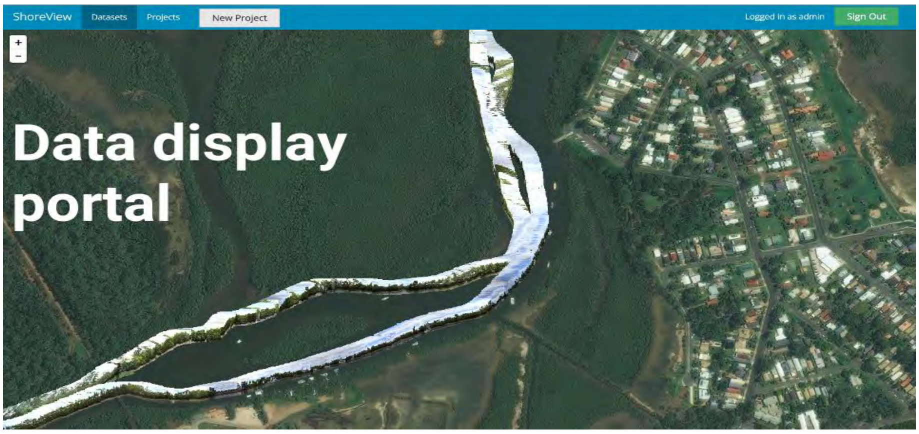

Figure 24. ShoreView display portal – the EnviroCOMS prototype for the online data upload and input facility.

Next Steps

The next steps are:

1. Purchase and implemented ShoreView web presence and branding https://shoreview.io/
2. Implement Redesigned and agree on features for ShoreView "street view for coastlines" v2.0
3. Development progress on target for the prototype demonstration in August 2016.
4. The security architecture is simple but will need to be defined explicitly including management of users on the PCPA CHAMP project. This will be integrated into the revised storage management solution.
5. A suitable storage solution, which may included RDSI, Amazon and Flicker will be defined to cope with the large amounts of imagery whilst still providing performance. Anticipated date of test completion will be 30 September 2016 with a new storage arrangement in place by the end of December 2016.
6. Concurrently, the project will need to create new streamlined business process to allow imagery to be loaded easily and rapidly rather than the current labour intensive management of imagery and data processing. The new process will be trialled in December 2016.
7. The full load of data and functioning user interface is expected to be completed by March 2017 for the PCPA CHAMP project.
8. User testing and changes will be done during the three months till June 2017.
9. Prior to the closure of the PCPA CHAMP project, support arrangements will be put in place to ensure the continuing support, function and improvement of ShoreView.

The new version will be a modern and scalable deployment method using Docker done with the underlying principle.

3.5 Additional Promotional and Relevant Contributions

Presentation by NC Duke at the 2016 AMSN Conference

Presentation made by Dr Duke was done to raise awareness of this PCPA CHAMP project amongst members of the Australian Mangrove and Saltmarsh Network (Fig. 25) (www.amsn.net.au).

TropWATER scientists directly support the informal independent network for people and organizations (Duke et al. 2015). The AMSN was established over a number of years. It was formed in response to the growing need for better communication amongst all stakeholders concerned about mangrove and saltmarsh tidal wetland habitats around Australia, and elsewhere. The network has supported regular independent conferences each year since 2014. With over 100 registered network members to date, the network includes professional researchers, managers, industry officers and environmental consultants, as well as community enthusiasts from every Australian State and Territory, plus a growing number from other countries. The aim has been to provide a professional focus group, a listing of current issues and pressures, a repository for information about solutions as with rehabilitation projects, and an overall one-stop-shop for anyone interested in tidal wetlands around the country. For more information about the network, please visit the website. Dr Duke facilitates the AMSN.

Figure 25. ***TropWATER supports the Australian Mangrove and Saltmarsh Network and its website, promoting its cause and its annual network conferences each year. The latest was in Darwin, early in May 2016. The 2017 meeting will held be in Hobart.***

Abstract for the oral presentation made on 3rd May 2016 at the Australian Mangrove and Saltmarsh Conference in Darwin, Northern Territory.

Indigenous ranger management of Southern GBR estuarine mangrove wetlands

Norman C Duke, MangroveWatch Hub, JCU TropWATER, Townsville, Qld.
Jock Mackenzie, MangroveWatch Hub, JCU TropWATER, Townsville, Qld.

Peter Brockhurst, Gidarjil Development Corporation (GDC), Bundaberg, Qld.

We report on two new projects aiming to improve management of southern GBR estuarine mangrove wetlands. Both enlist the support of local Traditional Owners and volunteers in the area from Rockhampton to Hervey Bay in Queensland. The JCU research team in partnership with the GDC is supported by: the Gladstone Ports Corporation's Ecosystem Research and Monitoring Program for Port Curtis and Port Alma areas until 2020; and, by the National Environmental Science Programme (NESP) Tropical Water Quality Hub for the wider area of the Port Curtis Coral Coast TUMRA until 2018. Both projects employ MangroveWatch-style monitoring methods (see: www.mangrovewatch.org.au) like the Shoreline Video Assessment Method combined with walkabout cultural evaluations plus identification of practical shoreline rehabilitation works. One key outcome is to develop a Mangrove Management Plan (MMP) in collaboration with local Natural Resource Management groups, the Burnett Mary Regional Group, and the Fitzroy Basin Association. The MMP will provide a strategic basis for estuarine repair activities and for maximizing water quality outcomes in the southern GBR region. These projects build human capacity and skills amongst Gidarjil rangers and local community volunteers for the conduct of scientifically-rigorous, ecological monitoring, assessment and rehabilitation. Such management and mitigation strategies will bolster efforts to effectively protect estuarine sea country resources as well as build lasting partnerships between community, scientists, industry, managers and local NRM agencies.

Film documentary about the PCPA CHAMP project

Two short documentary films (Fig. 26) and a training video were produced during the 2015 field campaign. The aim with the documentaries was to further inform people about the PCPA CHAMP projects – and to raise awareness of the partnerships between scientists, the Gidarjil Rangers and community volunteers for the monitoring of tidal wetlands – supported by industry.

Figure 26. Short documentary film on the PCPA CHAMP project.

The doco starts with scenes over the port, busy with ships moving about, lots of development – and all settled amongst extensive areas of mangroves with footage of sinuous waterways and healthy wildlife. There is environmental damage to be seen, but is it all related to port activities? Recent flooding has had its toll. Monitoring is much needed to show what are the drivers of change. Then with the mapping and monitoring information it should be possible to identify and quantify the dominant threats. Then we have a chance to do something about it.

Figure 27. TropWATER aerial survey team with Gidarjil rangers filmed the tidal wetland shorelines from Fitzroy River to Rodds Bay in 2 days.

The knowledge gained by monitoring gives managers the chances to more effectively management the vital and productive natural habitats of mangroves and saltmarsh flats. The message is also about 'who do you call?!' to get the monitoring done. It is the special partnership between scientists and rangers, and then with managers and industry stakeholders. What this doco is all about, is encouraging those who might strive for environmental best practice and sustainable long term monitoring. This is an innovative and exciting program (Fig. 27).

The documentary clips can be viewed at the following links:

1) Shoreline monitoring with the PCPA CHAMP project – 3-4 minutes
JAMES COOK UNIVERSITY - TROPWATER
https://www.youtube.com/watch?v=vVu_KZ219no

2) Shoreline monitoring with the PCPA CHAMP project – ~14 minutes
JCU TropWATER PCPA CHAMP Extended Cut
https://www.youtube.com/watch?v=kH3aU7fPDrY

Publication of the shoreline survey method used in the PCPA CHAMP project

See Mackenzie, Duke and Wood (2016) in the reference list.

Abstract

Climate change with human direct pressures represent significant threats to the resilience of shoreline habitats like mangroves. A rapid, whole-of-system assessment strategy is needed to evaluate such threats, better linking innovative remote sensing with essential on-ground evaluations. Using the Shoreline Video Assessment Method, we surveyed around 190 km of the mostly mangrove-fringed (78%) coastline of Kien Giang Province, Vietnam. The aim was to identify anthropogenic drivers of degradation, establishing baseline for specific rehabilitation and protection strategies. Fish traps occupy at least 87% of shoreline mangroves, around which there were abundant human activities – like fishing, crabbing, farming, plus collecting firewood and foliage. Such livelihoods were associated with remnant, fringing mangrove that were largely degraded and threatened by erosion retreat, herbivory, and excessive cutting. Our assessment quantified associated threats to shoreline stability, along with previous rehabilitation intervention measures. The method offers key opportunities for effective conservation and management of vulnerable shoreline habitats.

The full article is included in the Appendices.

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Mackenzie, J.R., N.C. Duke and A.L. Wood. **2016**. The Shoreline Video Assessment Method (S-VAM): using dynamic hyperlapse image acquisition to evaluate shoreline mangrove forest structure, values, degradation and threats. Marine Pollution Bulletin 109(2): 751-763.

A APPENDICES

Appendix A.1. Media Release by JCU TropWATER. The PCPA CHAMP program around Gladstone, dated around 21 August 2015.

MEDIA RELEASE

How healthy is your fish habitat?

Intensive mangrove monitoring is about to get underway around Gladstone Harbor to assess the health of fish habitat as part of the Port Curtis Port Alma Coastal Habitat Archive and Monitoring Program (CHAMP), launched in March this year, and the scientists want your help. Do you love fish or fishing? Are you interested in the marine environment? Want to have some muddy fun and contribute to real science? Then this is your opportunity to become a citizen-scientist and contribute to monitoring mangroves.

Scientists from James Cook University TropWATER Centre, together with Traditional Owner rangers from Gidarjil Development Corporation, will begin 10 days of shoreline environmental monitoring this Wednesday (26th August). The JCU team is looking for budding citizen-scientists to help out with mangrove field surveys from Monday the 31st August to Thursday 3rd September. To get involved, or to find out more about the project, contact Richard or Arthur at Gidarjil Development Corporation on 4972 1881or email mangrovewatch@gmail.com.

The monitoring work forms part of Gladstone Ports Corporation's (GPC) Ecosystem Research and Monitoring Program - a compliance requirement under GPC's approval for the Western Basin Dredging and Disposal Project.

The CHAMP project is incorporating Sea Country ranger knowledge, understanding and passion for the importance and beauty of the valuable coastal zone, in collaboration with expert JCU mangrove scientists. The plan is to report back to the wider community with annual reports and locally relevant observations. Project Leader Dr Duke said, 'The offer is there for those in the community to get involved in this 6 year program, helping protect critical natural coastal resources of the Gladstone region. If you have got the time, come join us!"

'This is a chance for interested locals to get involved, to learn about the health of their tidal wetlands, and to help gather valuable scientific data about one of our most undervalued natural ecosystems, mangroves." said Dr Duke.

The Gladstone area has abundant mangrove and tidal saltmarsh areas, but are they healthy? "More the 75% of the fish, prawns and crabs from around Gladstone depend on the mangroves. If the mangroves aren't healthy, then neither are the fish stocks and that will impact the local economy" added Jock Mackenzie another JCU scientist.

"Scientists need local community help and support to properly protect and manage our natural places," said Dr Duke, a world renowned mangrove scientist.

The CHAMP project with the Gidarjil Rangers and community volunteers is leading the way collecting valuable information using latest technology innovations for monitoring shorelines surrounding the Port area. Using MangroveWatch methods, the Rangers and volunteers will film, record and measure the condition of mangroves in the Gladstone region.

To properly record these activities the JCU team will also be making a film documentary that can be used to promote the project with its world's best practice approach to shoreline environmental monitoring.

The project work involves helicopter shoreline survey flights, as well as boat-based filming, and field plot sampling for validation of vegetation mapping and measuring ecosystem health.

For more information on mangroves and MangroveWatch programs, visit www.mangrovewatch.org.au

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TropWATER Centre
James Cook University
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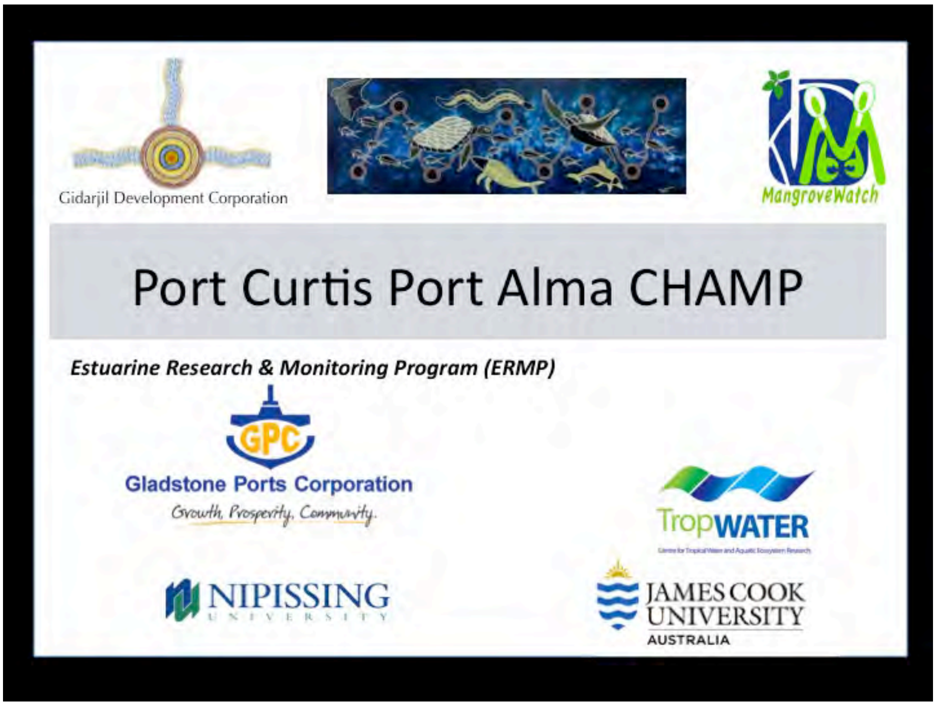
Appendix A.2. Presentation cover slides used in the Australian Mangrove and Saltmarsh Network (AMSN) Conference talk.

Held in Darwin during 3-6 May 2016.



Appendix A.3. 2016 publication in Marine Pollution Bulletin.

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Marine Pollution Bulletin xxx (2016) xxx–xxx
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The Shoreline Video Assessment Method (S-VAM): Using dynamic hyperlapse image acquisition to evaluate shoreline mangrove forest structure, values, degradation and threats☆

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ABSTRACT

Climate change with human direct pressures represent significant threats to the resilience of shoreline habitats like mangroves. A rapid, whole-of-system assessment strategy is needed to evaluate such threats, better linking innovative remote sensing with essential on-ground evaluations. Using the Shoreline Video Assessment Method, we surveyed around 190 km of the mostly mangrove-fringed (78%) coastline of Kien Giang Province, Vietnam. The aim was to identify anthropogenic drivers of degradation, establishing baseline for specific rehabilitation and protection strategies. Fish traps occupy at least 87% of shoreline mangroves, around which there were abundant human activities – like fishing, crabbing, farming, plus collecting firewood and foliage. Such livelihoods were associated with remnant, fringing mangrove that were largely degraded and threatened by erosion retreat, herbivory, and excessive cutting. Our assessment quantified associated threats to shoreline stability, along with previous rehabilitation intervention measures. The method offers key opportunities for effective conservation and management of vulnerable shoreline habitats.

1. Introduction

Mangroves deliver essential ecosystem services and socio-economic benefits to tropical and sub-tropical coastal communities (Barbier et al., 2011; Costanza et al., 1998; Lee et al., 2014; Mukherjee et al., 2014; Walters et al., 2008). These important coastal forests are being destroyed rapidly by coastal development, over-exploitation and land-use change (Polidoro et al., 2010). The estimated rate of habitat loss is 1% per annum (Duke et al., 2007; Friess and Webb, 2014; Spalding et al., 2010).

Mangrove forests are threatened by multiple indirect anthropogenic drivers that cause habitat degradation in addition to habitat loss from land-use change. These include pollution events such as oil spills (Burns et al., 1993; Duke et al., 1997; Duke and Watkinson, 2002), agricultural runoff (Duke et al., 2005; Lewis et al., 2011; Lovelock et al., 2009) and extreme sedimentation (Ellison, 1999), altered hydrological regimes (Gordon, 1988; Jimenez et al., 1985), habitat fragmentation (Nguyen et al., 2013) and over-exploitation for wood and other mangrove forest resources (Warren-Rhodes et al., 2011). These indirect anthropogenic drivers of change may result in a functional loss of habitat with reduced ecosystem service provision capacity. For example, degraded mangrove forest systems have a reduced capacity to withstand natural pressures such as storms, wind and waves (Dahdouh-Guebas et al., 2005; Lee et al., 2014; Schmitt et al., 2013; Tri et al., 2003; Vogt et al., 2012; Woodroffe, 2007).

Mangrove forests are threatened by the consequences of global climate change such as more frequent and severe storms and rising sea levels (Gilman et al., 2008). Degraded mangrove forests are less resilient to the impacts of climate change compared to healthy forests (Ellison, 2015; Gilman et al., 2008; McLeod and Salm, 2006). Healthy mangrove forests have the capacity to resist the effects of climate change through natural feedback mechanisms such as vertical accretion (Gilman et al., 2007; Krauss et al., 2014; McKee et al., 2007), and recover from impacts via natural regeneration processes ((Ellison, 2015; McLeod and Salm, 2006). It is unclear how well degraded mangroves with limited landward extent can withstand such pressures, although deleterious effects are likely (Dahdouh-Guebas et al., 2005; Ellison, 2015; Krauss et al., 2014; Lee et al., 2014). For example, mangrove forests impacted by anthropogenic stressors such as nutrient enrichment are less likely to withstand and recover from hurricane impacts (Feller et al., 2015). It

☆ This study was undertaken while the first author was undertaking a PhD at the Centre for Marine Studies, University of Queensland funded by an Australian Government APA scholarship. Funding for this research was provided by GIZ and AusAID, through UniQUEST at University of Queensland. At the time of this assessment, all authors were employed at the Centre for Marine Studies, University of Queensland.

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has also been demonstrated recently that mangroves in areas where sediment supply is limited by altered hydrological regimes are less likely to 'keep pace' with sea level rise through natural accretion processes (Lovelock et al., 2015). It is possible that habitat degradation combined with climate change impacts will contribute significantly to mangrove habitat loss in the near future.

The sheer scale of global mangrove habitat loss has previously overshadowed mangrove forest degradation as a conservation and management issue. In recent years however, mangrove forest loss has slowed in many regions (Friess and Webb, 2014), particularly South East Asia (Giri et al., 2015) and is now almost negligible in countries such as Australia and the USA (Friess and Webb, 2014). As the threat of climate change increases, so does the imperative to draw attention to mangrove forest degradation and focus on addressing anthropogenic drivers of change (Schmitt and Duke, 2015). Specifically, this requires moving the focus of mangrove assessment beyond habitat quantity to include habitat quality.

Recently Gilman et al. (2008) recommended a number of strategies to augment mangrove resilience and resistance to climate change. These included implementing 'no-regrets' policies to eliminate non-climate stressors on mangrove ecosystems, rehabilitating, restoring and enhancing mangrove habitat and establishing a regional mangrove-monitoring network. A global monitoring network was posited as a means to identify site-based influences from global climate change within a regional and global context. Ongoing global mangrove monitoring would improve understanding of mangrove response to sea level rise while concurrently enabling identification of local effects resulting from non-climate stressors. A 'no-regrets' mangrove adaptation strategy, including effective and informed mangrove rehabilitation could then be developed using mangrove monitoring data.

To date there is no system that provides timely and accurate information on the status and trends of mangroves at regional to global scales (Lucas et al., 2014). Most mangrove monitoring programs rely on remote sensing using air-photo and satellite data in combination with a geographic information system (GIS) (Kuenzer et al., 2011). Remote-sensing programs provide a cost-effective mechanism for relatively rapid data collection and monitoring over vast areas of remote tropical mangrove locations. But, despite technological advances, remote sensing has limited capacity to identify the specific drivers of change causing cryptic habitat degradation and sub-lethal stressors that reduce ecosystem function, resistance and resilience (Dahdouh-Guebas et al., 2005; Dahdouh-Guebas et al., 2006; Lee et al., 2014). Some important visual indicators used to identify drivers of change within mangrove forests may be imperceptible at the scale of freely available imagery (~30 m^2 pixel size) (Kuenzer et al., 2011) or visible only from an oblique view (Gardner et al., 2015). Furthermore, interpretation of remote sensing data, particularly from very high-resolution (VHR) imagery, demands levels of technical expertise, hardware and software often absent at the local management level in tropical locations where mangroves occur (Pettorelli et al., 2014). VHR imagery is also often prohibitively costly (Dahdouh-Guebas, 2002; Dahdouh-Guebas et al., 2006). Friess and Webb (2011, 2014) recently demonstrated that assessment of mangrove forest extent on a large regional scale is unreliable where on-ground reference data is inaccurate or unavailable. On-ground data is often limited in many regions where mangrove degradation occurs (Friess and Webb, 2011; Lee et al., 2014). Impediments to collecting sufficient on-ground data for effective mangrove ecological assessment include; remote location, logistical difficulties imposed by the structural and physical characteristics of mangrove forests, the time needed for appropriate data collection, limited local scientific capacity and cost (Kuenzer et al., 2011; Mumby et al., 1999). The absence of within-forest monitoring results in fragmented understanding of mangrove ecosystem function and process at both regional and local levels (Lee et al., 2014).

A multidisciplinary integrated GIS approach, combining remote sensing, field studies and socio-ecological data has been recommended as the most effective approach to mangrove management (Dahdouh-Guebas, 2002; Dahdouh-Guebas and Koedam, 2008). We propose that an additional spatially intermediary mangrove assessment method to link spatially constrained data-rich field sites with broader landscape-scale remote sensing is needed. To achieve this we have developed the Shoreline Video Assessment Method (S-VAM).

S-VAM is a mangrove habitat assessment method using the collection and assessment of boat-based geo-tagged video imagery of mangrove shorelines. Continuous geo-tagged video through space over time has recently been termed 'Hyperlapse' imagery (Kopf et al., 2014), a similar concept to time-lapse video, but using a camera moving through space, rather than spatially fixed shots over time. Videography has been used previously in a number of environmental and shoreline management contexts including for mangroves; for examples see Anderson et al., 2012; Doyle et al., 2009; Erftemeijer, 2002; Everitt et al., 1991; Neale, 1997; Paneque-Gálvez et al., 2014. S-VAM is a modification of these approaches designed specifically for mangrove shoreline assessment. Our goal in developing S-VAM was to create a mangrove assessment tool suitable for a global mangrove monitoring program that provides mangrove managers with information necessary to implement climate change adaptation strategies and improve mangrove climate change resilience as recommended by Gilman et al. (2008). S-VAM provides a mangrove classification and evaluation strategy that is easy to apply, and health and includes an environmental monitoring protocol, which is spatially referenced and applicable across landscape scales.

The S-VAM approach to mangrove forest assessment and monitoring is designed to complement and enhance existing remote sensing and in-situ on-ground monitoring methods and overcome some of their limitations. A combination of all these approaches is likely the best strategy for developing a global mangrove habitat assessment and monitoring program (Schmitt and Duke, 2015).

We present S-VAM here using a case study of shoreline mangrove forest assessment from the coastline of Kien Giang (KG), Vietnam. The purpose of the Kien Giang assessment was to determine mangrove habitat extent, structure, and condition, and the drivers of degradation in a region significantly affected by coastal development, coastal erosion and extreme risk from global climate change, and to inform the management of the Kien Giang Biosphere Reserve (KGBR). Global mangrove mapping by Giri et al. (2011) shows limited mangrove extent in Kien Giang. Consequently, mangroves in Kien Giang were not considered to be ecologically and economically important coastal habitat or threatened prior to this assessment. Results from the S-VAM assessment contradict these views. Mangroves were instead shown to be the dominant shoreline habitat of Kien Giang, providing shoreline protection, fish habitat, timber and seafood resources. But, it was also shown that Kien Giang mangroves were severely threatened by coastal erosion and over-exploitation requiring rehabilitation and better management to improve mangrove climate change resilience.

2. Methods

2.1. Location

Kien Giang is a province of southern Vietnam located in the southeast Gulf of Thailand and forms part of the greater Mekong Delta (Fig. 4). The coastal zone of Kien Giang has undergone rapid and substantial agricultural development since the early 1990s. Large areas of coastal wetland mangroves have been converted to alternative land use such as rice and shrimp and crab aquaculture. This change follows the general trend of mangrove loss throughout Vietnam where it is estimated that 49% of mangroves have been lost between 1943 and 2006. Under worst-case scenarios all mangroves within Vietnam could be lost within a decade (Friess and Webb, 2014).

Mangrove loss continues in Kien Giang due to illegal shrimp farms and urban development, although it varies between regions. In some locations mangroves are increasing due to a decline in shrimp farming as a result of disease and soil acidification, mangrove planting, and shoreline progradation (Nguyen et al., 2013). The coastline of Kien Giang is extremely vulnerable to sea level rise, with predictions of a 62–82 cm rise in sea level by the end of the 21st Century (Tran Thi et al., 2014). Recently local and national authorities, with the help of foreign agencies, have been working together to improve coastal zone and mangrove management as a strategy to improve coastal resilience to climate change and sea level rise.

2.2. Shoreline Video Assessment Method (S-VAM)

Shoreline mangrove habitat extent, structure, condition and drivers of degradation were quantified using a seven step process; 1) geo-referenced shoreline video data acquisition, 2) image processing, 3) geo-location, 4) criteria-based visual image classification, 5) ground-truth data, 6) data quality assurance and quality control (QAQC) and 7) spatial representation and data visualization (Fig. 1). These steps will herein be referred to as the Shoreline Video Assessment Method (S-VAM).

2.3. Geo-referenced shoreline video data acquisition

Geo-referenced video imagery data was collected from a slow moving (6–10 kts) shallow draft vessel travelling parallel to the shoreline (Fig. 2). A Sony HDR XR200VE 1080hd video Handycam® with in-built GPS was mounted on a hand-held tripod and positioned perpendicular to the side of the boat. The distance of the boat from the shoreline was within 25–150 m and adjusted relative to the height of vegetation and coastal features along the shoreline, with distance and zoom altered to ensure the majority of the image frame was shoreline features (Figs. 1 and 2). A Garmin handheld GPS 60 was used to track video camera position and record directional bearing using a 3-second tracking interval. The internal clock of the video camera was adjusted manually to match the GPS time to nearest 1 s (Fig. 2). Additional still photos were taken using a digital camera with time settings adjusted to match GPS time to the nearest 1 s. Audio notes of observations and anecdotes made by local observers on the boat were recorded onto the video during video recording to assist data processing.

Video imagery was collected over nine days in August and October 2009.

2.4. Video image processing and geo-location

High definition video was deconstructed into 1-second frame images using *iMovie* (a freely available movie editing software available on Apple computers). Frame images were associated with the 3-second GPS track based on time from video image timestamp data and the GPS track. Frame number, time, latitude, longitude and GPS compass bearing were included in a spreadsheet and imported into ArcGIS 10.0. To associate video images with actual shoreline locations, a generalized shoreline was generated from available satellite imagery and split into 10 m points using ArcGIS editing tools. Video track data was associated to each shoreline segment of 10 m points using the *Generate Near Table* Tool in ArcGIS and subsequent processing to associate the video track data point closest to 90 degrees from the direction of travel and the near angle generated by ArcGIS (Figs. 1–3).

2.5. Criteria-based visual image classification

Video frame images associated with each 10 m shoreline section were classified according to visual classification criteria such that data represents a set of continuous 10 m intervals (Figs. 1–3). Image classification was made on the visible shoreline in the centre of the frame. Classification was based on features present along the shoreline. For areas of extensive mangrove forest, the classification relates only to the fringe mangrove zone and areas of interior forest exposed by erosion.

The following shoreline features were assessed using criteria-based classification with visual features; Shoreline Habitat Type, Shoreline Physical Characteristics, Shoreline Vegetation (Mangrove) Characteristics, Mangrove Resource Use, Threats to Mangroves, and Mangrove Planting Activity. A set of criteria using multi-level classification scores was used for the initial assessment. Repeat assessments were made to test observer error and method repeatability. Five random sections of video data, each representing 1% of the total shoreline assessed, were selected for repeat assessment. Accuracy was assessed through overall

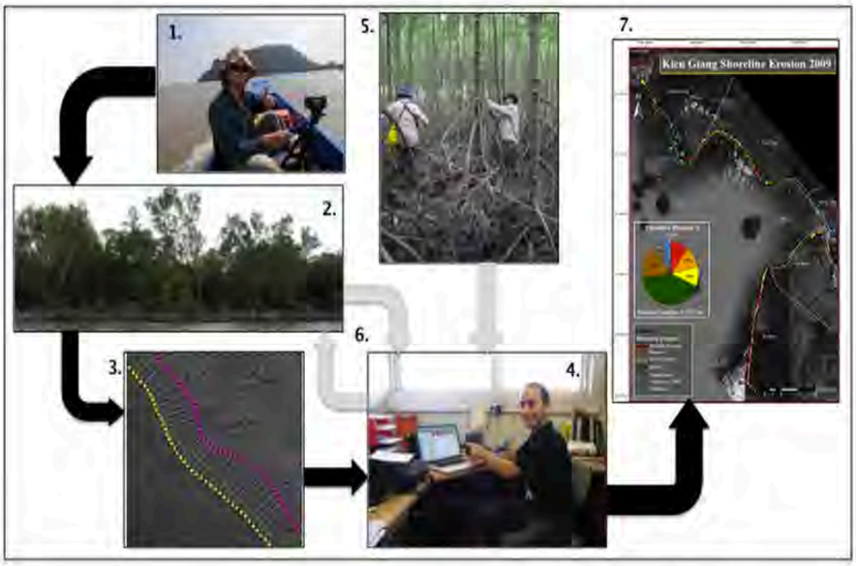

Fig. 1. Schematic diagram showing the steps involved in the shoreline video assessment method (S-VAM). 1. Image acquisition 2. Image processing 3. Image geolocation 4. Image classification 5. Filed plot validation and groundtruthing results. 6. QAQC 7. Mapped output and data visualization.

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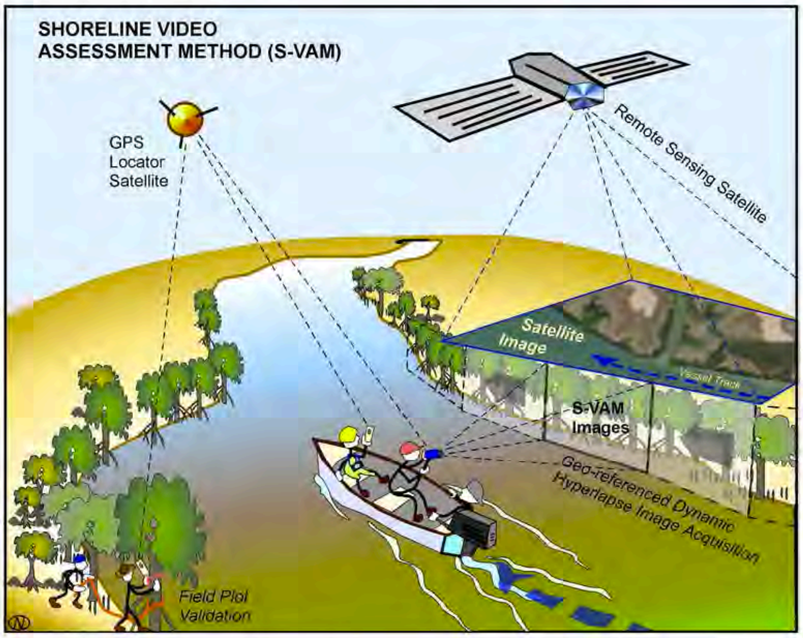

Fig. 2. The Shoreline Video Assessment Method (S-VAM) uses boat-based digital cameras to accurately record, display and evaluate shoreline resources and their condition that are linked to various types of concurrent assessments using satellite image remote sensing.

accuracy and the Kappa coefficient (K), with both indices based on the error matrix (also referred to as the confusion matrix). Overall accuracy and Kappa coefficient were determined from Cohen's *k* run in SPSS 20.0. The strength of agreement for each class based on the value of Cohen's kappa (k) coefficient was assessed using the guidelines produced by Gwet (2014).

Based on the outcomes of the observer error assessment, visual criteria ordinal scaling was reduced, with some scores combined to limit possible error indicated by low Kappa coefficients and overall accuracy. These reduced scores were used for all statistical analyses presented here.

The criteria used to assess shoreline features are detailed in Table 1. Example images are provided in Fig. 3.

For a detailed list of criteria used in the initial assessment with detailed user and producers accuracy and Kappa scores refer to the supplementary data in Appendix 1.

In a concurrent assessment of mangrove forest biomass in Kien Giang (see Duke et al., 2010), 40 forest plots were established to quantify mangrove forest structure, above-ground biomass and harvesting pressure (cutting). A total of 20 plots were located within shoreline mangrove forest. Transects were run parallel to the shoreline along the tidal profile to categorize shoreline forest using the variable area transect method to limit spatial variability associated with uneven tree distributions within fringing mangrove stands (Hijbeek et al., 2013). Plot locations ranged from 15 m to 100 m from the shoreline edge. These plots were used to validate visual classification of video image stills. Transect plot methods, data and locations are described in detail in Duke et al. (2010).

Video image processing, analysis and visual representation took an average of one (1) hour per kilometer to complete.

2.6. Statistical analyses and classification models

Logistic regression was used to model shoreline classification features to test for the effects of other shoreline habitat and physical characteristics. Binary presence/absence dependent variables were generated from the S-VAM classification for shoreline process, severe cutting, planting fence location, planting success, and fish trap presence.

For each model, independent variables were selected from assessed shoreline features at individual shoreline points, including mangrove dominant genus, mangrove forest structure, shoreline process, cutting presence and herbivory. Additional spatial covariates were generated to determine other influential spatial characteristics such as distance from waterways, mangrove forest patch length, distance to mangrove (for non-mangrove shoreline), distance from shoreline forest edge (within mangrove patches), and proximity of neighboring mangrove patches (Table 2).

Independent variables for each model were chosen based on ecological relevance. Where multi-co-linearity was detected between independent variables using VIF scores and assessing model standard errors, variables with the greatest model influence (Wald) were chosen. Only main-effects were assessed as higher order interactions had issues of quasi and complete separation of data within most interaction terms. Purposeful variable selection (Hosmer et al., 2013) and Akaike's Information Criterion (AIC) (Burnham and Anderson, 2002) were used to inform variable and model selection. Spatial autocorrelation was suspected due to the linear geographic nature of the data and was confirmed in all models based on Global Moran's I calculated in ArcGIS 10 using the residuals of non-spatial models. To account for spatial autocorrelation a residual auto-covariate (RAC) approach (Crase et al., 2012) was used, with a spatial auto-covariate calculated from mean logit of modeled residuals within 100 m of each dependent variable incorporated into the model. This distance was used as it represents the mean shoreline mangrove forest patch length along the Kien Giang coastline. Recalculation of Moran's I using the predicted residuals of each RAC model was used to reassess spatial autocorrelation in the RAC models. Incorporation of the RAC removed spatial autocorrelation in all models.

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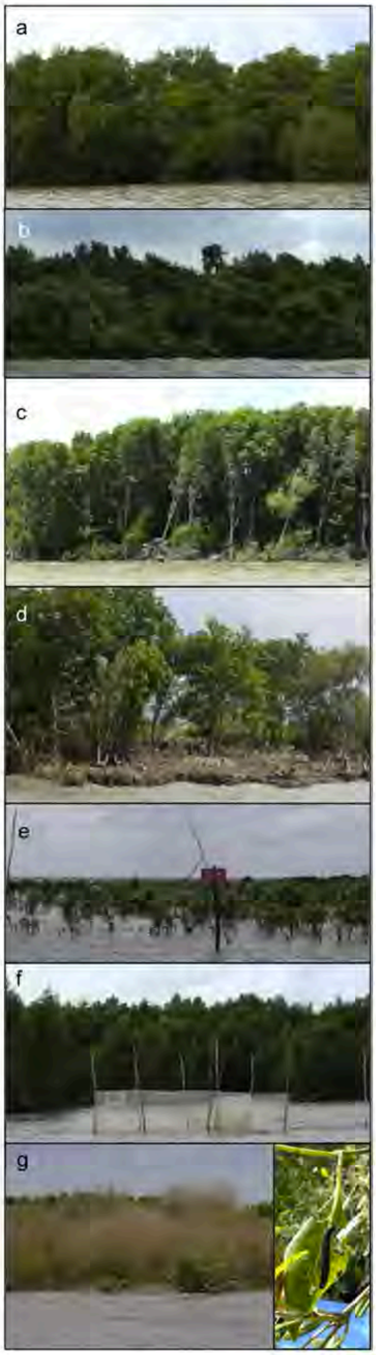

Fig. 3. Example images representing shoreline classification. a) Continuous stable forest b) Prograding tall forest c) Major erosion d) Severe Cutting with severe erosion e) Planted area with dense saplings/seedlings f) Fish trap g) Herbivory defoliation. See Table 1 for description.

2.7. Spatial representation

Data was imported into ArcGIS 10.0 and shoreline point data assigned symbology to produce maps highlighting mangrove forest structure, areas experiencing coastal erosion, mangroves experiencing heavy cutting pressure and areas of successful and unsuccessful planting, location of fish traps and areas of intense mangrove herbivory (for primary data base maps refer to Duke et al. (2010)). Significant variables relevant to the presence of erosion, cutting, fish traps and fenced shoreline areas and seedling establishment were also mapped (Fig. 4).

3. Results

3.1. Shoreline video assessment method

A total of 14,366 individual shoreline points were scored from 190 km of filmed coastline. The data presented here represents a random sample of 76% of the total shoreline with 24% percent of points having no data due to shoreline angle, poor image quality or open waterways.

3.2. Mangrove shoreline extent

Mangroves occupy 112.8 km (78%) of the Kien Giang shoreline and are the dominant shoreline vegetation type (Fig. 4.2). The majority of mangroves (87%) are represented within mangrove forest, with 77.7 km (69%) of mangroves being intact forest (Continuous, Prograding and Growth/Recovery classifications).

The dominant mangrove genera of shoreline forest were *Avicennia* (49%) and *Sonneratia* (20%). Continuous forest represents the most common forest type (41%), with a large extent of mangrove classified as either prograding (17%) or fragmented (18%). Continuous *Avicennia* dominated forest was the most frequently observed forest type (22%).

3.3. Shoreline mangrove forest condition – dead tree presence

Nearly one-quarter of mangrove forest had dead trees present (23%) with 8.5 km (8%) having many dead trees, indicating severe stress.

3.4. Shoreline mangrove forest stressors

Nearly half (43%) of all Kien Giang shoreline mangrove forest was affected by at least one stressor.

Erosion was the main issue observed threatening shoreline habitat. Erosion threatened nearly one-quarter of all shoreline (23%) and one-quarter of all mangroves (25%). Major erosion threatened 16% of mangroves (Fig. 4.3). Eroded mangrove shoreline was significantly associated with Mixed and *Rhizophora* dominated forest, with *Sonneratia* forest the least likely to be eroded (Table 3). Erosion was also more prevalent in sparse and fragmented mangrove forest compared to intact forest.

Erosion was more likely to be present in association with the presence of dead trees and severe cutting. The likelihood of erosion increased with proximity to mangrove forest edge and increasing distance from canals (Table 3).

Cutting was the predominant direct anthropogenic driver of mangrove forest disturbance, present in 22% of shoreline mangrove forest (Fig 4.4). The presence of cutting was significantly associated with the presence of shoreline erosion and fragmented mangrove forest (Table 3). *Sonneratia* was the least likely mangrove forest genera to be cut, with all other forest genera classes equally affected by cutting. The prevalence of cutting increased with increasing distance from forest edge along the shoreline.

Severe defoliation due to herbivory, likely associated with an infestation of teak defoliator moth (*Hyblaea puera* Cram) (Arun and Mahajan, 2012) was affecting 11% of mangroves, targeting *Avicennia* species.

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Table 1
Criteria used to assess shoreline features and classify images (modified from Shoreline Video Assessment Method (S-VAM), Duke et al. (2010)).

Classification category		Descriptor
Shoreline vegetation classification	*Mangrove*	Shoreline dominated by mangroves
	Terrestrial	Shoreline dominated by terrestrial trees
	Mangrove & terrestrial	A mix of both mangrove and terrestrial trees
	No trees	No trees present.
Mangrove dominant genera	*Avicennia*	*Avicennia alba* dominant, but also including *A. marina*, *A. officinalis* and *A. rumphiana*.
	Sonneratia	*Sonneratia alba* dominant, but also including *S. apetala*, *S. caseolaris* and *S. ovata*
	Rhizophora	*Rhizophora apiculata* dominant, but also including *R. stylosa*, *R. mucronata* and *R. × lamarkii*.
	Mixed species	No clear dominant species. Combination of above species or including other mangrove genera present in Kien Giang (Duke, 2012).
Shoreline mangrove forest classification	*Scattered/sparse*	Few mangrove stands and trees present.
	Continuous	Dense continuous cover of mangroves of even height with a clear decreasing height gradient toward the seaward edge.
	Fragmented	Dense forest with obvious gaps associated with tree felling/erosion, often showing the presence of fallen and dead trees.
	Planted	Monotypic stands of evenly spaced trees within clearly defined canals and bund walls, typically used for integrated aquaculture.
	Prograding	Continuous forest with a gradual incline in tree height away from the sea edge suggesting mangrove expansion toward the sea.
	Growth/recovery	Continuous forest with mangrove tree height variability suggesting infilling of previous forest gaps or recently established forest.
Mangrove forest height	*Tall*	Site average canopy height approximately greater than 5 m tall
	Short	Site average canopy height approximately less than 5 m tall
Mangrove condition – dead trees	*None*	No dead trees present.
	Few	~1–25% of trees dead
	Many	>25% of trees dead
Shoreward seedling presence	*None*	No seedlings present.
	Few	~1–25% shoreline percent cover
	Many	>25% shoreline percent cover
Mangrove cutting presence	*None*	No cut trees visible.
	Present	Cut trees visible
Shoreline process classification	*Depositional*	Dense seedlings present at shoreline seaward edge and/or apron of visible fine mud at seaward shoreline edge
	Stable	No visible signs of erosion or deposition
	Eroded	Visible signs of erosion (see Shoreline erosion classification
Shoreline erosion classification	*Minor*	Presence of one or a combination of; exposed roots clearly visible, leaning trees, dieback present, shoreline ledge < 15 cm tall.
	Major	Trees fallen, cable roots clearly visible, obvious shoreline ledge > 15 cm tall present, severe dieback and dead trees may be present.
Fenced area	*Presence/absence*	Shoreline protected by fence made of crossed stakes indicating protection area
Fenced area with seedlings	*Presence/absence*	>25% seedling cover within the fenced area
Herbivory	*Presence/absence*	Mangrove defoliation, mainly in *Avicennia*, differentiated from dieback as leaf mid-veins and stems remain giving a yellow hue (see Fig. 3).
Nypa harvesting	*Presence/absence*	Presence of cut Nypa fronds
Mangrove dwellings	*Presence/absence*	Presences of structures within or directly adjacent to mangroves the mangroves
Waterways	*Presence/absence*	Presence of canals, natural creek mouths and rivers greater than 10 m wide.

3.5. Presence of fish traps

Fish trap nets were observed along 17% (24.5 km) of shoreline (Fig. 4). A total of 571 individual fish traps were observed with a mean length of 34 m ± 7.5 m. The majority of fish traps (87%) observed were in front of mangrove forest shoreline. Fish trap presence was significantly associated with shoreline process, distance from mangrove and distance from canals (Table 4). Fish traps were more likely to be associated with depositional shoreline and least likely to be associated with eroded shoreline. Fish trap presence declined with increasing distance from waterways. Fish traps associated with shoreline mangroves were more likely to be associated with prograding forest and least likely associated with Fragmented and Sparse mangrove (Table 4). *Sonneratia* was the preferred dominant genus for fish traps with *Rhizophora* the least preferred. Fish traps were more likely to be associated with continuous mangrove stands within forest patches compared to mangrove stands at the linear edge of forest patches with fish trap likelihood increasing with distance from forest edges.

3.6. Shoreline mangrove forest protection, enhancement & restoration – fenced areas

Areas of shoreline fenced for the purpose of protecting natural and planted mangrove seedling establishment were observed along 14% (20.9 km) of Kien Giang shoreline. A total of 100 individual fenced areas were observed with a mean length of 1.71 km ± 0.92 km. Most fenced areas were observed on predominantly depositional shoreline (54%), with only 13% along mostly eroded shoreline. Nearly all (97%) fenced areas were along shoreline with more than 50% mangrove forest cover. Planting fences were significantly associated with intact forest dominated by *Avicennia* or Mixed and along depositional shoreline (Table 5, Fig. 4). Only 50% of fenced planting areas were observed to have established mangrove seedlings present. Along the shoreline where planting fences were present, seedling presence was mostly associated with depositional shoreline. Depositional shoreline was many more (128) times likely to have seedlings present than stable or eroded shoreline (Table 5). The likelihood of seedlings present within the fenced planting areas increased with increasing distance from the shoreline mangrove forest edge, increasing mangrove forest patch length and decreasing proximity to waterways. Shoreward mangrove seedling presence was least likely to be associated with *Sonneratia* dominated forest.

3.7. Other values

Nypa frond harvesting was observed along 3% of the Kien Giang shoreline.

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Table 2
Additional significant spatial independent covariates & fixed factors used in logistic regression models.

Independent variable	Descriptor
Distance to nearest waterway (m)	The total shoreline distance to the nearest recorded waterway.
Mangrove forest patch shoreline length (m)	Linear length of forest patch along the shoreline. A forest patch was defined as a continuous stand of forest with no gaps >10 m wide.
Distance to patch edge (m)	Shoreline distance to the closest patch edge within a forest patch.
Distance to mangrove forest patch (m)	Distance to the nearest mangrove forest patch for shoreline with no mangrove forest present ordered into 5 categories (>1500 m, 500–1500 m, 100–500 m, 1–500 m, 0 (mangrove))

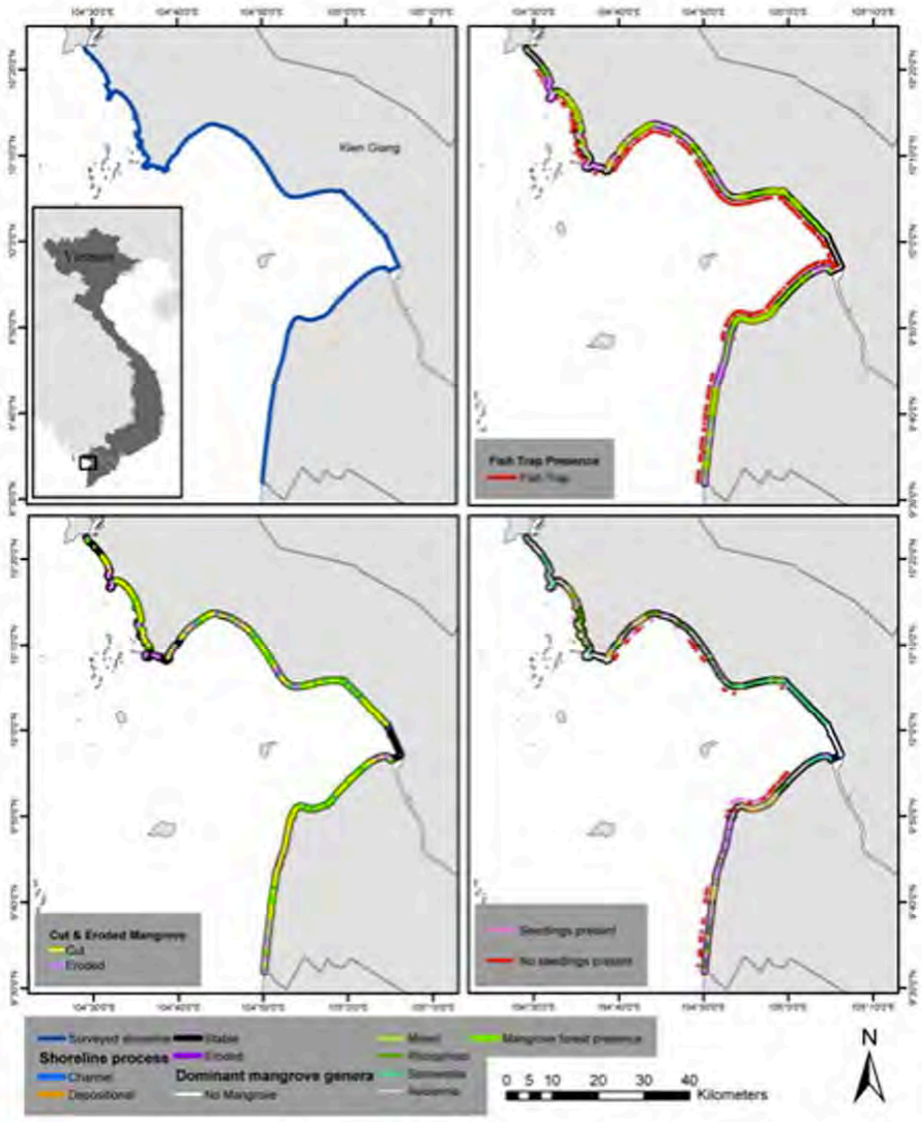

Fig. 4. Maps showing Shoreline survey and shoreline features. From left to right clockwise 1: Kien Giang study location. 2. The presence of fish traps and associations with mangrove dominant genera and shoreline process. 3. The presence of fenced shoreline areas with and without seedlings and associations with shoreline process and the presence of mangrove forest. 4. Eroded shoreline and cut mangroves and associations with dominant mangrove genera and waterways.

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Table 3
Logistic regression results showing the influence of significant variables on the probability of shoreline erosion presence and cutting presence. The Wald statistic shows the overall contribution of individual predictors to the model and Exp(B) is the odds ratio.

	B	se	Wald	Df	Sig	Exp(B)
Erosion presence						
Intercept	−4.22	0.25	281	1	<0.01	0.02
Forest type			100	2	<0.01	
Sparse	2.07	0.25	68	1	<0.01	7.90
Fragmented	1.86	0.21	80	1	<0.01	6.43
In tact[e]	0[a]	.	.	.	.	1.00
Dominant genus			301	3	<0.01	
Mixed	2.44	0.21	138	1	<0.01	11.49
Rhizophora	1.90	0.27	49	1	<0.01	6.67
Sonneratia	−6.46	0.54	140	1	<0.01	0.002
Avicennia	0[b]	.	.	.	.	1.00
Dead tree presence	1.58	0.18	74	1	<0.01	4.84
Severe cutting presence	2.06	0.18	131	1	<0.01	7.88
Dist to forest edge (km)	−2.55	0.44	34	1	<0.01	0.08
Dist to waterway (km)	0.31	0.08	16	1	<0.01	1.37
RAC	1.28	0.05	650	1	<0.01	3.60
Cutting presence						
Intercept	−3.20	0.16	422	1	<0.01	0.04
Forest type			100	2	<0.01	
Sparse	0.35	0.13	8	1	0.01	1.42
Fragmented	1.42	0.10	217	1	<0.01	4.15
Planted	0.24	0.22	1	1	0.27	1.28
Growth/recovery	−1.18	0.16	54	1	<0.01	0.31
Prograding	−2.19	0.20	116	1	<0.01	0.11
Continuous	0[c]	.	.	.	.	1.00
Dominant genus			61	3	<0.01	
Mixed	−0.16	0.10	3	1	0.11	0.85
Rhizophora	0.23	0.16	2	1	0.14	1.26
Sonneratia	−0.85	0.12	53	1	<0.01	0.43
Avicennia	0[b]	.	.	.	.	1.00
Process			252	2	<0.01	
Eroded	1.79	0.16	131	1	<0.01	6.00
Stable	0.46	0.14	10	1	<0.01	1.59
Depositional	0[d]	.	.	.	.	1.00
Dist to forest edge (km)	1.56	0.12	167	1	<0.01	4.78
RAC	1.14	0.02	2510	1	<0.01	3.14

[a] Faorest type for severe erosion presence is for In-tact forest compared to Sparse and Fragmented forest.
[b] Dominant genus is for *Avicennia* compared to Mixed and Other (*Rhizophora* and *Sonneratia* combined) genera.
[c] Forest type for cutting presence is for Continuous forest compared to Sparse, Fragmented, Planted, Growth/recovery and Prograding forest.
[d] Process is Depositional compared to Stable and Eroded classifications.
[e] In -tact forest represents Continuous, Prograding and Growth/recovery forest combined.

4. Discussion

The goal of the Kien Giang mangrove assessment was to evaluate shoreline mangrove forest structure, values, degradation and threats. This information is needed to inform better mangrove management to improve mangrove forest climate change resilience by reducing identified anthropogenic stressors and implementing targeted mangrove restoration, enhancement and protection strategies. Here we have demonstrated the suitability of hyperlapse shoreline imagery collection and assessment using S-VAM to accurately quantify shoreline mangrove forest attributes and as an effective and informative mangrove conservation and management tool.

The Shoreline Video Assessment Method (S-VAM) was employed for the Kien Giang study, in part, to supplement the limited availability and cost of suitable high-resolution satellite imagery and the narrow landward extent of remnant fringing mangrove forests (<50 m) (Nguyen et al., 2013) which make the usual methods of remote sensing assessment difficult. Additionally, field-based assessment was limited by the spatial scale of the study area, the highly fragmented and structurally diverse mangrove forest types present, and the limited access to some areas due to deep mud. Alternative aerial assessment methods previously employed for mangroves (Doyle et al., 2009; Erftemeijer, 2002; Everitt et al., 1991; Verheyden et al., 2002) and other habitats (Gardner et al., 2015; Paneque-Gálvez et al., 2014) were not possible because of bureaucratic constraints. Boat-based geo-referenced hyperlapse video imagery data acquisition with criteria-based image assessment, data validation and integration with GIS, (S-VAM) provided a means to capture a visual baseline of shoreline and fringing mangrove forest attributes at a point in time, and accurately capture mangrove and shoreline attributes across a large spatial extent (190 km) over a relatively short time period (9 days). Such an approach has been demonstrated to be an effective method of data collection in other shoreline habitat settings (Anderson et al., 2012).

This assessment was able to be completed using readily available off-the-shelf equipment. The total S-VAM kit can be purchased for around $3000 AUD. Computer software used to process imagery only requires widely used tools such as iMovie and ArcGIS that have alternative PC and open-source equivalents. The time taken to process imagery and level of expertise required depends on the level of detail required. A very fine-scale 10 m resolution, with multiple assessment categories and multi-level ordinal classification was used for the Kien Giang Assessment. This assessment took approximately 1 h per km of shoreline to complete. Coarser spatial resolution assessment using presence/absence assessment or fewer assessment categories is likely to reduce processing time and still generate useful results. Simpler assessments may be applicable in instances where assessment covers larger shoreline distances, assessment time is limited or local assessors are starting from a lower skill base. Careful consideration must be given to the desired

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Table 4
Logistic Regression results showing the influence of significant variables on the probability of fish trap presence along all shoreline and fish trap presence along shoreline with mangrove forest. The Wald statistic shows the overall contribution of individual predictors to the model and Exp(B) is the odds ratio.

	B	se	Wald	DF	Sig	Exp(B)
Fish trap presence						
Intercept	−1.25	0.08	168	1	<0.01	0.29
Shoreline process			202	3	<0.01	
Channel	0.17	0.33	0	1	0.61	1.19
Eroded	−1.55	0.12	176	1	<0.01	0.21
Stable	−0.89	0.09	104	1	<0.01	0.41
Depositional	0^a	.	.	.	.	.
Dist to mangrove (km)			108	4	<0.01	
>1500 m	−0.13	0.20	0	1	0.52	0.88
500–1500 m	−2.98	0.54	31	1	<0.01	0.05
100–500 m	−7.37	1.47	25	1	<0.01	0.00
1–500 m	−1.52	0.19	61	1	<0.01	0.22
0 (mangrove)	0^b	.	.	.	.	1.00
Dist to waterway (km)	−0.23	0.04	26	1	<0.01	0.80
RAC	1.28	0.02	3596	1	<0.01	3.59
Fish trap within						
Intercept	−1.81	0.07	772	1	<0.01	0.16
Dominant genus			41	3	<0.01	
Mixed	0.37	0.09	17	1	<0.01	1.45
Rhizophora	−0.32	0.16	4	1	0.04	0.72
Sonneratia	0.32	0.07	21	1	<0.01	1.38
Avicennia	0^c	.	.	.	.	1.00
Forest type			156	5	<0.01	
Sparse	−0.40	0.11	14	1	<0.01	0.67
Fragmented	−0.62	0.10	39	1	<0.01	0.54
Planted	−0.11	0.23	0	1	0.64	0.90
Regrowth	0.02	0.10	0	1	0.85	1.02
Prograding	0.63	0.07	75	1	<0.01	1.87
Continuous	0^d	.	.	.	.	1.00
Dist to forest edge (km)	0.36	0.10	14	1	<0.01	1.43
RAC	0.44	0.01	1429	1	<0.01	1.56

[a] Shoreline process is for Depositional compared to Stable and Eroded classifications.
[b] Distance to mangrove is for the 0 distance class, representing mangrove forest areas compared to other distance classes (1–500 m, 100–500 m, 500–1500 m, >1500 m).
[c] Dominant genus is for *Avicennia* compared to Mixed and Other (*Rhizophora* and *Sonneratia* combined) genera.
[d] Forest type for cutting presence is for Continuous forest compared to Sparse, Fragmented, Planted, Growth/recovery and Prograding forest.

outcome of the assessment and questions to be answered before a simpler approach is taken. It is likely that repeat assessments detecting change will take less time compared to baseline assessment.

Using the S-VAM approach to assess Kien Giang mangroves provided a number of advantages that overcame limitations of existing available mangrove assessment approaches. These advantages are summarized in Table 6.

For mangrove and shoreline managers, baseline information on mangrove forest status and drivers of degradation to effectively inform mangrove conservation (Schmitt and Duke, 2015) is often absent. The S-VAM approach provides a means to assess indicators of mangrove condition, cryptic threatening processes and human-use, representing habitat values that may otherwise be difficult to detect from top-down aerial views or difficult to quantify spatially using on-ground data collection methods. Assessment of the Kien Giang shoreline using S-VAM provided new insights into the extent, structure, values, degradation and threats to shoreline mangrove forests that can now be incorporated into future management decisions and mangrove conservation planning. For example, using S-VAM it was possible to demonstrate that mangroves are the dominant shoreline habitat along the Kien Giang coastline. Prior to this assessment, global estimates of mangrove cover (Giri et al., 2011) showed limited mangrove extent in Kien Giang and mangroves were not considered an important coastal habitat in this region. This assessment shows that much of the extant mangroves in Kien Giang occupy a thin fringe or are highly fragmented. These narrow but linearly extensive mangroves are difficult to detect using 30 × 30 m pixel size Landsat imagery (Kuenzer et al., 2011; Nguyen et al., 2013) resulting in previous underestimates of mangrove extent.

Fringing shoreline mangroves are important components of mangrove forest systems (Ewel et al., 1998; Friess et al., 2012; Koch et al., 2009; Lee et al., 2014). Their position at the land-sea interface means they are the site of maximal ecosystem service provision for most of the recognized mangrove ecosystem services. These fringing mangroves provide the greatest accessibility to fisheries resources (Lugendo et al., 2007), experience maximum tidal exchange for coastal productivity contributions (Ewel et al., 1998) and sediment and nutrient retention (Adame et al., 2010; Healy et al., 2002), and absorb a large proportion of shoreline wind and wave energy (Koch et al., 2009), buffering coastlines. Fringing mangroves are also likely sites of climate change resilience, with sediment trapping in the mangrove fringe allowing mangroves to keep pace with sea level rise (Krauss et al., 2014). However, narrow mangrove fringes are often overlooked because management strategies focus on maintaining larger mangrove expanses or even forest creation. The importance of these fringing mangroves to the coastal communities of Kien Giang is highlighted in this study by the presence of fish traps, mangrove timber harvesting and Nypa frond collection as quantified by the S-VAM assessment. Fish traps were found to be predominantly associated with mangrove forest, indicating a strong dependence on mangroves and associated soft-bottomed substrates habitats for food and livelihoods. The link between mangroves and near-shore fisheries is well understood (Lee et al., 2014), but often this link is expressed in general terms only, with little locally explicit information available. Providing locally relevant data that validates generally accepted mangrove ecosystem service paradigms can assist coastal zone managers to better communicate local mangrove habitat values with better outcomes for mangrove conservation. It is expected that assessments of fringing mangrove forest, such as this study, will generate greater conservation effort for these often overlooked but vitally important mangrove habitats.

A whole-of-system, broad scale quantification of shoreline and mangrove forest attributes using S-VAM, as presented here, gives greater

Table 5
Logistic Regression results showing the influence of significant variables on the probability of fence presence and the presence of seedlings within fenced areas. The Wald statistic shows the overall contribution of individual predictors to the model and Exp(B) is the odds ratio.

	B	se	Wald	Df	Sig	Exp(B)
Fence presence						
Intercept	0.57	0.29	4	1	0.05	1.77
Forest type			2	2	0.34	
Sparse	−1.00	0.90	1	1	0.27	0.37
Fragmented	−0.80	0.70	1	1	0.26	0.45
In tact[e]	0[a]	.	.	.	.	1.00
Dominant genus			73	3	<0.01	
Mixed	0.07	0.64	0	1	0.92	1.07
Rhizophora	−2.61	0.67	15	1	<0.01	0.07
Sonneratia	−6.77	0.83	66	1	<0.01	0.00
Avicennia	0[b]	.	.	.	.	1.00
Shoreline process			65	2	<0.01	
Eroded	−1.00	0.90	1	1	0.27	0.37
Stable	−0.80	0.70	1	1	0.26	0.45
Depositional	0[c]	.	.	.	.	1.00
RAC	1.50	0.12	150	1	<0.01	4.47
Fenced area with seedlings						
Intercept	−4.48	0.34	172	1	<0.01	0.01
Forest type			15	2	<0.01	
Sparse	−2.54	0.74	12	1	<0.01	0.08
Fragmented	−2.57	0.66	15	1	<0.01	0.08
In tact	0[a]	.	.	.		1.00
Dominant genus			178	3	<0.01	
Mixed	0.84	0.65	2	1	0.20	2.32
Rhizophora	1.98	1.05	4	1	0.06	7.24
Sonneratia	−6.10	0.47	170	1	<0.01	0.00
Avicennia	0[b]	.	.	.	.	1.00
Depositional[d]	4.86	0.30	263	1	<0.01	128.40
Forest patch length (km)	0.54	0.17	11	1	<0.01	1.72
Dist to forest edge (km)	2.63	0.50	28	1	<0.01	13.84
Dist to canal (km)	−0.37	0.16	5	1	0.02	0.69
RAC	2.20	0.10	497	1	<0.01	8.99

[a] Forest type is for In tact forest compared to Sparse and Fragmented forest.
[b] Dominant Genus is for *Avicennia* compared to Mixed and Other (*Rhizophora* and *Sonneratia* combined) genera.
[c] Shoreline process is for Depositional compared to Stable and Eroded classifications.
[d] Depositional process is compared to Stable and Eroded classifications combined.
[e] In -tact forest represents Continuous, Prograding and Growth/recovery forest combined.

insight into the key associations between mangrove structural attributes, threatening processes and values that can inform coastal zone spatial conservation planning. The S-VAM assessment of the Kien Giang coastline identified that one-quarter of Kien Giang's shoreline mangrove extent was threatened by coastal erosion. Eroded mangrove shoreline was more likely to occur where mangrove forests were of low stem density or disturbed by fragmentation and harvesting of shoreline trees, in poor condition, and further away from waterways where they may experience reduced sediment supply. Degraded mangrove forests with limited sediment supply were found to be more vulnerable to shoreline erosion on the western shoreline of the Gulf of Thailand (Thampanya et al., 2006). Eroded shoreline also have lower fisheries value as fish traps are less likely to be present along eroded shoreline. This information not only highlights that erosion poses an immediate threat to the Kien Giang coastline, but also that mangrove forest degradation is likely to be a significant contributor to increased erosion risk and mangrove loss is likely to negatively impact on local livelihoods.

Specifically identifying factors associated with shoreline erosion enables coastal zone managers to improve coastal resilience by more effectively addressing causes of forest degradation and implementing targeted, efficient and cost-effective erosion mitigation and mangrove forest rehabilitation strategies in high-risk coastal areas. This information is often lacking in the planning of mangrove rehabilitation efforts and the failure of many mangrove shoreline rehabilitation programs suggests that such data would likely be beneficial (Schmitt and Duke, 2015). This failure is demonstrated in the results of this assessment, showing that half of the fenced mangrove planting areas identified along the Kien Giang shoreline were located in areas with a low likelihood of seedling establishment success. Fenced areas with successful seedling establishment were more likely to be associated with areas of low erosion risk such as along naturally depositional coastline. Successful seedling establishment is much more likely on accreting coastlines, with low wave and wind exposure (Balke et al., 2013). These results suggest that at the time of assessment, much of the mangrove rehabilitation effort in Kien Giang was ineffective, did not enhance natural processes and did little to prevent erosion and improve coastal resilience. Since then different approaches to shoreline protection, such as Melaleuca pole fences (Van Cuong et al., 2015a) have been trialed and implemented, based on the initial findings of the study published in Duke et al. (2010). The specific location of restoration actions and identification of at-risk mangrove areas can be informed by maps and GIS layers generated from using georeferenced imagery (Schmitt and Duke, 2015). Using the S-VAM approach provides a relatively easy means of spatially representing data to inform coastal zone management decision and communicate results.

A multidisciplinary integrated GIS approach, combining remote sensing, field studies and socio-ecological data has been recommended as the most effective approach to mangrove management (Dahdouh-Guebas, 2002; Dahdouh-Guebas and Koedam, 2008). While the stand-alone data generated from S-VAM assessment is useful to inform management, it is likely to be further enhanced when combined with remote sensing and other spatial data (Schmitt and Duke, 2015). A recent study by Nguyen et al. (2015) incorporated the S-VAM results from this assessment (based on Duke et al. (2010) into a broader assessment of shoreline change along the Kien Giang coastline to identify key drivers of coastal retreat. The results of Nguyen et al. (2015) confirm that mangrove degradation is closely linked with coastal retreat, and that other factors not

Table 6
Advantages of Shoreline Video Assessment Method (S-VAM) as a tool for mangrove forest assessment.

Advantages of S-VAM	Description
Whole of system assessment	S-VAM enables capture of data from entire shorelines, or estuarine systems, reducing selection bias and enabling accurate, repeatable quantification of attributes.
Enhances existing shoreline assessment practices, like remote sensing and field plots	An important role of S-VAM is that it addresses the broad gap between remote sensing and field plot evaluations by quantifying the large number of influential processes with their relevant drivers of change.
Suitable for fringing mangroves and/or other shoreline features	S-VAM is an assessment tool suitable for quantifying mangrove ecotones such as fringing mangroves. Fringing mangroves with limited landward extent are often overlooked or not detected using remote sensing and field-based assessment methods.
Generally informative	Analysis of shoreline attributes using statistical modelling techniques can be used to identify attribute associations and identify key threats and drivers at high-risk and high-value areas.
Rapid image data acquisition	Image data acquisition at approximately 10 km/h allows for large spatial coverage in a relatively short period of time compared to similar field-based assessments. For this study ~190 km of data was collected over 9 days.
Accuracy of data	Image collection enables observer error assessment and quantification for QAQC purposes. Accuracy of data is comparable to similar manual attribute classification using aerial imagery (Verheyden et al., 2002).
Repeatability	S-VAM provides a georeferenced visual baseline archive of shoreline attributes than can be compared over time.
Ease of image acquisition	Uses readily available equipment with cost-effective image acquisition requiring a low skill-base for data collection. Data is easily transferrable. Reduces the need for logistically challenging within-forest sampling.
Non-invasive sample and data collection	S-VAM data acquisition is remote, so collections are mostly made without entering and damaging, delicate intertidal habitats.
Inclusive participation of local community members & traditional owners and incorporation of local knowledge	S-VAM data and imagery is readily collected by community members, Traditional Owner Rangers and others after receiving minimal training. Participants can actively contribute to the assessment process by providing local knowledge and socio-ecological perspectives that enhance ecological understanding (Dahdouh-Guebas and Koedam, 2008) using on-board video commentary or remote community-based assessment of imagery. Participants are often excited about being able to contribute to the gathering of useful scientific data. And, they are empowered by the results given in feedback sessions, as with the MangroveWatch program (www.mangrovewatch.org.au) (see also (Mackenzie et al., 2011; Schmitt and Duke, 2015)
Visual display representation	Shoreline attribute data is easily displayed on maps using GIS platforms. Maps are a useful means for communication of results and conservation planning. Imagery and data can be displayed online and made publically available.
Identification of cryptic indicators of mangrove condition, drivers of degradation and their quantification	Oblique and parallel assessment of shorelines enables identification of attributes often undetectable from aerial views and potentially missed, or inadequately quantified by spatially limited and logistically constrained field-based assessment.
Compatible with existing remote sensing and field based data acquisition methods	S-VAM is a stand-alone tool for mangrove forest assessment but is designed to complement existing remote sensing and field-based techniques. An integrated approach is likely to provide the most effective outcomes for mangrove conservation (Schmitt and Duke, 2015)
Report card style associated, on-going assessment outcome	The outcomes from S-VAM can be delivered as report card evaluations based on specific criteria for particular sites and shoreline systems of interest. On-going comparison of results links with shoreline management practices.
Baseline starting point followed by change detection along with on-going delivery	The first pass using S-VAM at a particular location is considered baseline from which all future passes will be used to keep track of change.
Multiple outcomes for management, monitoring and research	S-VAM can be used in many disciplines and sectors by various users, for their specific objectives and outcomes.
Various vector device platforms for image acquisition	Imagery and data may be acquired using various vector devices as well as small vessels, including: small aircraft drones, helicopters or simply walking cameras.

assessed in this study, such as adjacent landuse and mangrove forest landward extent (width) are also important. The Nguyen et al. (2015) study demonstrates that visual classification of shoreline process, such as erosion, does accurately represent longer-term shoreline process, but is limited to quantifying presence/absence rather than rates of change. It should be noted that (Nguyen et al., 2015) relied on the base data used for this study that was not subject to QAQC through repeat assessment of observer error. Results of this study show that more accurate outputs are likely if simplified levels of shoreline classification are used, and that this reduced classification still provides meaningful and applicable outcomes. The ability to undertake repeat assessment to address such issues in data quality control and accuracy management is a further benefit of using image-based data collection and assessment. Repeat assessments comparing georeferenced imagery over time is also possible using S-VAM and has already been applied in Kien Giang to further inform coastal management in this region (Van Cuong et al., 2015b).

5. Conclusions

The Shoreline Video Assessment Method provides a tool that accurately quantifies shoreline mangrove forest extent, structure, degradation and values to better inform mangrove management and conservation, and improve mangrove forest resilience to climate change. Climate change, including sea level rise, poses significant threats to mangrove forests. Mangrove forests are much more likely to withstand climate change impacts if other direct anthropogenic drivers of degradation are reduced. The outcomes of this study demonstrate the importance of undertaking whole-of-system shoreline mangrove forest assessments using S-VAM to accurately quantify the scale and drivers of shoreline mangrove degradation. Data analysis showing direct links between shoreline and mangrove attributes, mangrove forest degradation and increased risk of mangrove loss can be directly applied by coastal zone managers to implement effective and spatially targeted mangrove conservation and rehabilitation strategies and to directly target relevant local drivers of mangrove degradation. Maps generated from the data provide powerful visual tools to communicate results to promote and inform mangrove conservation.

We suggest that S-VAM be used in future mangrove forest assessments to complement remote sensing and field-based data collection. Furthermore, S-VAM can be used as part of regional mangrove monitoring networks to inform conservation planning, mangrove management policies, rehabilitation, and habitat enhancement that increase shoreline mangrove resilience to climate change through the identification and management of anthropogenic stressors. For a review of current applications of the S-VAM approach relevant to mangrove forest management refer to Table 7.

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Table 7
Potential Applications for Shoreline Video Assessment Method (S-VAM) to improve mangrove management.

Applications of S-VAM	Description	Reference
Conservation planning & Integrated Coastal Zone Management (ICZM)	Identification of high value and at-risk mangrove forests and associated attributes. S-VAM attributes could potentially be included in spatial conservation planning tools such as MARXAN (for example of the use of MARXAN to inform mangrove conservation see (Adame et al., 2015)). S-VAM should form part of adaptive management of mangrove shorelines in conjunction with other seascape and coastal zone management strategies.	Albert et al. (2012) Duke et al. (2015) Van Cuong et al. (2015b)
Managing anthropogenic drivers of degradation	Identification of cryptic drivers of degradation, associated mangrove forest attributes, their spatial location and regional extent.	This study Nguyen et al. (2015)
Rehabilitation planning and implementation	Identifying areas for rehabilitation. Assigning rehabilitation measures of success using adjacent unimpacted areas. Monitoring rehabilitation success.	Van Cuong et al. (2015a) Van Cuong et al. (2015b) This study
Communicating values and threats	Mapped outputs and online imagery display provide a means to communicate conservation and management issues to coastal zone managers, policy makers and the wider public.	This study Duke et al. (2015)
Integrated assessment with GIS, remote sensing and field-based assessment	Using S-VAM data attributes, in combination with other spatial data, remote sensing data and field-based groundtruthing to inform specific questions relevant to mangrove management. For example identifying drivers of shoreline retreat.	Nguyen et al. (2013) Nguyen et al. (2015)
Groundtruthing for satellite and aerial remote sensing data acquisition	Using S-VAM data attributes to ground-truth and inform remote sensing data acquisition	Nguyen et al. (2013)
Scaling up field-based assessment	Using field-based assessment to inform S-VAM shoreline attribute classification to increase spatial scale of spatially limited field-assessment. For example, scaling up mangrove forest biomass and blue carbon assessment to whole of shoreline scales based on mangrove forest tree height and density attributes.	Albert et al. (2012)
Monitoring	Using S-VAM imagery to assess mangrove shoreline change over time as an adaptive management strategy to inform mangrove management and conservation.	Van Cuong et al. (2015b)
Citizen-science	Due to the ease of imagery acquisition and remote imagery classification, the S-VAM method could be used as a tool for use in citizen-science mangrove monitoring program such as MangroveWatch (www.mangrovewatch.org.au) (Schmitt and Duke, 2015)	Duke et al. (2009) Mackenzie et al. (2011)

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Appendix A. Supplementary data

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