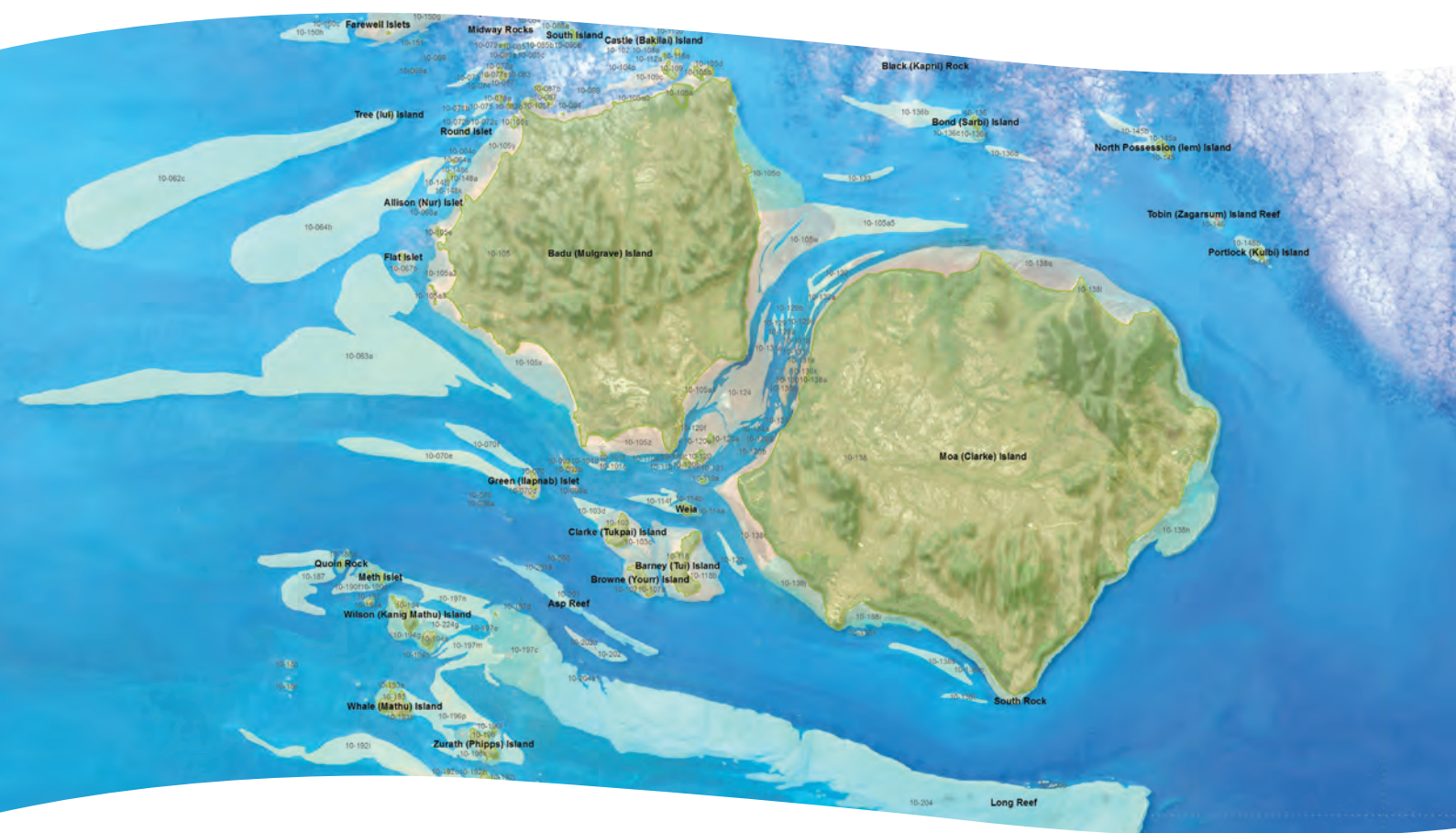


Mapping the Torres Strait Reef and Island Features

Extending the GBR Features (GBRMPA) dataset

Eric Lawrey and Melanie Stewart



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ACRONYMS

AGRI	Australian Geographic Reference Image (by Geoscience Australia)
AHO	Australian Hydrographic Office
AIMS	Australian Institute of Marine Science
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DOE	Department of the Environment
EotR	Eye on the Reef
ESRI	Environmental Systems Research Institute
GA	Geoscience Australia
GBR	Great Barrier Reef
GBRMPA	Great Barrier Reef Marine Park Authority
GBRMP	Great Barrier Reef Marine Park
GIS	Geographic Information System
NASA	National Aeronautics and Space Administration
NERP TE	National Environmental Research Program Tropical Ecosystems
NESP	National Environmental Science Programme
PDF	Portable Document Format
POW	Prince of Wales Island
RHIS	Reef Health Impact Survey
RRRC	Reef and Rainforest Research Centre Limited
TSRA	Torres Strait Regional Authority
TWQ	Tropical Water Quality

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1.0 EXECUTIVE SUMMARY

Torres Strait has a rich and diverse marine environment with hundreds of islands and thousands of small coral reefs. It is an extension of the Great Barrier Reef (GBR) that is often overlooked, possibly due to a lack of openly available digital maps of the region.

The Great Barrier Reef Marine Park Authority (GBRMPA) developed digital Geographic Information System (GIS) maps of the Great Barrier Reef Marine Park (GBRMP) in the 1980's to assist them with management and zoning development. This mapping dataset (*GBR Features*) has been widely used for research, for reference mapping and for public maps such as Google Maps. Unfortunately this mapping did not extend into Torres Strait and so this region appears blank in many of these maps.

This project was developed to extend the mapping of the GBR into Torres Strait to allow the creation of a single consistent dataset covering the islands and marine features of the entire GBR. It was initiated to allow the processing of data from coral reef surveys in Torres Strait by the Eye on the Reef database run by GBRMPA and was developed as a collaboration between AIMS and TSRA.

This project mapped Torres Strait using a combination of existing island datasets as well as semi-automated and manual digitising of marine features (reefs and sand banks) from the latest aerial and satellite imagery. No features were added to the dataset without confirmed evidence of their existence and position from at least two satellite image sources.

The new *Torres Strait Reef and Island Features* dataset was mapped at scale of 1:50,000 which is significantly finer mapping than the 1:250,000 scale of the *GBR Features* mapping of the GBRMP. This increased level of detail was important to capture the large number of small islands and reefs in Torres Strait.

Over 3900 features were mapped in Torres Strait, of which 2600 were reefs and shoals, many which are very small. This compares with 5600 features for the rest of the GBRMP, of which 3695 were reefs and shoals.

It is often quoted that the GBRMP has 3000 coral reefs, which corresponds to reefs larger than 0.15 km². Using the new Torres Strait mapping we can now estimate the number of coral reefs for the whole GBR. With the same minimum reef size there are 3680 reefs (28,348 km²) in the whole GBR of which 18% (684) by number and 14% (3,972 km²) by area are in Torres Strait.

All mapped features were allocated permanent identification numbers (IDs) in a manner compatible with the *GBR Features* dataset allowing easy integration between the two datasets. Names were also attached to features from existing maps; however future work is needed to review these names with the community to check their accuracy, particularly for traditional names.

The final result of this project is a highly detailed map dataset of the marine and island features of Torres Strait with permanent IDs that are compatible with the *GBR features* dataset allowing the compilation of a complete and consistent map of the entire GBR.

This dataset is available under a creative commons license from the eAtlas at <http://eatlas.org.au/data/uuid/d2396b2c-68d4-4f4b-aab0-52f7bc4a81f5>.

2.0 INTRODUCTION

Torres Strait is situated between Papua-New Guinea and Australia. It has a rich and diverse marine environment with hundreds of islands, thousands of small shoals and hundreds of large reefs. It is an extension of the Great Barrier Reef (GBR) that is often overlooked because there are no publicly available detailed digital maps of the region.

Many parts of Torres Strait were mapped in detail between 1850 and 1899s (see 2.2 History of mapping Torres Strait). These maps were so accurate and detailed that they rival even modern Nautical charts in some parts. Paper maps were further improved in the 1970's with the introduction of the 100k Topographic Map series. Unfortunately these maps were never produced in a digital GIS format that could be used for analysis and reuse. The only existing moderately high resolution digital maps of the region are not freely available or compatible with the *GBR Features* mapping of the Great Barrier Reef Marine Park (GBRMP).

The GBRMP was first digital mapped by the Great Barrier Reef Marine Park Authority (GBRMPA) in the 1980's and was continually improved over the following 20 years. The *GBR Features* (Great Barrier Reef Marine Park Authority, 2007) dataset mapped coral reefs, islands, rocks and cays from early Landsat imagery and was vital for establishing the zoning of the marine park. Known names of the features were recorded in this dataset and all features were assigned an easy to communicate ID (such as 19-185a). For many unnamed features the IDs serve as de facto names that are routinely used in scientific literature for communicating study sites. Unfortunately the mapping undertaken by GBRMPA only included the southern-most parts of Torres Strait, and additionally these features were only roughly mapped.

This project was initiated to allow GBRMPA to process reef survey data undertaken in Torres Strait by the Torres Strait Regional Authority (TSRA) as part of a coral reef monitoring program developed as part of the National Environmental Research Program Tropical Ecosystems (NERP TE) hub. GBRMPA needed a dataset compatible with the *GBR features* datasets for the survey data to be integrated into the Eye on the Reef (EotR) database system.

The aims of this mapping project were:

- To extend the mapping of the GBR into Torres Strait.
- Make the new dataset compatible with the existing *GBR Features* dataset.
- Allocate permanent IDs for all features in a manner similar to the *GBR Features*.

The final dataset would be easy to merge with the *GBR Features* dataset to create a single dataset of the entire GBR.

Once the mapping and ID allocation was complete, a first cut of identifying and assigning names to the features was undertaken to make the dataset more complete and useful.

2.1 What was mapped

In this project we develop a spatial dataset that maps the marine and island features of Torres Strait. It maps the extent of marine features from the top (islands) through to the bottom (reef boundaries). These basic types of features were chosen to match the approach used in the *GBR Features* dataset. The islands correspond to features that remain out of the water at mean high tide and the reef boundaries correspond to any marine feature that are raised off the ocean floor boundaries. These two main feature types are broken down into several basic classifications types based on their geological origin. The intention of the marine features is to encompass all non-open water features, so that if the area of all the marine features is masked out of a satellite image of the region then only open water or sea bed can be seen. This dataset maps areas around islands and the mainland that are not coral reefs or fringing reefs, but are an extension of the foreshore to the bottom of the seabed.

This project did not map the tops of reefs, only the bottom boundaries and the islands.

2.2 History of mapping Torres Strait

The first detailed maps of Torres Strait were developed in the 1850's after surveys undertaken by Francis Blackwood and Charles Yule in 1842 - 45 and Owen Stanley and Charles Yule in 1846 - 50 (Pearson, 2005). They developed maps of the central and eastern parts of Torres Strait at an incredibly detailed scale of 1:148,000. These maps contained most of the island features in the region. These maps were further improved in the 1890s for areas associated shipping. These maps were basis of future maps for nearly 100 years. It was not until the development of the 100k Topographic Map series in the late 1970's that the maps were further significantly improved.



Figure 1: A cropped section of one of the oldest detailed maps of central Torres Strait (Great Britain. Hydrographic Dept., 1855). This map was created in 1855 and is one of the earliest records of the European names of the islands. A full version of this map is shown in Appendix 9: Key Historic maps.



Figure 2: Cropped section of the 1976 Topographic 100k series of paper maps published by the Royal Australian Survey Corps (Geoscience Australia (2006). These maps cover most of Torres Strait, but are hard to obtain and do not have a digital version.

With the development of computerised Geographic Information Systems (GIS) in the 1980's there was a need to start the creation of digital versions of maps. It was during this time that GBRMPA and CSIRO investigated (Jupp et al. 1985) and later developed digital GIS maps of the GBRMP based on Landsat imagery and aerial photography. The GBRMP stops at the tip of Cape York and so this mapping only covered the very southern parts of the Torres Strait.

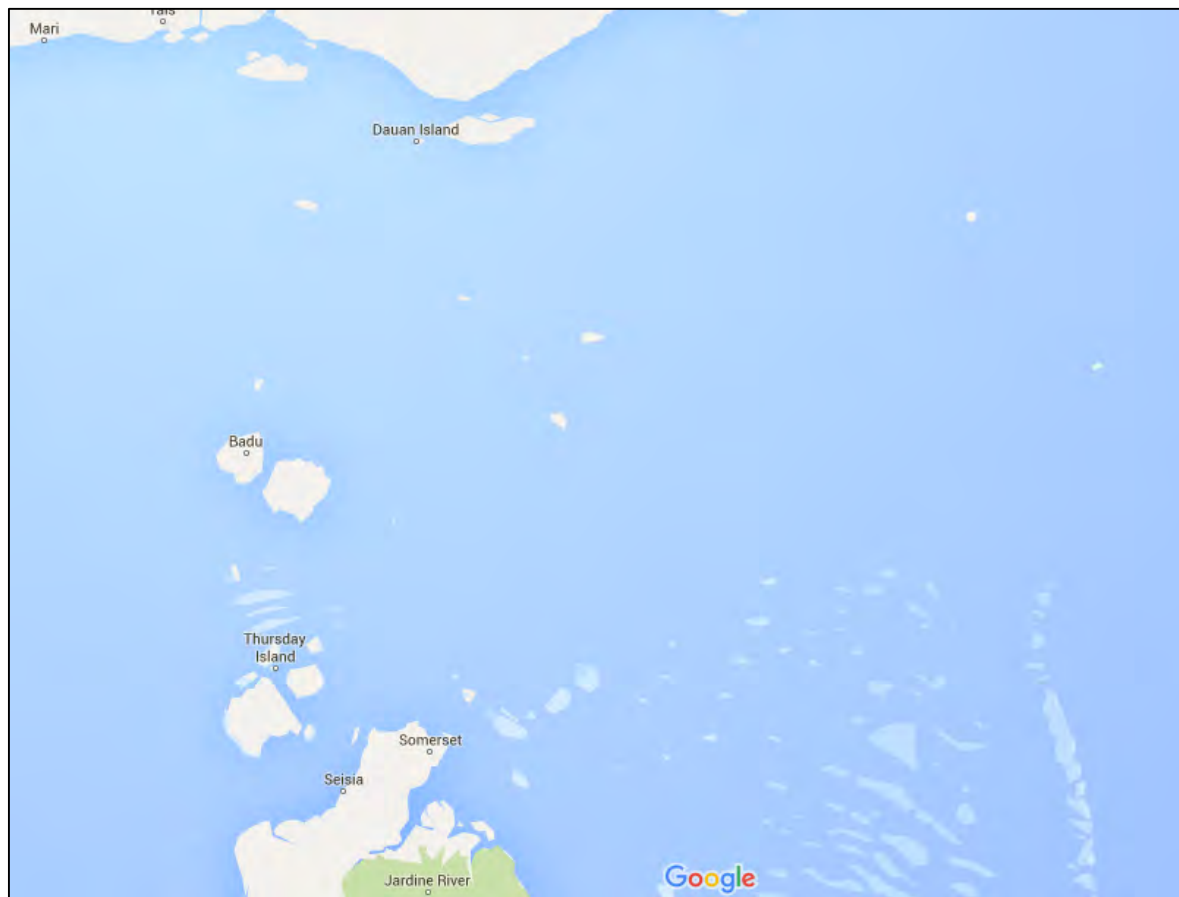


Figure 3: Google maps (from 4th April 2016) includes the reef features from the GBRMPA *GBR Features* dataset, but no mapping of Torres Strait reefs. The *GBR Features* dataset stops just north of the GBRMP (tip of Cape York) and so most of Torres Strait appears blank.

The lack of digital mapping of Torres Strait has meant that for almost a generation many people have forgotten that the GBR does not stop at the northern edge of the GBRMP, but continues up to Papua-New Guinea. In the digital age the mapping of Torres Strait went backwards for 30 years as is evidenced by the complete lack of Torres Strait reefs in Google Maps (see Figure 3).

2.2.1 Australia Hydrographic Office (AHO) Marine Nautical Charts

The most detailed mapping of the Torres Strait Region are the Australian Nautical Charts (Australian Hydrographic Office, 2014). These provide detailed mapping at a range of scales from 1:37k around Thursday Island through to 1:150k for all of Torres Strait. These maps show depths, marine features such as banks and record many of the features' names. While these maps are generally very good in well surveyed areas there still remains areas of Torres Strait that are unsurveyed. Additionally, and most importantly, these maps are restricted in their access (not openly available) and are not available in a digital form suitable for integrating with the existing *GBR features* mapping.

It should be noted that the new *Torres Strait Reef and Island Features* dataset is not intended to be a replacement for the Marine Nautical Charts. The *Torres Strait Reef and Island Features* dataset **DOES NOT** contain some of the marine hazards that are in the Marine Nautical Charts (such as Quetta rock) because they were not visible in any of the satellite imagery and thus their position could not be independently validated from the imagery. No features in the 1st version of the *Torres Strait Reef and Island Features* dataset were copied from the Marine Nautical Charts. For this reason the *Torres Strait Reef and Island Features* dataset is **NOT** suitable for navigation.

Future versions of this dataset may include some of the missing marine hazard features once additional information about their exact positions can be obtained.

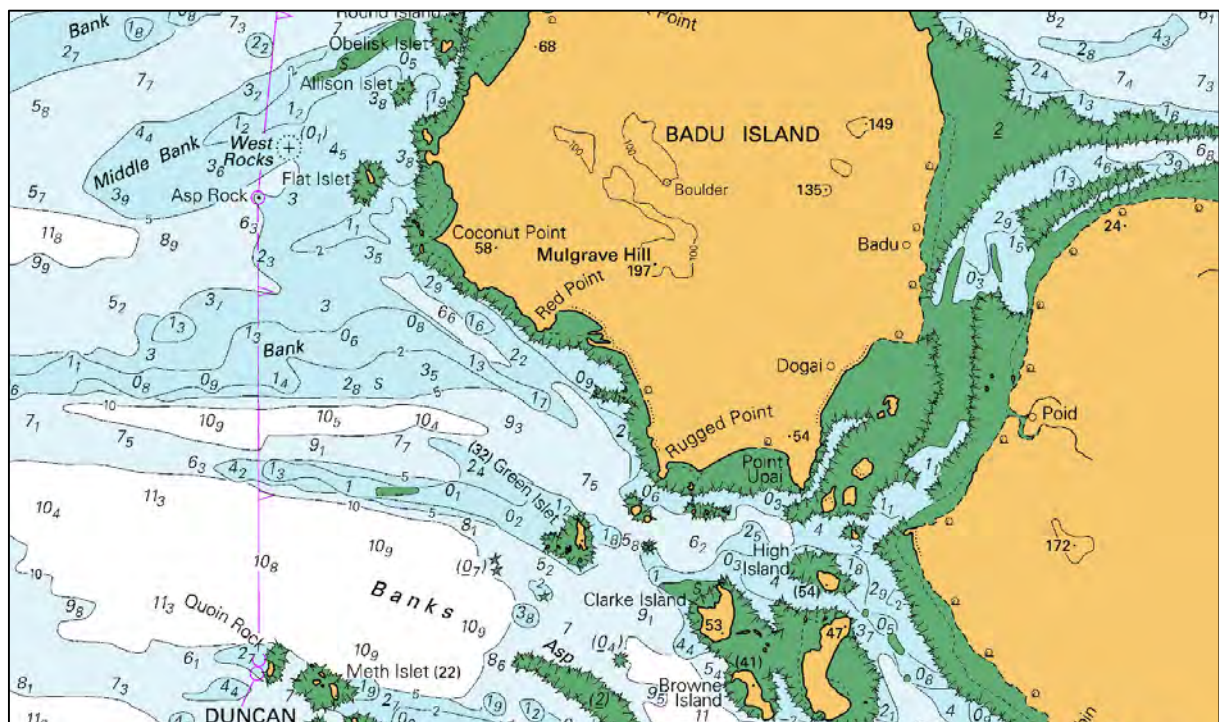


Figure 4: Cropped section of the 1:150,000 scale Nautical Marine Chart (Aus841).

2.2.2 CSIRO Torres Strait Atlas

To remedy the lack of a digital version of the reef mapping in Torres Strait, CSIRO undertook a project (Taranto, Jacobs, Long, 1997) to compile and digitise features from the available 1:100,000 Australian Topographic Series maps and to supplement them with basic digitisation of Landsat Thematic Mapper Satellite Imagery for areas not covered by these paper maps. This project incorporated the Australian Gazette placenames and traditional names supplied by the Torres Strait Island Co-ordinating Council. The final maps were released as the Torres Strait Atlas, a series of PDF 1:200k and 1:500k maps. The digital shapefiles from the project were never publicly released and so were never integrated with the mapping of the whole GBR.



Figure 5: Extract of the CSIRO Torres Strait Atlas at 1:200k.

2.2.3 New Torres Strait Reef and Island Features dataset

Figure 6 shows an extract of the newly created dataset produced by this project. The full dataset covers all of Torres Strait and some of Papua-New Guinea. Example maps from the new dataset are available in Appendix 10: Maps of the new Torres Strait Reef and Island Features Dataset.



Figure 6: Extract of the *Torres Strait Reef and Island Features* dataset developed by this project.

3.0 METHODOLOGY

The development of the *Torres Strait Reef and Island Features* dataset was broken into three parts, each with their own process: mapping of the sand banks, mapping of the reefs and mapping of the islands. The overall dataset development was as follows:

- 1. Dataset collation and image preparation:**
 - a. Collation of existing maps and datasets.
 - b. Download and preparation of the Landsat 5, 7, and 8 satellite image archive for Torres Strait.
 - c. Spatial position correction of Landsat imagery against a known reference image.
- 2. Sand Bank features:**
 - a. Manual digitisation of sand banks from Landsat 5 imagery.
 - b. Conversion to a polygon shapefile for integration with the reef features.
- 3. Reef features:**
 - a. Semi-automated digitisation of the marine features from Landsat 5 imagery.
 - b. Manual trimming, cleaning and checking of marine features against available aerial and satellite imagery.
- 4. Island features:**
 - a. Compilation of island features from existing datasets (DNRM 1:25k Queensland Coastline, and Geoscience Australia Geodata Coast 100k 2004)
 - b. Correction of the island features from available aerial and Landsat imagery.
- 5. Merging:** of marine and island features into one dataset.
- 6. Classification:** of mapped features, including splitting fringing reefs based on changes in classification.
- 7. ID allocation:**
 - a. Clustering to make groups of related features (i.e. an island, plus its fringing reefs and related sand banks; a reef plus its neighbouring patch reefs, etc.).
 - b. Merging with the *GBR Features* dataset. This was to ensure that there were no duplicate allocations of feature IDs.
 - c. Allocation of group IDs (i.e. 10-362) following the scheme used in the *GBR Features* dataset. Using R scripting.
 - d. Allocation of subgroup IDs (10-362b) to each feature in the dataset. Using R scripting.
- 8. Allocation of names:**
 - a. Names of features were copied from some existing maps (Nautical Charts, 250k, 100k Topographic maps, CSIRO Torres Strait Atlas).

Note: Proper review of identifying all historic and traditional names of features was out of the scope of this project and so future work is needed to complete the collation of all feature names (in particular the traditional names) and to review the correct application of the names with the Torres Strait community.

The processing and digitisation of the marine features (sand banks and reefs) from satellite imagery was performed using Photoshop rather than the traditional GIS tools such as ArcMap. Photoshop provided a highly flexible interactive platform for image manipulation

suitable for the semi-automated digitisation approach used. It allowed rapid iterative optimisation of all the contrast and thresholds levels applied to the images, helping to ensure the best results could be achieved across the different turbidity and sea depth conditions seen across Torres Strait. Manual adjustments were applied using the paint tools in Photoshop. This allowed rapid adjustments and corrections to be made to the developed reef mask prior to conversion to a polygon shapefile. After the raster marine feature masks images were developed they were converted to shapefiles by first reattaching the original spatial coordinates back to the images (as Photoshop does not maintain the spatial metadata in the images) using GDAL tools and then using OGR command line tools to convert them to polygon shapefiles.

The subsequent stages of development (merging of feature types, checking and correction against high resolution imagery, ID allocation and allocation of names) were processed using a combination of ArcMap, QGIS, Excel and R scripts.

3.1 Data collation and Image Preparation

3.1.1 Landsat image selection

The entire library of Landsat 5, Landsat 7 and Landsat 8 (up to August 2015) was downloaded (from the Google Earth Engine) and processed to true colour images for review.

From the complete catalogue of images a number were selected based on the task being performed. For mapping of the reef boundaries clarity of the water and lack of clouds was the most important aspect of the image, whereas for mapping of the islands the boundary of the mean high tide was needed and so images with the high tide levels were selected.

In Torres Strait clouds obscure most of the images with approximately 80% having too much cloud cover to be of use. Additionally the high to very high water turbidity in Torres Strait prevented many of the images from being useful for mapping deeper reef features. As a result only a few images from the entire Landsat archive were suitable for the semi-automated digitisation of the reef features (Appendix 2: Algorithm for Digitisation of Reef features). A greater range of images were used for the manual checking and boundary adjustments as it was easier for a human to ignore the clouds.

This project predominantly used images from the 98, 67 and 99, 67 Landsat scenes.

Table 1: Number of images downloaded and previewed for each scene; the number of images used in marine feature mapping and checking, and the number of images used for island boundary adjustments.

Scene	Location	Satellite	Available	Marine mapping	Island mapping
98, 67	Eastern TS	Landsat 5	145	6	0
98, 67	Eastern TS	Landsat 7	78	1	0
98, 67	Eastern TS	Landsat 8	54	1	7
99, 67	Central and Western TS	Landsat 5	145	9	0
99, 67	Central and Western TS	Landsat 7	81	0	0
99, 67	Central and Western TS	Landsat 8	54	1	9
99, 66	Saibai, Boigu, PNG	Landsat 5	140	1	1
98, 66	PNG, Fly river, Bramble Cay	Landsat 5	140	2	2

The Landsat 5 archive is the longest (from 1988 - 2011) and largest. The marine features were digitised using a semi-automatic algorithm, outlined in 3.3 *Mapping of reef features process*. This algorithm required that the source images to have a very low cloud cover and low water turbidity. As a result the long and large Landsat 5 archive was key to finding images suitable for this purpose.

The Landsat 8 archive was relatively short (2013 - 2015) when this project was undertaken. Unfortunately none of the Landsat 8 images were very low in cloud cover and low in turbidity and so they were used for manual checking and boundary correction steps.

3.1.2 Landsat Position Offset Correction

After comparing the Landsat imagery to the other higher resolution imagery it was found that there was a positional error in the Landsat 5 and 8 imagery in the order of 25 - 35 m. If left uncorrected this image positional error would result in a significant positional error in any digitised features.

The Australian Geographic Reference Image (AGRI) (Geoscience Australia, 2011) is a national mosaic that provides a spatially correct reference image at a 2.5 metre resolution across Australia. Geoscience Australia developed AGRI to address the need for a higher resolution reference image, of known accuracy, over the entire Australian continent. In Torres Strait the AGRI image has a 90% error radius of 2.6 - 5 m in central Torres Strait and 5.1 - 7.5 m in Eastern Torres Strait.

To ensure the best possible positional accuracy of the final maps the Landsat imagery used in this project was aligned to the AGRI by iteratively shifting the Landsat imagery until the best alignment was achieved. The imagery was aligned to within 1/3 of a pixel (5 m) and then checked for any residual errors across the image. The final residual errors were typically less than 12 m resulting in an estimated total positioning error (including the AGRI error) of 16 m, which is approximately a doubling in the positional accuracy of the image. An example of this improvement can be seen in Figure 8.

Further details of the alignment process are outline in Appendix 1: Offset corrections applied to Landsat imagery.



Figure 7: Wharfs of Thursday Island showing reference AGRI (GA) imagery overlaid with a trace of the island outline (yellow) for comparison with the Landsat images below. In this case the boundary of the island was traced from aerial imagery.

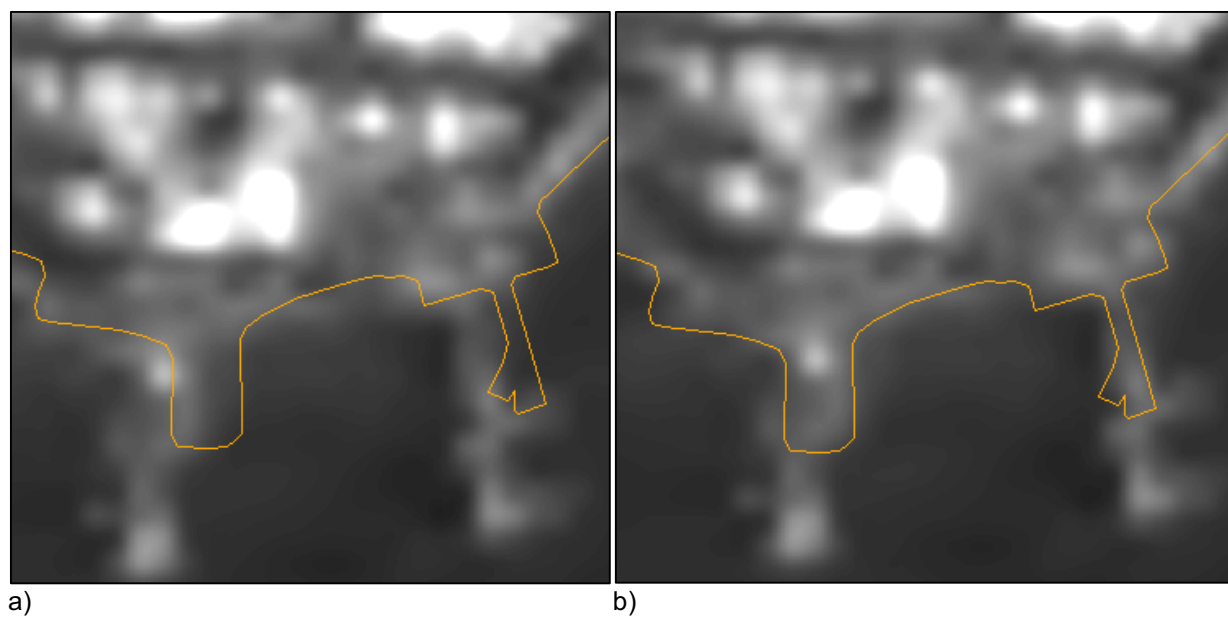


Figure 8: Same digitised outline of Thursday with 15 m resolution Landsat 8 B8 channel image (LC80990672014351LGN00_B8.TIF) background. a) The uncorrected Landsat 8 image shows a clear misalignment at the wharf. b) After offset correction the imagery aligns well with the outline. In this case the original was offset by 25 m in X direction and 13 m in the Y direction.

3.2 Mapping the sand bank features

On the western side of Torres Strait, particularly in the north, there are hundreds of submerged sand dunes (classified as sand banks in this dataset). Most of these sand banks are in relatively shallow water (3 - 7 m LAT) with their tops typically reaching 0.1 - 2 m LAT (Australian Hydrographic Office, 2014). Despite being in shallow water their boundaries are difficult to see due to the highly turbid water. For this reason these features were mapped manually.

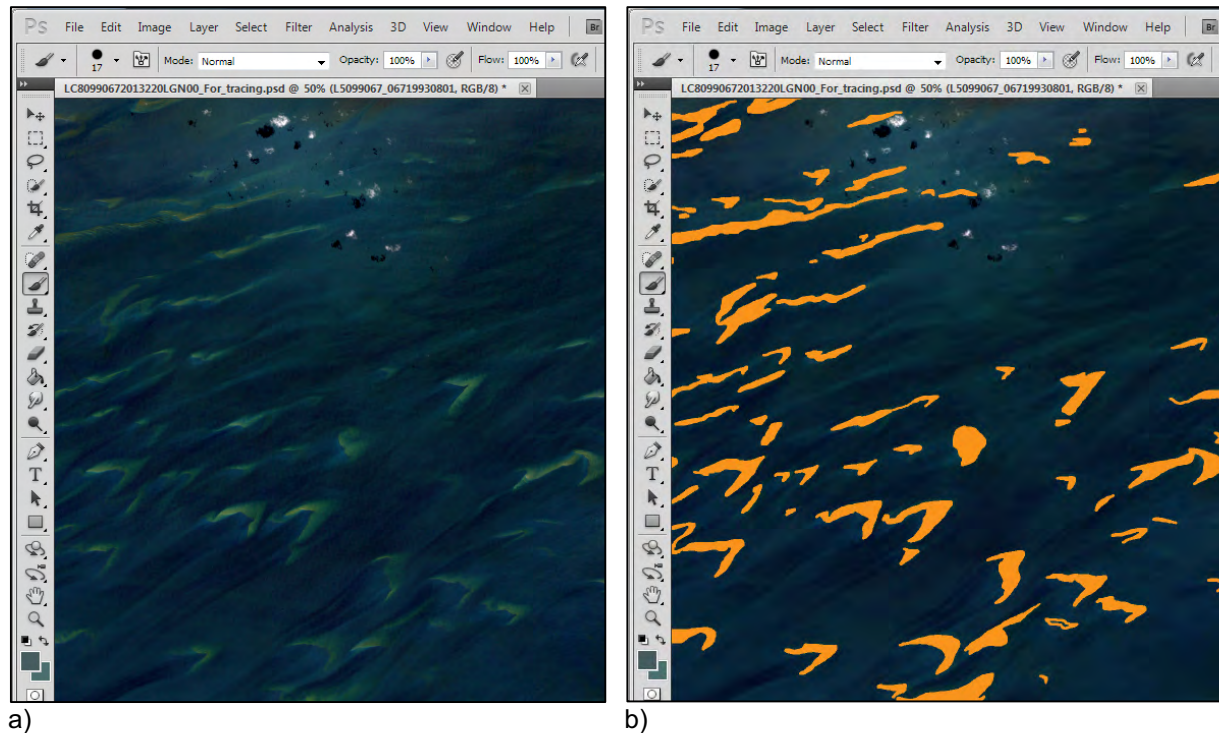


Figure 9: Manual digitisation of the sand dunes was performed using painted layers in Photoshop. a) One of the reference Landsat images (L5099067_06719930801) used for determining the sand bank boundaries. b) Manually drawn boundaries of the sand dunes.

Four Landsat images were used to map the sand banks (L5099067_06719930801, L5099067_06720040815, L71099067_06720020919, LT50990671997288DKI00). These images were chosen as they were the clearest images in the archive for seeing the sand banks. These images were upsampled using cubic interpolation in Photoshop (from 30 m to 15 m) and aligned with a reference 15 m resolution Landsat 8 pan-sharpened image (LC80990672013220LGN00). This reference image was the same as that used to digitise the reef features and served as the spatial reference for the final drawing of the sand banks.

When the sand banks were drawn, the most recent image in which the feature was evident was used. The sand bank boundaries were mapped less precisely than the reefs and islands as the sand banks move and are less distinct.

The sand banks were then drawn on a 15 m resolution raster layer in Photoshop using the brush and erase tools. This technique allowed rapid digitisation of the hundreds of features. The final output sand bank mask image was combined with the reef features mask (outlined in the next section) in Photoshop prior to conversion to a polygon shapefile.

3.3 Mapping of reef features process

The intention of the reef feature mapping process was to establish the boundaries of all features raised off the sea floor. These features were then subsequently classified based on manual classification of available imagery.

The reef mapping was predominantly based on Landsat imagery with trimming, verification and classification of features using available Landsat, aerial and Google imagery as well as referencing the AHO Nautical Charts, Topographic 250k and CSIRO Torres Strait Atlas for names of features.

Due to the large number of reef features to be digitised a semi-automated digitisation technique was developed.

The following is an overview of the process was used to map the reef features:

1. A raster mask of the reef features was created using a semi-automated digitisation of the best Landsat 5 images using Photoshop, with the following sub-steps:
 - a. **Local water brightness:** A moving minimum filter of 1 km diameter (with smoothing) was used to estimate the brightness of the water without the marine features. This estimate was then subtracted from the original image to enhance the contrast of the marine features against the open water. This process effectively de-trended the brightness of the water across the image due to differences in water turbidity and sun glint. (see Figure 10)
 - b. **Marine feature raster mask:** A threshold was then applied to each of the de-trended images. The threshold applied was manually chosen to best separate the marine features from the open water without introducing too many false positives. This process was repeated for each of the channels (B10, B20, B30, B40). The channel best used to map each of the features depended on the local depth and water turbidity. The masks from each of the channels and from multiple Landsat images were combined manually in Photoshop to create a single mask of all reef boundaries.
2. Manual cleaning of this reef raster mask to remove clouds, noise, missing features, false positives and checking of all features against multiple images.
3. Combining the sand bank and reef mask rasters together followed by a conversion to polygons to create a marine features polygon shapefile.
4. Smoothing of the marine features polygon to remove the jagged stair case boundaries of the polygons from the raster vectorisation.
5. Checking and cleaning the digitised marine features against available aerial, AGRI and Landsat 8 imagery.
6. Merging with the island features by cutting the islands out of the reef boundaries.

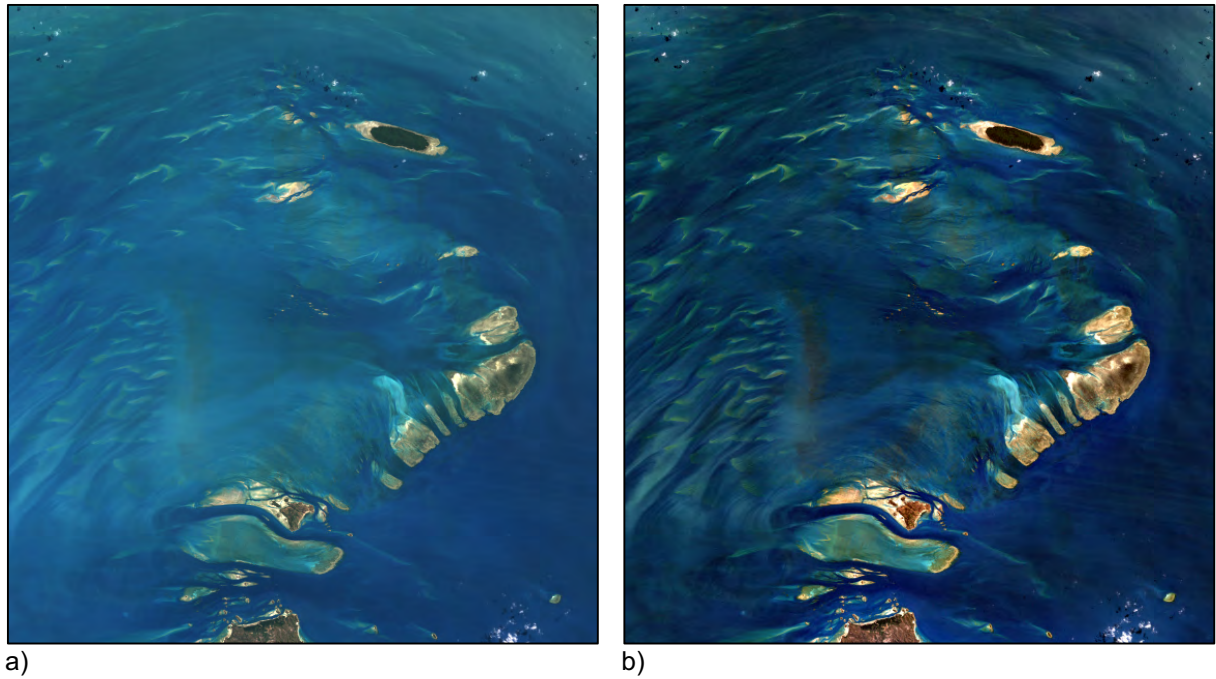


Figure 10: Images were normalised in water brightness prior to digitisation to improve detection of features above the seafloor. a) Original true colour Landsat 5 image (L5099067_06719930801), b) same image after contrast enhancement based on local water brightness.

The reef mask for each scene was combined with the sand bank mask to create a raster layer with both of these two features types. This raster was then converted to a polygon using the ogr2ogr command line tool, and then subsequently smoothed prior to checking and refining of the feature boundaries.

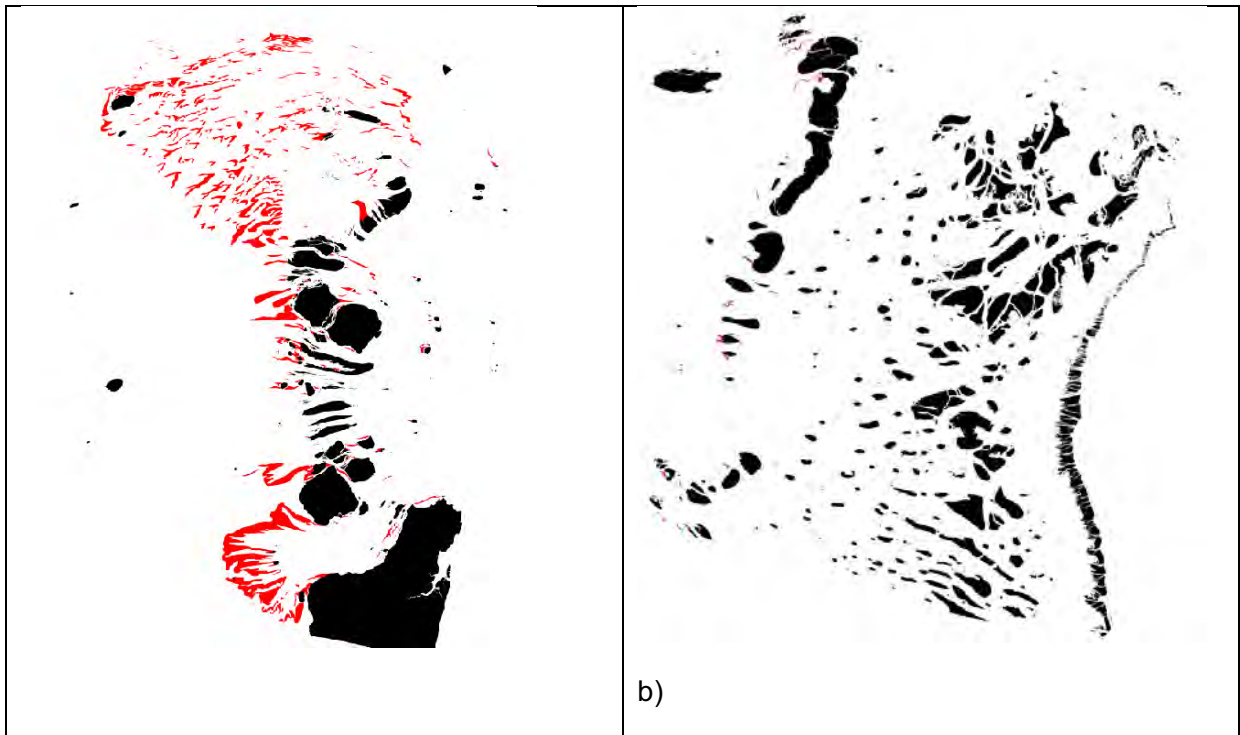


Figure 11: Final marine feature masks prior to conversion to polygons. Sand banks are in red, all other marine features are in black. a) Landsat scene 99, 67. b) Landsat scene 98, 67

More details of the algorithm used are outlined in Appendix 2: Algorithm for Digitisation of Reef features.

3.4 Island outline development

The starting point for the island mapping was the *Coast100k 2004* (Geoscience Australia, 2004) and *Queensland Coastline 25k* (Department of Natural Resources and Mines, 2010) datasets.

The *Queensland Coastline 25k* dataset is a polyline vector shapefile of the coast and the islands. It had several problems that prevented its direct use including variable quality of the island boundaries, inconsistent handling of river mouths, no gazetteer of names and absence of some island features.

The *Coast100k 2004* dataset provides coverage of the whole of Australia, is quite consistent in quality, and has a gazetteer of names. While it did however contain a number of islands not shown in the *Queensland Coastline 25k* dataset its scale of 1:100k was coarser than the desired final dataset.

A basic working version of the Torres Strait Islands was created from the *Queensland Coastline 25k* dataset by converting the lines features to a set of polygons using the process outlined in <http://support.esri.com/en/knowledgebase/techarticles/detail/35321>. The extra islands in the *Coast 100k 2004* dataset were then copied into this datasets.

3.5 Checking and correcting Reef and Island polygon boundaries

After the initial polygon reef and island shapefiles were developed, they were subsequently passed through a round of quality checks on their boundary accuracy. At this stage in the process additional high resolution (including AGRI, Aerial and Google Earth) and Landsat 8 pan-sharpened imagery was used as reference information to manually adjust and correct the boundaries of the islands and reefs.

The boundaries of all features were corrected if their error exceeded 20 m from the ideal digitisation of the feature as seen in the available imagery. This maximum error was chosen to ensure the final digitisation would be sufficiently accurate for a map scale of 1:50,000. In some limited areas the digitisation was performed more carefully. Where there was aerial imagery available or the area was close to populated areas, the digitisation was corrected to ensure a maximum digitisation error of approximately 5 m.

The data for the island features was sourced from existing datasets and so each island feature was checked to see if they remained dry at high tide (island) or were likely to be submerged at high tide (reef). Those features that were identified as likely to be submerged at high tide were removed from the islands dataset. To assist in this assessment, false colour infrared Landsat images were prepared to help identify features that were in or out of the water. Infrared light does not penetrate the water, but does reflect strongly off any features out of the water (even if they are damp).

It was found that prior to the manual correction process many of the island features from the source datasets had position errors in the order of 90 m and had many smaller island features were not islands but shallow reefs and so needed to be removed from the islands layer.

Table 2: Types of imagery used to check the reefs and islands mapping and what purpose they were used for.

Preference	Imagery	Resolution	Digitisation	Classification
1	Aerial	0.2 m	True	True
2	Google	0.5 - 1 m	False	True
3	AGRI PRISM	2.5 m	True	True
4	Landsat 8 Pan sharpened	15 m	True	True
5	Landsat 5	30 m	True	True

Note that Google Earth imagery was only used for classification of the features as its licensing prevented its use for tracing purposes. The historical imagery feature in Google Earth was however used, where there was imagery available, to assist in the classification of the features and to confirm of the existence of small mapped reefs, rocks and shoals.

Where no high resolution imagery was available, or the imagery was not clear due to sun glint, clouds or turbid water conditions then Landsat imagery was used.

The manual corrections were performed in ArcMap using the polygon editing tools. During this stage a moderate number (~100) of small reef features were added to the dataset manually.

3.5.1 Detection and identification of small submerged shoals

During the checking phase of the dataset development it was found that the semi-automated digitisation missed many small submerged shoals that were in highly turbid waters. These features were not directly visible in the Landsat 5 imagery used for the digitisation due to the shoals depth and the water turbidity. They were known to exist from the Nautical charts and so to ensure these features were included a technique was developed to allow the detection and mapping of these features was developed.

These difficult to detect shoals identified not by direct observations but by their effect on the flow of water and sediment. In turbid water the raised bathymetry of a shoal causes a wake in the flow of water that is clearly visible in some of the Landsat 8 imagery. The size and shape of the wake allowed the shoal position and size to be estimated.

To verify this approach as a viable method for mapping shoals a comparison was performed between shoals that could be mapped directly from an image with a clear enough image to see the shoals directly and how these shoals appeared in a more turbid image where they could not be seen directly (Figure 12). This comparison shows that the shape of the wake of these shoals is directly related to the size and shape of the actual shoal allowing mapping to be performed directly from the shoal wake.

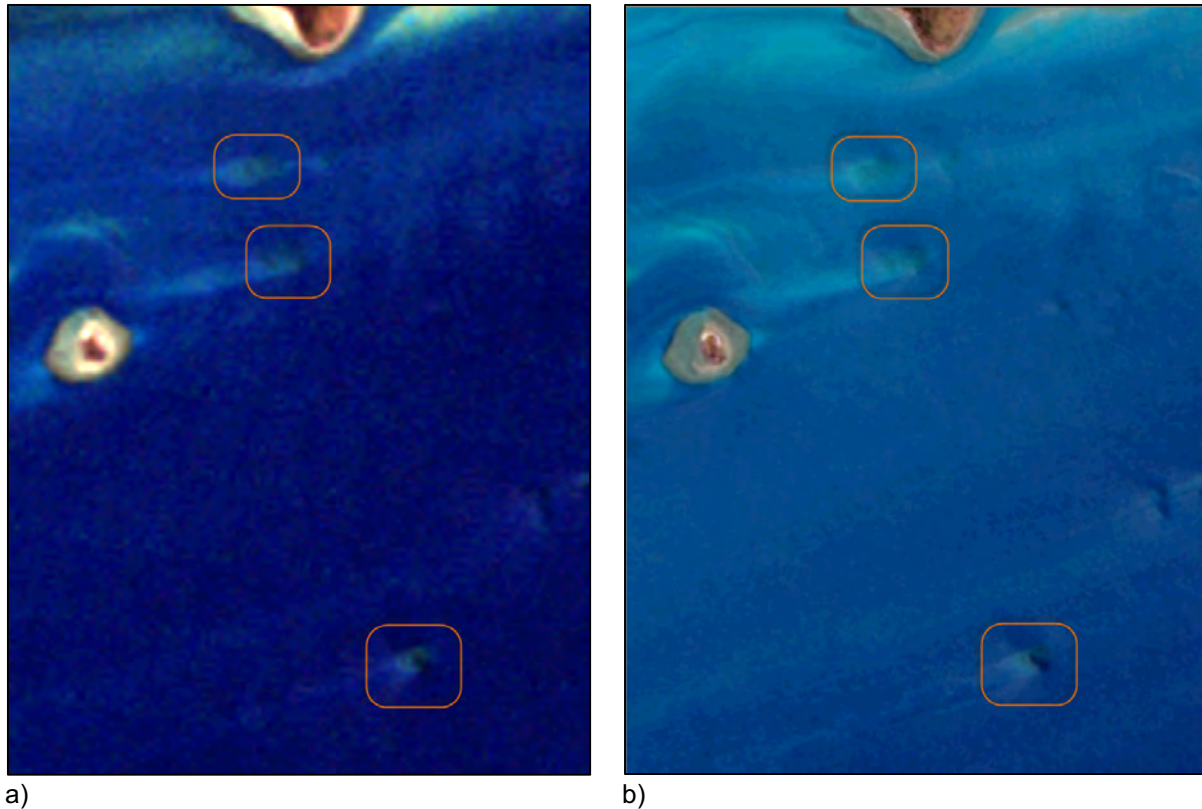


Figure 12: Comparison of three shoals (10-244, 10-243, Eagle rock: 10-246) south of Packe Island as they appear in with direct observation in clear water conditions and they appear as a wake in turbulent water. a) In this image (L5099067_06720040815) the shoals can be directly be seen. The evidence of this is the green tinge where the shoals are. b) In this image these same shoals are barely directly visible, however their effect on the water allows their size and shape to be estimated. The submerged shoals appear as neighbouring dark and light patches.

An example of where this was used was in Endeavour Strait where there were numerous small shoals with depths of 3 - 10 m that make up Peebles Shoals (10-242) and Eagle Rock (10-246). These shoals are deeper than the visible depth from the remote sensing; however their wake could be easily seen in some of the Landsat 8 imagery (LC80990672013220LGN00). Once these features were mapped from their wake they were checked against the shoals in the Nautical Marine Charts and found to be in perfect alignment. This is thus an independent (from the Nautical charts) verification of the positioning of these shoals.

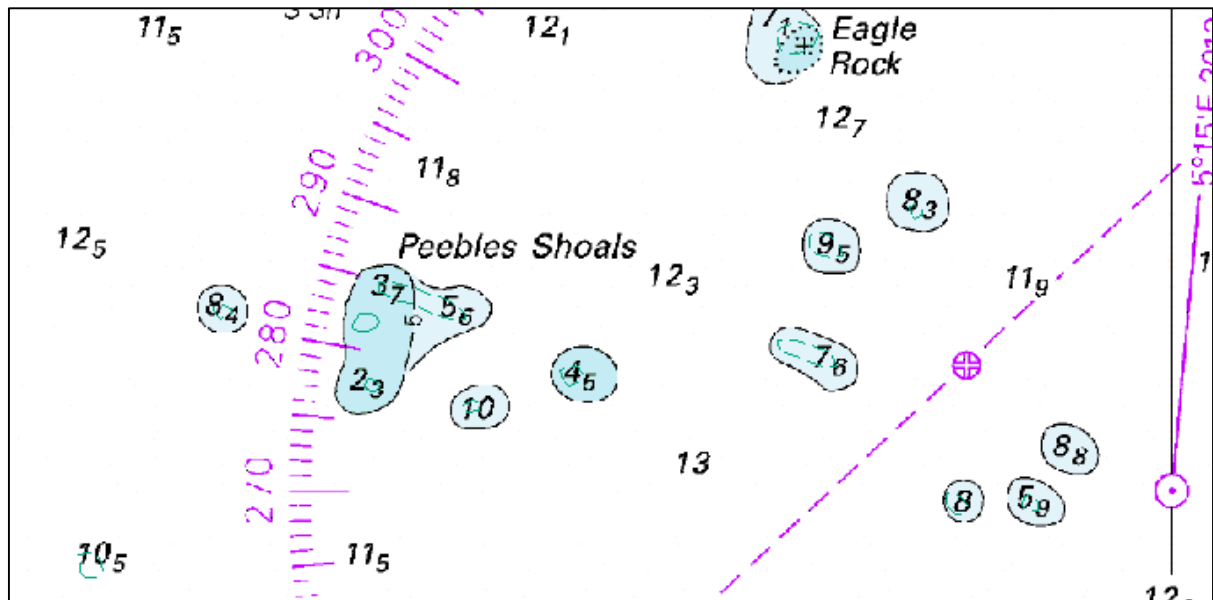


Figure 13: (Top) Submerged shoals in turbid water that are only visible by their effect on the water. These shoals are in the Endeavour Strait south of Prince of Wales Island. The water is always too turbid to directly see these shoals, however their effect on the water flow is distinct. (Bottom) The mapped shoal features (green dashed lines) line up with each of the shoals on the Nautical Marine chart, verifying the validity of using this technique to find these deeper shoals.

3.6 Classification scheme

The classification system for the Torres Strait Reef and Islands dataset was originally based on *GBR Features* dataset (GBRMPA, 2007). The *GBR Features* dataset contains marine features classified as *mainland*, *island*, *reef*, *cay*, *rock* and *sand*. The *sand* classification is only used for one feature out of 5300. The *reef* features in this dataset focus on coral reefs and fringing reefs where coral is likely to occur. The *rock* features correspond to shallow rocky reefs or rocky islands.

To make the *Torres Strait Reef and Island Features* dataset compatible with the *GBR Features* dataset the same classification scheme, where possible, was applied to the mapped features. This classification scheme was however extended to include a few extra categories as the new mapping included terrestrial foreshore, sand bank features and some other marine hazards and features that were not part of the *GBR Features* dataset. For this reason a number of new categories were added to the scheme.

In addition to the *GBR Features* classification a second more detailed classification system was applied based on a simplified version of the classification outlined in (Hopley, 2007). At the top level of this classification the marine and island features are split into five main types of features: *Mainland*, *Islands*, *Reefs*, *Banks* and *Other*. This classification divides the features into those that are above water (*Mainland* and *Islands*), those below water (*Reefs* and *Banks*) and an '*Other*' category, which was only used for river mouths. The river mouths features were a bit of an oddity in the classification scheme as they are probably slightly raised area (above the sea floor), but would not be considered a reef. The below water features were subdivided into those that have a solid foundation (*Reefs*) and those which were an accumulation of mobile sediment (*Banks*).

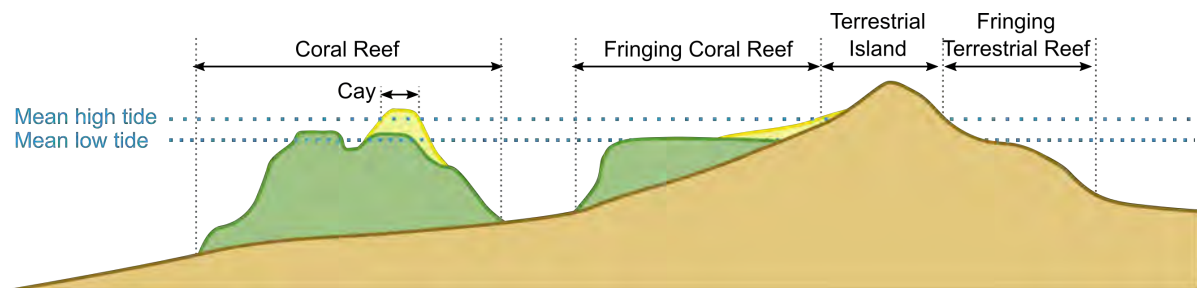


Figure 14: Diagram of the definition of some of the key classifications used in the development of the *Torres Strait Reef and Island Features* dataset.

The *Islands* correspond to features that stay dry at high tide, the *Reefs* and *Banks* correspond to all marine features raised off the sea floor, up to the high water mark. *Reefs* correspond to marine features that have a solid foundation and don't change significantly over a 20 year time frame and banks correspond to raised areas of mobile sediment. These 5 basic structural classifications are further divided into 13 categories based on their broad scale geomorphology.

The aim of the sub-classification system was to distinguish features that were significantly different in structure and habitat, whilst minimising the classification types to those that could be reliably determined from remote sensing.

A detailed description of each classification can be found in Appendix 1: Offset corrections applied to Landsat imagery.

Table 3: Top level classification applied to the mapped features. * These classifications were added as there are no equivalent set of features in the *GBR Features* dataset.

GBR Features FEAT_NAME	Torres Strait Reef and Island Features classification scheme			
	LEVEL_1	LEVEL_2	LEVEL_3	No. Mapped Features
Mainland	Mainland	Mainland	Mainland	7
Island	Island	Terrestrial Island	Terrestrial Island	204
Rock	Island	Terrestrial Island	Rocky Island	114
Island	Island	Reef Island	Low Wooded Island	68
Cay	Island	Reef Island	Unvegetated Cay	25
Island	Island	Reef Island	Vegetated Cay	28
Reef	Reef	Coral Reef	Coral Reef	2205
Terrestrial Reef*	Reef	Terrestrial Reef	Isolated Terrestrial Reef	123
Rock	Reef	Terrestrial Reef	Rocky Reef	60
Terrestrial Reef*	Reef	Terrestrial Reef	Fringing Terrestrial Reef	86
Terrestrial Reef*	Reef	Terrestrial Reef	Fringing Rocky Reef	2
Reef	Reef	Coral Reef	Fringing Coral Reef	147
Reef	Reef	Shoal	Shoal	378
Other*	Reef	Man Made	Pearl Pontoon	8
Other*	Reef	Man Made	Channel Marker	1
Bank*	Bank	Sand Bank	Sand Bank	461
Other*	Other	Other	River Mouth	3

3.7 Feature ID Allocation

Each of the newly mapped features was allocated a permanent ID in a manner similar to that used in the *GBR Features* dataset.

3.7.1 GBR Features ID allocation scheme

When the GBR was mapped each of the reefs and islands were given a short ID (such as 18-054, 19-009a). These could be used in place of a name to unambiguously communicate to others locations of interest. Many reefs don't have names and so the IDs themselves became their de facto names and are routinely used in reporting and research papers.

The *GBR Features* ID allocation scheme has three parts to the ID:

- Integer latitude of the feature (Latitude ID).
- 3 digit counter ID of all the group features within the latitude area (Group ID).
- Letter sub ID (blank, a, b, c, ...) of all the features within the group (Subgroup ID).

For example Great Palm Island has an ID of 18-054 indicating that it is at a latitude of between -18 and -19 degrees and it was the 54th feature allocated to that latitude. It has a blank subgroup ID indicating that it was the first feature in the group. The reefs around the island have allocated letter subgroup IDs of a - f resulting in each of these fringing reefs having IDs such as 18-054a, 18-054b, 18-054c, 18-054d, 18-054e and 18-054f.

For a feature ID of 18-054c the Latitude ID is '18', the Group ID is '054' and the Subgroup ID is 'c'.

This allocation scheme has the following benefits:

- Short IDs, suitable for communication on maps and research papers.
- The ID provides some indication of the feature's place (at least latitude). Features close to each other are typically allocated close Group IDs.
- Related features are given the same Group ID.

This semi hierarchical allocation scheme helps to ensure that related features are allocated similar IDs making it easier to understand the relationships between the features, far better than if all the features were allocated sequential numbers.



Figure 15: Extract map of the *GBR Features* west of Whitsunday Island. Whitsunday Island and its fringing reefs all have the same Latitude and Group ID of 20-041. Individual features then have subgroup IDs (a, b, c ...) resulting in final IDs such as 20-041a. In this example Whitsunday Island is allocated a subgroup ID letter of 'a'. Most islands in the *GBR Features* dataset have a blank subgroup ID, such as North Molle Island (20-033).

The pattern of allocating related features to the same group ID and ordering the subgroup ID based on the feature type (islands, then reefs, etc.) is not always consistently applied in the *GBR Features* dataset, and is probably a result of manual allocation of IDs and historical adjustments. For the *Torres Strait Reef and Island Features* dataset the group and subgroup IDs were consistently applied to the features using an automated set of scripts (Appendix 8: Algorithms for allocation of Group IDs and Subgroup IDs).

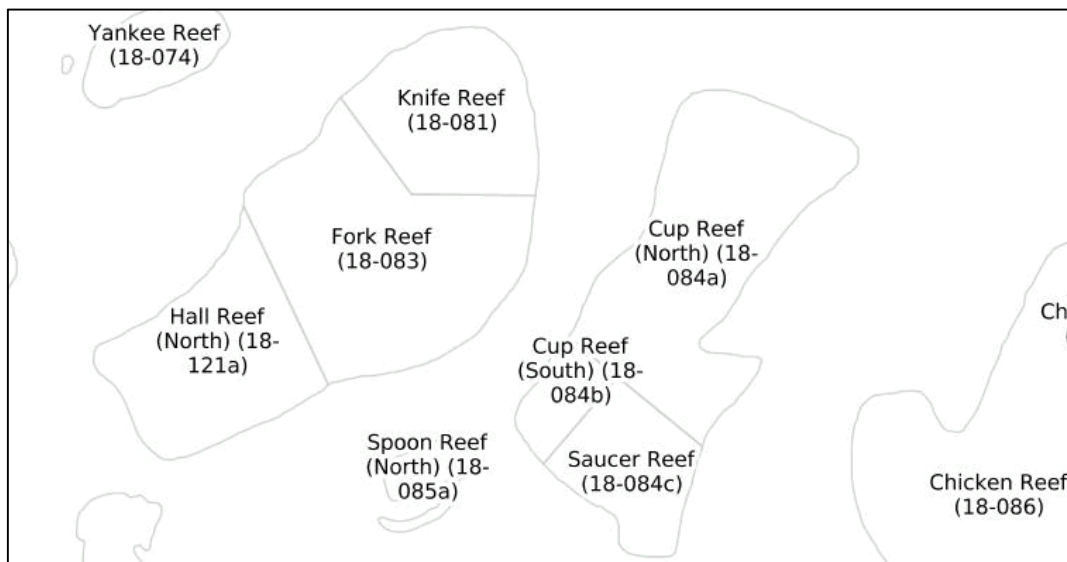


Figure 16: Extract of the *GBR Features* dataset. In general features that are part of one connected system (such as Cup Reef and Saucer Reef) are given the same Group ID (084), however this approach is not always consistently applied as can be seen with the IDs of the cluster made up from Knife Reef (18-081), Fork Reef (18-083) and Hall Reef (North) (18-121a).

3.7.2 Torres Strait Features ID allocation scheme

The application of the *GBR Features* ID allocation scheme presented a number of problems in the Torres Strait mapping including:

- Torres Strait has many small shoals, reefs and sand banks resulting in a higher density of features than seen in the rest of the GBR with approximately 1500 features per degree of latitude. Allocating one Group ID to each coral reef or shoal would exceed the 3 digits for the Group ID.
- Some of the southern Torres Strait was mapped as part of the *GBR Features* dataset, resulting in an overlap of features between the two datasets. Each of these features had already been assigned an ID. Unfortunately in the *GBR Features* dataset all features outside the Great Barrier Reef Marine Park were assigned a Latitude ID of 99 rather than their latitude as expected. As a result Thursday Island has a *GBR Features* Group ID of 99-479 rather than the expected 10-479. The use of 99 instead of the latitude breaks with the consistency of the ID scheme and so the 99 was replaced to the latitude in the Torres Strait mapping. One complication with this approach was that some these adjusted Group IDs clashed with existing allocations in the *GBR Features* dataset. When this occurred a new Group ID was allocated to the feature. This occurred for Hawkesbury Island, Twin Islands, Marina Rock, Watson Cay and Hovell Shoal.
- The *GBR Features* dataset was updated in 2012 by Rob Beaman to improve the mapping precision and add newly detected reefs. These new features were however not assigned IDs as the time of this project and as a result there were 41 new features in the -10 degrees of latitude to be allocated sometime in the future and they cannot clash with the Torres Strait mapping.
- Torres Strait has more degrees of longitude than latitude and so the Latitude ID is not a good spatial differentiator of features.

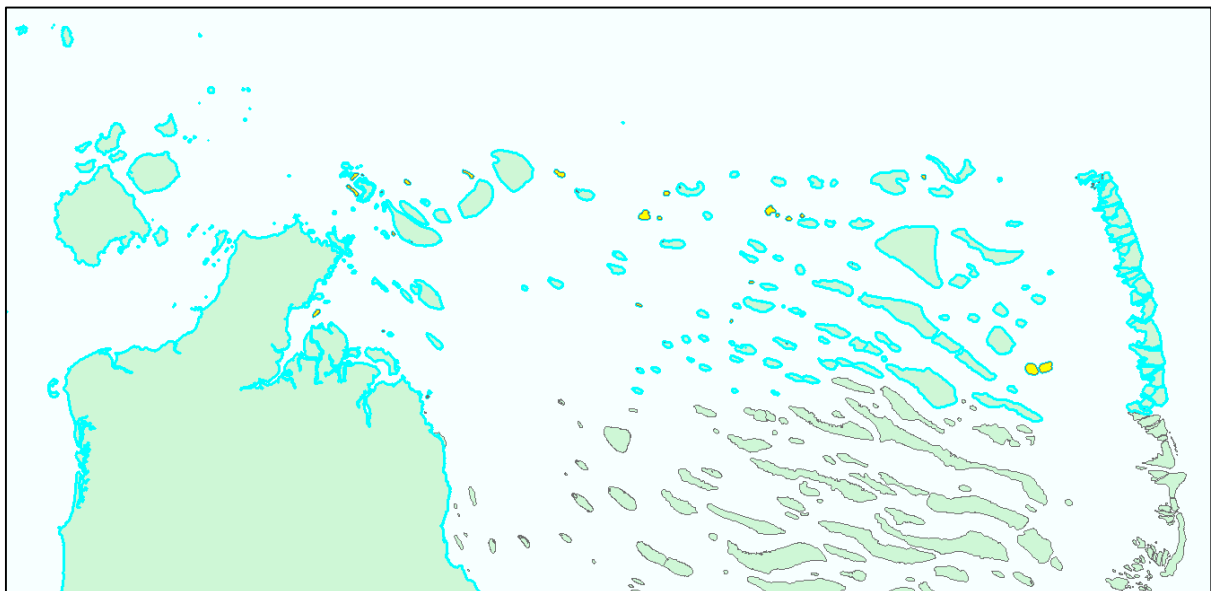


Figure 17: Map of the NEW *GBR Features* (Rob Beaman 2012) with features from -10 degrees latitude highlighted in cyan. All these features will already have Group IDs allocated that must be copied from the *GBR Features* dataset. The features in yellow correspond to new features in the *GBR Features* dataset that will need IDs allocated by GBRMPA in the future. We must leave space for these features in the allocation of the -10 degrees latitude Group ID scheme. For this purpose a chunk of 10-000 - 10-050 were set aside for this purpose.

3.7.3 Group ID allocation algorithm

To apply the Group ID allocation scheme to the Torres Strait mapping the following conventions were followed:

- Sand banks created as a result of the presence of a reef or island were typically included as part of the reef or island's group.
- Typically all islands or rocky features on top of a reef base were grouped together. The exception to this was if the reef base included two or more large islands (at least 500 m across).
- Satellite features (small reefs typically less than 200 m across) close to a larger reef (up to 500 - 1000 m) were grouped with the larger reef.
- In areas where there were clusters of sparse small reefs they were grouped based on proximity. The patch reefs were clustered into groups approximately 2 - 4 km in diameter.
- Neighbouring separated reefs that would potentially be grouped together based on proximity would not be clustered if they had islands on them or if they had their own names.
- The Group IDs of the features in Torres Strait that already had IDs from the *GBR Features* datasets were reused. The Latitude ID of 99 was replaced with the latitude of the centroid of the feature. An example is Thursday Island which was given the ID 10-479 based on the *GBR Features* ID of 99-479. Where clashes occurred with existing IDs these features were given new IDs.
- Where a group of shoals or reefs was known by a name then this was used to determine the clustering. The names on the AHO marine charts and the CSIRO Torres Strait Atlas traditional names were used to determine this clustering.
- If one physical or logical cluster of reef features was known by different names on different parts of the reef, then the reef was split to represent these different regions.
- Each degree of latitude was broken into approximately 30 regions each with 10 - 150 features, see Figure 20. Features were assigned their Region ID using a spatial join with the Region allocation map. Features were then sorted by their Latitude ID and Region ID prior to allocation of Group IDs. This ensured that features physically close together (within one region) would be given similar Group IDs. This process was somewhat interrupted in places by the existing *GBR Features* Group IDs.

Each group was created, where possible, to capture features that were connected or related to each other in some way. The heavy use of clustering was important to reduce the number of groups in each latitudinal band to less than the maximum of 999 allowed by the *GBR Features* ID scheme.

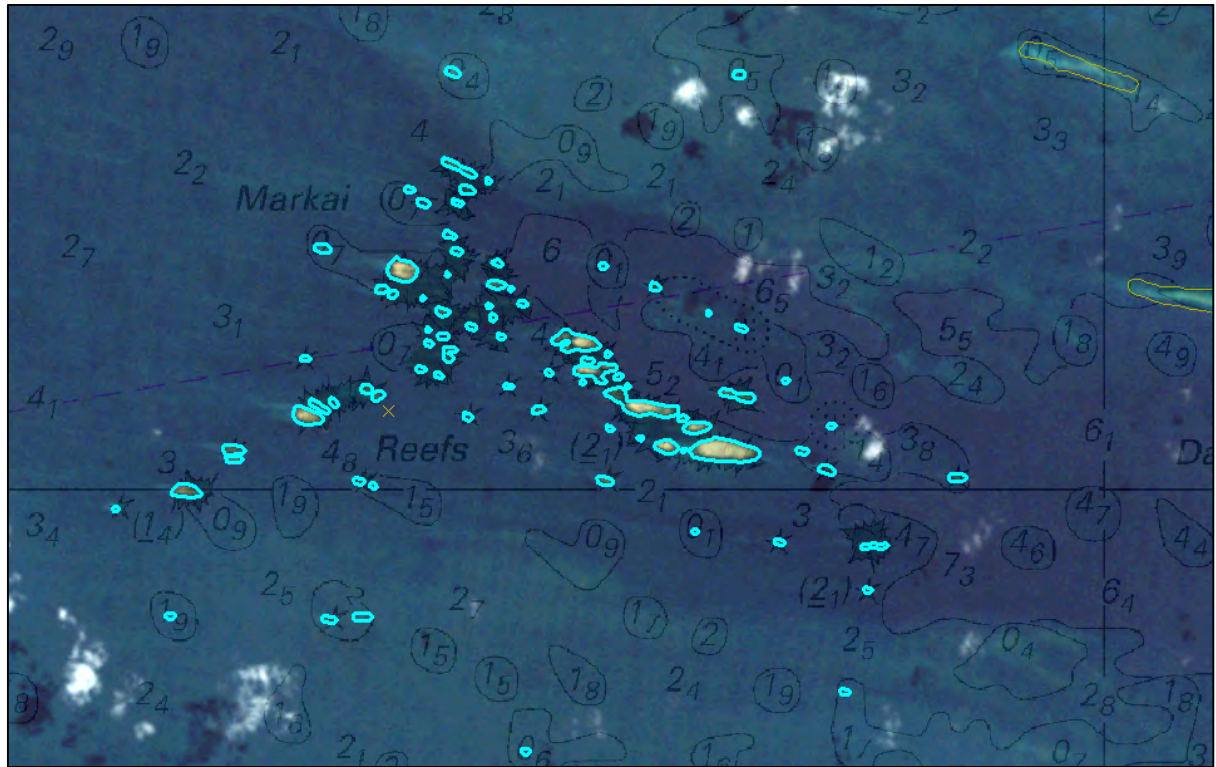


Figure 18: Markai Reefs in the northern central region of Torres Strait approximately 20 km north of Mabuiag Island is a clustering of many small reefs. This region is known by a single name (Markai Reefs) and so all these shoal features were grouped together to have a single Group ID (240). (Image: Landsat 5 with transparent AHO A0000841 marine chart).

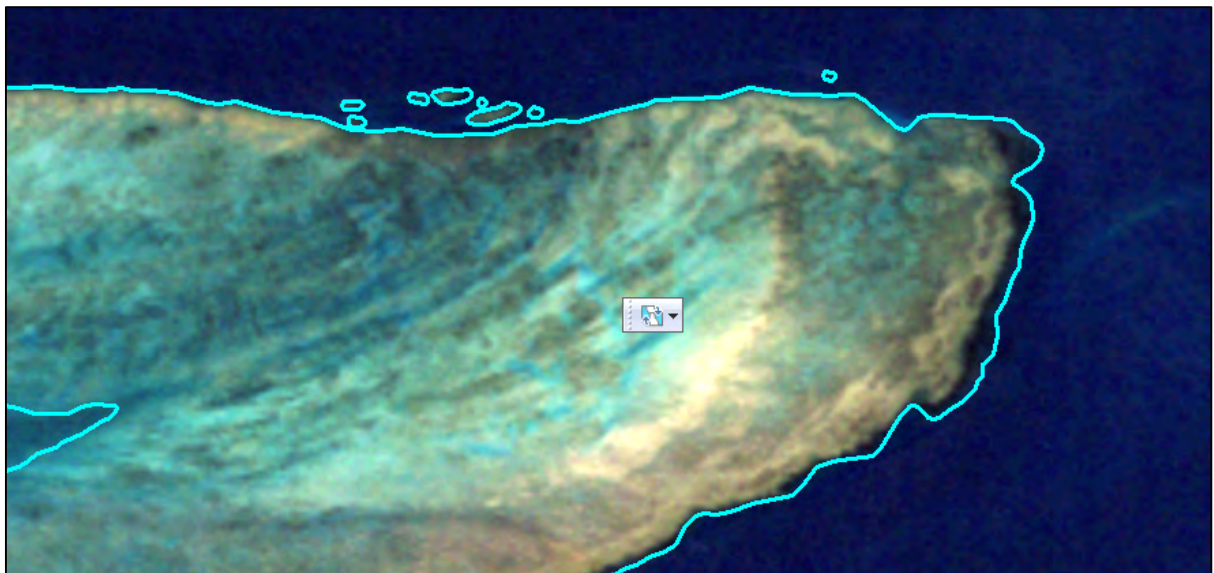


Figure 19: Long Reef in central Torres Strait, an example of clustering small patch reefs neighbouring a larger main reef. These patch reefs were clustered to have the same Group ID (204) as with Long Reef (Image: Landsat 5)

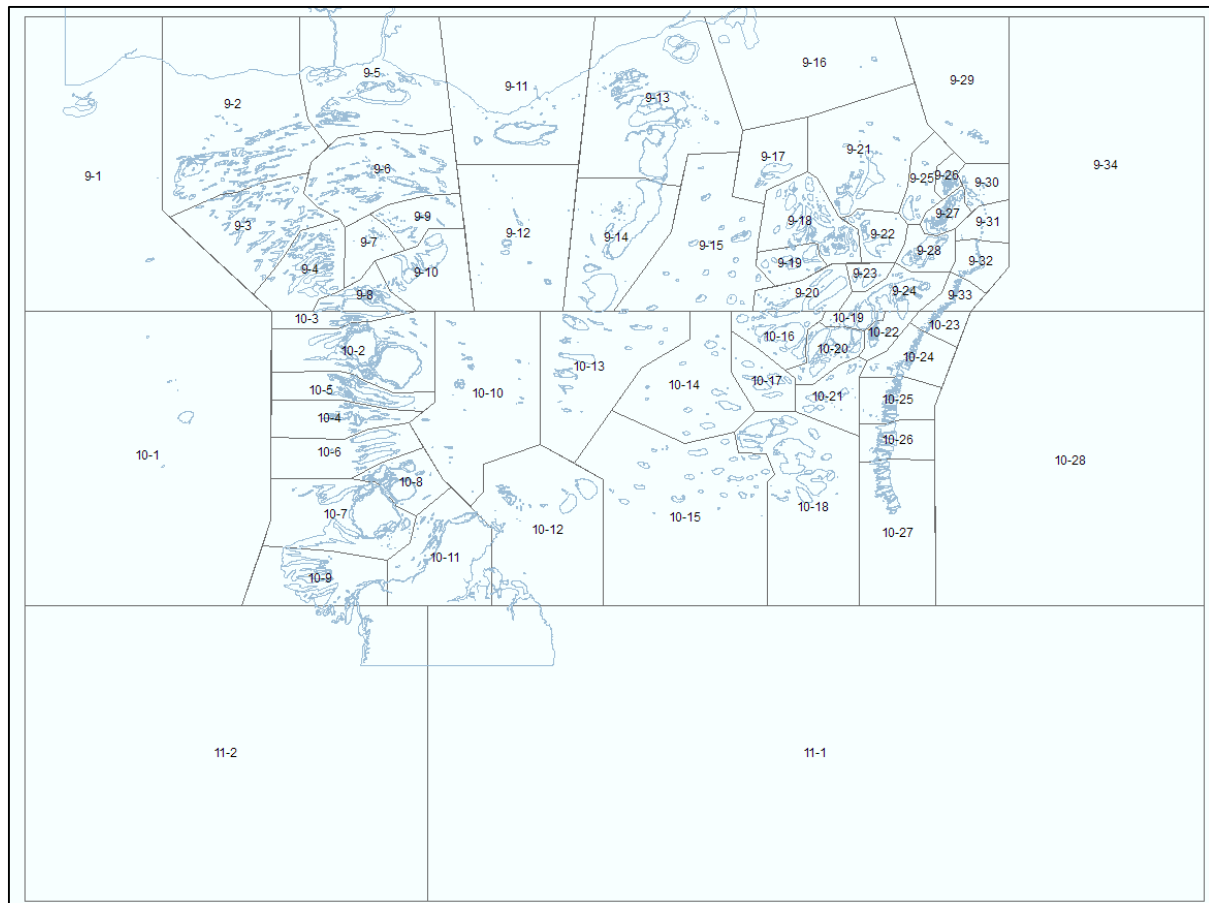


Figure 20: Latitude ID and Region ID map. All features within each region were assigned the same Latitude and Region ID. These were used to sort the features to help ensure that features close to each other were assigned numerically similar Group IDs. The labels on each region in this map correspond to the Latitude ID and the Region ID. This map was created manually with regional clusters created around similar features. Care was taken to not cut through any features when this regional map was created.

The Torres Strait Island and Reefs features were prepared prior to Group ID allocation in the following way:

1. A spatial layer representing all the Group ID allocations was created manually by merging mapped islands and reef features into groups based on the approach outlined above.
2. The Latitude ID and Region ID attributes were added using a spatial join with the prepared region map shown in Figure 20.
3. The existing Group IDs that were already assigned by the *GBR Features* dataset were added using a spatial join. The SORT_GBR_I attributes from the *GBR Features* dataset was used for this purpose.
4. The X_COORDS (longitude) attributes of the groups was updated using the Geometry Calculator. This is used to sort and order the allocation of IDs within each Region.
5. The attribute table from the Group ID shapefile from exported to CSV for processing.
6. The Group IDs were then allocated using the script outlined in Appendix 8: Algorithms for allocation of Group IDs and Subgroup IDs.

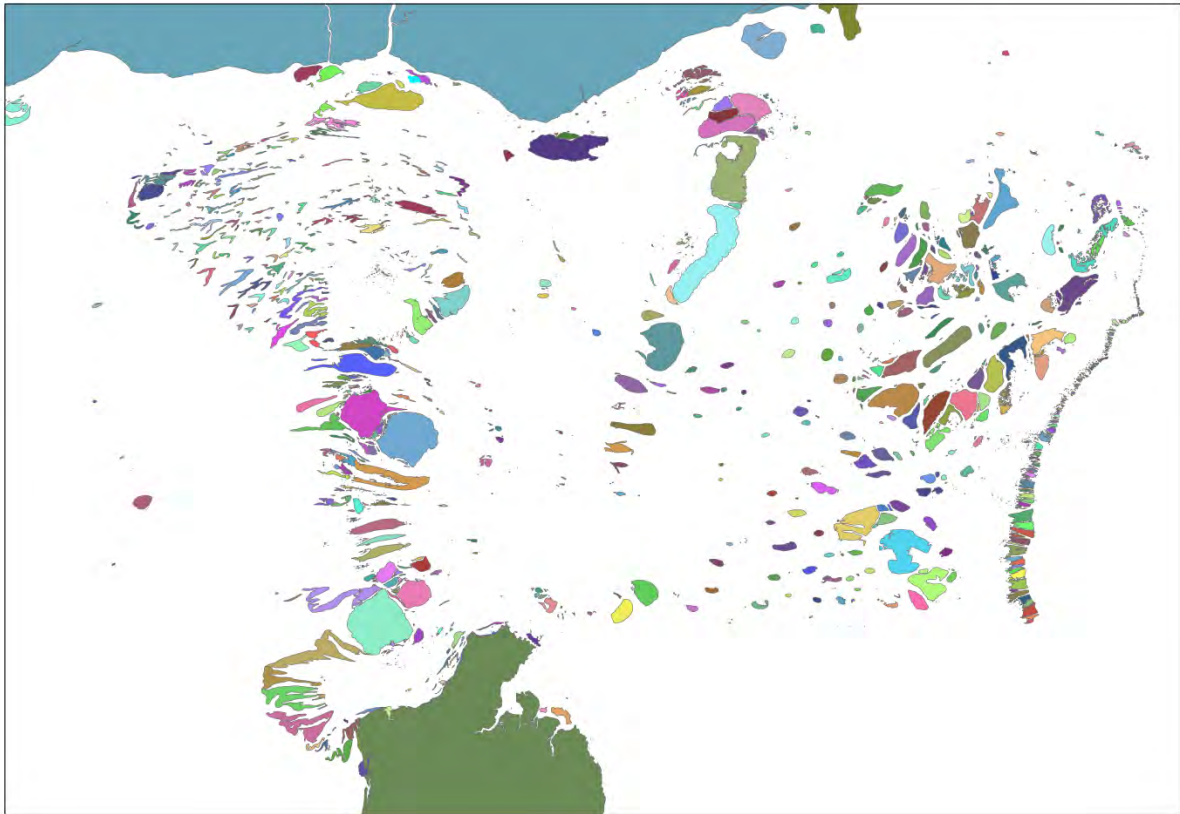


Figure 21: Map of Torres Strait showing the allocation of Group ID to areas. Each Group ID area is shown with a different colour. All features (reefs, islands, sand banks) within each of these Group ID areas are allocated the same Group ID. They are then subsequently uniquely identified with an allocation of a subgroup ID.

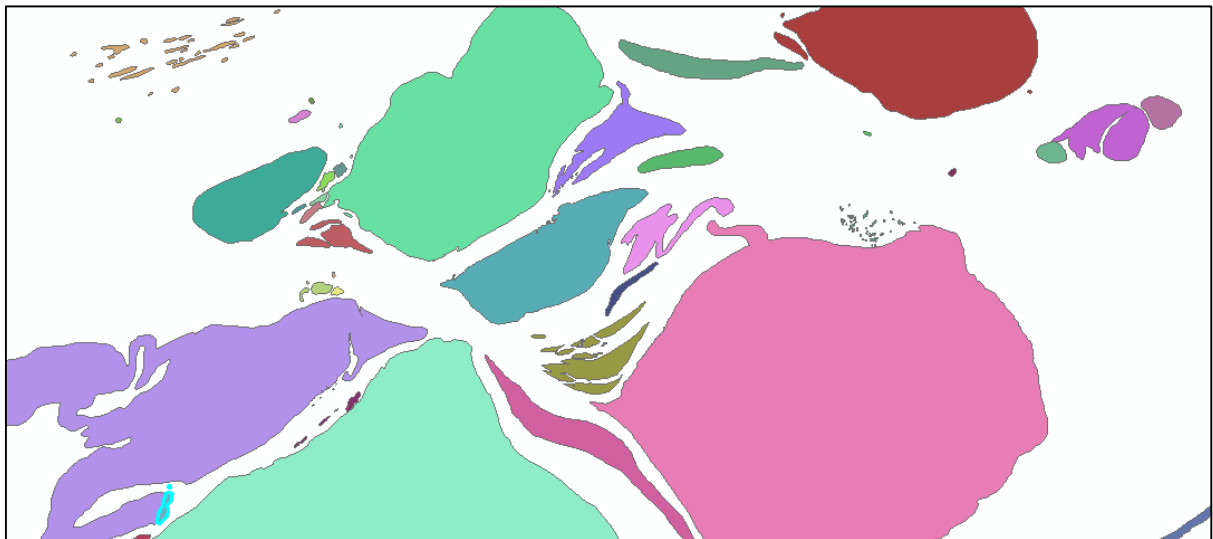


Figure 22: Close up of the clustering of features for Group ID allocation centred around Thursday Island. To create this layer all features within each cluster were dissolved together.

3.7.4 Allocation of Subgroup IDs

Once all Group IDs were allocated they were applied to each of the features overlapping the group using a spatial join they were then allocated subgroup IDs based on their classification type (islands and reefs getting preference to the first allocation of subgroup IDs) and area. The algorithm used for this allocation is outlined in A8.2 Subgroup ID allocation.

The Latitude ID, Group ID and subgroup ID all combined to create a unique permanent ID for each of the mapped features in the dataset.

4.0 DISCUSSION

This project mapped over 3900 marine and island features in Torres Strait covering a 77,000 km² area (Figure 23). A breakdown of the mapped features is shown in Table 4. This compares with 5,600 features in 350,000 km² for the *GBR Features* dataset, excluding the features that were originally in Torres Strait, and the Queensland mainland. The *Torres Strait Reef and Island Features* dataset therefore has a three times feature spatial density then the *GBR Features* dataset. This difference is partly a result of the higher resolution mapping applied to Torres Strait and to the large number of small coral reef features (< 1 km²) in the region.

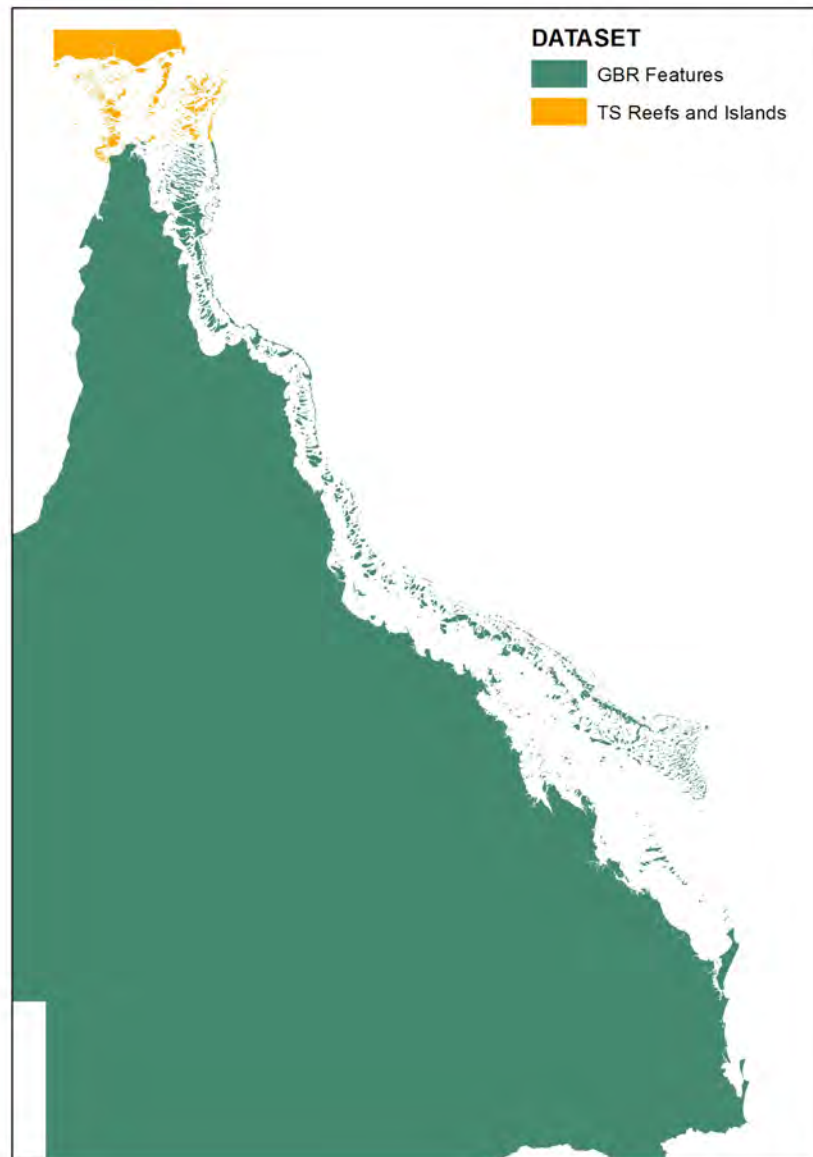


Figure 23: Extent of the features of the new dataset developed in this project (*Torres Strait Reef and Island Features*) (77,000 km²) and the existing *GBR Features* (350,000 km² excluding the Queensland mainland). In this map the overlap between the *GBR Features* and the Torres Strait mapping was removed. The result is a single dataset that covers the entire Great Barrier Reef (GBR).

Nearly 400 features were classified as shoals. Some of these features may be coral reefs but there was insufficient evidence or information to classify them as such. The shoal classification was used as a general classification for any submerged feature that could not be accurately classified. It is expected that with further field work and improved imagery that many of these features would be reclassified.

Table 4: Summary of the classification of the *Torres Strait Reef and Island Features* (version 1.0) dataset based on the Level_3 classification scheme. Note this also includes some reef features that are part of Papua-New Guinea's territory such as the north parts of Warrior Reef.

Level_3 Feature Type	Features < 1km ² (Area km ²)	Number of features > 1km ² (Area km ²)
Coral Reef	1921 (156)	284 (3509)
Fringing Coral Reef	99 (25)	48 (326)
Fringing Rocky Reef	2 (1)	0 (0)
Fringing Terrestrial Reef	51 (12)	38 (228)
Isolated Terrestrial Reef	106 (14)	17 (110)
Low wooded Island	52 (3.6)	16 (360)
Sand Bank	295 (103)	168 (1046)
Pearl Pontoon	8 (0.002)	0 (0)
River Mouth	1 (0.8)	2 (16.6)
Rocky Island	114 (0.4)	0 (0)
Rocky Reef	60 (0.5)	0 (0)
Shoal	377 (13.2)	1 (2.8)
Terrestrial Island	182 (19.1)	24 (650)
Unvegetated Cay	25 (0.6)	0 (0)
Vegetated Cay	27 (6.8)	1 (1.6)

Table 5: Comparison between the *GBR Features* dataset, excluding the overlaps in Torres Strait, and the new *Torres Strait Reef and Island Features* dataset.

FEAT_NAME	GBR Features < 1km ² (Area km ²)	GBR Features > 1km ² (Area km ²)	TS Features < 1km ² (Area km ²)	TS Features > 1km ² (Area km ²)
Banks	0	0	295 (103)	168 (1046.3)
Cay	252 (15.1)	2 (8.2)	25 (0.6)	0 (0)
Island	786 (102.8)	122 (5,494.1)	303 (27.0)	41 (1011.3)
Mainland	439 (57.3)	33 (1,699,786)	5 (0.07)	2 (14599.6)
Other	0	0	10 (0.8)	2 (16.6)
Reef	1903 (615.5)	1792 (23,812.8)	2395 (192.9)	214 (3836.7)
Rock	354 (12.6)	1 (4.4)	126 (0.54)	0 (0)
Sand	1 (0.05)	0 (0)	0	0
Terrestrial Reef	0	0	160 (29.0)	56 (338.7)

4.1 Number of reefs in Torres Strait

It is often quoted that there are 2900 - 3000 reefs in the Great Barrier Reef Marine Park (Great Barrier Reef Marine Park Authority, 2013, 2016). The *GBR Features* dataset has over 3600 reef features which is significantly higher than this typical quoted number. To get

3000 reefs we must exclude reefs smaller than 0.151 km². These largest 3000 reefs have a total area of 24,376 km².

Applying the same minimum reef size to Torres Strait there are 647 (3450 km²) reefs in Torres Strait Australian waters and 37 (522 km²) reefs in the Torres Strait Papua-New Guinea waters.

If we ignore reefs smaller than 0.151 km² then there are approximately 3680 reefs (28,348 km²) in the whole GBR of which 18% by number and 14% (by area) are in Torres Strait.

4.2 Macro-scale characteristics of the Torres Strait marine environment

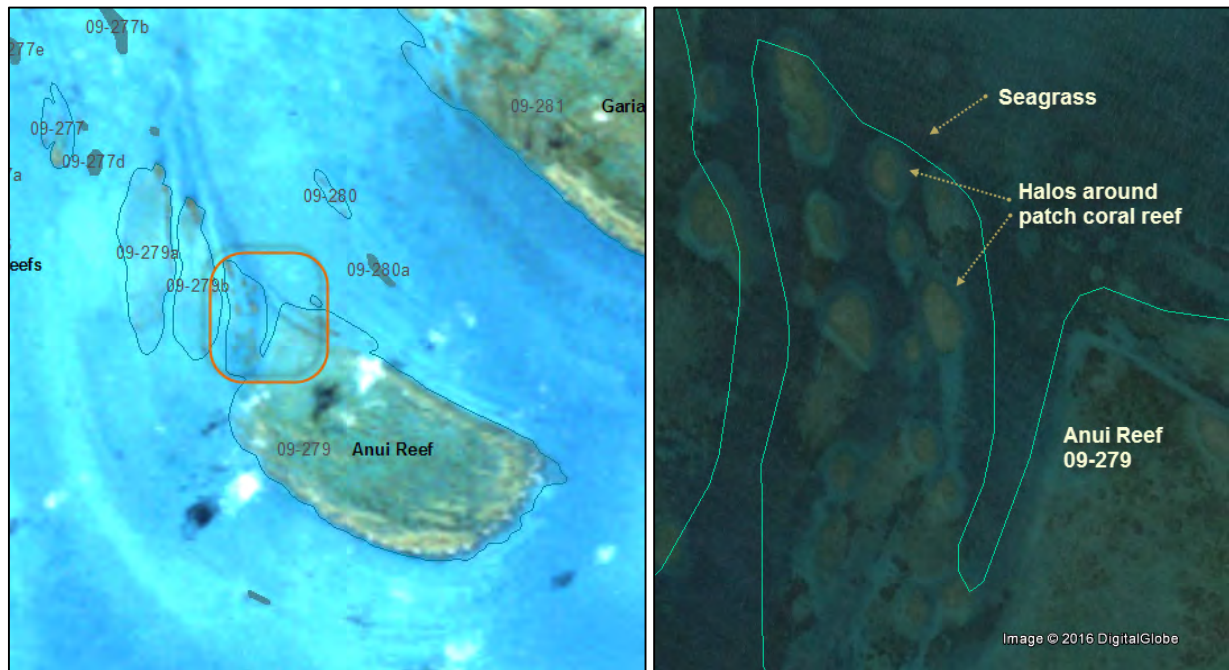
The mapping and classification of the marine features were particularly challenging due to the diverse range of marine habitats created by the shallow and turbid water of much of Torres Strait. From the tip of Cape York up to Papua-New Guinea there is a chain of islands surrounded by shallow water (10 - 15 m around the Southern and Western islands and 1 - 5 m north of the Western islands). This forms almost a land bridge (see Figure 24) that is subjected to strong tidal currents formed by the flow of water from the eastern Coral Sea across into the western Arafura Sea. This tidal shear stress makes the water highly turbid due to continual resuspension. In addition to this the Fly River (north of the Eastern Torres Strait islands) discharges large quantities of fine sediment, some of which flows west along the PNG coastline passing over the Northern Islands and then south west to the Western Islands. This fine sediment settles on the reefs in the area giving them a brown inshore terrestrial reef look.



Figure 24: This map shows the island regions in Torres Strait, the approximate visibility of the water and the shallow chain of islands that almost forms a land bridge between Australia and Papua-New Guinea. The visibility regions are very approximate and are for illustrative purposes. They were estimated from point checks of whether features of a known depth (from marine charts) were visible in typical Landsat imagery.

4.3 Coral reefs in turbid waters

During the early phase of the reef classification stage of the dataset development it was assumed that most of the reef features within the high turbid environments around the Southern, Western and Northern Islands would be terrestrial in origin rather than coral reefs. However after reviewing high resolution Google Earth satellite imagery there was good evidence of coral reef construction in many of these areas. It can only be assumed that these reefs are likely to be similar to inshore reefs along the Queensland coastline; having a significantly different coral community structure than clear water coral reefs found in the eastern side of Torres Strait.



a)

b)

Figure 25: Anui Reef is just north of the Western Islands in a very shallow (1 - 2 m depth LAT) and a very turbid environment. a) A fairly typical Landsat 5 image (L5099067_06720060821) of Anui Reef taken at low tide. The water is a highly turbid turquoise colour and the bottom cannot be seen despite the shallow depth. b) Close up of the back of Anui Reef (09-279) from Google Earth. This shows patch reefs surrounded by seagrass. Each patch reef appears to have a grazing halo (Odgen 1973, Sweatman 1994) providing a strong indication that they are coral reefs with herbivorous fish that eat the surrounding seagrass.

This dataset does not differentiate between clear water coral reefs (similar to outer reefs on the GBR) and those in turbid water (similar to inshore reefs on the GBR), even though they would be significantly different habitats.

5.0 RECOMMENDATIONS AND CONCLUSION

The new *Torres Strait Reef and Island Features* dataset represents the most detailed mapping of the region done to date with a dataset scale of 1:50,000. Over 3900 features were mapped at a spatial density three times that of the *GBR Features* mapping which has 5900 features for the rest of the Great Barrier Reef Marine Park.

The mapping performed in this project was based on a novel semi-automated and manual digitisation of aerial imagery and Landsat imagery that was developed to work with the highly turbid water found in most of Torres Strait. The classification of these features was also performed using remote sensing (including high resolution imagery available in Google Earth). No in-situ validation was performed on this classification or mapping process as part of this project.

All mapped features were given permanent IDs (such as 10-320) in a similar manner to that used in the *GBR Features*, and a preliminary set of names were copied from existing maps.

The *Torres Strait Reef and Island Features* dataset was integrated with the existing *GBR Features* dataset to create a dataset that now finally maps the entire GBR. This is now a resource that can be used by environmental managers for resource planning, by researchers for communications, mapping and modelling work and by the community to better understand their marine environment.

It is intended that this dataset is a foundation of mapping that will be improved overtime as new imagery and information about each of the features becomes available.

Further work should be done on establishing some in-situ validation of the feature classifications, particularly in areas where the currently classification confidence is low. Also more work should be done to confirm and expand on the names allocated to features and to develop printed poster maps that can be distributed to the community.

This dataset is available openly under a creative commons license from the eAtlas at <http://eatlas.org.au/data/uuid/d2396b2c-68d4-4f4b-aab0-52f7bc4a81f5>.

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APPENDIX 1: OFFSET CORRECTIONS APPLIED TO LANDSAT IMAGERY

A positional shift correction was applied to the Landsat imagery used for checking and digitising the features in the *Torres Strait Reef and Island Features* dataset. The Landsat imagery was corrected to align accurately with the Australian Geographic Reference Image (AGRI) (Geoscience Australia, 2011) for the region which has a 90% circular error of 2.6 - 5 m in central Torres Strait and 5.1 - 7.5 m in Eastern Torres Strait. After the shift adjustment the residual error was estimated by reviewing, where possible, the alignment errors across the full scene. The residual error for most images was reduced to less than 12 m. When this error is combined with the error of the AGRI image then the total error for the Landsat imagery is likely to be better than 16 m.

To calculate the positional correction to apply to each scene (and image) the highest resolution band available (15 m B8 for Landsat 8 and 30m B10 for Landsat 5) was compared with the AGRI PRISM (GA) imagery.

The shifting process was done as follows. In ArcMap:

1. The Landsat image was overlaid on the AGRI PRISM reference layer. The map was then zoomed to an island feature visible in both images.
2. The flicker feature on the Effects toolbar was used to alternate the between the two images (every 2 seconds) allowing any misalignment to be easily seen.
3. The ruler tool was used to estimate the X offset and Y offset needed bring the Landsat imagery in alignment. This process was then repeated at a number of locations and the resulting estimates were averaged.
4. The Data Management / Shift tool was then used to apply the estimated offset correction to the Landsat image.
5. The shifted Landsat image was then compared with the reference layer to check for any residual error in position and to use this to estimate a better offset correction. The residual error was checked on multiple islands (typically 3) at the top and bottom of the image. This process was repeated (going back to step 4 with the new estimated offset correction) until no improvement could be made. This process was repeated 2 - 6 times depending on the scene.

The above technique was found to be able to reliably detect offset positional errors larger than 1/3 of a pixel. For Landsat 8 B8 images this corresponded to 5 m. For Landsat 5 images this corresponded to 10 m.

The Landsat images were found to have a slight warping that prevented perfect alignment across the whole scene when using only a positional offset correction. The remaining residual error varied from scene to scene. Since the AGRI PRISM (GA) reference imagery has an error of approximately 5 m we can expect that the final positional accuracy of the Landsat imagery to be approximately 10 - 20 m, which is approximately half the error when compared with no correction.

Table 6: Landsat 8 images used for island mapping and the applied positional correction.

Image	Landsat Scene	X offset (m)	Y offset (m)	Approx. X Residual	Approx. Y Residual
LC80980672014200LGN00_B8.TIF	98, 67	18	12	< 5 m	< 5 m
LC80980672014088LGN00_B8.TIF	98, 67	18	12	< 5 m	< 5 m
LC80980672013229LGN00_B8.TIF	98, 67	18	12	< 5 m	< 5 m
LC80980672014280LGN00_B8.TIF	98, 67	18	12	< 5 m	< 5 m
LC80980672014360LGN00_B8.TIF	98, 67	18	12	< 5 m	< 5 m
LC80980672015187LGN00_B8.TIF	98, 67	18	12	< 5 m	< 5 m
LC80980672015171LGN00_B8.TIF	98, 67	18	12	< 5 m	< 5 m
LC80990672013220LGN00_B8.TIF	99, 67	25	13	10 m	5 m
LC80990672013236LGN00_B8.TIF	99, 67	25	13	10 m	5 m
LC80990672013364LGN00_B8.TIF	99, 67	25	13	10 m	5 m
LC80990672014191LGN00_B8.TIF	99, 67	25	13	12 m	8 m
LC80990672014351LGN00_B8.TIF	99, 67	25	13	10 m	5 m
LC80990672015018LGN00_B8.TIF	99, 67	25	13	10 m	5 m
LC80990672015130LGN00_B8.TIF	99, 67	25	13	10 m	5 m
LC80990672015178LGN00_B8.TIF	99, 67	25	13	10 m	5 m
LC80990672015226LGN00_B8.TIF	99, 67	25	13	10 m	5 m

Table 7: Landsat images used for marine mapping and the applied positional correction.

Image	Landsat Scene	X offset (m)	Y offset (m)	Approx. X Residual	Approx. Y Residual
L5098067_06719881031.tif	98, 67	25	10	10 - 15 m	< 8 m
L5098067_06720040621.tif	98, 67	30	25	< 8 m	< 8 m
L5098067_06720040808.tif	98, 67	30	20	< 8 m	< 8 m
L5098067_06720100129.tif	98, 67	20	15	10 - 15 m	< 8 m
L5098067_06720110217.tif	98, 67	30	10	< 8 m	< 8 m
L5098067_06720110321.tif	98, 67	30	10	10 - 15 m	< 8 m
L5099067_06719870716.tif	99, 67	35	20	15 m	< 8 m
L5099067_06719930801.tif	99, 67	30	20	10 m	< 8 m
L5099067_06720040815.tif	99, 67	35	20	10 m	< 8 m
L5099067_06720060821.tif	99, 67	30	20	< 8 m	< 8 m
L5099067_06720090712.tif	99, 67	35	20	10 m	< 8 m
L5099067_06720090728.tif	99, 67	35	20	10 m	< 8 m
L5099067_06720100715.tif	99, 67	35	20	10 m	< 8 m
LT50990671997144DKI00.tif	99, 67	35	20	10 m	< 8 m
LC80990672013220LGN00	99, 67	24	10	< 8 m	< 8 m
L71098067_06720021201	98, 67	20	10	10 m	10 m
L5098066_06620040301.tif*	98, 66	50	25	20 m	20 m
L5098066_06619881031.tif*	98, 66	25	45	20 m	20 m
L5099066_06619930801*	99, 66	45	25	25 m	25 m

*These images did not overlap with the AGRI reference image and so they were corrected against the neighbouring Landsat imagery (L71098067_06720021201) that had been corrected against the AGRI image.

APPENDIX 2: ALGORITHM FOR DIGITISATION OF REEF FEATURES

In deep clear water most of the incident light is absorbed. A small amount of light is reflected due to light scattering (particularly in the blue part of the spectrum) resulting in the water appearing as a dark blue colour. The depth that the light penetrates the water varies across the spectrum with blue penetrating far more than red light. Table 8 shows the penetration depth of each of the image channels measured in Landsat 5 satellite images.

Table 8: Spectral bandwidth, water penetration and use of each of the Landsat 5 image channels.

L5 Channel	Colour	Wavelength ¹	Approx. Clear water penetration (m)	Comment and use
B10	Blue	0.45-0.52	15 - 25 m	Effected heavily by low turbidity. Not good for estimating shallow depths as the brightness is dominated by substrate reflectance.
B20	Green	0.52-0.60	10-15 m	Midway between blue and red in depth sensitivity. In some turbid conditions the features are easier to see in green then blue or red.
B30	Red	0.63-0.69	4-6 m	In clear water this channel matches the GBR dry reefs mapping. On land areas shadows in hilly regions can appear very dark. Needs to be combined with B40 and B50 to be confident of land areas.
B40	Near Infrared	0.76-0.90	0.6 m	Useful for identifying features very close to the surface of the water.
B50	Infrared	1.55-1.75	<0.1 m	Land areas appear bright even in shadowed areas of B30.
B60	Thermal	10.40-12.50	0	High level clouds appear dark as they are much colder than the sea or land. This allows this channel to be used to create cloud masks. It is best for detecting high level cirrus clouds. Low level clouds are quite often not that easy to separate from the land and ocean features.
B70	Infrared	2.08-2.35		Useful for detecting clouds.

If there is sea floor feature (such as a reef or sand bank) shallower than the penetration depth of the light then this feature will reflect some additional light, increasing the observed brightness. This increase in the brightness due to the raised features compared to the surrounding sea water brightness is the basis for the semi-automated digitisation algorithm used to map reef boundaries.

¹ http://landsat.usgs.gov/band_designations_landsat_satellites.php

In turbid water conditions the level of light scattering is greatly increased resulting in significant reflection from the particles in the water column. These particles also decrease the amount of light that reaches the bottom. Both these effects make mapping features in turbid water difficult. In extreme cases the turbid water is so bright that shallow reef features (which only have a minimal amount of turbid water over the top of them) appear darker than the surrounding environment. This flips the relationship where the water is brighter than the visible reef features. For this reason images with high turbidity were not be used for the semi-automated digitisation. They were however still useful for manual checking.

The following algorithm was developed as part of this project to digitise the reef boundaries:

1. Selection of clear images

The Landsat archive was reviewed to find the clearest images of each scene. These needed to have a very low cloud cover, low water turbidity and be at low tide. The best two images from each scene were used to digitise the reef features. Another three images were used to check this mask and as a reference for any manual modifications.

Scene	Image	Use
99, 67	L5099067_06719930801	Digitisation of reef features
99, 67	L5099067_06720040815	Digitisation of reef features
99, 67	LT50990671997288DKI00	Checking and cleaning of reef mask
99, 67	L71099067_06720020919	Checking and cleaning of reef mask
99, 67	LC80990672013220LGN00	Checking and cleaning of reef mask, spatial reference.
98, 67	L5098067_06720040808	Digitisation of reef features
98, 67	L5098067_06720040621	Digitisation of reef features
98, 67	L5 20070630	Checking and cleaning of reef mask
98, 67	L5 19881031	Checking and cleaning of reef mask
98, 67	LC80980672014200LGN00	Checking and cleaning of reef mask, spatial reference.

2. Basic contrast enhancement

A level adjustment was used to increase the contrast of the images prior to subsequent processing to reduce the quantisation errors in subsequent processing. The minimum and maximum brightness levels were chosen manually so that the darkest sea regions were just brighter than black and the brightest island and reef areas were white. This manual approach was used to ensure the contrast range was not affected by the amount of cloud cover in the images.

Table 9: Level adjustments used for images that were used to digitise the reef features. *1 B10 was not processed because the water was too turbid to get a useful result from this channel.

Scene	Image	Atmospheric Correction	B80	B10 min, max	B20	B30	B40
98 67	L5098067_06720040808	True	-	43, 111	14, 58	9, 50	
98 67	L5098067_06720040621	False	-	44, 112		9, 50	3, 69
99 67	L5099067_06719930801	False	26, 56	*1	16, 45	10, 50	3, 69
99 67	L5099067_06720040815	False	-	*1	17, 52	9, 50	3, 69

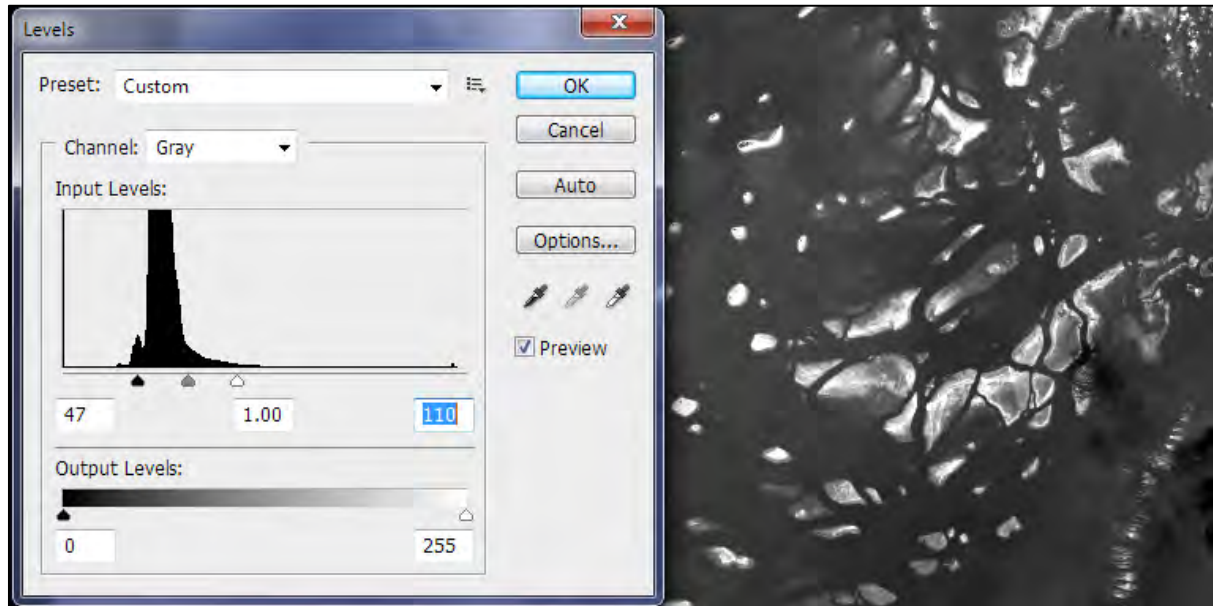


Figure 26: Level adjustment to improve the contrast of the image prior to subsequent processing. This is for B10 of L5098067_0672004080.

3. Local water brightness

This step estimates the background regional brightness of the seabed or turbid water. This is then subsequently subtracted from the original image to allow features slightly brighter than the background sea water to be made more visible.

This step is to help normalise the image against the effects of varying turbidity and the depth of the water. After this step the sea floor should be close to black. This algorithm attempts to estimate the brightness of the water, without the bright features such as islands, reefs and cloud in the image.

The estimate of the sea water colour cannot be simply estimated using a simple linear blur of the image as the bright features (such as reefs and islands) would bleed out into the water area resulting in a significant over estimate of the brightness estimate. Instead we use a minimum filter to erode bright features from the image. We cannot however perform this in one step because of two effects. The minimum filter in Photoshop uses a square kernel and thus each dark point becomes a larger square. This is not a natural shape and so some smoothing is necessary. The second problem is that applying the minimum filter straight to the image will result in picking up fine scale noise in the image.

To overcome these problems we first applied a small Gaussian filter (4 pixels radius) to effectively average out the fine scale noise. We then applied in stages (4, 8, 16, 32 pixels) a minimum filter, followed by a Gaussian filter of the same diameter. The minimum filter eroded the bright features while the Gaussian filter smoothed the square kernel of the minimum features. At the maximum filter size the local brightness estimate has a diameter of approximately 1 km (32 pixels x 30 m per pixel).

This part of the process was not applied to channel B40 (near infrared) as this channel is not susceptible to turbidity due to the limited depth penetration of this channel.

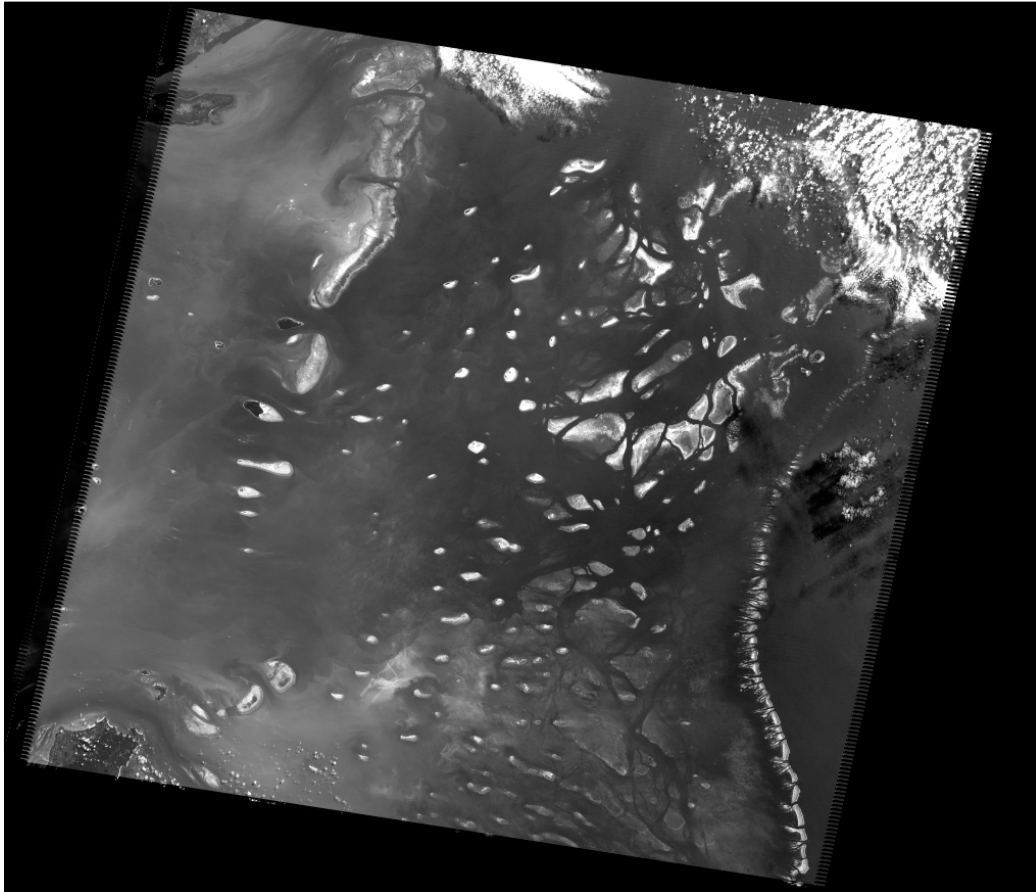
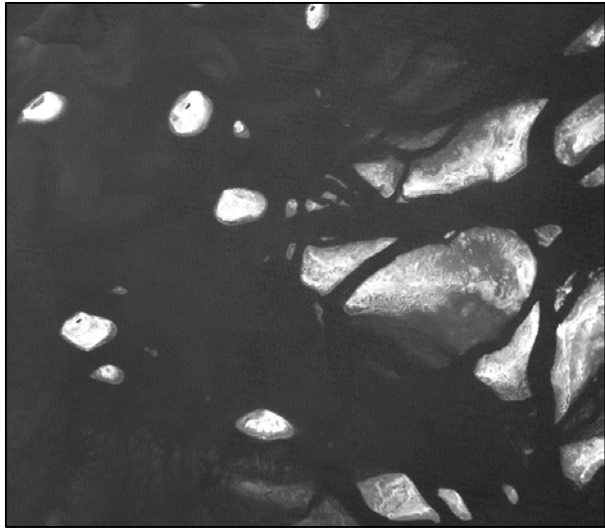


Figure 27: Original B10 image after contrast enhancement.



Cropped section of original image



After final filtering with 4, 8, 16 and 32 pixel stages of Minimum filters and Gaussian filters.

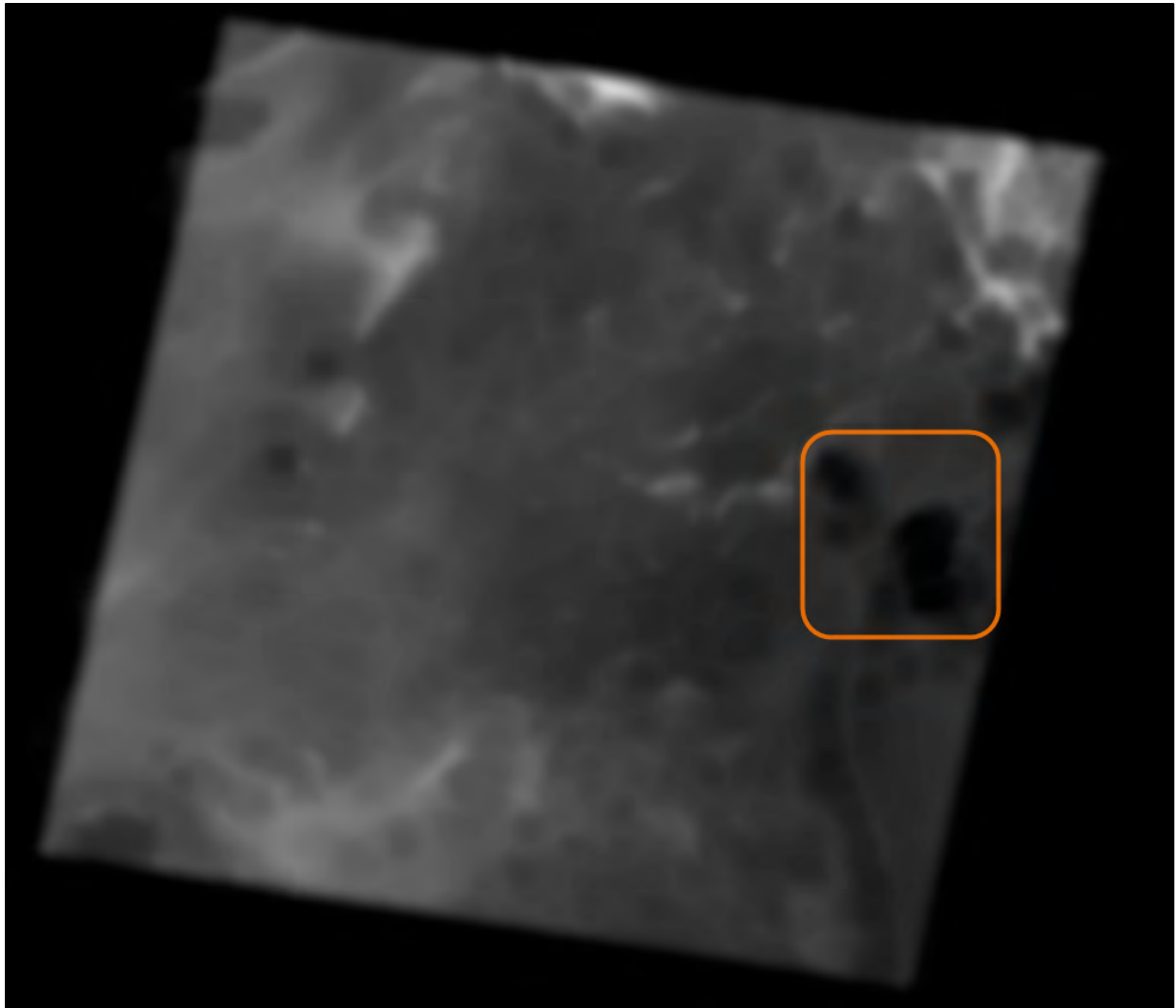


Figure 28: Final estimate for the Local Water Brightness. Note the dark patches highlighted are a result cloud shadows.

This algorithm assumes the water is darker than the islands and reefs. If the water is very turbid, making it very bright, then there will be a bright halo around each of the islands as the islands are the darkest element in the local region and so will set the minimum.

4. Highlighting the features (removing the Local water brightness)

The calculated Local water brightness was added as a second layer to the image then subtracted with an opacity of 95% to remove the water brightness from the image. An opacity of 95% was used rather than 100% to retain some local variations and ensure the subtraction would not reduce the background all the way to black.

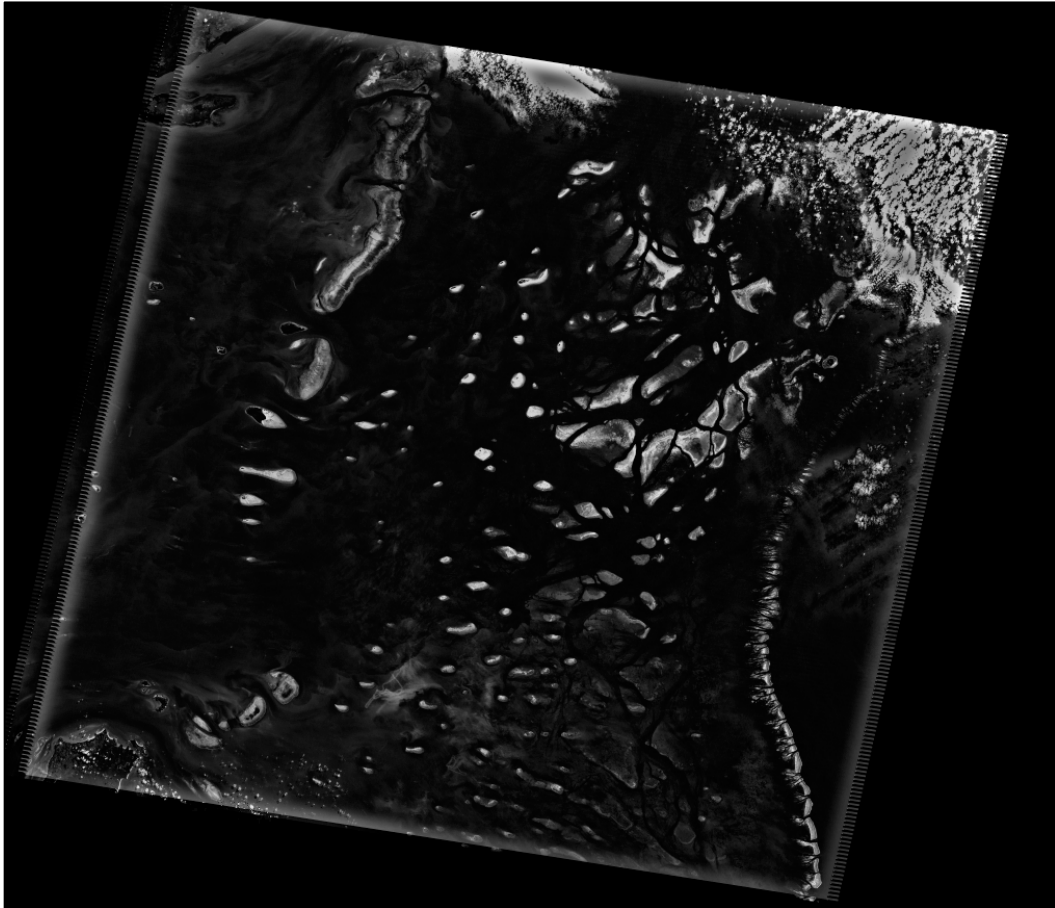


Figure 29: B10 image after local water brightness removal

5. Noise removal

Noise plays an important role in determining the depth limit that can be reliably detected with each channel. If the image is noisy then it results in spurious features and fragmented edges on the boundaries of features. One method of reducing the noise is to use a Gaussian filter to effectively apply a moving average applied to the image. This however has the disadvantage of significantly reducing detail level of the image, even in areas where the contrast between features and the water is high. A better approach is to use the *Remove Noise* Photoshop filter. This reduces the noise in the image, but manages to retain most of the feature details.

To achieve the best result in noise reduction the *Reduce Noise* filter was applied twice, each time ensuring the preserve detail is not set too low. The *Reduce Noise* filter mainly filters areas that are close to black and so it has the most effect on the water areas.

Channel	Remove Noise settings
B10_boundary	Strength 10, Preserve 13 % x two
B20_boundary	Strength 10, Preserve 13 % x two
B30_boundary	Strength 10, Preserve 13 % x two
B30_reef_top	Strength 10, Preserve 30 % x two
B40	Strength 10, Preserve 30 % x two

6. Upsizing the image

Prior to quantising the image into features and sea areas the images were doubled in resolution ensure that precision was not lost in the shape of the boundaries. For the image resizing bicubic resampling was used.

7. Separating features from seafloor - applying a threshold

This stage involved choosing a threshold to separate the features from the sea floor. Applying a binary threshold close to black classified the image into "features above the sea floor" and "sea floor". The success of this classification varied depending on the water clarity and the amount of clouds. For this reason the classification contained numerous false positive features that needed to be manually removed.

The threshold was chosen manually to capture as much of the features as possible without getting too much false positives in the image due to noise and turbidity.

Scene	Image	Channel	Threshold	Notes
98 67	L5098067_06720040621	B10 Boundary	27	
98 67	L5098067_06720040621	B30 Top	15	This level was chosen to select the same depth of features in the main middle reefs
98 67	L5098067_06720040621	B40	40	
98 67	L5098067_06720040808	B10 Boundary	27	At this level not all of the deep reef platforms visible in the image were digitised. Setting the threshold any lower however resulted in noisy reef boundaries.
98 67	L5098067_06720040808	B30 Top	33	
98 67	L5098067_06720040808	B30 Boundary	23	
98 67	L5098067_06720040808	B40	40	
99 67	L5099067_06719930801	B20 Boundary	75	The threshold was chosen to give approximately the same feature depth as the B30 boundary.
99 67	L5099067_06719930801	B30 Top	70	
99 67	L5099067_06719930801	B30 Boundary	20	
99 67	L5099067_06719930801	B40	44	The aim of this threshold was to detect the areas out of the water and the first 0.5 m of depth. This will help to fill in

				holes in the land and mangrove areas in B30.
99 67	L5099067_06720040815	B20	45	This threshold was chosen to highlight some of the large reefs.
99 67	L5099067_06720040815	B30 Top	70	
99 67	L5099067_06720040815	B30 Boundary	20	
99 67	L5099067_06720040815	B40	40	

On the western Torres Strait where the water was very turbid the feature boundary digitisation was dominated by using the red channel (B30). In this region the red channel was pushed as far (low threshold to see as deep as possible) as the image noise and turbidity would allow. The green channel was not pushed too far as it resulted in lots of false positives and features were being joined that were not desired. Instead the green channel threshold was chosen to give similar coverage to the red channel. The green channel was then added to the red channel (using lightening mode) to ensure that features that were dark in red light, and thus not included in the red mask, were included in the result.

8. Combining channels to get the best mapping

The quality of the mapping of the features from each image varied depending on the image noise, sun glint, cloud cover, turbidity and tides. In highly turbid or shallow areas features were best mapped using the red channel (B30), while those in deeper clear water were best mapped deeper using the blue channel (B10). To allow the best mapping for each of the features a stack of layers was set up in Photoshop containing all the channels from the previous steps from B10 at the bottom to B40 on top. The blue channel B10 was the deepest mapping but the most likely to be affected by the water turbidity. Moving up the spectrum (B20, B30, B40) the penetration depth of the channels is less and so the depth mapped is less; however the susceptibility to turbidity is less and so the images contained less false positives.

The layers in the stack were set up so that they would "lighten" the overall image. This meant that prior to manual editing the sandwich of layers resulted in areas being white if they were white in any of the channels.

To remove the false positives from the resulting sandwich layers causing problems were selected and the erase tool was used to "cut" a hole in the layer, removing it from the final result.

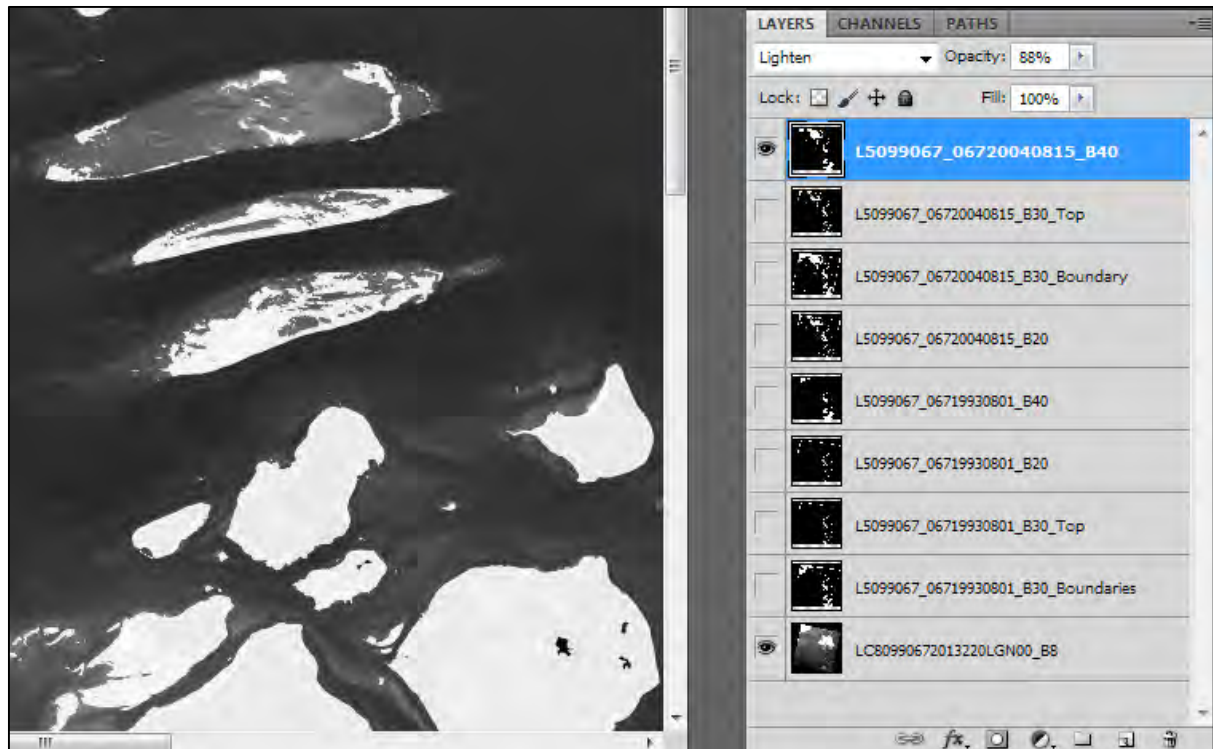


Figure 30: Basic stack of digitised features. The Landsat 8 image was used to align the different images together.

A Landsat 8 Panchromatic (B8) image with 15 m resolution was used to as the spatial reference for all the layers. This allowed the layers to be aligned with each other as well as gaining the spatial accuracy of the Landsat 8 image.

9. Cloud, Turbidity and Ship masking

For each of the images used in the digitisation a cloud mask was created to ensure that any features created due to clouds were removed from the final image. The clouds were identified by the brightness, shape and the presence of an offset shadow. In addition to looking for clouds the features highlighted by the digitised boundaries were check to see if any other spurious features appeared. In some images ships were found to be detected as features and so these were also added to the mask. When there was any doubt about whether a feature was a cloud additional images were checked.

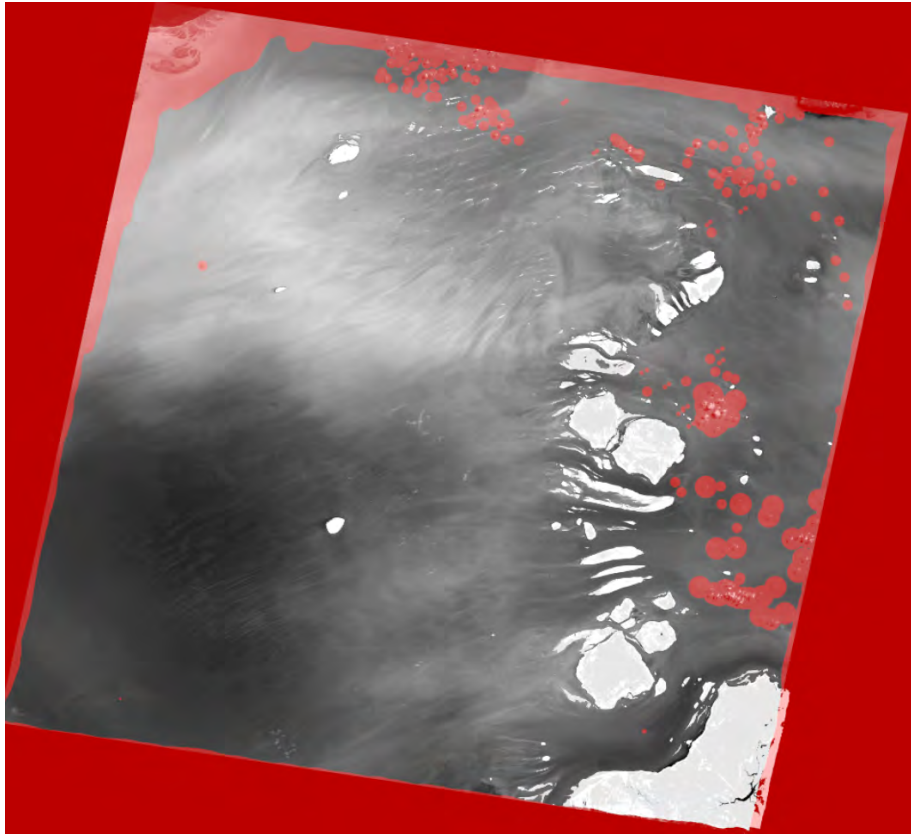
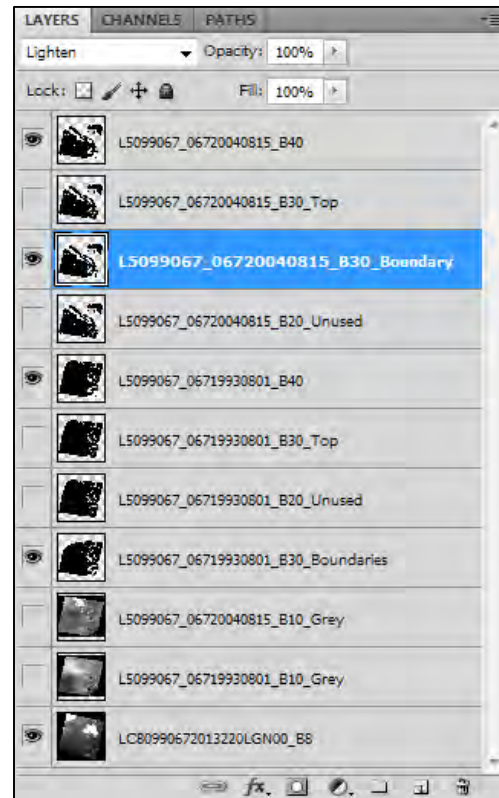


Figure 31: Example of one of the manually created cloud masks (L5099067_06720040815). This technique was applied to each of the images used in the digitisation.

10. Trimming of layers

Each of the digitised layers was trimmed to remove cloud features, false positives due to high turbidity and spurious features around the edges of the images. The mask was applied to each of the layers associated with the image and those areas were then deleted.



The layers were then sandwiched using the "lighten" mode to combine the areas of features detected by each image and channel. The layers were then inspected for spurious detections in each layer. These were then deleted from the images.

Only grey scale reference images were used at this stage to reduce the amount of computer memory needed to process the images (~3 GB for grey scale verses 9 GB for colour). Features that were questionable were left in so that they could be reviewed further at the next stage where the combined mask would be compared with colour reference images.

Once the reef masks were complete they were then checked against an additional set of images to ensure that there were no missed features or false positives. The reef mask was applied as a black mask over the top of the Landsat image, blocking out all the mapped reefs. The resulting image would then only show open water and any remaining unmapped reefs. Figure 33 shows the effectiveness of the final reef mask to block out all reefs from the Landsat image indicating that there are no missing mapped reefs in this particular example area.

After the final reef features masks were developed they were combined with the sand banks digitisation (each with their own colour) then converted to a vector polygon using the ogr2ogr command line tool.

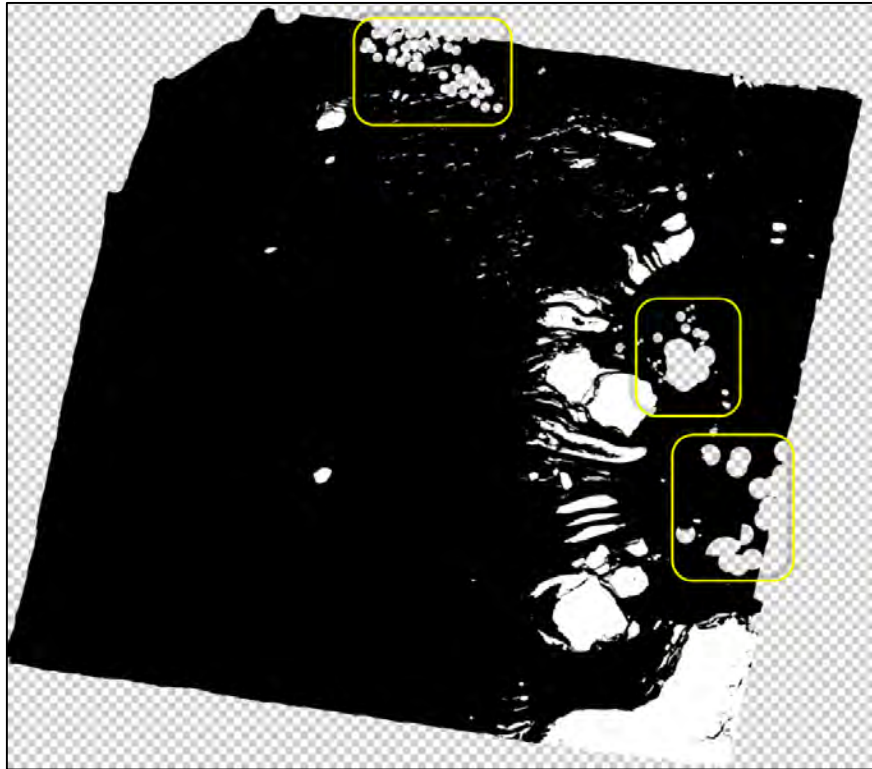
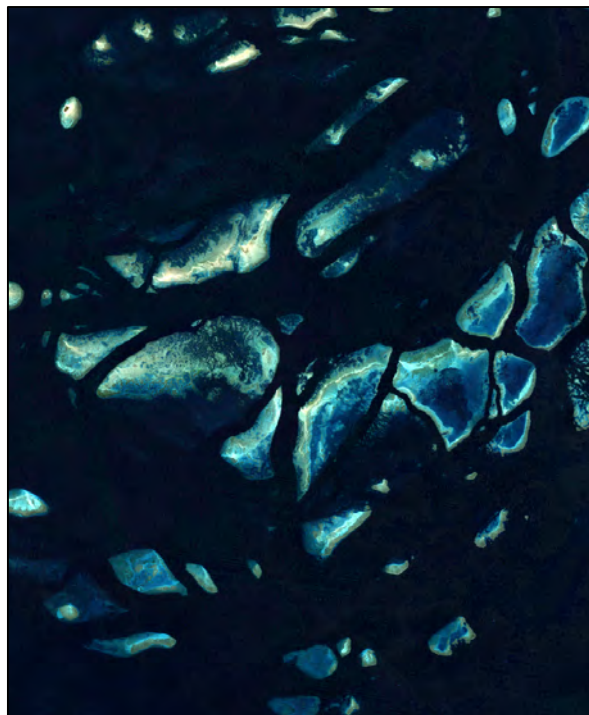
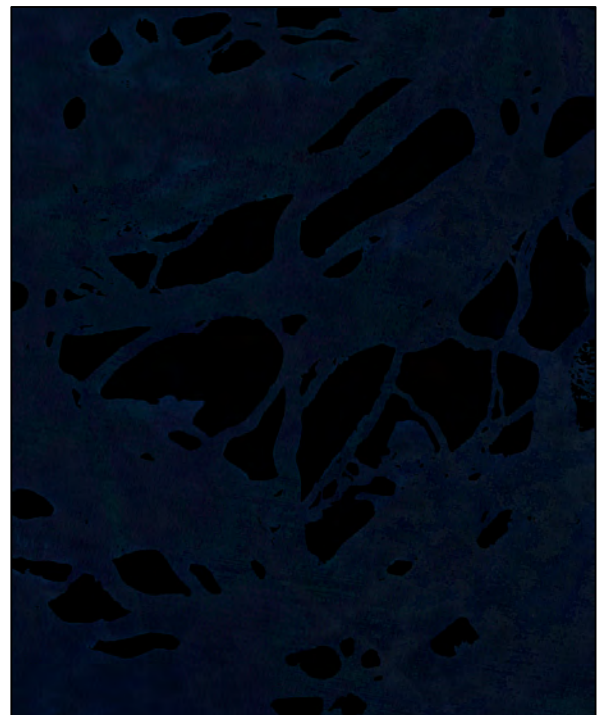


Figure 32: Combined boundary features from L5099067_06720040815_B40, L5099067_06720040815_B30_Boundary, L5099067_06719930801_B40 and L5099067_06719930801_B30_Boundaries. Note that areas highlighted in yellow correspond to holes in the automatic detection, that were manually filled.



a)



b)

Figure 33: Applying the reef mask to a Landsat image only shows the open water areas. This was used to check the mask for missing marine features. a) Landsat 5 image (L5098067_06720040808) of eastern Torres Strait reefs. b) Same Landsat image but with the reef mask applied (in black). Only water is visible. Note the local water brightness removal algorithm (see 3. Local water brightness) was applied to image and so the water is very dark.

APPENDIX 3: FEATURE CLASSIFICATION DESCRIPTIONS

A3.1 Level 1 Classifications

LEVEL_1	Definition
Mainland	Any area that is part of the continental land mass, such as Australia. The boundary corresponds to the mean high tide.
Island	Any area that remains out of the water at mean high tide that is not part of the <i>mainland</i> .
Reef	Any marine feature that has a solid substrate, is a rise above the sea floor, and is not dry at mean high tide. Often islands are a cut out in the middle of a reef. The extent of the reef boundaries is determined by the visible transition from open water to the reef feature from the clearest available satellite imagery. In choosing the boundary the approach is to use the maximum extent visible from the imagery, plus a small amount to cover the uncertainty in the mapping boundary due to poor water visibility. The extent of the expansion above and beyond the visible boundary is dependent on the quality of the imagery. The intent is to ensure that the probability of not including the full extent, due to poor visibility, is low. A consequence of this is that the boundary in some cases will be larger than reality. This extension of the boundary will typically be about 50 - 200 m.
Bank	A <i>bank</i> is a marine feature defined similarly to a <i>reef</i> , except that there is no solid substrate or foundation and thus these features typically move over time.
Other	Any features that do not fit the above categories.

A3.2 Level 2 Classifications

LEVEL_2	Definition
Mainland	Same as level 1.
Terrestrial Island	An island feature that is at least in part formed from a bed rock foundation i.e. its basic structure was not formed from reef building organisms. Reefs around terrestrial islands are fringing reefs.
Reef Island	An island that has formed from the sediment built up from a coral reef. These islands only occur on top of <i>Coral Reefs</i> .
Coral Reef	A reef that was built from coral and other reef building organisms.
Terrestrial Reef	A reef (a shallow area) around a <i>Terrestrial Island</i> made from terrestrial sediment. A typical example is the foreshore of an island.
Shoal	A small submerged feature that is of unknown origin; that is it could not be reliably classified as a Terrestrial or Coral Reef from the available information.
Other	River mouth features that are likely to be shallow.

A3.3 Level 3 Classification definitions and Examples

Mainland

Mainland of Australia. Small features in river outlets are also included as part of the Mainland classification.



Barron River, North of Cairns

Terrestrial Island

An island feature that is of terrestrial origin. A classic feature is that the islands have vegetation and hills or rocks.



Zuna Island (Entrance Island) in Torres Strait.
Classic large terrestrial island.



Clack Island

This island is terrestrial in origin as can be seen by the rocks but contains an extensive vegetation/mangrove area, with a surrounding fringing reef.

Rocky Island

An island that is bare rock with no vegetation and no sandy beaches.



Rocky islands (10-197i, 10-197b and 10-197) at the eastern end of Long Reef (10-204).

Low wooded Island

Island feature that is predominantly covered in vegetation. These islands are low, flat and mostly (>90%) covered in vegetation. In general, the vegetation extends to the edge of the island with little or no beach.

They are also typically mangrove islands. These islands are assumed to be built from accumulated terrestrial sediment. Reefs around Low wooded Islands are Fringing Terrestrial Reefs.



Bewick Island.

On this island the vegetation extends to the edge of the island indicating that it is mangroves and that the sediment will likely be a mix of reef sand finer terrestrial sediment.

Unvegetated Cay

A sandy cay is a supratidal (above the tide) feature on top of coral reefs that are developed from the accumulation of reef sand. This classification corresponds to cays that have no vegetation. This indicates that the cay is generally less developed and lower in elevation than a sandy cay with vegetation.

These cays will always be on top of a Coral Reef.



Unnamed cay (13-087) on Magpie Reef.

Vegetated Cay

Sandy cay with vegetation. If the island has vegetation (typically mangrove) right to the edge of the water with no beach then this would be classified as a *Low Wooded Island*.

Reefs around vegetated cays are Coral Reefs.



Erskine Island.

This has considerable sandy beaches around the vegetation.



Rennel Island, Torres Strait



Masig (Yorke Island), Torres Strait

While this has extensive vegetation on this cay there is no mangrove areas and so the island has a full perimeter of sand.

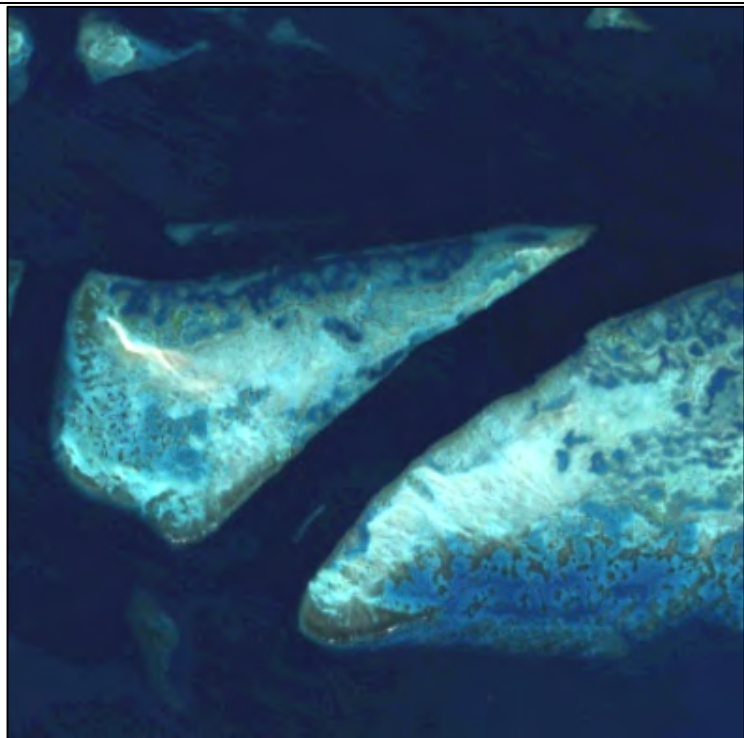
Coral Reef

Reef feature that has a structure built by coral. This will generally be determined by the shape of the feature.

If the coral reef has a terrestrial island on it then the reef is considered to be a Fringing Coral Reef.

To be considered a coral reef there must be some evidence of coral building (i.e. that part of the structure was built by coral).

This classification has a low threshold for the amount of coral required to be considered a coral reef. It includes reefs that would probably have a very low coral cover.

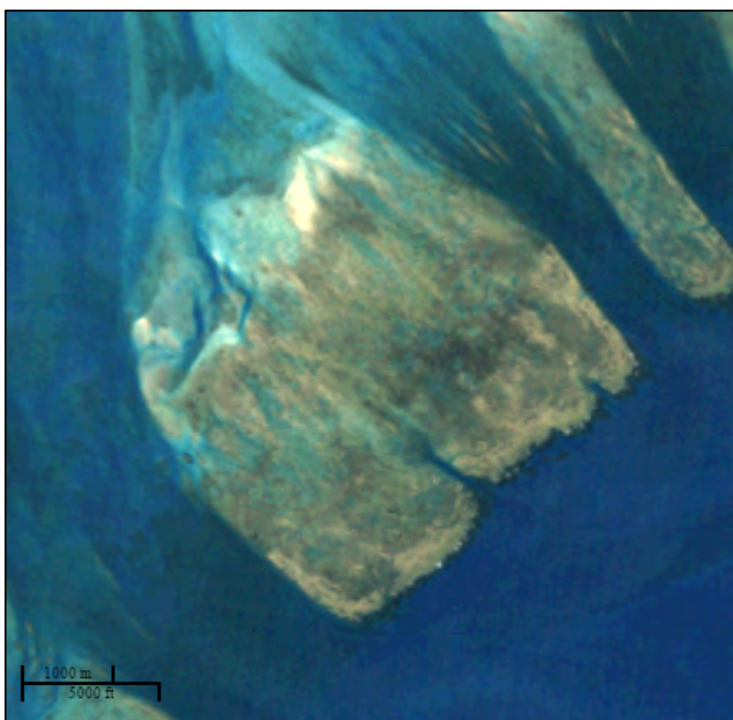


Derder Reef, Torres Strait

This is a classic coral reef in the relative clear waters of eastern Torres Strait.



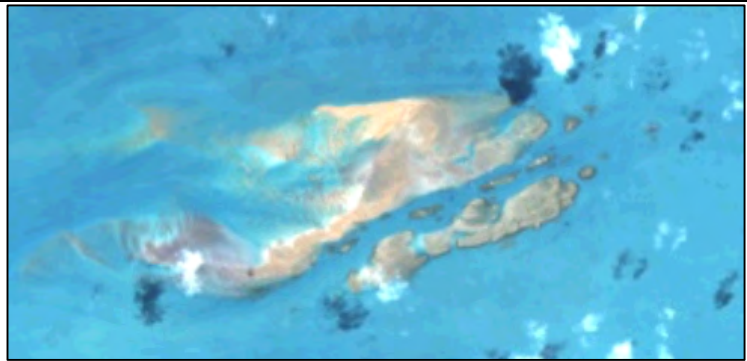
Half Way Island (top), Kodnasem Reef (bottom), Torres Strait
This shows two platform coral reefs with the uppermost one having a vegetated cay island on top of the reef.



Gariar Reef, Torres Strait
This occurs in the central northern region of Torres Strait where the water is very turbid, shallow and contains a lot of sediment. From the colour of this reef we can see that it contains lots of terrestrial sediment, however the shape, particularly on its front edge (on the lower right of the reef) is suggestive of a coral reef. For this reason it is classified as a Coral Reef. This reef, along with its neighbours in Torres Strait, are close to the limit of what would be considered a coral reef. It is likely that the coral cover in these locations is very low and that they are dominated by macro-algae and seagrass.

Isolated Terrestrial Reef

This corresponds to a reef (submerged region, raised from the seabed that has a solid foundation) that is terrestrial in nature. This type of reef is quite common in the highly turbid and shallow area in the central and northern areas of Torres Strait. This classification is determined from the overall shape of the feature. If the reef does not have the shape of a coral reef and terrestrial in its colouring (brown) then this is categorised as a Terrestrial Reef.



Aldai Reef, Torres Strait

This reef occurs in one of the shallowest and most turbid parts of Torres Strait where the sea floor is only about 6 -10 m deep. This reef is only partly exposed at low tide and so is not an island. This reef appears to be terrestrial in origin with no evidence of coral reef building based on its shape and colour. Since there is no island associated with this reef it is not a *Fringing Terrestrial Reef* but instead an *Isolated Terrestrial Reef*.

In general the confidence in the classification of these features is low as most of these features only have low resolution imagery available and there is no in-situ experience with this feature type.

Fringing Terrestrial Reef

Foreshore down to the visible depth around a terrestrial island that is NOT a fringing coral reef. This typically corresponds to sandy and high sediment areas. It also corresponds to areas with high macro-algae cover or seagrass. Coral Fringing Reefs are cut out from this region and are a subset of these regions where there is evidence that there may be significant coral.



Friday Island (top) and Prince of Wales Island. The sections indicated by the arrows would be classified as Fringing Terrestrial Reefs as there is no evidence that the structure has been built by coral or marine organisms. These structures are most likely the result of erosion of terrestrial features.



Reefs around Mabuiag. All of these reefs are in shallow waters and do not have the characteristics of structures built by coral.

Fringing Coral Reef

Areas of the fringing reef that has a high likelihood of supporting coral growth. This is determined by the colour, texture and shape of the region.

This corresponds to reef fringing around a terrestrial island only. If it is fringing a coral cay then it is classified as a coral reef.

If the area is part of a larger Fringing Terrestrial Reef then it should only correspond to the sections of the coast where there is evidence of coral formation.

The Fringing Coral Reef includes from the coral reef slope all the way back to the island. This means that it will include the reef flat, back reef, foreshore and beach. This segmenting was used to be consistent with the *GBR Features* mapping.



Fringing reef around Wednesday Island (Mawain). The reefs highlighted by arrows **A** are clearly coral reefs, however the fringing reef marked by **B** is not so obviously coral. Both of these sections would be classified as *Coral Fringing Reef* as section **B** has a characteristic shape and edge profile of a coral reef.



Prince of Wales Island. This area shows a structure that has a shape that is not typical of erosion and may be formed by coral growth on the edge. This area is however at the outlet of a river with mangroves and so a significant amount of the structure is likely to be terrestrial sediment. This would be classified as a Coral Fringing Reef because there is a moderate change that its structure was built by coral and is potential habitat for coral.

Shoal

Small submerged reef feature that is not large enough to determine its origin. It may be terrestrial (rock) or coral in origin.

This classification is typically applied to small features that cannot be classified as coral or terrestrial reefs.



Shoals south of Prince of Wales Island. These features can be seen in the imagery but are at the edge of detection and so their characteristics (coral or rock) are not known. In this case the shoal on the lower right is called Eagle Rock based on marine charts.



Shoals south of Prince of Wales Island (Dumaralug Island (top), Eagle Rock (middle, right), Peebles Shoals (bottom, left). Some shoals are only visible from the wake they cause in the water. Each shoal identified this way requires visual confirmation with other available imagery, or the marine charts. If no other evidence could be found then the feature was not mapped.

Pearl Pontoon

Floating man made structure for pearl farming.



Pearling Pontoon off Friday Island. These structures are floating wooden pontoons for attaching oyster racks. They perhaps are not permanent structures and are not islands or reefs.

Sand Bank

Sand banks are a deposit of sand forming a shallow area in the sea or a river. These may be partly exposed at low tide. To be considered a sand bank it should correspond to mobile sand that is submerged and away from an island or the mainland. To determine if it is mobile sand the shape is considered and if there is movement of the feature over time (over 10 years+). In general sand banks are only roughly mapped because they can move over time.



Sand banks west of Buru Island in Torres Strait.

APPENDIX 4: DATA DICTIONARY

This section outlines a description of some of the attributes of the *Torres Strait Reef and Island Features* dataset.

During the feature boundary and classification step of the dataset development the following attributes were assigned to each feature to record the origin of the imagery used to trace the outlines, the classification and confidence in the classification.

Attribute	Possible Values	Description
DATASET	TS Features, GBR Features	Which dataset this feature belongs to. This attribute is used when the <i>Torres Strait Reef and Island Features</i> dataset is merged with the GBRMPA <i>GBR Features</i> dataset.
LOC_NAME_S	e.g. Tobin (Zagarsum) Island (10-147a)	Location Name: Name of the feature and its ID
GBR_NAME	e.g. Tobin (Zagarsum) Island	Name of the features with no ID
CHART_NAME	e.g. Tobin Island	Name of the feature on the Australian Nautical Charts
TRAD_NAME	Zagarsum	Traditional name. From various sources.
UN_FEATURE	TRUE, FALSE	Unnamed Feature: If TRUE then the feature is unnamed. Useful for limiting labels in maps to features with names.
LABEL_ID	10-147a	ID of the feature
SORT_GBR_I	10147	ID of each feature cluster made up from the Latitude ID and Group ID. Used for sorting the features.
FEAT_NAME	Island, Rock, Reef, Cay, Mainland, Bank, Terrestrial Reef, Other	Classification of the feature that is used in the GBR Features dataset. See 3.6 Classification scheme for more information.
LEVEL_1, LEVEL_2, LEVEL_3		Hierarchical classification of the features. See Appendix 3: Feature Classification Descriptions.
Checked	T, F	Flag to record if the feature was reviewed in detail (at a scale of approximately 1:5000) after the initial digitisation (T - True, F - False). Unchecked features were only reviewed at a coarser scale (1:25000) to spot significant problems.
IMG_SOURCE	Aerial, AGRI, Landsat	Imagery type used for the final digitisation checking and correction. (AGRI - AGRI PRISM by GA, Landsat is Landsat 8 or Landsat 5)
CLASS_SRC	Aerial, AGRI, Landsat, Google, Marine Chart	Imagery type used to determine the classification of the feature. Often the classification will be an aggregation of information from multiple image sources. This field will record the highest resolution source used. For some small features the classification was obtained from the Marine Chart, generally for Rocky Reefs.
CLASS_CONF	High, Medium, Low	Confidence of the classification applied to the feature. The confidence is dependent on the clarity and range of the imagery available for classification. High - Clear high resolution imagery available (Aerial, Google) with good water visibility. Key characteristics of the classification clear visible. Feature classification fits the context for the neighbouring region. For unconsolidated features (such as sand banks) a High confidence classification would be applied if the

		shape, colour and context fit and in particular if movement is visible over time-lapse Landsat imagery.
		Medium - Moderate imagery available (Landsat 8 pan sharpened, some high resolution imagery) that shows key characteristics of the feature and the classification fits the context for the neighbouring region.
		Low - Only Landsat 5 imagery is available, the feature is small and its origin is unclear from the neighbouring context. This is the default confidence rating for any features that were not individually checked.
POLY_ORIG	QLD_DNRM_Coastline_25k, New, GBR_Features, AU_GA_Coast100k_2004	Original source of the polygon prior to any modifications. New features correspond to all the mapped marine features. Most features from the other source would have been modified as part of the checking and trimming of the dataset.
IMG_SRC	Landsat, AGRI, Aerial	Source of imagery used to trace the boundary of the feature. Landsat corresponds to Landsat 5, 7 or 8.
SUB_NO	100, 101, ...	Subgroup number. Numeric count, starting at 100 of each feature in a group. Matches the subgroup ID i.e. 100 -> blank, 101 -> a, 102 -> b, etc.
CODE	e.g. 10-147-102-101	Unique code made from the various IDs. This is a GBR Feature attribute.
UNIQUE_ID	10147102101	Same as the CODE but without the hyphens, This is a GBR Feature attribute.
FEATURE_C	100 - 110	Code applied to each of the FEAT_NAMES.
QLD_NAME	Tobin Island	Same as the GBR_NAME
X_COORD	Longitude	Longitude in decimal degrees east, in GDA94.
Y_COORD	Latitude	Latitude in decimal degrees north, in GDA94.
SHAPE_AREA		Shape Area in km ²
SHAPE_LEN		Shape perimeter length in km
CHECKED	TRUE, FALSE	Whether the features was carefully checked (at a scale of better than ~1:5000) and manually corrected to this level of precision. If FALSE then the feature was only checked to approximately a 1:25000 scale.
GROUP_LB	TRUE, FALSE	If TRUE then this features label that should be included in a map. Usually correspond to features with names. Used to reduce near duplicate labels of the islands and their surrounding fringing reefs.
COUNTRY	Australia, Papua-New Guinea	Sovereignty of the feature. This is based on a spatial join with the Australian Maritime Boundaries 2014a. The Territorial Sea and the Exclusive Economic Zones were merged to create a mask of the Australian maritime boundary. Note this should not be considered authoritative.

APPENDIX 5: SPLITTING OF FRINGING TERRESTRIAL REEFS

Torres Strait contains a number of large terrestrial islands with fringing reefs. These reefs were split around the boundary to produce reef features that are relatively homogenous in nature. The reef features were split into areas spanning from cape to cape and further subdivided if necessary to segment into regions with coral.

On the land side the fringing reef areas were only very roughly cut in from the coastline, with a margin in from the coast to ensure overlap with any island mapping. This was to ensure that when the islands are cut out from the island features that there are no holes (gaps) created.

Examples:



Figure 34: This fringing reef, on Badu's eastern side, was split in the middle to capture the transition from a coral reef (top, light blue section) to a terrestrial reef with no evidence of coral building. In this case the reef flat is very long making the split between the coral reef section and the terrestrial section somewhat arbitrary. The mapping includes the reef flat back to the shore and so the mapping does not just trace around the coral areas.



Figure 35: This section of the fringing reef on Badu's southern side was separated out as Rugged Point (on the left) and Upai Point (on the right) pinch the surrounding reef. In addition to this, the separated reef faces a distinctly different direction to the neighbouring reefs, one facing west and one facing east. This is likely to cause each of these regions to have slightly different ocean and habitat conditions.



Figure 36: The highlighted section of reef, on Moa Island, was split from the left neighbouring section because there was evidence of coral reefs in this area, particularly on the seaward side towards the bottom. The boundary of these types of cases is difficult and probably error prone as the ability to see and identify coral reef structures is limited from Landsat imagery in turbid waters.



Figure 37: Normally when there is evidence of coral reef on a fringing area of island the reef is considered to be from the reef edge back to the shore, capturing the reef flat. The above reefs on the north west of Prince of Wales Island jut on to a mud flat area with little evidence that the bay contains a coral reef base. It would be misleading to classify the entire bay as a coral reef and so these areas were classified as fringing coral reefs touching the fringing terrestrial reef.



Figure 38: This shows the resulting segmentation of the reefs. This also shows the Landsat 8 pan sharpened image used for the tracing.

APPENDIX 6: ISLAND MAPPING CORRECTIONS

This section outlines some of the difficult cases that were encountered during the development of the island boundaries mapping.

The starting point for the islands features were the Coast100k (Geoscience Australia, 2004) and Queensland Coastline 25k (Department of Natural Resources and Mines, 2010) datasets. These initial datasets were merged then manually checked and corrected based on the available imagery. This involved correcting their position, boundary shape and verifying their classification (i.e. checking that the feature was an island). This process also included digitising any island features that were not included in the original data sources.

The island boundaries were considered to be the mean high water mark or the outer edge of dense mangroves. Features that were found to not remain out of water at high tide were removed.

These notes outline some of the difficult cases where the simple definition of an island was hard to apply.

Areas that were particularly difficult were:

- Rocky foreshores around continental islands
- Mangrove forests on sand/mud bars of more defined islands.
- Sparsely vegetated sand bars and cays
- Areas where there was only low resolution Landsat 8 imagery.



Many of the continental islands had rocky outcrops that were marked out as being islands. When looking at these more closely it was usually found that they were submerged at high tides and therefore deleted

This example is on the South East coast of Prince of Wales Island. The Island was deleted as it appeared to be underwater in a few images.



Difficult cases were where trees slowly transition from dense forest to sparse individual trees. If the surface was visible through the trees, then the boundary was determined by the likely high tide level on that surface.

Small stands of trees were not included if they were obviously inundated at high tide.

This example is from the south east of

Prince of Wales Island (10-485b), where there were sandy islands on a terrestrial islands platform. These islands were classified as 'low wooded islands' because their foundation was terrestrial in origin. They were not considered to be 'vegetated cays' because there was no surrounding coral reef.



Another example of a difficult coastline to define – West coast of Moa Island. The example map shows the island outlines (in purple) prior to correction.

Break off islands formed by 'gullies' were included as separate islands (10-138a, 10-138c, 10-138d, 10-138e, 10-138g), when they were completely cut off. These were classified as 'Terrestrial Islands' because they contain vegetation. The exact high tide boundary of these islands was difficult to identify from the available imagery and so the vegetation was used as the boundary.

The rocky area around these islands was mapped as a rocky reef (10-138k).

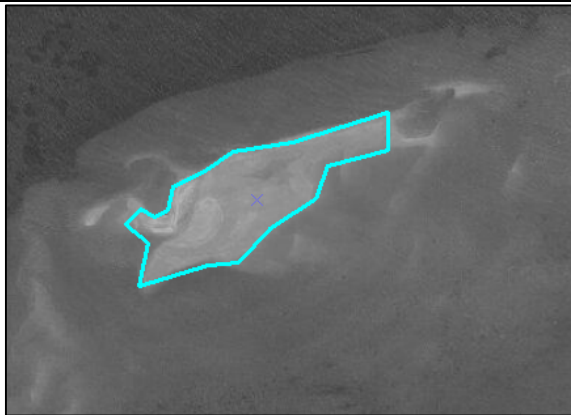
The random polygon shaped island in the central bottom of the example map was deleted.



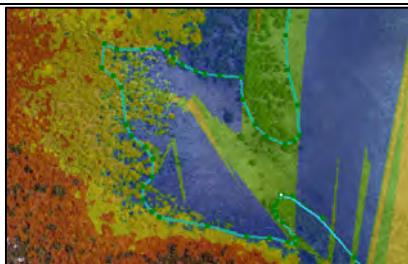
Sparsely vegetated and ever-changing sandbars were difficult to map, as they appeared significantly different in the available aerial imagery due to different tidal conditions.

The high tide level on the exposed sand banks was estimated from the prepared infrared Landsat imagery.

Crab Island shown in this picture has sandbars that are almost completely closed off to from a narrow gully. Infrared image was used to understand the high tide boundary.



There were many cays in the source datasets marked out on reef platforms including reefs 1, 2, 3 (10-214, 10-216, 10-215) that were submerged at high tide based on the infrared Landsat imagery and look like they are slightly submerged in clearer imagery available (ESRI). These cays were deleted.



Many outlines have been drawn for lama (09-332). Rocky outcrops on the reef, mangroves that slowly disperse and gullies in between made it difficult to define the island boundary.

In cases where data was available, coastal hazard mapping datasets (high resolution elevation data) were used to get a better idea of where the water level sat. This combined with the tree lines were deciding factors in drawing the boundaries.

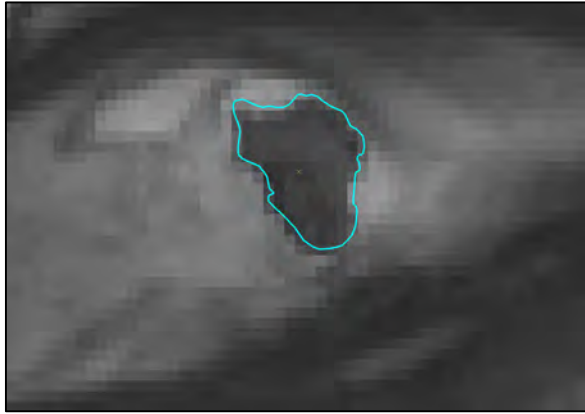


A man made rocky groin also lies off the western shore of lama. Surprisingly this was the only groin of sorts in the region. It was categorized it as a rocky island.



There were some rocks marked as islands such as these ones off the coast of Badu.

They were deleted as they looked to be mostly submerged in imagery.



Imagery around Mabuiag and particularly the islands to the east of Mabuiag was extremely poor (Landsat 8 15 m resolution). Therefore the accuracy of the shape, positioning and classification was less precise. Perhaps 1:20000.

APPENDIX 7: REEF NAME COMPLICATIONS

A7.1 Parakari Reef

The positioning of this Parakari Reef could not be unambiguously determined from the available information and so it was not added to the dataset mapped by this project.



Figure 39: This map shows the Aus840 Nautical chart overlaid with the new digitised features (in red for reefs and orange for sand banks). Parakari Reef (labelled A) does not exist in the location shown on the Nautical chart. This was verified by review of multiple Landsat images. This area is unsurveyed in the Nautical charts.

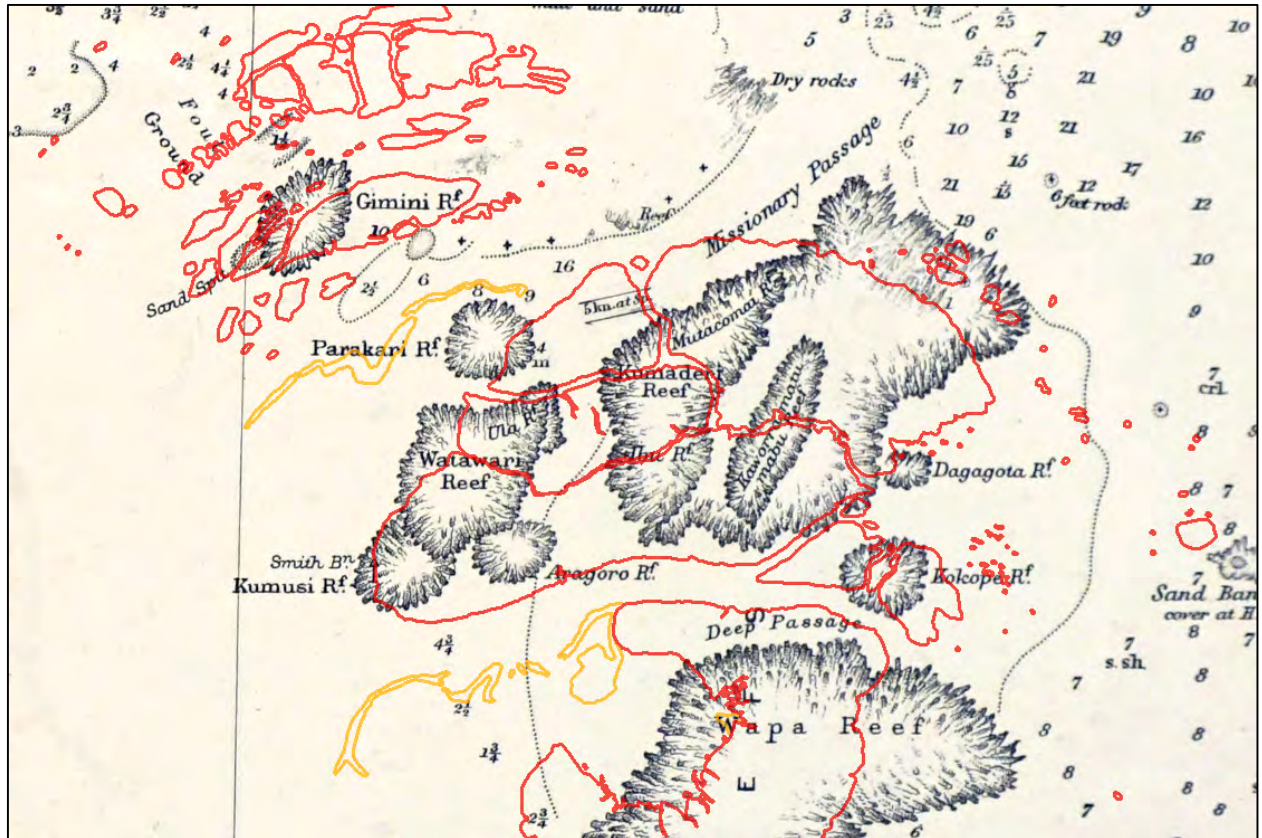


Figure 40: Map of the same area from by the Great Britain. Hydrographic Office (1907) from 1843-45 surveys. This is the oldest detailed map of this region that was found. This shows the potential source of the names and approximate reef positions used in the Nautical charts. It shows separate reefs where there are none in practice.

Allocation of the traditional names and splitting up of the reefs to match these old maps was not done as part of this project. It was considered that local knowledge was needed to resolve the correct allocation of names, rather than copying directly from older maps.

A7.2 Round Island

When a comparison between the various charts was made it was found that the labelling of Round Island, near Badu, is misplaced on the Nautical charts (Aus841). Round Island is more north in the historic maps (Figure 43) and the 100k and 250k Topographic maps. As a result this positioning was used in the Torre Strait Reef and Islands dataset.

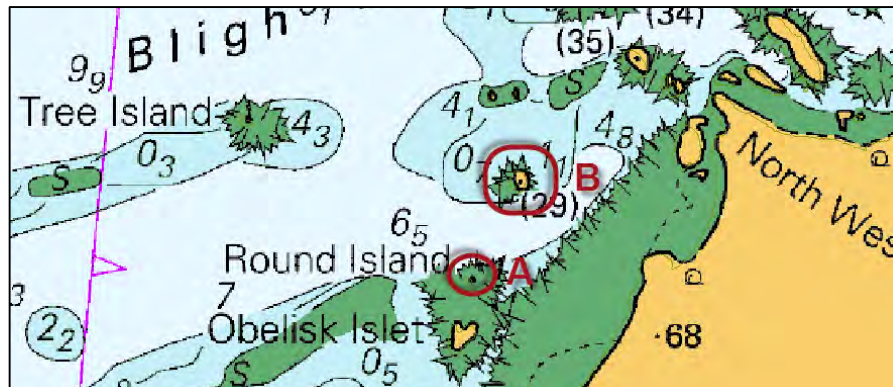


Figure 41: Round Island is mislabelled on the Nautical Charts (Aus841). It is labelled on feature A but should be more north on the island labelled B.

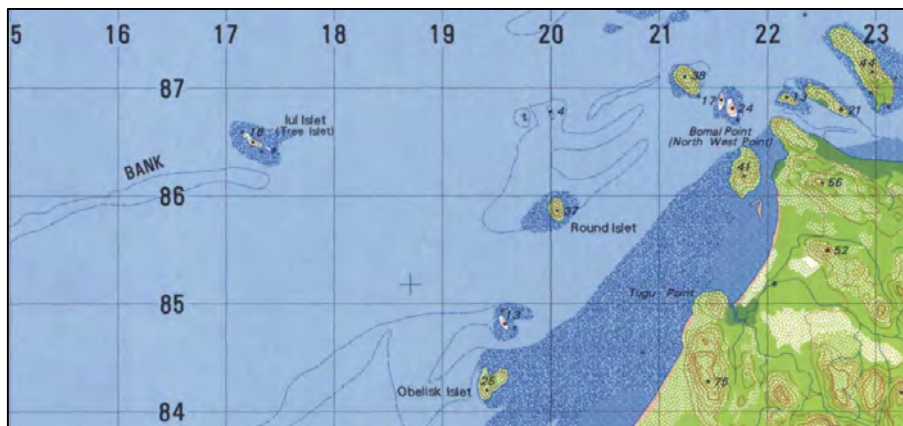


Figure 42: Topographic 100k map shows Round Island (labelled Round Islet) further north on an island that is quite round. The Topo250k maps agree with the Topo 100k maps.



Figure 43: The first high resolution maps (Great Britain. Hydrographic Dept., 1855) of the islands around Badu show Round Island's placement matching that shown in the Topographic 100k maps not the Nautical charts.

APPENDIX 8: ALGORITHMS FOR ALLOCATION OF GROUP IDS AND SUBGROUP IDS

A8.1 Group ID allocation

The allocation of Group IDs (for example: 10-274) was performed using an R script run on a CSV export of the *Torres Strait Reef and Island Features* shapefile. Prior to running this script each of the features within a group were merged together to create one feature per group. The location (X, Y centroids) and Region IDs and the existing Group IDs already allocated by the *GBR Features* dataset were inputs to the algorithm.

CalculateGroupIDs.R:

```
# This script allocates GroupIDs to each feature in the input
# dataset. For this to work the polygons making up each group
# must be merged to create one multiple part polygon feature
# per group. In the input CSV file this will correspond to
# one row per group.
# This grouping should dissolve all items that make up the
# group, merging features of different classifications.
# Once the GroupID has been calculated it should be applied
# back to all the features using a Spatial Join.
#
# It must have the RegionID from the regional allocation and
# have the latitude (Y_COORD) and longitude (X_COORD) of each feature.
groupIDFeaturesTableCsv <- "17_Whole_GBR_Group_Clusters.csv"
groupIDOutTableCsv <- "17_Whole_GBR_Group_Clusters_with_GroupIDs.csv"

# Return the next ID after the current ID. This will test
# if currentID+1 is available. If not it will keep iterating
# until it is not found in existingGroupIds.
getNextID <- function (existingGroupIds, currentID) {

  testId <- currentID+1
  while (testId %in% existingGroupIds) {
    testId <- testId+1
  }
  return(testId)
}

getLatRegionKey <- function(groupIdTable) {
  return(paste(groupIdTable$LatitudeID, groupIdTable$RegionID, sep="-"))
}

# Load the existing data for the features
groupIdTable <- read.csv(groupIdFeaturesTableCsv, stringsAsFactors=FALSE)

# Calculate the LatitudeID from the Y_COORD of the polygon
# centroid. This relies on the Y_COORD being calculated
# prior to running this script.
# Convert -10.725 -> 10
groupIdTable$LatitudeID <- floor(-groupIdTable$Y_COORD)

# Exclude mainland features from the convention of using
# the Y_COORD as the LatitudeID. The mainland features have
```

```

# a SORT_GBR_I of 99000 for Australia and 98000 for PNG.
# Note: the PNG mainland feature was manually preallocated
groupIdTable$LatitudeID[groupIdTable$SORT_GBR_I == 99000] <- 99
groupIdTable$LatitudeID[groupIdTable$SORT_GBR_I == 98000] <- 98

# Handle odd feature in the GBR Features dataset. This feature
# has a 0 latitude
groupIdTable$LatitudeID[groupIdTable$SORT_GBR_I == 21371] <- 21

# Create Table of all the existing GroupID allocations from
# GBR Features. We must make sure we do reallocate these.
# We must extract these from the SORT_GBR_I attribute and
# keep the last three characters. 99340 -> 340, 10512 -> 512
# Features with no existing ID will have ""
groupIdTable$GroupID <- substr(groupIdTable$SORT_GBR_I, 3,5)

# Work out how many features exist in each region. Use this
# to calculate amount of spare IDs for each region, assuming
# 5% unallocated IDs for future improved mapping.
# Join the LatitudeID and RegionID to make a composite key
# to count. We need this because the RegionIDs reset in each
# LatitudeID.
# Use table to count rows, see
# http://stackoverflow.com/questions/25293045/count-number-of-rows-in-a-data-frame-in-r-based-on-group
featuresPerRegion <-
  data.frame(table(getLatRegionKey(groupIdTable)))

# Allow 5% or 2, which is ever larger, unallocated features
# Use this to calculate the increment between Regions.
allocBufferPerRegion <- floor(pmax(featuresPerRegion$Freq * 0.05,1))
allocLUT <- data.frame(key=featuresPerRegion$Var1,
  alloc=allocBufferPerRegion)

# Sort the data by LatitudeID, RegionID then by Longitude (X_COORD)
sGroupIdTable <- groupIdTable[
  order(
    groupIdTable[, "LatitudeID"],
    groupIdTable[, "RegionID"],
    groupIdTable[, "X_COORD"]), ]

# Iterate through each of the features allocating GroupIDs.
# This relies on the previous sort order.
# If there is already an existing group ID from the GBR Features
# datasets then use that, else use an incremental counter.
# Check to see if the ID is already allocated (from GBR Features)
# if so keep incrementing until a hole in is found.
# If we tick over a region boundary then increment the IDs by
# allocBufferPerRegion to leave space for future mapping

groupIDcnt <- 1
prevRegionID <- 0
prevLatitudeID <- 0
for (i in 1:nrow(sGroupIdTable)) {

  groupIdRow <- sGroupIdTable[i,]

  # If there is no existing ID then allocate one.
  if (is.na(groupIdRow$GroupID) || groupIdRow$GroupID == "") {

```

```

# Start of new latitude band so restart the group ID
# counter.
if (groupIdRow$LatitudeID != prevLatitudeID) {
  print(paste("New Latitude: ",groupIdRow$LatitudeID, sep=","))
  # In the -10 degree band allow IDs features in GBR Features NEW
  # that don't yet have IDs and are outside this dataset.
  if (groupIdRow$LatitudeID == 10) {
    groupIdCnt <- 50
  } else if (groupIdRow$LatitudeID == 11) {
    groupIdCnt <- 500
  } else {
    groupIdCnt <- 0
  }
}

# If we have ticked over into a new region then allocate
# unused GroupIDs based on allocLUT
if (groupIdRow$RegionID != prevRegionID) {
  key <- getLatRegionKey(groupIdRow)

  alloc <- allocLUT[which(allocLUT$key==key),"alloc"]
  print(paste(key,alloc, sep=","))
  if (alloc > 0) {
    for (k in 1:alloc) {
      groupIdCnt <- getNextID(sGroupIdTable[
        sGroupIdTable$LatitudeID==groupIdRow$LatitudeID,
        "GroupID"], groupIdCnt)
    }
  }

  # Check against only GroupID in the current LatitudeID
  groupIdCnt <- getNextID(sGroupIdTable[
    sGroupIdTable$LatitudeID==groupIdRow$LatitudeID,
    "GroupID"], groupIdCnt)
  sGroupIdTable[i,"GroupID"] <- formatC(
    groupIdCnt, width=3, flag="0")
  prevRegionID <- groupIdRow$RegionID
  prevLatitudeID <- groupIdRow$LatitudeID
}
}

sGroupIdTable$LatitudeIDStr <- formatC(
  sGroupIdTable$LatitudeID, width=2, flag="0")
# Keep just the fields of interest
outTable <- data.frame(
  TARGET_FID=sGroupIdTable$TARGET_FID,
  LatitudeID=sGroupIdTable$LatitudeIDStr,
  GroupID=sGroupIdTable$GroupID,
  SORT_GBR_I=paste(
    sGroupIdTable$LatitudeIDStr,
    sGroupIdTable$GroupID, sep=""),
  ORIG_SORT=sGroupIdTable$SORT_GBR_I
)

# Save the results
# The results table should be joined with the Group cluster shapefile
# then this shapefile should be spatially joined with each of the
# exploded features to assign the GroupID and LatitudeID to all features
# within each Group.
write.csv(outTable, file = groupIdOutTableCsv, row.names=FALSE)

```

A8.2 Subgroup ID allocation

After all clusters of features were allocated Group IDs these were then applied to each of the features within each group using a spatial join. Subgroup IDs were then assigned to each feature to ensure that each and every feature had a unique ID. The subgroup IDs (a, b, c, ..., a1, a2, ...) were allocated based on the classification of the features so that features that are most likely to be named such as islands were assigned lower subgroup IDs.

CalculateSubgroupIDs.R:

```
# This script allocates subgroupIDs for each row of the input
# table. This script assumes that groupIDs have been allocated
# and assigned to all elements in each group.
# This script sequentially allocates subgroupIDs to each feature
# with a group allocating IDs first to any islands within a group
# The subgroupID is represented as the SUB_NO (attribute of the
# GBR Features dataset) which is a sequential code starting at
# 100 in each group.
# It is also represented as a subcode letter. Special consideration
# is made if there are more than 26 features with a group.
# Feature within group LetterCode
# 1 None
# 2 - 27 a, b, c
# 28+ a0, a1, ... a9, b0, b1, ...
inputTableCsv <- "19_GBR_Whole_Exploded_with_GroupIDs2.csv"
outTableCsv <- "19_GBR_Whole_Exploded_with_GroupIDs_SubIDs.csv"

inputTable <- read.csv(inputTableCsv, stringsAsFactors=FALSE)

# This function converts the subgroup count into a LetterCode
# count Letter Code
# 0 ""
# 1 - 26 a, b, c
# 27+ a0, a1, ... a9, b0, b1, ...
count2LetterCode <- function(count) {
  # Generate a lookup array of letters from "a" to "z"
  val <- 97:122
  mode(val) <- "raw"
  letterArray <- sapply(val, rawToChar)
  if (count == 0) {
    return("")
  } else if (count < 27) {
    return(letterArray[count])
  } else if (count <= 260+27) {
    adjCount <- count-27
    letterDigit <- floor(adjCount/10)
    numDigit <- adjCount-letterDigit*10
    print(paste(letterDigit,numDigit))
    return(paste(
      letterArray[letterDigit+1],
      as.character(numDigit), sep=""))
  } else {
    warning(paste(
```

```

        "count (",count,") exceeds maximum Letter Code",
        sep=""))
    }
}
# Sort the data by groupID (SORT_GBR_I) then by the feature code
# (FEATURE_C). The use of the feature code is to allocate
# subgroupIDs
# to islands then reefs then to sand banks.
# Also sort by the size of the feature. This way if there is a large
# island and smaller islets on the same reef base (in the same
# group)
# then the large island will be allocated first and will be given
# an ID such as 10-352 and the islets 10-352a, etc.
# We apply a negate to the SHAPE_AREA to sort in reverse order.
sortedTable <- inputTable[
  order(
    inputTable[, "SORT_GBR_I"],
    inputTable[, "FEATURE_C"],
    -inputTable[, "SHAPE_AREA"]), ]

# Iterate through each of the features sequentially processing
# each group. Track the current SORT_GBR_I to detect changes
# to a new group
subgroupIDcnt <- 0
prevSORT_GBR_I <- 0

for (i in 1:nrow(sortedTable)) {
  if (sortedTable[i, "SORT_GBR_I"] != prevSORT_GBR_I) {
    subgroupIDcnt <- 0
  }

  # Only allocate a sub number if not already allocated
  if (sortedTable[i, "SUB_NO"] == 0) {
    subNo <- subgroupIDcnt + 100
    subString <- count2LetterCode(subgroupIDcnt)
    # Ensure that the LatitudeID and the GroupID are formatted
    # properly with leading zeros
    latitudeID <- formatC(
      sortedTable[i, "LatitudeID"], width=2, flag="0")
    groupID <- formatC(
      sortedTable[i, "GroupID"], width=3, flag="0")

    sortedTable[i, "CODE"] <- paste(
      latitudeID, groupID, sortedTable[i, "FEATURE_C"], subNo,
      sep = "-")
    sortedTable[i, "UNIQUE_ID"] <- paste(
      latitudeID, groupID, sortedTable[i, "FEATURE_C"], subNo,
      sep = "")
    sortedTable[i, "SUB_NO"] <- subNo
    sortedTable[i, "LABEL_ID"] <- paste(
      latitudeID, "-", groupID, subString, sep = "")
    # Add an extension such as "(No 2)" if there is more than
    # one feature in the group with the same feature type

    # The GBR_NAME includes the number extension such as (No 2)
    #sortedTable["GBR_NAME",i] <- paste(

```

```

#       sortedTable["QLD_NAME",i], "-", groupID, subStr, sep = "")

sortedTable[i, "LOC_NAME_S"] <- paste(
  sortedTable[i, "GBR_NAME"], " (",
  sortedTable[i, "LABEL_ID"], ") ", sep = "")
}
subgroupIDcnt <- subgroupIDcnt+1
prevSORT_GBR_I <- sortedTable[i, "SORT_GBR_I"]
}

sortedTable$UN_FEATURE <- substr(sortedTable$GBR_NAME, 1, 3) == "U/N"
# Save the results
# The results table should be joined with the combined GBR Whole
# Features shapefile should be spatially joined with each of the
# exploded features to assign the GroupID and LatitudeID to all
# features within each Group.
write.csv(sortedTable, file = outTableCsv, row.names=FALSE)

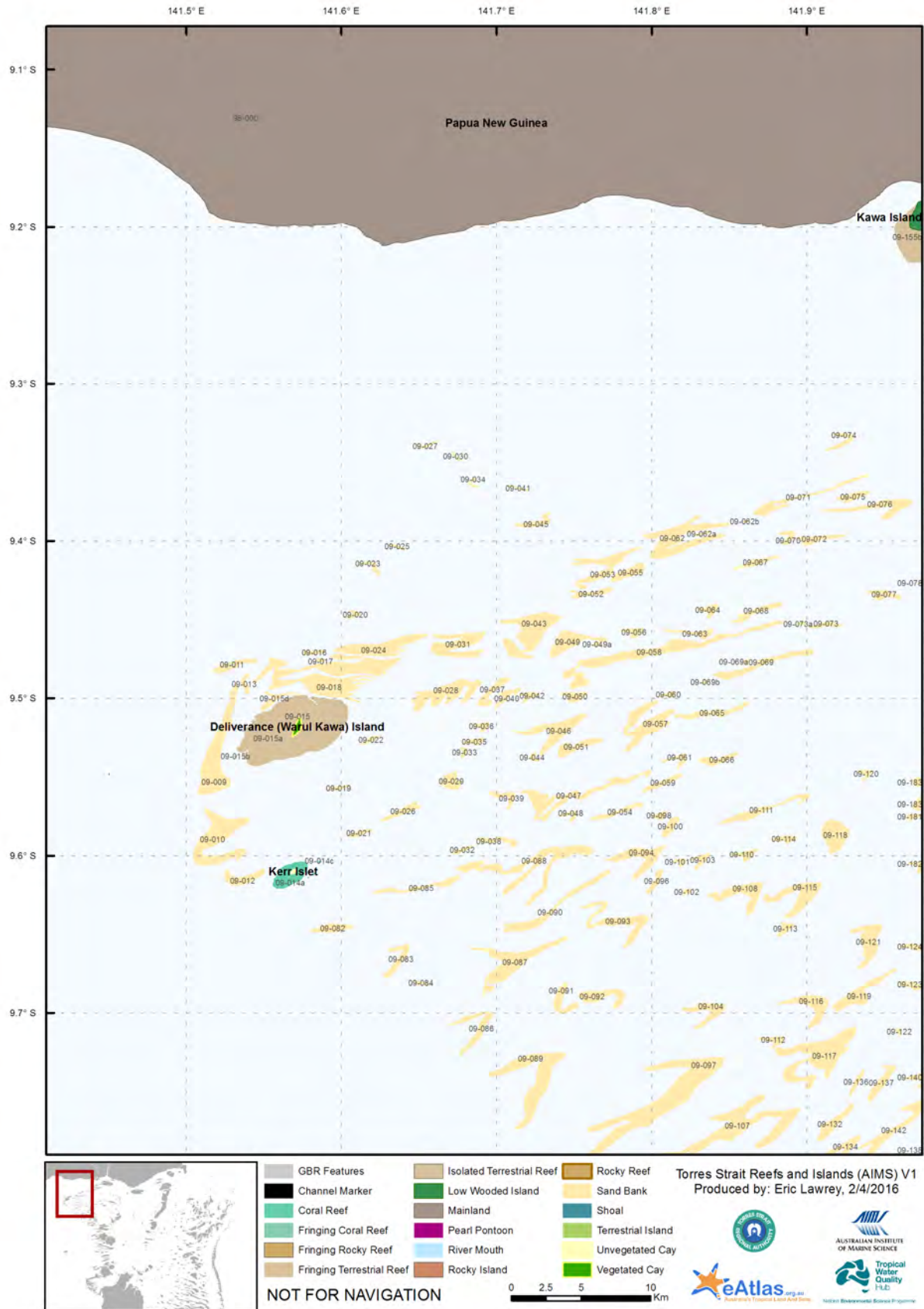
```

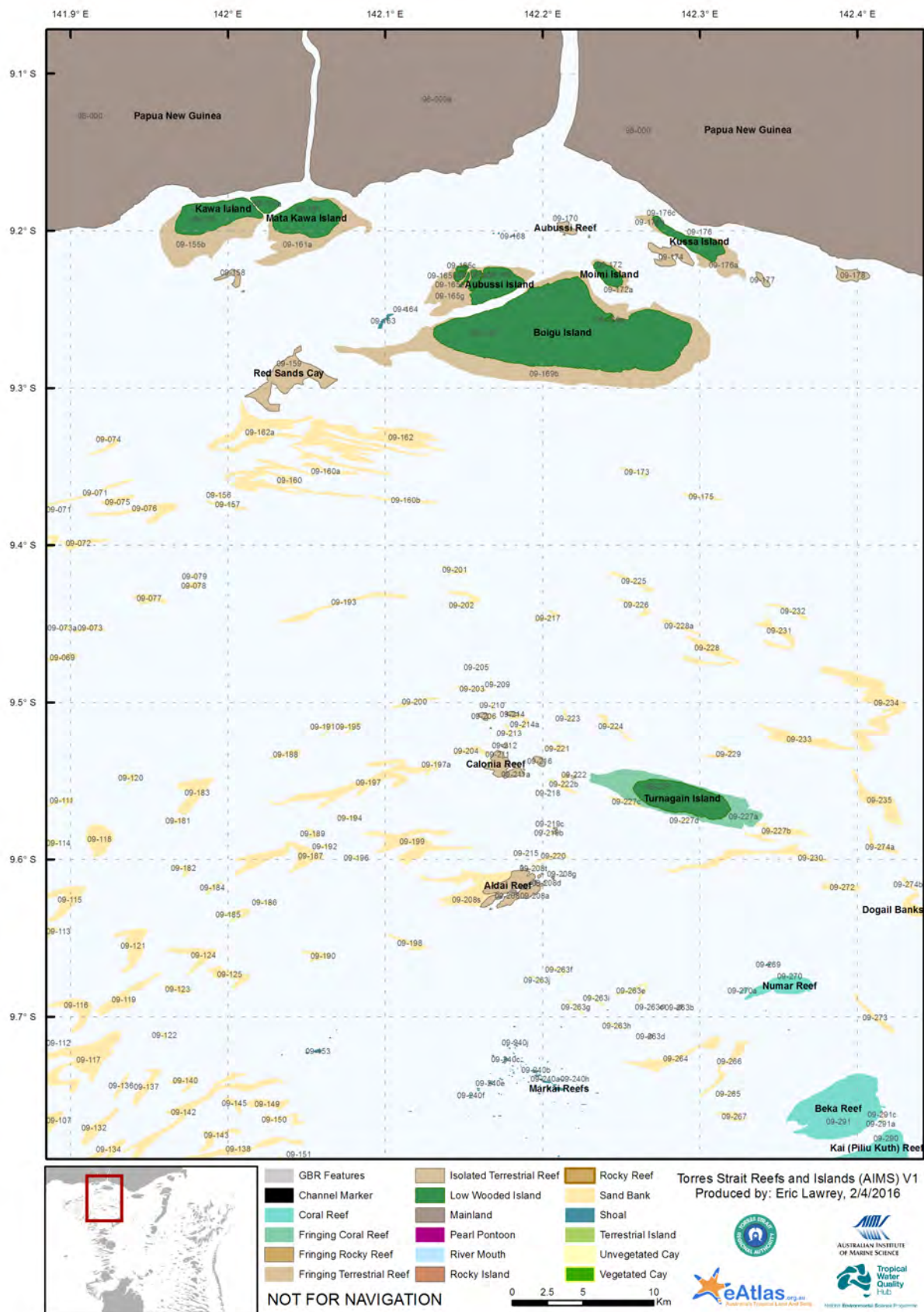


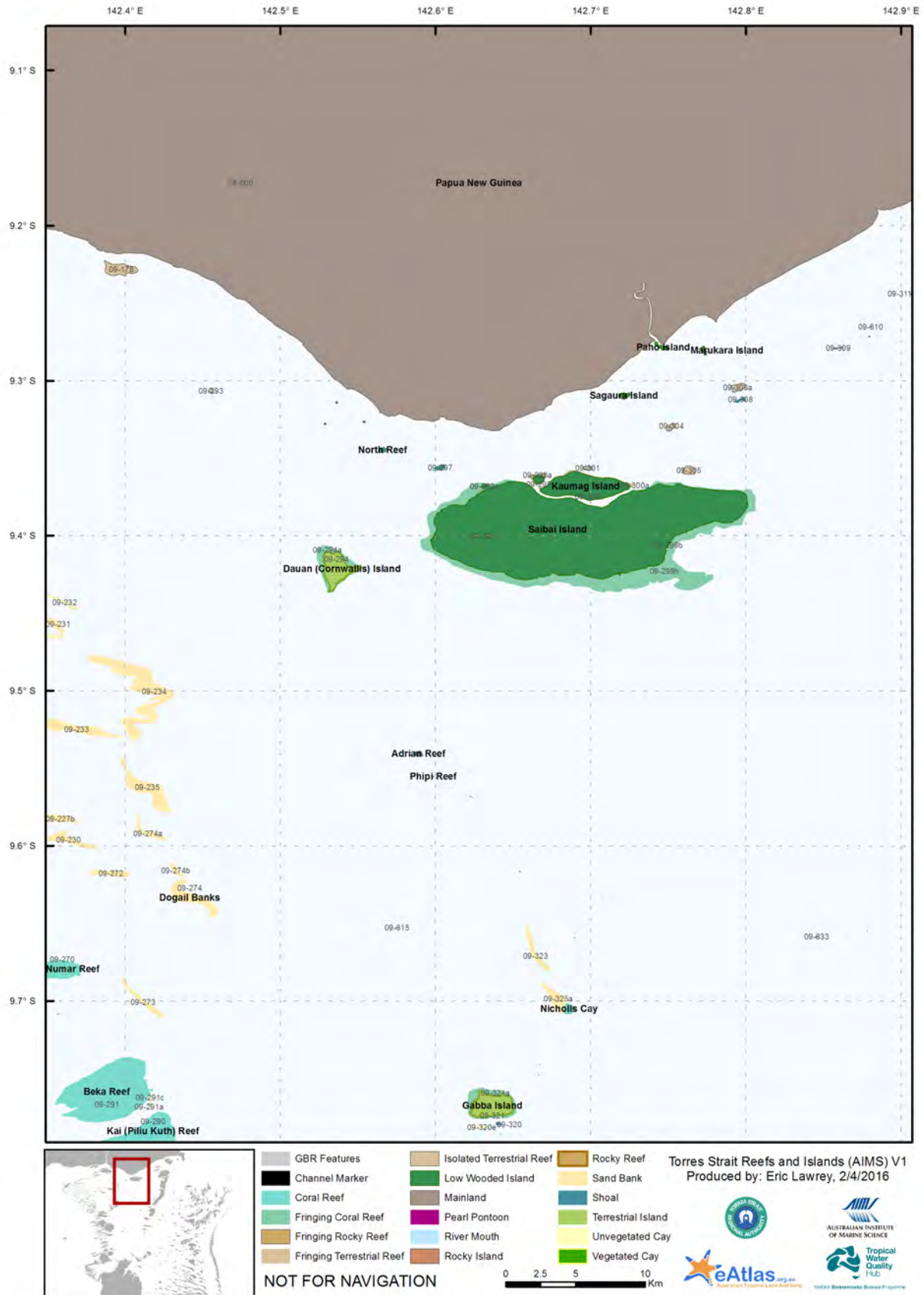

Figure 45: One of the oldest (1855) maps of southern, western and northern Torres Strait (Great Britain. Hydrographic Dept., 1855).

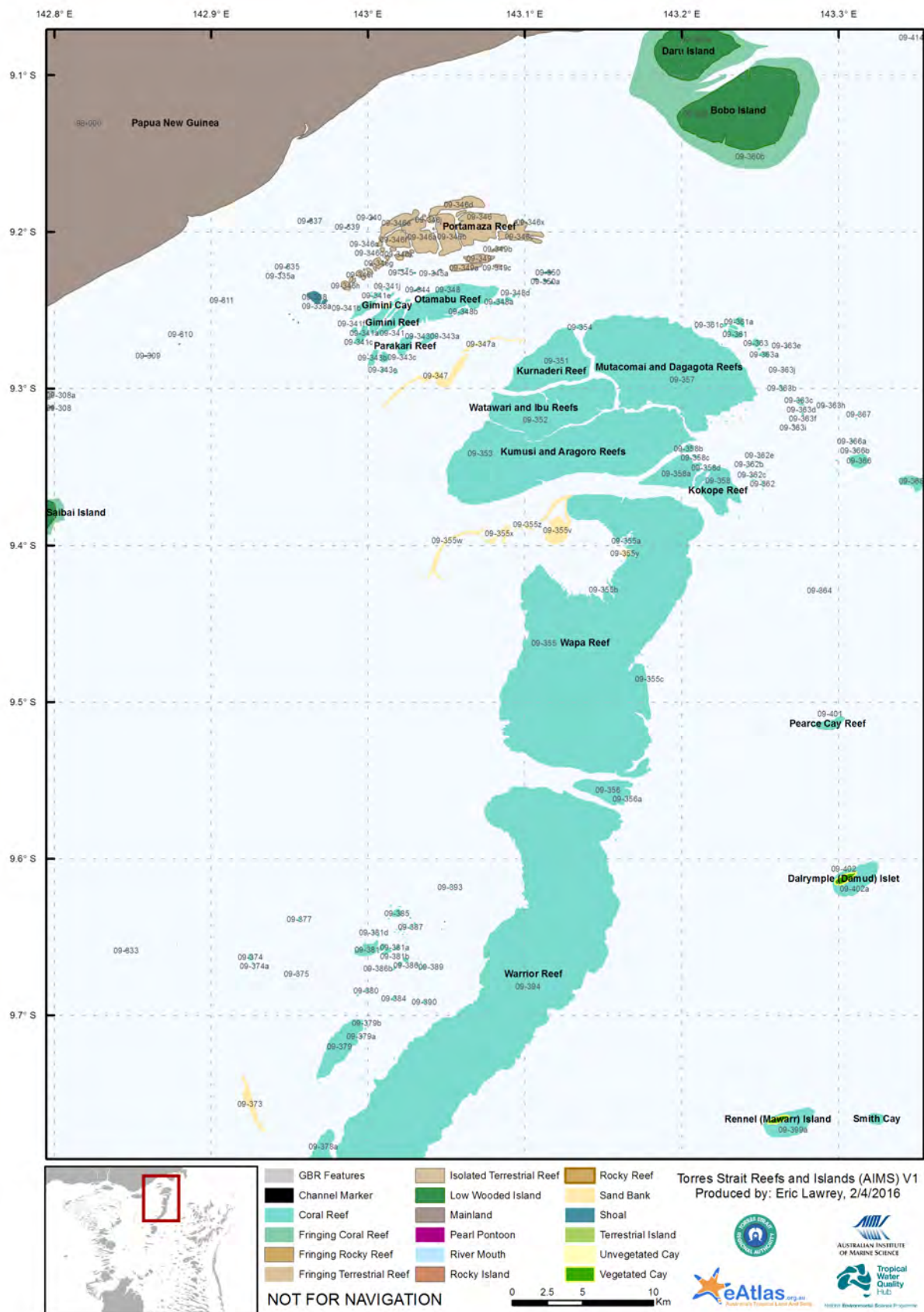
APPENDIX 10: MAPS OF THE NEW TORRES STRAIT REEF AND ISLAND FEATURES DATASET

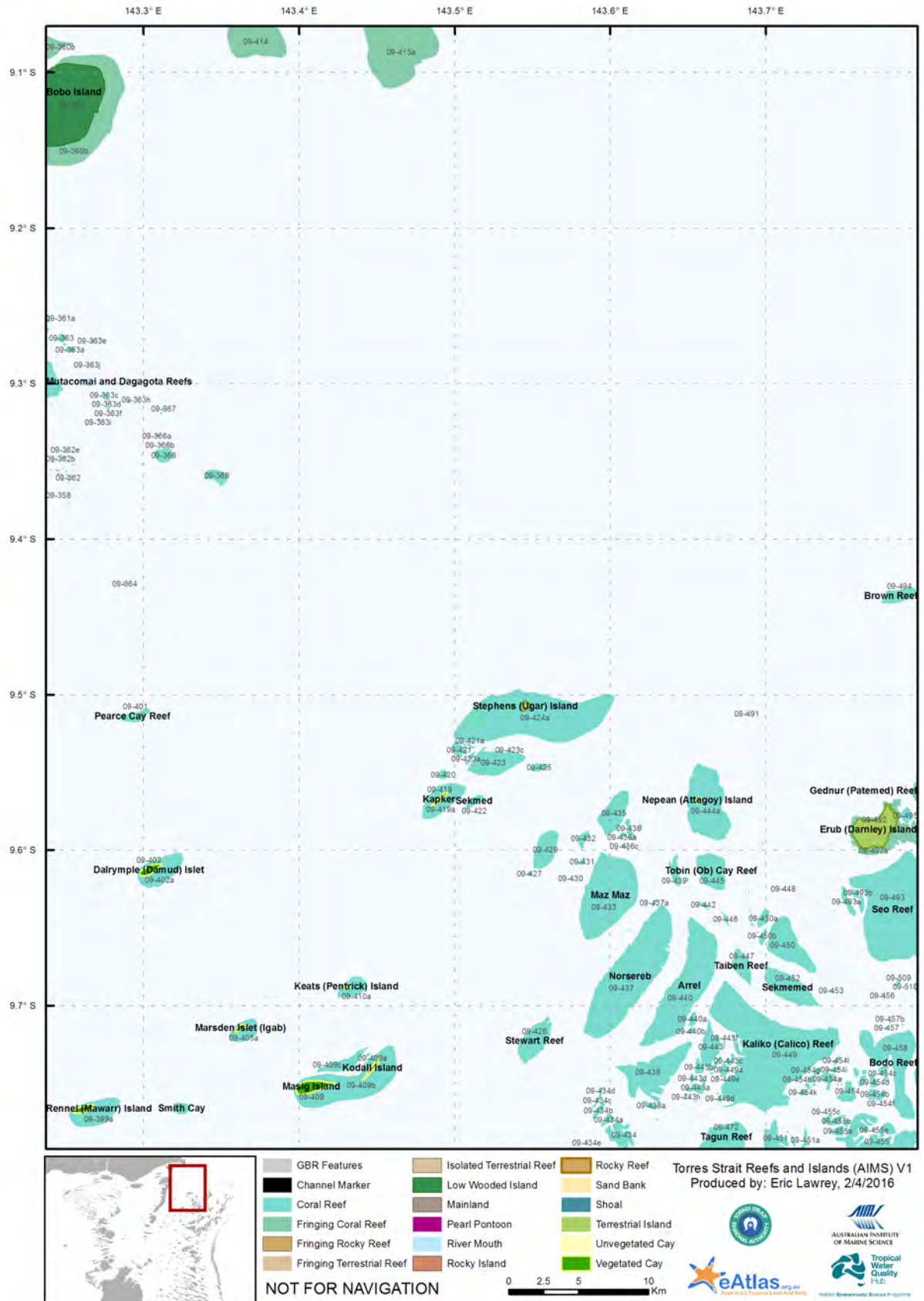
The following are a set of sample maps made from the new dataset. These maps are at a scale of approximately 1:330k and as a result many of the details in the dataset are not visible in these maps. These maps are intended as a preview for the dataset.

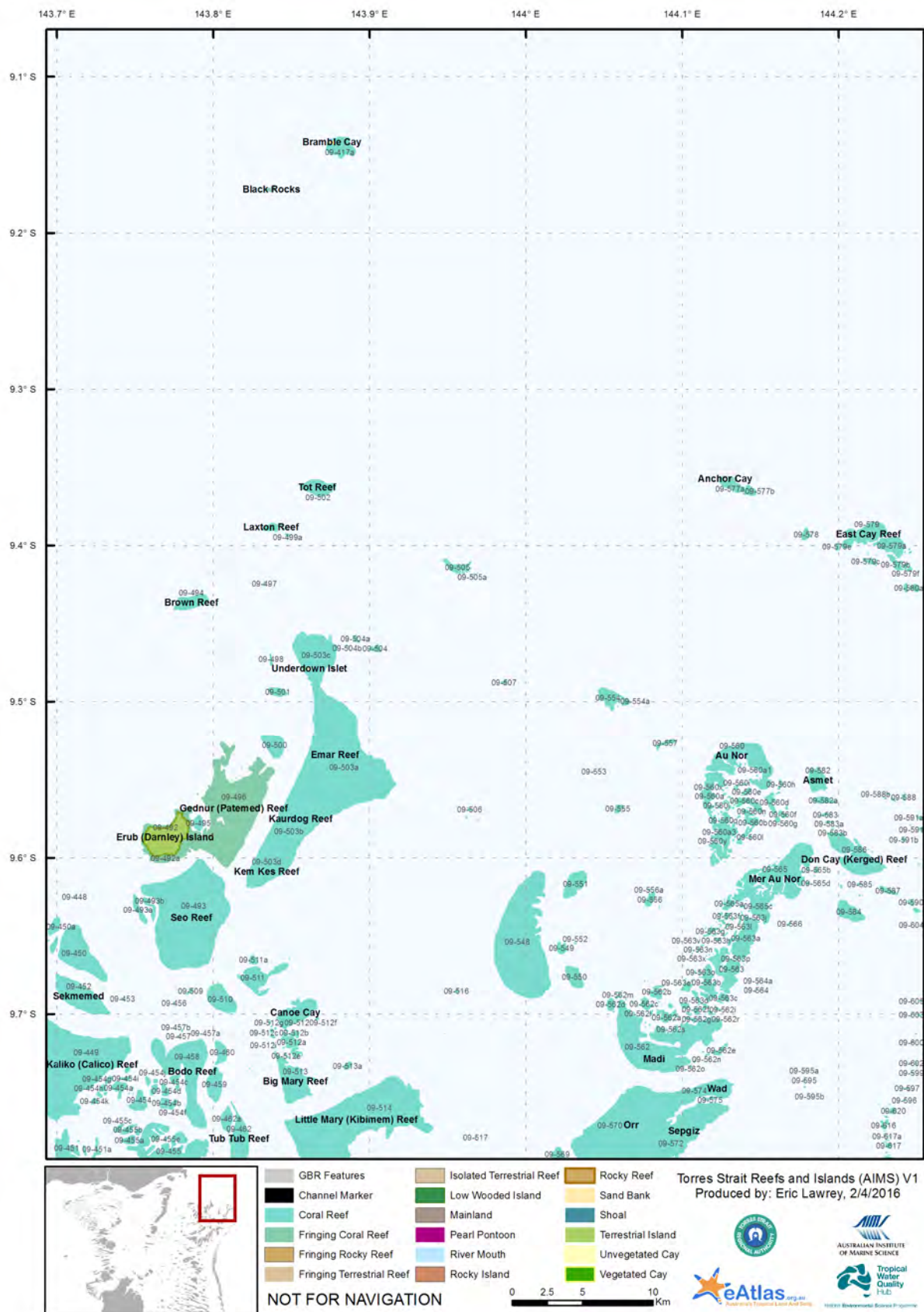


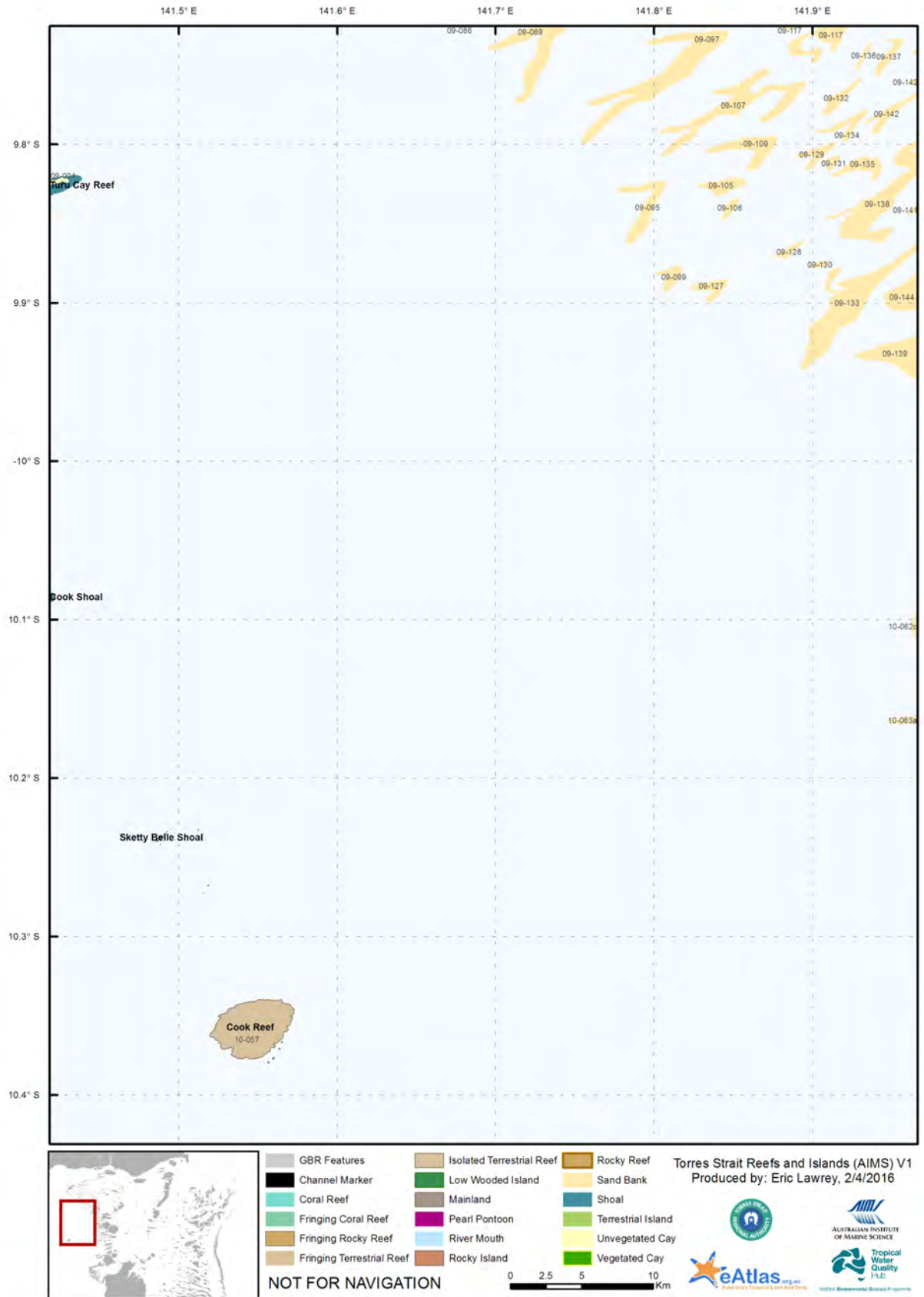


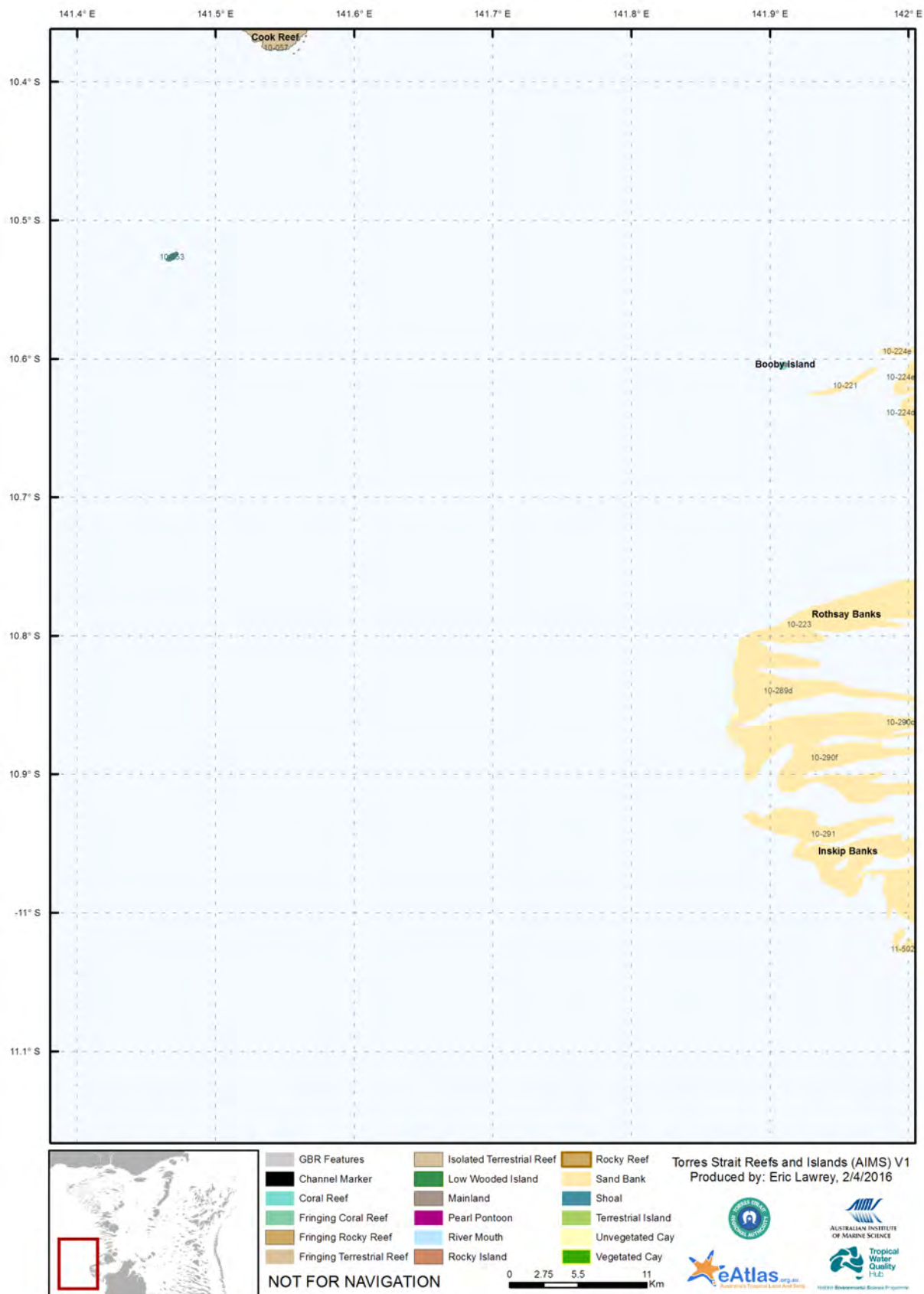


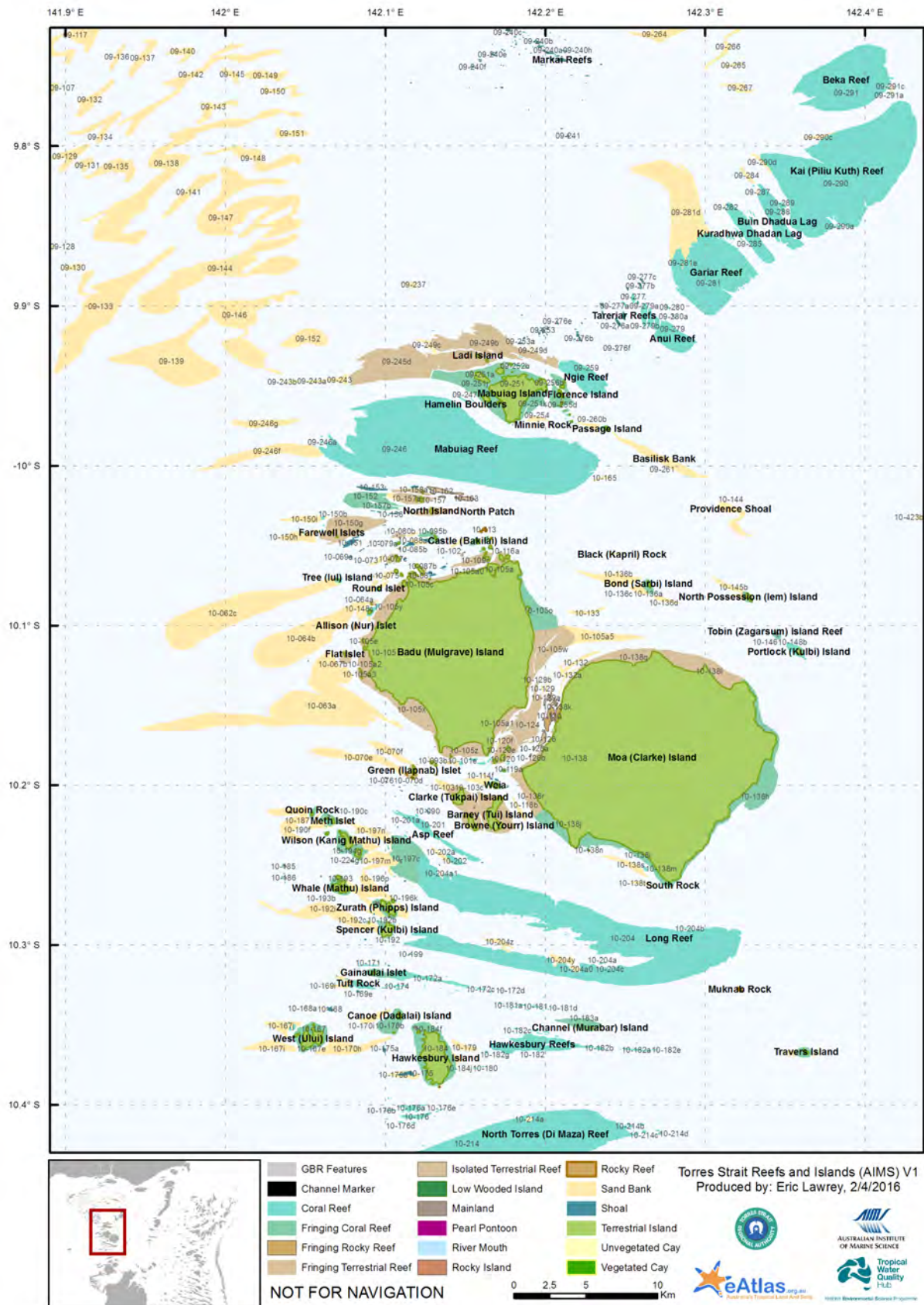


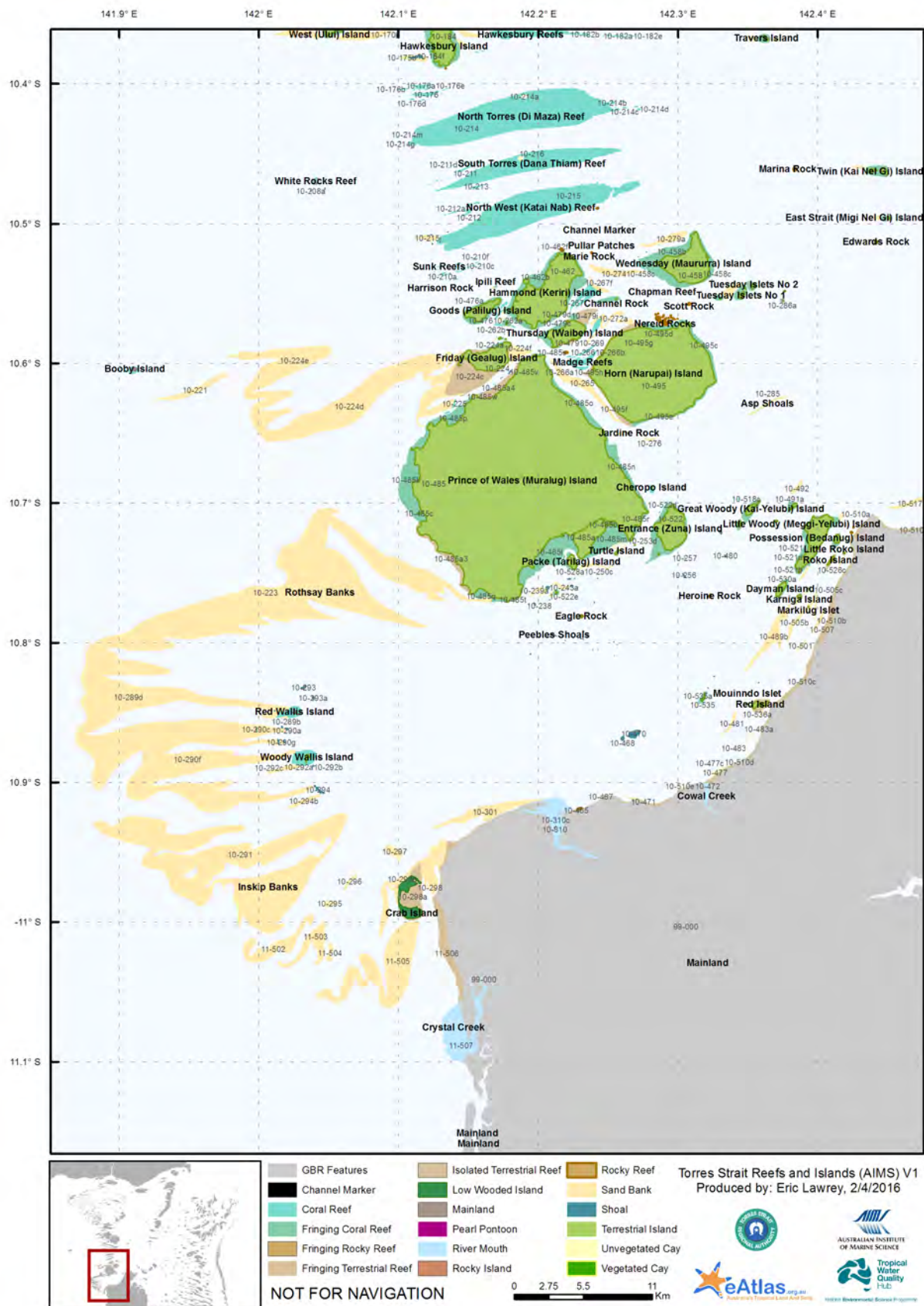


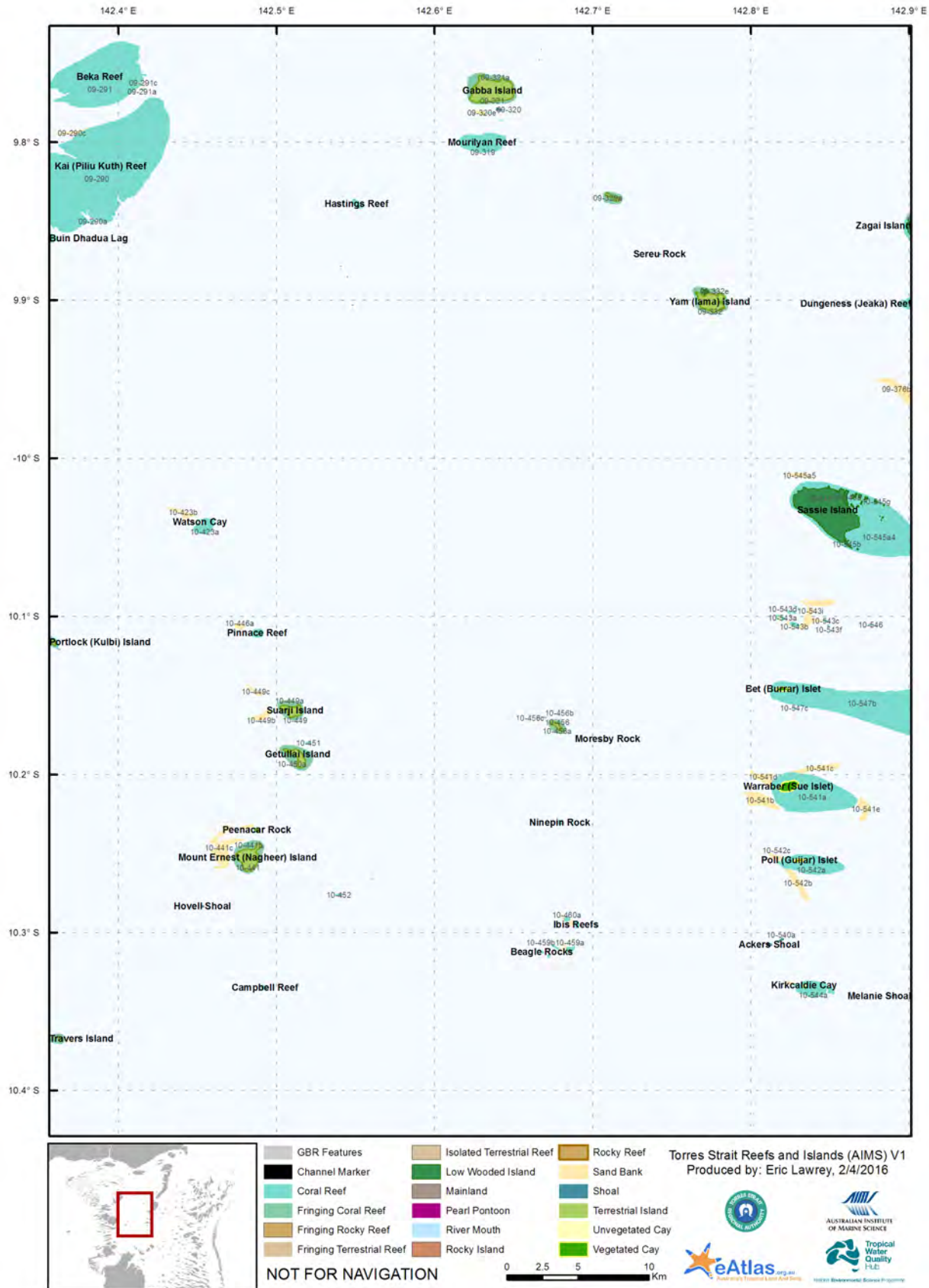


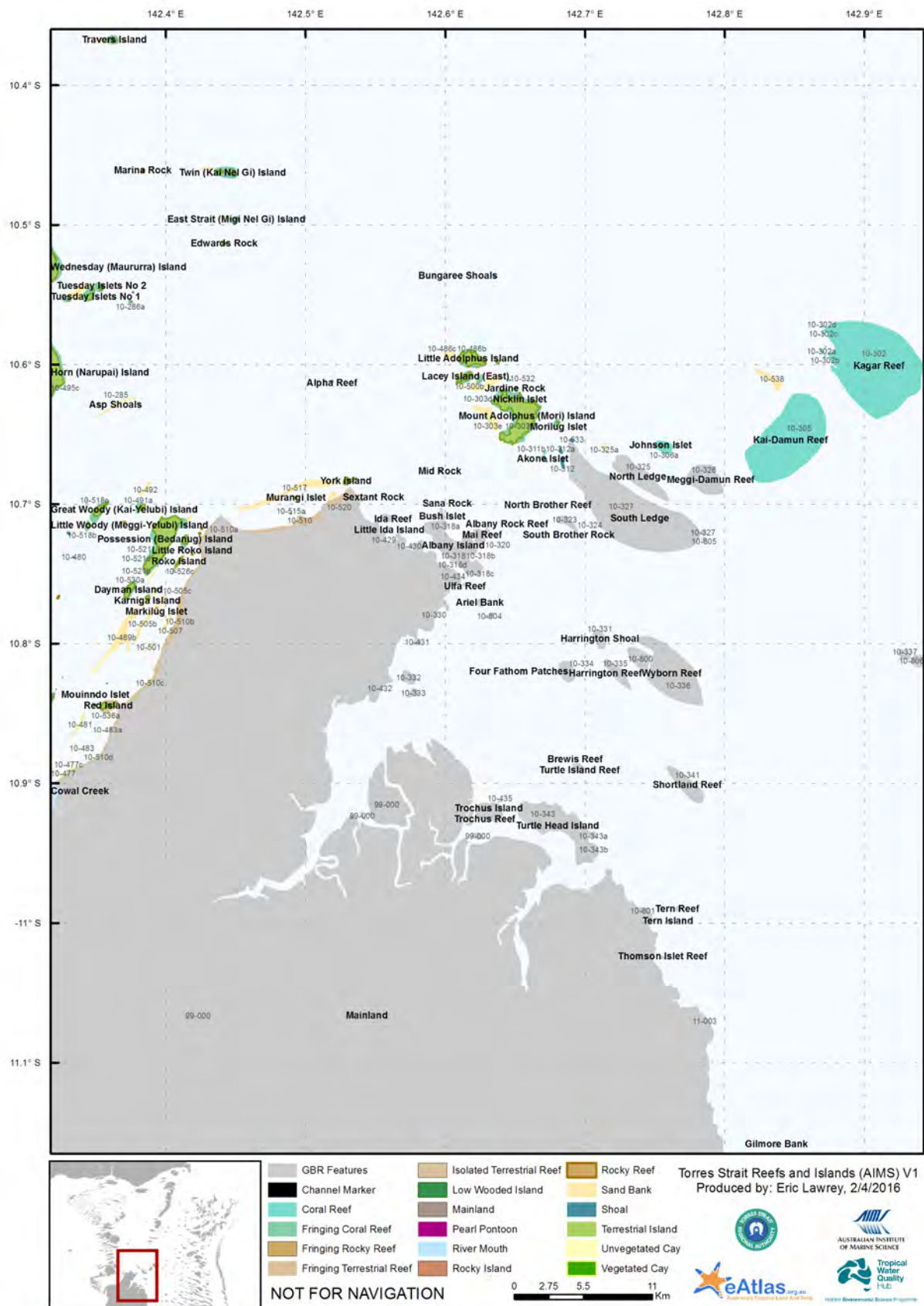


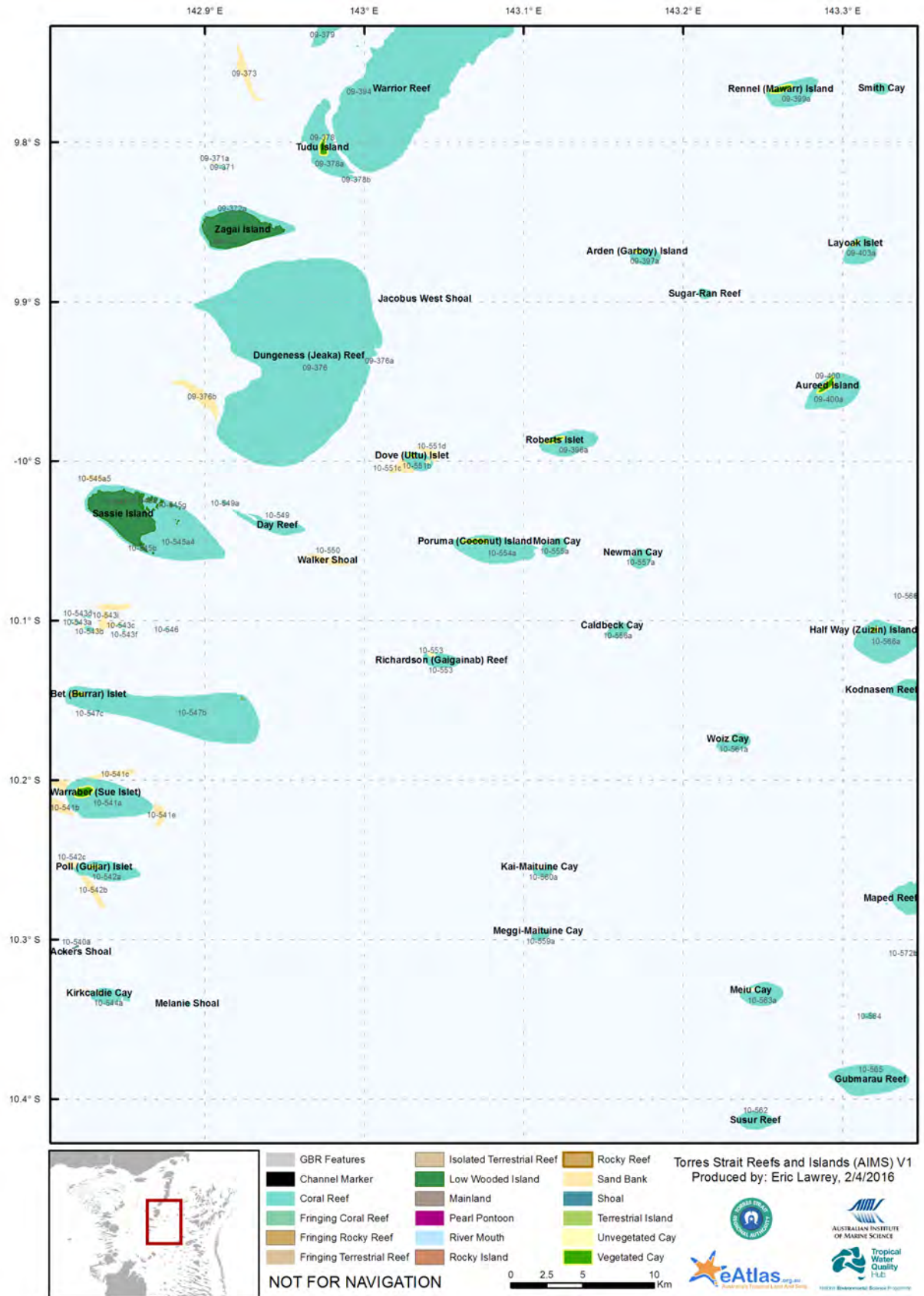


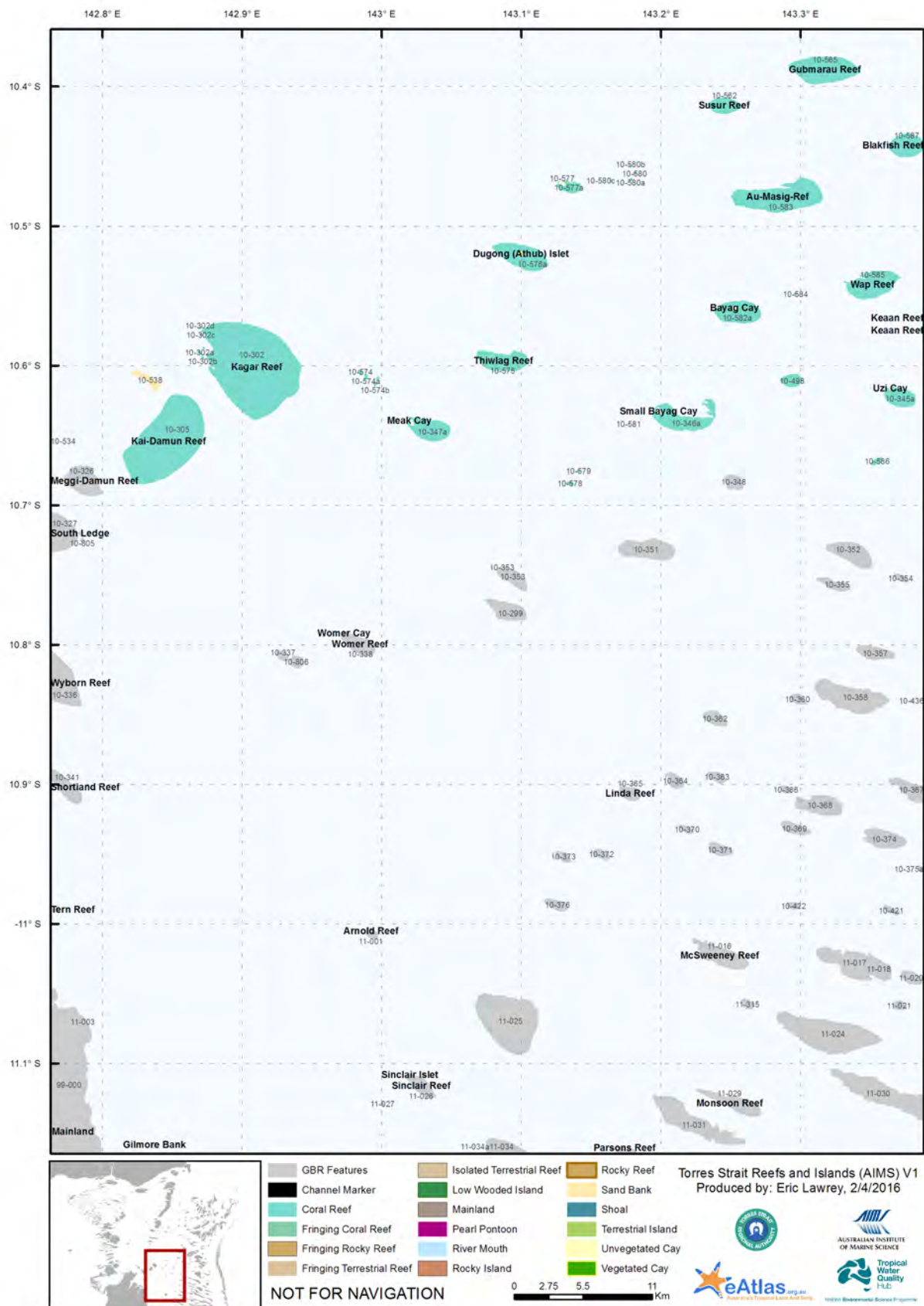


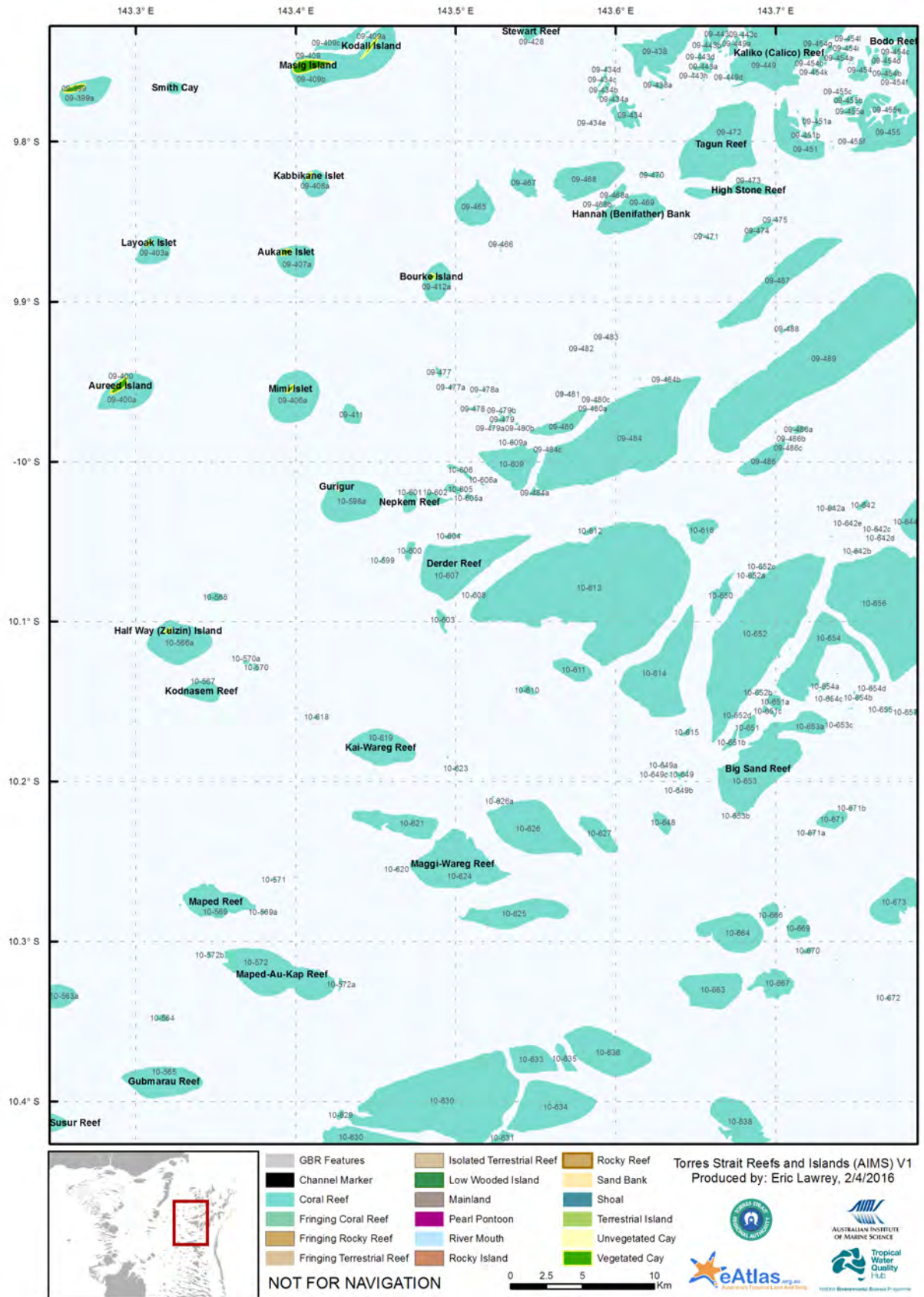


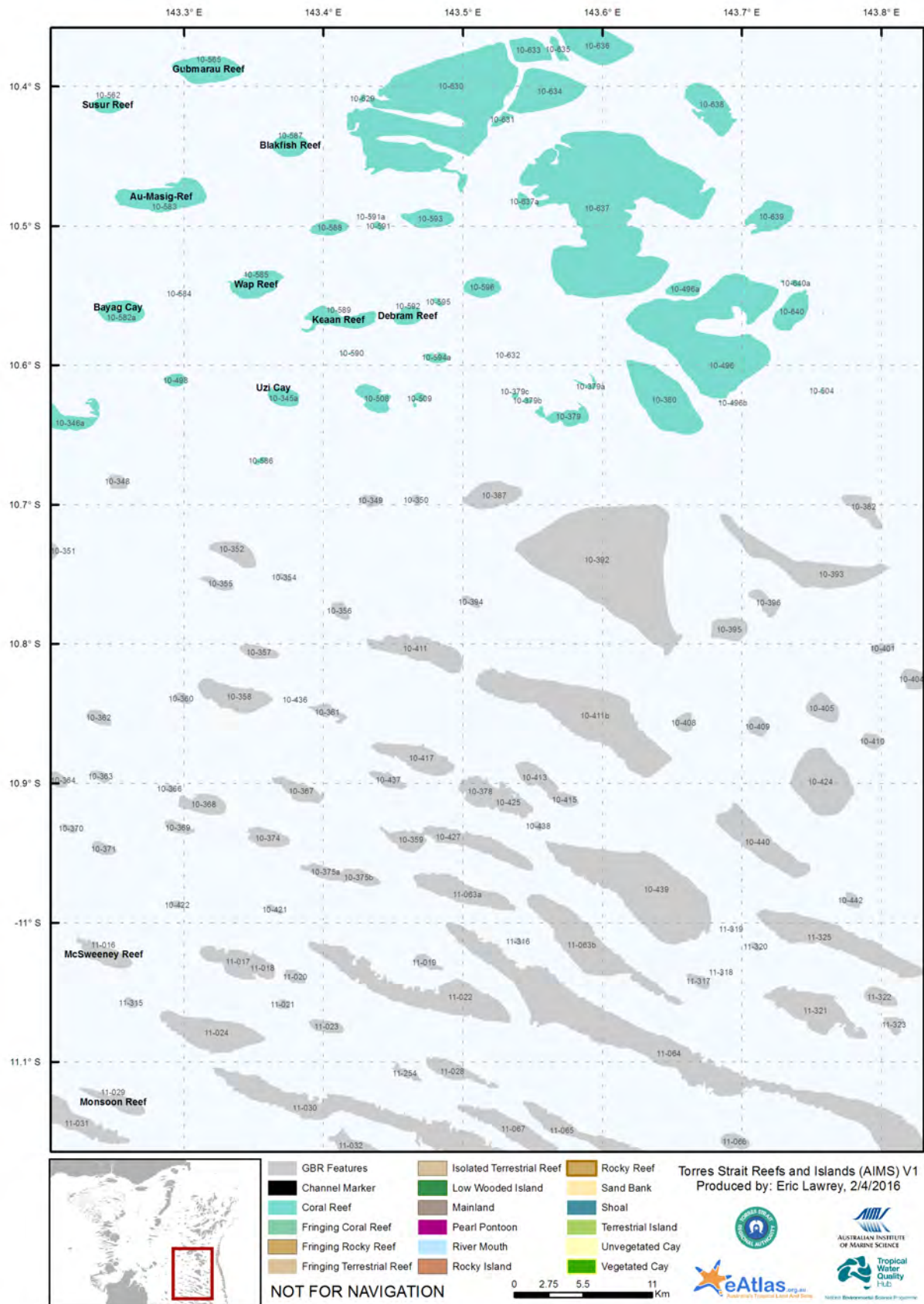


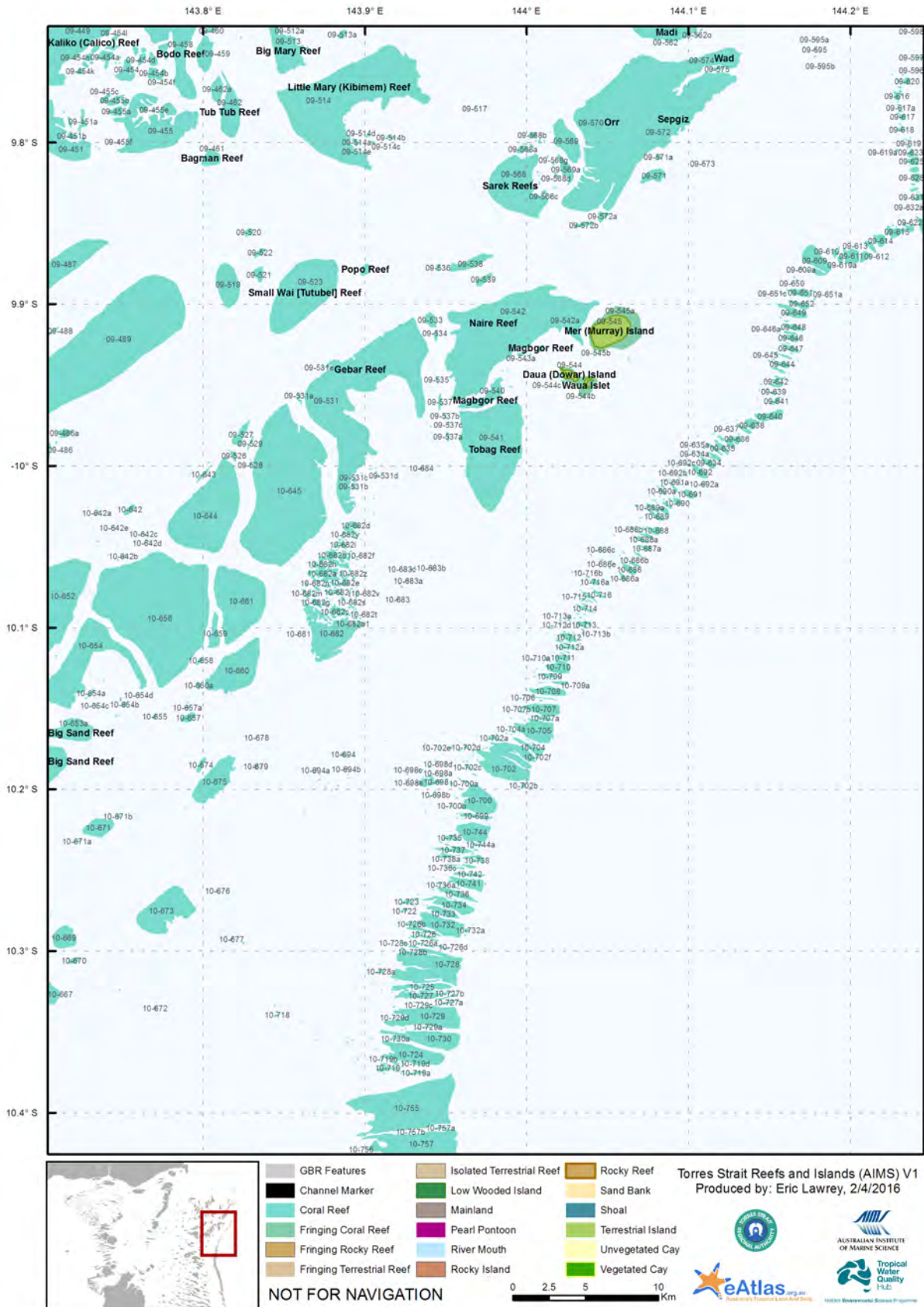














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