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AUSTRALIAN INSTITUTE OF MARINE SCIENCE

Aerial surveys of coral bleaching

Standard Operational Procedure Number 11

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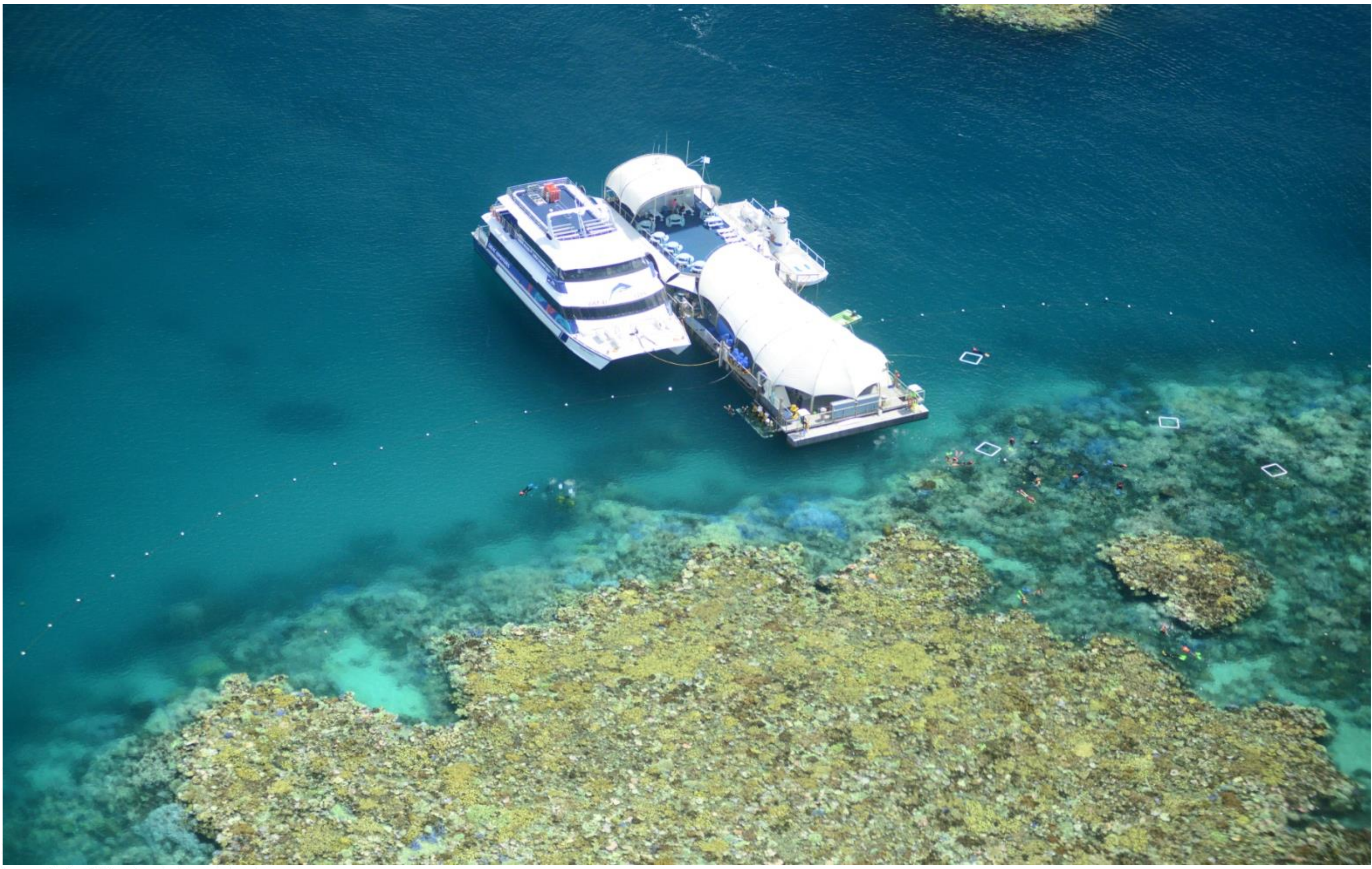

SOP II – Edition I (2017)

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Cover photo:
Extreme bleaching (>60% of live coral cover affected) at Moore Reef near Cairns in March 2017.
Photo: Sam Noonan, AIMS

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1 PREFACE

The environmental and ecological monitoring programs of the Australian Institute of Marine Science contribute to the sustainable use and development of the tropical marine environment by setting baselines and by advising managers of changes in ecosystems and the environment[1].

This Standard Operational Procedure (SOP) is Volume 11 is part of a series of AIMS SOPs. Produced in collaboration with the Great Barrier Reef Marine Park Authority it details a standard procedure to conduct aircraft-based aerial surveys of coral bleaching extent and intensity. Details on data management, training, and quality control are also provided.

2 INTRODUCTION

Mass coral-bleaching events, evident as widespread regional-scale episodes of stress in reef corals, typically follow periods of warmer than average sea temperatures. Bleaching stress manifests as paling or whitening of coral tissues as symbiotic zooxanthellae are expelled. As part of this process, any fluorescent or other animal pigments sometimes produced by the coral host tissues becomes accentuated often giving the coral a vivid ("fluoro") colouration of blue, pink, purple or yellow. White and fluoro corals are easily seen from the air.

Mass coral-bleaching events do not necessarily affect all reefs within a region during a bleaching episode and rarely are bleached reefs affected to the same intensity. Obtaining a large-scale (100s – 1000s km) synoptic overview of bleaching events is important because it documents the spatial extent, intensity and "patchiness" of reef wide community bleaching responses. This information is helpful because it:

1. Provides rapid and important information on the current status of reefs.
2. offers a historical context by comparing with past events.
3. allows possible cumulative effects to be assessed.
4. enables objective communication of the event in a timely manner.
5. provides a valuable dataset for assessing the ultimate impact of the event in a large spatial marine region.
6. provides a valuable dataset for research into spatial patterns of coral bleaching and analyses of correlations with environmental drivers.
7. builds a catalogue of reference data which can be used to improve our understanding of bleaching and refine reef management where appropriate.

Broad-scale aerial surveys are an effective and rapid method for documenting bleaching across large scale marine ecosystems.

They are generally conducted using fixed, high-wing aeroplanes at low altitude (~150m) but they can also be done by helicopter. Aerial surveys are generally carried out in partnership with the Great

[1] For more information visit https://www.aims.gov.au/measuring-change

Barrier Reef Marine Park Authority (GBRMPA) and possibly other research agencies[2]. They are one component of GBRMPA's Coral Bleaching Risk and Impact Assessment Plan which provides a framework for decisions, actions and responses to bleaching events (GBRMPA 2013). According to the plan, when response levels 2 or 3 (Fig 1) have been reached, a two-tiered reef assessment is triggered.

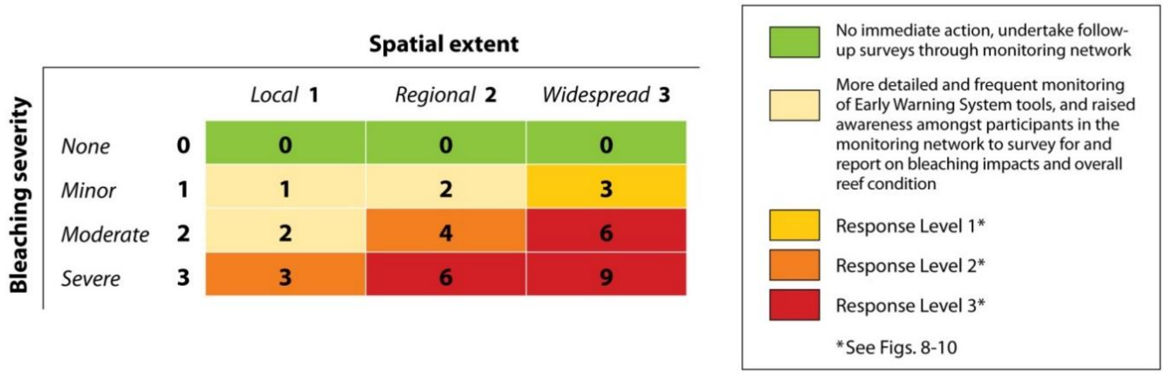

Figure 1. The classification matrix used in GBRMPA's Coral Bleaching Risk and Impact Assessment Plan used to inform the final decision as to which response level needs to be triggered. From: Coral Bleaching Risk and Impact Assessment Plan (GBRMPA 2013).

The Great Barrier Reef Marine Park stretches 2300km along the Queensland coastline, covering an area of 344,400km2 and is composed of more than 3000 individual reefs. Documenting the full extent of coral bleaching events in a marine region of this scale requires an aerial approach in combination within water surveys. Aerial surveys provide a broad-scale overview for coral communities on the reef flat (<3m) and the upper reef slope (0-6m). At a subset of reefs and sites, in-water surveys provide more detailed information on community type, taxon-level responses, attenuation of bleaching with depth and verification of aerial observations.

3 DETAILED PLANNING

GBRMPA coordinates the aerial surveys as the agency responsible for implementing the Coral Bleaching Risk and Impact Assessment plan, generally in consultation with science agencies such as AIMS and other stakeholders.

Detailed planning takes into consideration:

1) Specific objectives of the survey, e.g.
   a) Regional overview of bleaching, severity and extent.
   b) Training of personnel
   c) Inter-observer comparison
   d) Historical comparisons to bleaching
2) Geographic scope of the survey taking into consideration supporting information on the unfolding bleaching event to date, time, budget and logistics. Full coverage of the GBRMP is required but should focus on regions that are most likely impacted by SST anomalies.

[2] Note: the Australian Institute of Marine Science does at present not conduct aerial coral bleaching surveys as part of its routine Long-Term Monitoring Program

3) Identification of observers and their roles. Depending on the specific objectives of the survey, these should include as a minimum two observers. One for the left and one for the right side of the plane. Depending on seats and weight restrictions, more observers and a navigator can be included. An example of roles could be:

   a) Observer 1 – Recording data into tablet, left. Photographs,
   b) Observer 2 – Recording data onto hardcopy maps, right. Photographs
   c) Observer 3 – Recording data into hardcopy maps, left. Photographs
   d) Observer 4 – Recording data onto tablet, right. Photographs, left.
   e) Navigator – Flight path adherence, liaison between observers and pilot, verbal cues on location to observers.

4) Drawing up a flight plan. For consistency and comparison with past aerial surveys, the flight plan should replicate previous flight paths as much as possible. A "priority list" of reefs should be drawn up which includes in-water survey sites/long-term monitoring sites, reefs with in-situ temperature loggers and/or reefs of particular interest for other justified reasons. If any of these reefs are not on the flight path, they may be added subject to flight constraints. Flight constraints usually relate to maximizing the flying time with highest number of priority reefs and total reefs covered by the survey.

5) Timing of surveys. This takes into consideration the need to conduct the surveys when bleaching is at its peak (most intense), but before major mortality sets in. This will be informed by early warning systems (e.g. satellite-derived temperature/bleaching products, real-time temperature monitoring, bleaching thresholds, etc.), in-water surveys from tourism and industry partners, anecdotal reports from the general public and scientists actively accessing the local coral reefs. In the past, the GBR surveys have generally been undertaken in March.

   Early warning systems include:

   Satellite SST

   NOAA Coral Reef Watch: https://coralreefwatch.noaa.gov/satellite/index.php (Global)

   Bureau of Meteorology Reef Temp Next Generation- Sea Surface Temperatures Anomalies and Degree Heating Days (14-day IMOS climatology): http://www.bom.gov.au/environment/activities/reeftemp/reeftemp.shtml (Great Barrier Reef)

6) Weather. Bleaching observations can be severely affected by weather. Wind can cause sediment resuspension which can dramatically reduce visibility of bleached coral below the surface. This is more of an issue inshore than offshore. However even offshore, breaking waves over reefs and bommies can severely affect bleaching observations and photographic documentation of the observations. For this reason, it is advised to conduct aerial surveys when wind forecasts are <15kn. Consideration also needs to be given to whether inshore reefs should be surveyed in the morning or afternoon given wind forecast, cloud cover and tide.

7) Rain often has only a modest impact on surveys. Pilots generally don't take small planes through rain showers if they can avoid them, preferring instead to go around the showers. Due to the localized nature of showers, often this precludes only a limited area from being covered in the survey. Rain radar information can inform on conditions shortly prior to the flight and provides an opportunity to make minor adjustments to the flight path if required.

8) Time of day and tides are generally also of secondary importance. Surveying at a low or medium tide height is certainly preferable but high tide observations can also be made provided water clarity is good and tide is not too high (<3.5m). Sun glint can be a problem, particularly in late afternoon but this can be ameliorated by changing the direction of approach to the reef. Low sun angle in the late afternoon (>5pm) however can severely limit observations. The optimal time to document, assess and photograph the reef from the air is between 9am and 3pm.

4 EQUIPMENT

Equipment required for aerial surveys consists of:

- GPS's for navigation and flight path (track) recording
- Tablets for real-time visualization of location/position
- Tablets and/or paper maps for data entry
- Intercom system and audio recorder
- Cameras (still and video)
- Personal gear

These are discussed in more detail below.

4.1 GPS Recorders

Prior to the survey a GPS is used to as a time reference to synchronize cameras and audio recorders to. This is an important step because it allows all images and audio tracks to be geo-referenced later (see Section 2.5).

During the survey, they are used mainly to provide a detailed track of the flight path. Care should be taken to ensure the GPS's are setup to record at pre-determined 5 second intervals. Place a few around the cabin, preferably near windows, but avoid the GPS's from overheating and turning off!

If you are using a tablet without a built-in GPS, it may be necessary to either tether a GPS or set up a WIFI/Bluetooth GPS transponder to get your electronic maps to show your position. Using tablets with built-in GPS is preferable. Make sure you have tested and understand your equipment before you set off! Flight time can be wasted on the ground dealing with equipment issues. Pre-flight preparation is crucial to ensure the flight time is used to its full potential.

One set of fresh AA batteries will last a Garmin GPSMAP78 a whole day. It has sufficient storage capacity for 10,000 track points. Be aware that smaller, cheaper units may be more power hungry and less generous on track point storage.

It is advisable to check the battery status of each GPS after each flying leg. It can be useful to turn the GPS's off between flights provided you don't forget to turn them back on again for the next flight.

IMPORTANT DOs AND DON'Ts

1. DON'T use any automatic track log features your GPS may have! Usually this feature seeks to minimize the number of points recorded by only recording a point when the direction has changed. ALWAYS choose to record at fixed 5-second (or more frequent) intervals.
2. DON'T hit the save button at the end of the trip. That is right – DO NOT SAVE! Modern GPS's can be too smart for our good! A common feature is that they remove waypoints with the same (or close) coordinates upon Save. Some even change the time stamp format from UTC time to some other time format when saving to save space. This can play havoc with geo-referencing your images. Track logs are normally written to flash memory which means they are automatically saved when data is written to it and are not erased when the GPS is turned off.
3. DO test your GPS to ensure that the track is saved automatically when the GPS is turned off.
4. DON'T leave your GPS under the front windscreen of the plane. GPS's have built-in temperature sensors and turn off when they get too hot. Use multiple GPS's to be sure! Check them from time to time if possible.
5. DO make sure you put fresh batteries in the GPS before the survey.
6. Do make sure your GPS's have enough memory to store your track points for a day's flying. Some smaller, cheaper models don't! Check their specifications!
7. DO download your GPS tracks every day!

4.2 Tablets/computers for real-time navigation

If you are recording onto paper maps, some form of real-time visual position information can be a lifesaver. This is particularly important if you are not in the front seat and have a restricted wide view. A laptop computer or tablet with a real-time geo-reference and appropriate maps can provide this navigational information and simplify the survey assessment. If your laptop or tablet has a built-in GPS, so much the better (highly recommended!). If not, you will need to either tether a GPS or find a wireless GPS solution.

A good choice of software to run on the computer or tablet is Memory Maps which have GBRMPA Marine Park zoning maps as one of the map options that can be purchased. This software is available in your App Store for Windows PC, Android, or iPhone/iPad operating systems. These maps are preferable because they contain all the relevant reef-related information such as reef name, reef sub id, indicative reef outlines and zoning. As a bonus, this app also provides aircraft speed, altitude and other potentially useful information. Other map systems may also be suitable if they provide an equivalent level of information.

One tablet/computer per observer/navigator would be ideal. Tablets in 8" (200mm) configuration take up very little space and can be easily handled next to, or on the observers' lap.

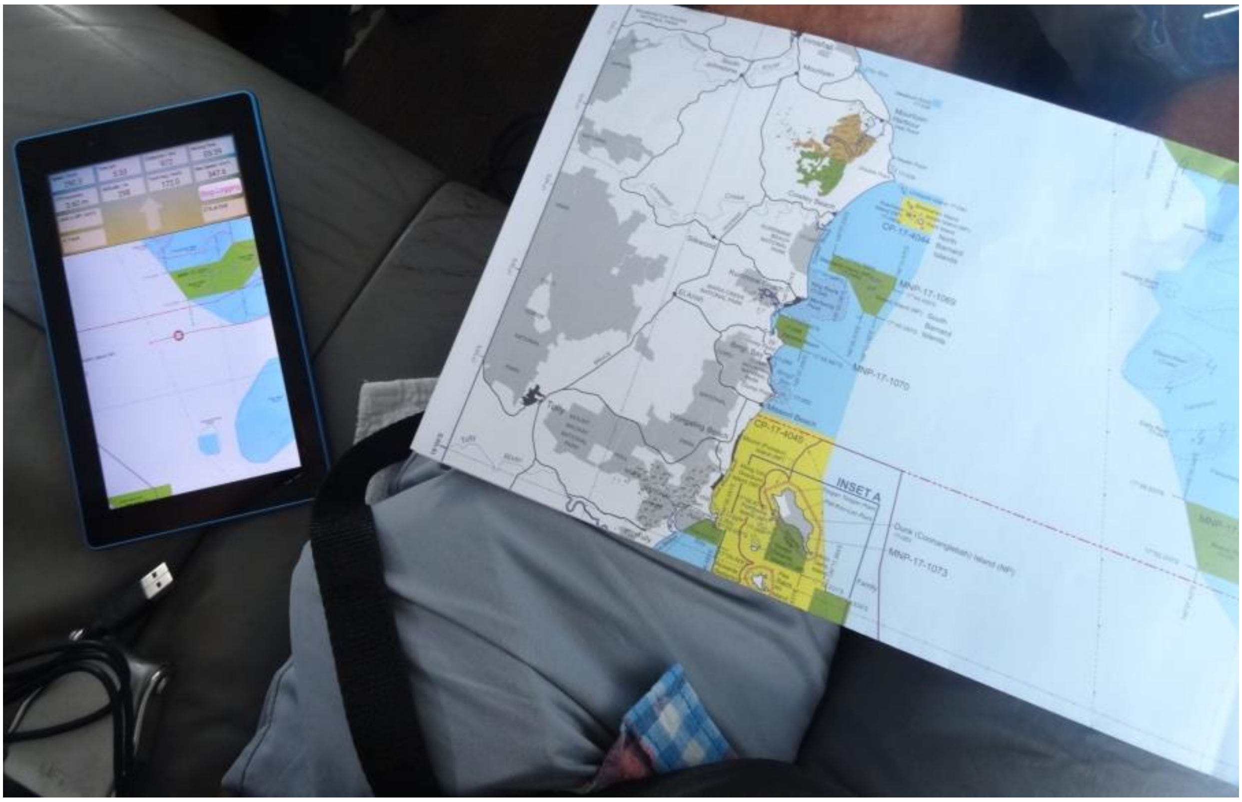

Figure 2. As used in 2017, real-time navigational information is provided by an 8" Android tablet running Memory Maps mapping software, used in conjunction with hardcopy GBRMPA zoning maps to record bleaching.

4.3 Tablets and/or paper maps for data entry

Until (and including) the 2016 bleaching event, all data entry was onto hardcopy GBRMPA zoning maps. This is a tried and proven, low-tech method of data entry with very little that can go wrong. However, there are down-sides to this method of data entry. These include cumbersome folding of large paper sheets, changing and stowing maps with each change in map coverage and, most significantly, considerably more time and effort in digitizing hand-written scores and notes with associated potential for error.

In 2017, a digital data entry system was trialed by one of the four observers involved in the survey in addition to the traditional paper data record. This involved an 8" (200mm) Android tablet (the same used for navigation) running the "ArcGIS collector" app, developed by AIMS and available in both Android and iPad operating systems from your App Store. This app enables the collection of geo-referenced bleaching observations and images from aerial and on-ground surveys. Some major advantages of this system are that all entries are automatically geo-referenced. It is also quick and easy to use, and the results can be instantly viewed during and after the survey. Once back in mobile/wireless range, your data are automatically uploaded to a server. No manual data entry is required. The 2017 trial was largely successful and bodes well for wider use in future

Figure 3. The trusted “paper database” in action

INSTRUCTIONS FOR USING THE AIMS CORAL BLEACHING APP

This app allows the collection of bleaching observations and geo-referenced images from aerial and in-water surveys. Your device should be set up while in mobile/wireless range. Afterwards, the app uses GPS only to record the points and will upload your data once you are back in mobile/wireless range.

For questions or problems, contact Ben Radford b.radford@aims.gov.au; James Gilmour j.gilmour@aims.gov.au or Kylie Cook 0427529077.

Downloading & installing the app

Use the links below, or search for ‘arcgis collector’ in your store

Android: https://play.google.com/store/apps/details?id=com.esri.arcgis.collector&hl=en

Apple: https://itunes.apple.com/au/app/collector-for-arcgis/id589674237?mt=8

- Click on “Collector”, choose ArcGIS Online
- Click “Continue” at next screen, which will bring you to sign in page
- Sign in (first time use only, or if you sign out)

Username: AerialSurveyUser

Password: CoralReef02

- Click on the “AIMS Coral Bleaching Aerial Survey App” or “AIMS Coral Bleaching Field Survey Pro” (depending on your type of survey). AIMS Coral Bleaching Field Survey Pro is designed for in-water or on-ground surveys.

Choose your work area (by dragging the boundaries of the box) and click “Download” (this downloads the base map – less than 5MB).

A complete set of instructions for this app can be found here.

4.4 Intercom and audio recording system

The 2016 and 2017 aerial surveys were the first to use an audio recording system with dedicated intercom between observers. This system was borrowed from the JCU dugong research team from Helene Marsh. It consisted of:

1) Audio recorders – 4-channel "Zoom Handy Recorder H4n". The kit included a primary recorder and a spare. This unit records to an SD card. A full day of recording resulted in an 8 Mb audio file. The audio recording has a timestamp which needs to be set to the GPS time (refer Section 2.5) so that recordings can be geo-referenced. At the time of writing the audio recording was used as a back-up in case there were discrepancies in digitizing data from paper maps.

   In future, even if all data recording is done digitally via tablets, the audio recording may be a useful backup in case of equipment failure, or if an observer misses entries for other reasons. It is therefore important that each observer calls out their scores as they make them. It is also useful if the navigator calls out location information on a regular basis, e.g. "approaching Noggin Reef from the SE, …traversing Noggin Reef south to north, … leaving Noggin Reef on the NW side…"

Figure 4. A four-channel Zoom Handy recorder H4n. The plug at the bottom right connects directly to the intercom box. Two intercom boxes can be plugged into the recorder at once. The stereo microphones on top of the recorder are only used when in autonomous mode

2) Intercom boxes – "Pilot Communications PA400S-ASC". The kit included two boxes which can each accommodate up to four headsets. The two boxes can be daisy chained to expand the system to seven headsets (the eighth socket-pair being taken up by the daisy-chain plugs). Each box runs off 2 x 9V batteries. Batteries were exchanged after each flying leg.

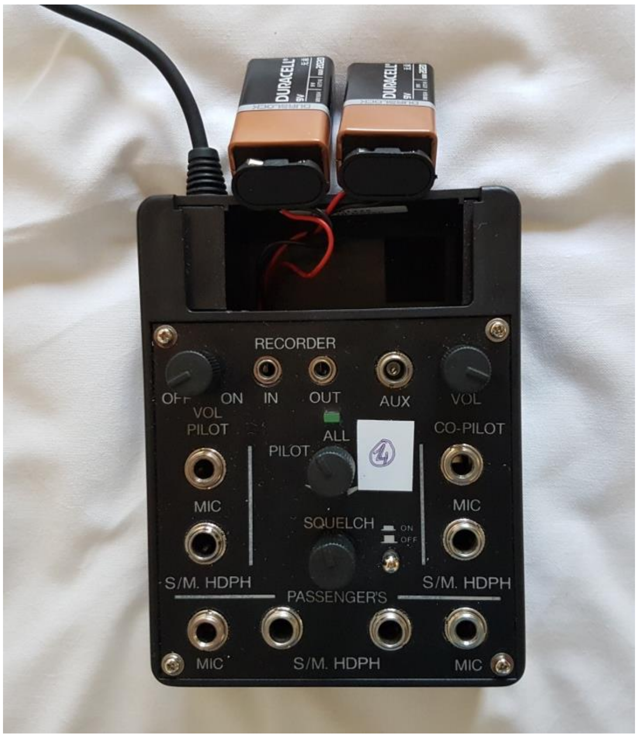

Figure 5. A 4-channel PA400S-ASC intercom box by Pilot Communications. There are 4 pairs of sockets to take headsets – designated as "pilot", "co-pilot", and two "passengers". The audio recorder plugs into the "Out" socket

3) Aviation headsets – "David Clark Company". The kit included seven headsets. Each set terminates into two plugs, one for the L and R speakers and one for the microphone. The microphone and speaker plugs are different diameters so there can be no confusion about what plugs go where. Any plug-pair can go into any socket-pair.

   With a single intercom box, a four-headset configuration is shown in Fig 6.

Figure 6. Four headsets plugged into a single intercom box with an audio recorder. To use it so that all four persons can talk to each other, the selector switch must be in the CENTRE position. Note that the daisy-chain plug-pair (top left of the intercom box) is left unplugged in this configuration.

With two intercom boxes and four headsets, the configuration looks like the set-up in Fig 7. If required (e.g. for inter-observer comparison), the top two headsets can be isolated from the bottom two by unplugging the daisy-chain leads while the recorder still records both sets of communication.

Headset extension leads may be required to provide enough reach from the intercom box to observers and navigator sitting in different rows and/or different sides of the plane, particularly if the plane is “large” (e.g. a 12-seater).

Figure 7. Four headsets plugged into two intercom boxes with a single audio recorder plugged into each intercom box. The two boxes are daisy chained via a set of connector leads which can plug into any socket-pair. The top intercom box can accommodate one more headset while the bottom intercom box can accommodate another two headsets. To use it so that all four (or seven) persons can talk to each other, the selector switch must be in the LEFT position.

4.5 Cameras

Photos provide an invaluable means of permanently capturing small-scale views of the bleaching state of reefs. Since observers only get a very short dwell-time over each reef (seconds – 10’s of seconds) and >100 reefs may be flown in a day, repeated over multiple days, it can be highly taxing on the brain (image overload). Committing this wealth of visual imagery to memory is near impossible. Reviewing the aerial images provides an opportunity for more of this information to “sink in” and regain perspective.

It is often also the case that new things are seen in photos which were missed during the flight (e.g. presence and extent of recent coral mortality, community types, deep bommies etc).

Photos and video are also very important for communication and training.

The rule of thumb is: “take lots”, even when you see little or no bleaching! For scientific and training purposes, the best images are ones that are zoomed-in (e.g. Fig 8). For communication purposes, the best images are ones which provide a wide view and have easily recognizable features in them (e.g. an island, boat, tourist pontoon etc). However, for the latter images to “work” (i.e. illustrate bleaching, bleaching must be intense and coral cover high (e.g. Fig 9, Front cover).

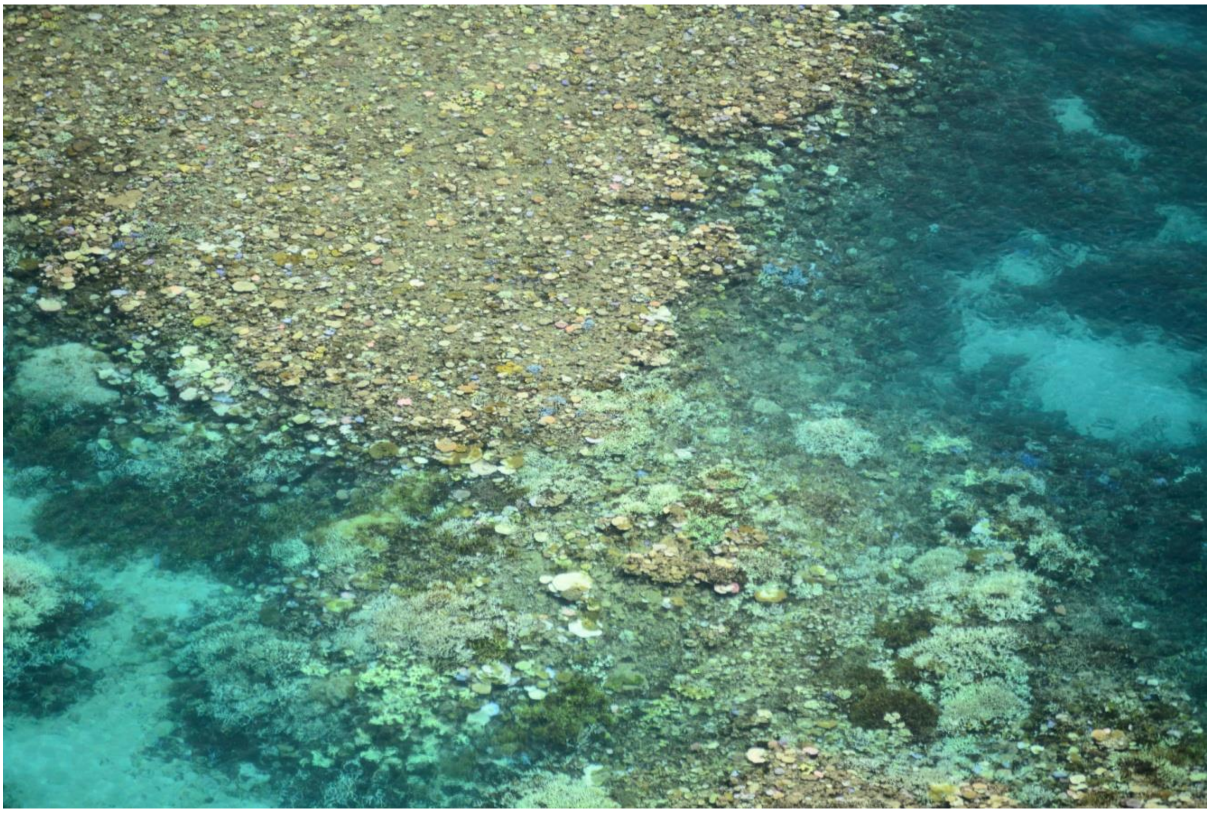

Figure 8. An example of a zoomed-in image for scientific purposes. It shows > 60% of corals bleached (white, pale or “fluoro”), recent mortality of staghorn/branching coral (green patches in the foreground) and that the community is dominated by plate corals on the reef flat and branching corals on the reef slope.

Figure 9. An example of a wide-view image suitable for communication showing extreme bleaching on Lorne Rf, an inshore patch reef, with Rattlesnake Island in the background. (Image taken March 1998).

For best results, use a good quality digital SLR camera fitted with a 70 – 300mm zoom lens. A circular polarising filter is recommended for reducing glare and improving the clarity of underwater features. Since the images "move" fast, use the fastest shutter speed your camera will allow in the light conditions. Shutter speeds of <1/1000th second are recommended. To achieve this, it may be necessary to reduce the F-stop (open the aperture, e.g. F1.8 - F5.6) and use a moderately high ISO number for increased light sensitivity (e.g. 800-1800 depending on the light conditions. Lower ISO settings give less "grainy" images). Turn the automatic image stabilization feature on your camera to "ON" and try not to support the camera (or arm, shoulder, elbow) on the side of the plane to minimize image blurring due to vibration. It is important to review photos as you go (when practical!) and adjust the settings as required throughout the flight as light conditions will change dramatically through the day.

Video imagery of the flight may be recorded using one or more Go-Pro video cameras (or equivalent) and a suction-cup mount through one of the back windows. Choose a window towards the back of the plane to avoid the landing gear and wings disrupting the field of view. Battery life on the Go-Pro was not sufficient for a single camera throughout the entire day. Four cameras were used in 6 hours of flight. Cameras were changed when possible by the closest observer and angled down to minimize the reflection and glare from the window. In future flight planning, aircraft with a vertical downward facing port would be ideal to equip the aerial survey with high-resolution video cameras and hyperspectral imaging cameras to obtain richer and more quantitative data of bleaching.

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IMPORTANT:

1. To geo-reference your photos, you need to set the camera clock to the time shown on a GPS. Ensure that the GPS has a clear view of the sky and a good fix (i.e. not indoors). Set it to the nearest second and check. Repeat until you get it spot on. This can save work later!
2. Take a photo of the GPS time with your camera so that the camera clock time can be verified and, if necessary, minor changes can be made.

4.6 Personal gear

On small planes, weight and room are at a premium. Therefore, it is important to keep personal gear to an absolute minimum. Take enough water with you to last the day, food, a towel to sit on and not much more. There is enough clutter in the plane with your scientific equipment!

5 AIRCRAFT CHARTER

The choice of what type of aeroplane to charter for the surveys can be a challenge. At a minimum, it should have high wings so that the view is not obstructed. Everything else (apart from safety!) is of secondary importance. Small single-engine planes such as the Cessna 172 (3 seats, plus pilot, Fig 10) are the cheapest to charter and most manoeuvrable (handy around islands and bays) and can fly quite slow (<100kn, also a plus). On the other hand, they only take a maximum of 3 observers and are somewhat cramped, especially with our equipment.

Larger-single engine planes such as the Cessna Grand Caravan (Fig 11) can seat up to 12 people (plus pilot and co-pilot), but for weight, manoeuvrability and comfort, no more than five people is recommended. It is considerably less manoeuvrable and more expensive than the Cessna 172. A Cessna 210 (Fig 12) with 5 seats (plus pilot) may be a good compromise, if you can find one.

Figure 12. Cessna 172

Figure 11. Cessna Grand Caravan

Figure 10. Cessna 210

Twin-engine, high-wing planes are intrinsically safer, and for remote offshore surveys, this may be preferable. They are generally more expensive to charter than their single-engine equivalent but for increased safety and size, they may be a wise choice. The smaller Cessna 337 Skymaster (5 seats, plus pilot, Fig 13) with its distinctive front and rear engines is excellent for aerial survey work and the pick of the bunch, but rare. The Partenavia P.68, now Vulcanair P68 (5 seats, plus pilot, Fig 14), is more common and also excellent.

Larger twin-engine planes such as the Aero Commander 500 (Fig 15) are also good, but expensive and hard to find.

Figure 15. Cessna 337 Skymaster

Figure 14. Partenavia P.68

Figure 13. Aero Commander

Corporate safety standards may require extra equipment to be carried on board the plane such as a life raft and a personal EPIRB/radio beacon for each passenger. For the 2017 survey, each passenger was equipped with a Nautilus LifeLine VHF-GPS Radio. If a life raft is needed, this should be communicated to the charter company early to allow them to find and fit it as they are not a normal aviation requirement over water.

Corporate safety standards and the availability of suitable aircraft may severely limit the choice of plane for the survey.

TIPS:

1. For the right aircraft and the right price, it may be worth relocating a plane from another airport, especially if the survey is for multiple days.
2. An aircraft broker who knows the industry and the availability of charter planes may save you a lot of time and effort!
3. Vertical ports for camera equipment would be an excellent feature when shopping for the survey plane.

6 SURVEY TECHNIQUE

6.1 Basic protocol

The survey technique is simple. The aircraft flies along a pre-determined flight path (refer Section 2) at an altitude of approximately 150m (500') and, upon entering visible reef area, each observer looks for live coral and scores the percentage of live coral that appears bleached. "Bleached" in this instance can be any coral colony that appears pale, white or "fluorescent" ("fluoro").

At this point the observer checks their position within the reef and writes their score on a paper map in the appropriate place. If an electronic data entry method is used, this step is taken care of in the software as all entries are automatically geo-referenced.

Using the AIMS Aerial survey bleaching app, the observer hits the (+) to add a new observation and then selects the bleaching category from the available radio buttons. If the plane traverses multiple reef habitats (Fig 16) observers score as many of these habitats as they can.

Reefs are classified into five bleaching categories based on the proportion of coral cover that appeared white in a zone covering the reef crest and upper reef slope (Berkelmans et al. 2004):

0 = <1% of live coral is bleached

1 = 1 – 10% of live coral is bleached

2 = 10 – 30% of live coral is bleached

3 = 30 – 60% of live coral is bleached

4 = > 60% of live coral is bleached

It is recommended that each observer keep a laminated copy of these categories and their ranges in front of them for ready referral (Fig. 16, Appendix 1).

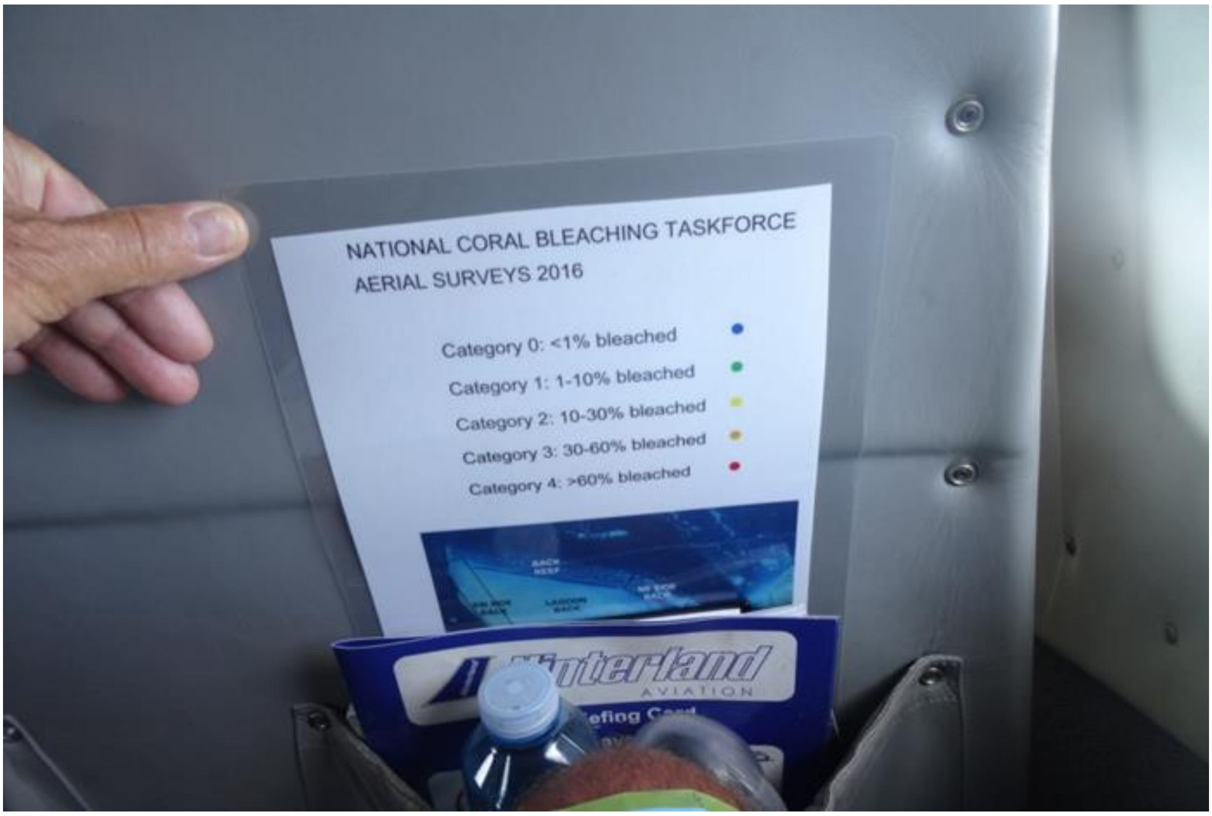

Figure 16. A laminated copy of the bleaching categories and a diagram of reef zones is kept in the seat pocket in front of the observer.

6.2 Discerning between categories

Scoring the bleaching state of a reef is by nature a subjective process. To maintain a high-quality dataset that is consistent between observers and with in-water observations, it is important that all observers be experienced in coral reef field ecology. It is also highly advisable that they have undergone a process of training and standardisation in the office/lab and in the air.

The technique requires observers to the know where on a reef to look for live coral, recognize what type of coral community is present and to know the difference between normally pigmented coral and bleached (or partially bleached) coral. In addition, observers also must discern living coral from dead coral, recently dead coral and bare substratum.

It is ultimately about very subtle differences in colour, shape and texture which only someone intimately familiar with how things look in the field are likely to be able to do well.

The mental process of deciding on a bleaching category for an observed patch of reef can be difficult even for trained observers, but the decision process can be thought of along these lines:

1) The two extremes: Category 0 (no bleaching evident, all corals look normally pigmented) and Category 4 (>60% bleached, most if not all corals are white, pale, fluoro or a combination) are normally easy to recognize. Seeing a category 4 is often a "wow, look at that!" moment.
2) Category 1 (1-10% bleaching) is when you see only a few colonies standing out from the reef as bleached white or fluoro, nothing major in the overall scene of typical reef substrate (brown green) but definitely present.
3) If your observation doesn't fall into the above categories, that only leaves two categories to decide between: Category 2 (10-30% bleached) and 3 (30-60% bleached).
    i. Category 2 (10-30% bleached) can be thought of as "low-level" bleaching. Bleached white corals are plentiful, although most corals look normal.
    ii. Category 3 (10-30% bleached) can be thought of as "moderate to high" bleaching. Bleached corals are very abundant, but by no means is everything bleached. Look between bleached colonies and get a perspective of the proportion of bleached vs healthy corals. This will also help differentiate Category 3 from 4 bleaching.

Prospective observers should review photo examples of each category and talk through the differences before the survey. At the beginning of the first flight especially, it is important to communicate observations among all observers to standardise scores as much as possible. It may be helpful to start with reefs close to home that observers are all familiar with. Do a few passes over a handful of reefs until observers have their "eye in".

7 EXAMPLE PHOTOS

Examples of visual aerial bleaching and scores are presented below. It is recommended that a more extensive database of photos be established, and added to, for the benefit of training observers.

Figure 17. Examples of bleaching Category 0 (<1% bleaching). Individual coral colonies may be hard to see, however the reef zone where you would expect to find living coral on the reef slope and edge suggests well pigmented corals.

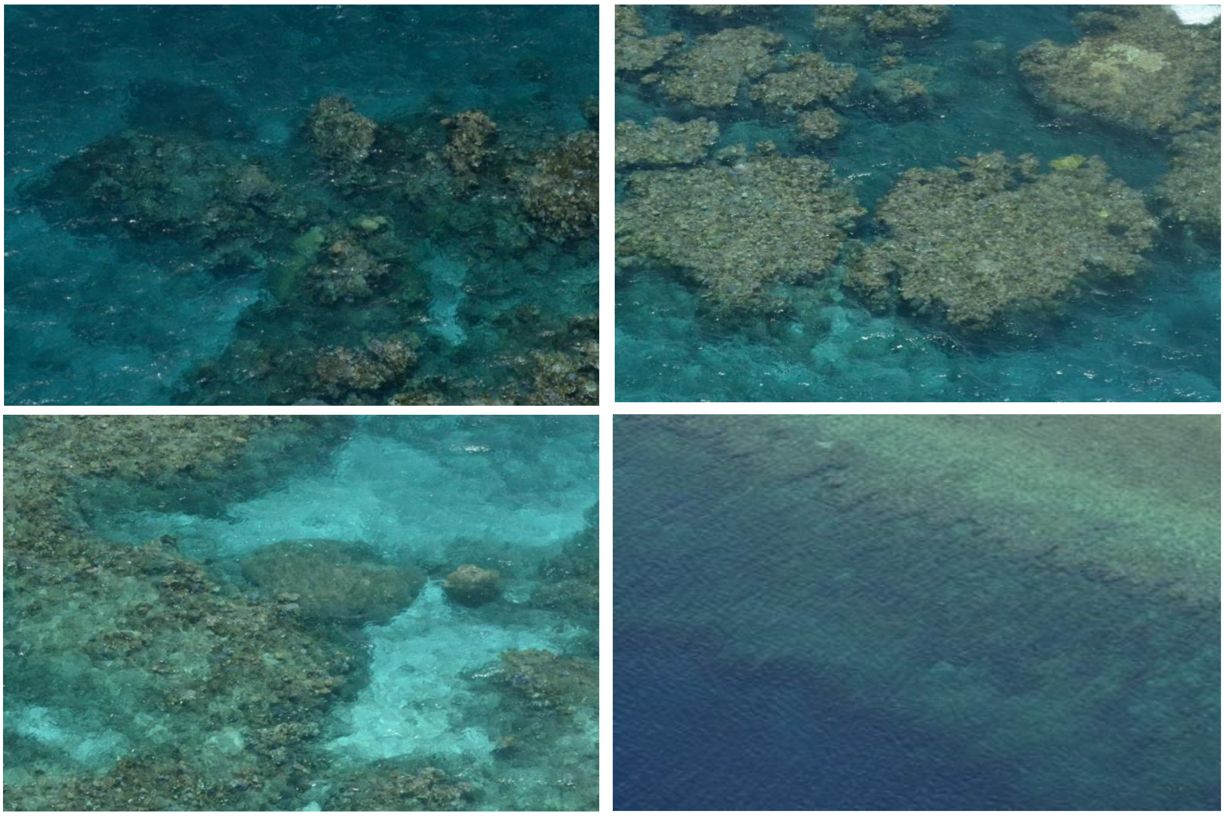

Figure 18. Examples of bleaching Category 1 (1-10% bleaching). It is challenging to portray this category from a photo but to the discerning eye once exposed to higher levels of bleaching, this category is characterized by a low % of pale corals among a reef scene that otherwise looks normal.

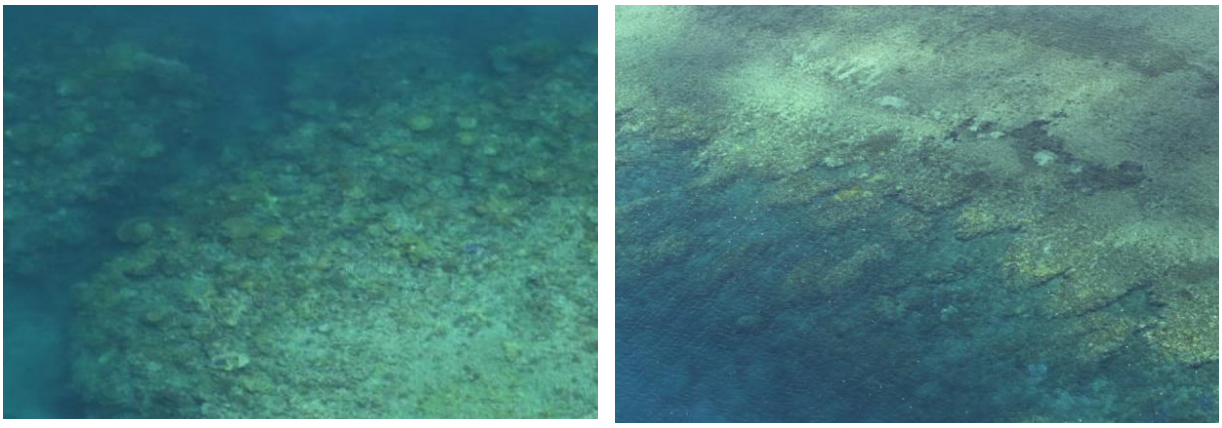

Figure 19. Examples of bleaching Category 2 (10-30% bleaching). A close look at the reef crest shows quite a few pale colonies, but most are still normally pigmented, especially down the reef slope.

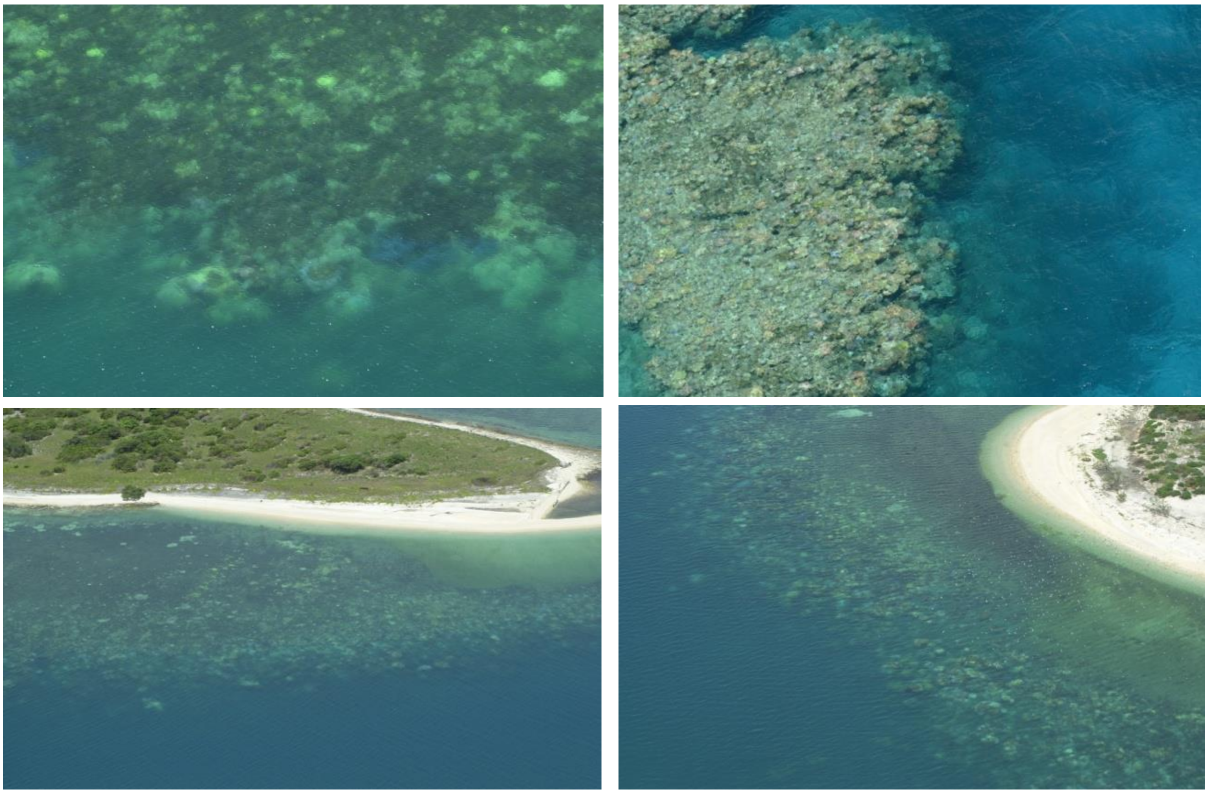

Figure 20. Examples of bleaching Category 3 (30-60% bleaching). About half the corals in these photos have started to bleach. In between bleached corals you can see an equivalent number with normal pigment, especially down the reef slope.

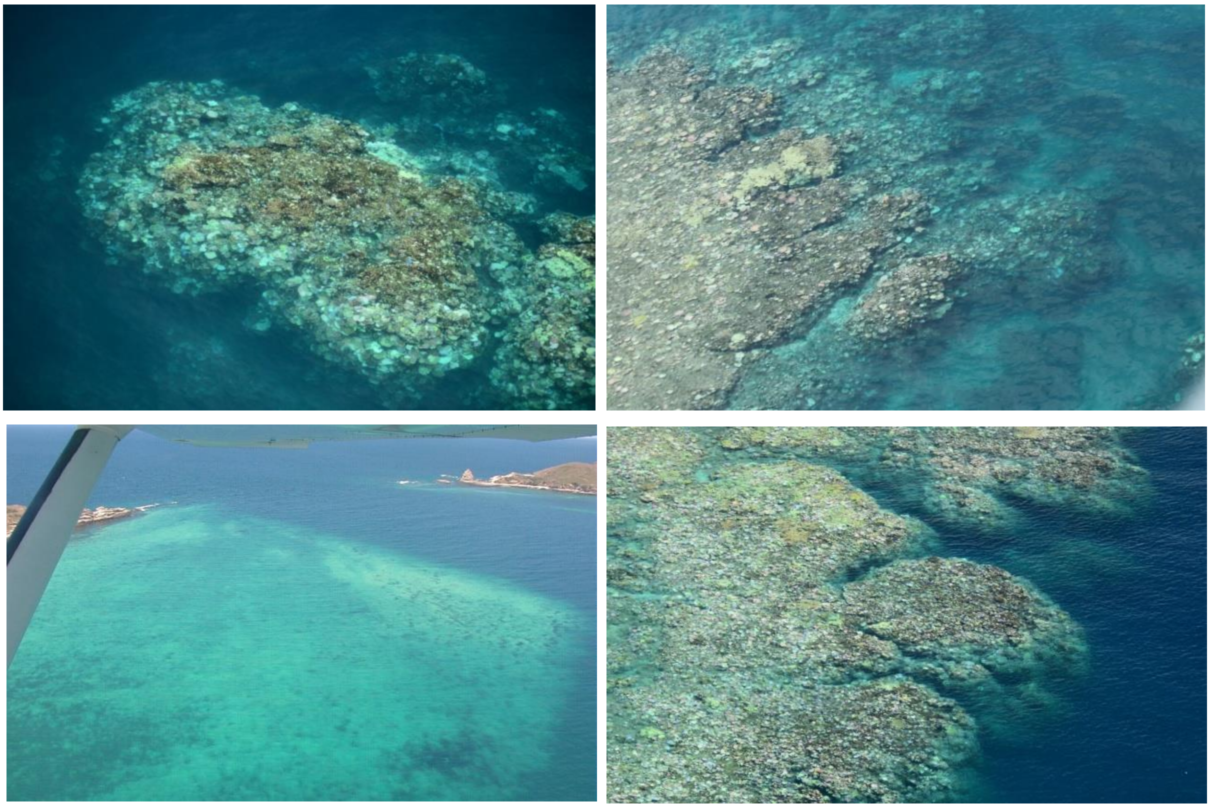

Figure 21. Examples of bleaching Category 4 (>60% bleaching). Virtually every coral colony is white or "fluoro" in these photos. Where coral cover is high the reef appears to "glow".

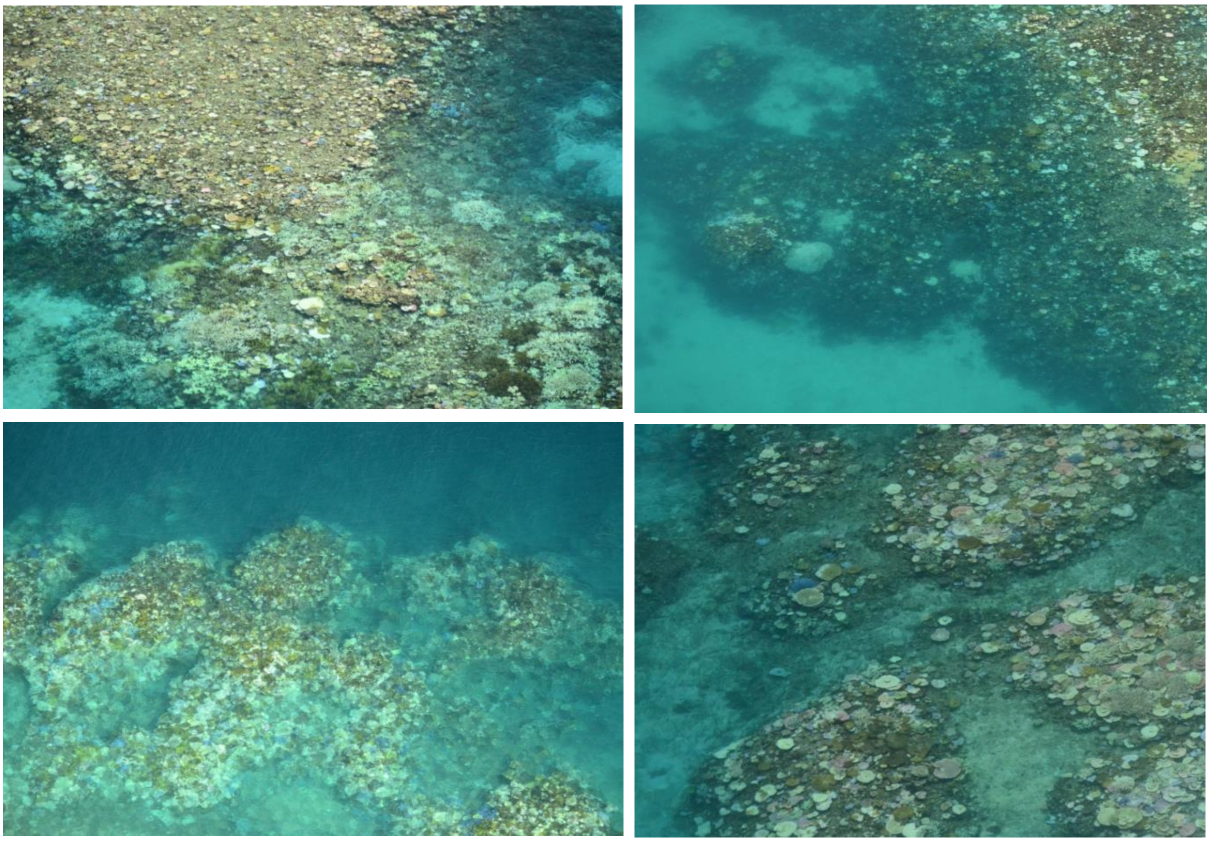

Figure 22. Examples of Category 4 bleaching with moderate to high recent mortality, which is evident as green turf algae overgrowing the coral skeleton.

8 INTER-OBSERVER COMPARISON

To assess the variation in bleaching scores between observers, a comparison was made between two pairs of observers during an aerial survey of reefs between Townsville and Cairns on 9 March 2017. For the comparison, two observers were seated on the left side of the plane, the other two on the right, however only one observer on the left could communicate with one on the right and vice versa (Fig 23). Thus, the two left observers (Pair 1) scored reefs independently of each other, as did the observer pair on the right (Pair 2). Observers 1 and 4 communicated freely and were isolated in communication from Observers 2 and 3, except for the first six reefs at the start of the survey.

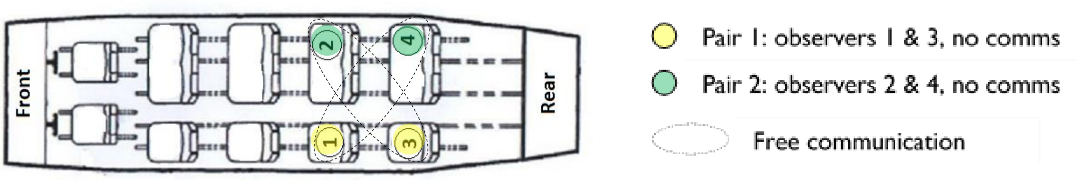

Figure 23. Seating arrangement of observers in the Cessna Grand Caravan used for the inter-observer comparison. Observers 1 and 4 were in communication as were observers 2 and 3. Observations by observer 1 and 3 were therefore independent of each other, as were those between observers 2 and 4.

During the first 6 reefs, observers in Pairs 1 and 2 made hand signals to calibrate observations which then ceased for the rest of the survey.

On most reefs, observers scored a number of different reef habitats. For each observer, scores were averaged for each reef and rounded to the nearest integer to retain the original bleaching categories (0 – 4). Scores within each pair were then subtracted from each other (Pair 1: observer 1 – observer 3; Pair 2: observer 2 – observer 4). Pair 1 scored a total of 46 reefs while Pair 2 scored a total of 52 reefs in the abbreviated dataset (not all reefs are available on both sides of the plane, particularly around island fringing reefs).

On a reef-by-reef basis, the results show that for both observer-pairs the median and modal scores were 0 (i.e., no difference, Table 1). Where there were differences in scores, these differences were few and not consistent in one direction or the other (i.e. no bias, Fig 24). Kurtosis, an indicator of the "tallness" or "narrowness" of the distribution of score differences, was high in both pairs (5.3 and 12.4). A normal distribution has a Kurtosis of 3 (3 standard deviations), so the values found here indicate that the distributions are highly concentrated around the means. Skewness was slightly higher in observer Pair 2 than Pair 1 (1.70 vs 0.93 respectively). This was entirely due to two outliers in the Pair 2 data: one point with a value of 3 and another of 2. A difference in observer scores of 3 is large and a close inspection of the data shows that this observation was from a small section of coastline along Cape Grafton near Cairns. Observer 2 saw bleached coral through the highly turbid water whereas Observer 4 did not. Live coral was very difficult to see hence both scores may be wrong and in opposite directions.

The only other large difference (2 categories) was at Needle Rf. One observer (Observer 2) scored this reef category 1 whereas the other three observers scored it category 3. This difference could not be further resolved with the assistance of the available photos. Aside from these two outliers, only 11 out of 98 reefs in the combined dataset of the two pairs had a difference of one category. All other differences were zero indicating a very high overall level of agreement among observers.

Table 1. Summary statistics on a reef-by-reef basis: comparison of observer pairs

	Pair 1 (Obs1 vs Obs3)	*Pair 2 (Obs2 vs Obs4)*
Mean	0.05	-0.07
Median	0	0
Mode	0	0
Standard Deviation	0.36	.62
Kurtosis	5.31	12.39
Skewness	0.93	1.7
Range	2.38	5
Minimum	-1.38	-2
Maximum	1	3
Count	46	52
Confidence Level (95.0%)	0.11	0.17

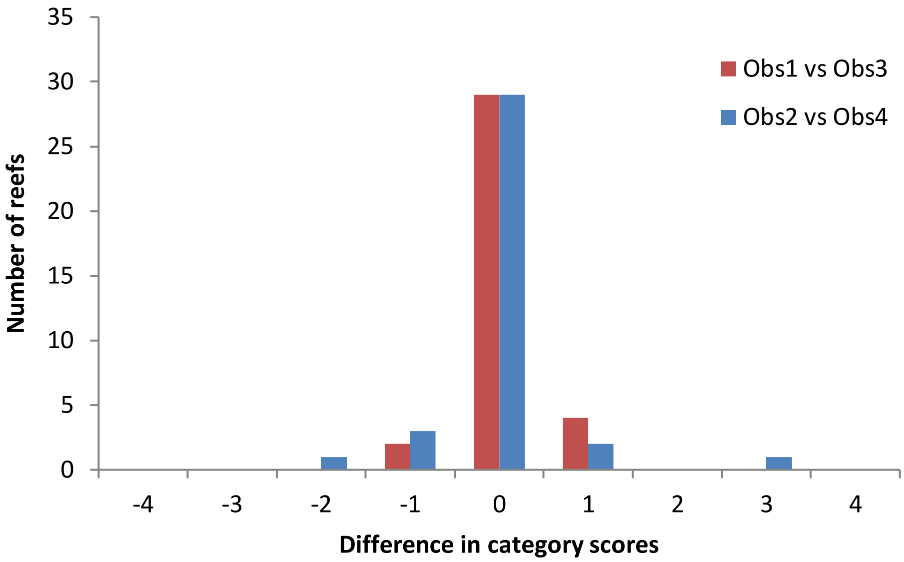

Figure 24. Distribution of differences in scores between observers in each pair (Pair 1, left, observer 1 – observer 3; Pair 2: right, observer 2 – observer 4).

Table 2. Summary statistics by bleaching category: individual observers

	Observer 1		Observer 2		Observer 3		Observer 4	
	# Reefs	%	# Reefs	%	# Reefs	%	# Reefs	%
Observations as 0	0	0	0	0	0	0	0	0
Observations as 1	2	2.99	4	6.45	1	1.49	3	4.76
Observations as 2	10	14.93	10	16.13	10	14.93	7	11.11
Observations as 3	14	20.90	11	17.74	14	20.90	11	17.46
Observations as 4	41	61.19	37	59.68	42	62.69*	42	66.67

Table 3. Summary statistics by bleaching category: front row and back row observers

	Av of Obs1 & Obs2		Av of Obs3 & Obs4	
	Avg %	SE	Avg %	SE
Observations as 0	0	0	0	0
Observations as 1	4.72	1.73	3.13	1.63
Observations as 2	15.53	0.60	13.02	1.91
Observations as 3	19.32	1.58	19.18	1.72
Observations as 4	60.44	0.76	64.68	1.99

Based on summary data, there were relatively small differences in the overall number and proportion of reefs in each category as scored by the individual observers (Table 2). Around 63% of reefs were scored as bleaching category 4 (range 59 – 67%) while ~19% of reefs were scored as category 3 (range 17 – 21%) and ~14% as category 3 (range 11 – 16%).

When the front row observers (observers 1 and 2) are averaged to account for "availability bias" (left and right side of the plane) and compared to the average of the back-row observers (observers 3 and 4) the difference in numbers and proportion of reefs is even smaller in each bleaching category (Table 3). Averaging across observers clearly provides a very robust summary of bleaching observations.

Overall, these data clearly show that inter-observer variation is small, and that the method is robust. However, it should be noted that there were relatively few reefs in categories 0 to 2 (11 out of 76 unique reefs, all observers combined). A higher number of reefs with low or no bleaching may increase the spread of scores as some of the middle categories are more difficult to score, especially if coral cover is low and water is turbid. Under these conditions, interpreting the data on a reef-by-reef basis is not advisable. However, as a regional overview of bleaching, aerial survey data are highly robust with respect to observer bias.

9 REFERENCES

Berkelmans, R., G. De'ath, S. Kininmonth, and W. J. Skirving. 2004. A comparison of the 1998 and 2002 cortal bleaching events on the Great Barrier Reef: spatial correlation, patterns, and predictions. Coral Reefs 23:74-83.

GBRMPA 2013. Coral Bleaching Risk and Impact Assessment Plan. http://elibrary.gbrmpa.gov.au/jspui/handle/11017/2810

10 APPENDICES

10.1 Appendix 1 – Reference Sheet of Bleaching Categories and Reef Habitat Diagram

CORAL BLEACHING AERIAL SURVEYS

Category 0:	<1% bleached	Blue
Category 1:	1-10% bleached	Green
Category 2:	10-30% bleached	Yellow
Category 3:	30-60% bleached	Orange
Category 4:	>60% bleached	Red