Using Unmanned Aerial Vehicles for surveys of marine mammals in Australia: test of concept

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EXECUTIVE SUMMARY

The conservation and management of many marine mammal species is largely dependent on monitoring population status by conducting aerial surveys from manned aircraft. Recent developments in the technical capacity and civilian use of Unmanned Aerial Vehicles (UAVs) have led to some investigations into the potential use of these systems for aerial surveys of marine mammals. UAVs operating under autopilot and mounted with GPS and imaging systems have the potential to replace traditional manned aerial surveys and provide an improved method for monitoring marine mammal populations through: (1) reduced cost, (2) reduced human risk, (3) increased accuracy of detection, location and identification of species, and/or (4) provision of a permanent record of the survey.

To investigate the potential for UAVs to be used in marine mammal survey, this study had three main objectives:

1. Provide a review of current UAV capabilities and potential use for marine fauna surveys,
2. Test the basic capabilities of UAVs for viewing and surveying marine mammals, and
3. Directly compare the capabilities of UAV imaging systems with human observer marine mammal counts from a manned plane.

The outcomes of this project are summarised below in accordance with each objective.

Objective 1: Review of UAVs

Within the timeframe and budget of this project there has so far been no single UAV available to purchase or hire that could fulfil our requirements for conducting a trial survey of either dugongs or humpback whales.

Of the companies available to hire, *Insitu* Pacific, and Cyber *Technology* have the most suitable UAV systems. They are both currently focused on designing UAVs for the military, so are relatively costly. However, they are interested in developing the civilian applications for their UAVs. A potential niche market for them is monitoring marine fauna as part of the regulatory and/or environmental impact assessment requirements for the oil and gas industry. *Insitu Pacific* have approached *Woodside Energy* and confirmed their interest in UAV technology, particularly for eliminating human risk in aerial surveys.

Cyber Technology offered this project some low cost trials. However, these trials were stalled by the permitting requirements of the Civil Aviation Safety Authority (CASA), and the long wait time for CASA to issue their UAV Operators Certificate.

Silvertone Electronics has the most promising UAV airframe for purchase, for which researchers would need to source their own payload, autopilot, data link and ground station.

There are a number of benefits to hiring a UAV operator: (1) the relatively costly outlay for purchasing, insuring and maintaining a technology is avoided, (2) all risk of system failure or loss is borne by the operator, and (3) hiring multiple operators means you can trial different UAVs. The option of purchasing a UAV would require a large commitment to the development of UAVs by a single research institute, due to the permitting requirements, maintenance costs and the need to retain personnel with the skills to operate the systems.

Objective 2: Testing UAV capabilities

(a) <u>Using small UAVs</u>

We used the Warrigul UAV operated by *V-TOL Aerospace* to conduct scoping flights over both land and water. This UAV was small (1.5 m wingspan) but robust as it was made out of polypropylene materials and could withstand relatively high impacts with minimal damage. Warrigul had limited endurance and control range however, so flights were restricted to within 10 km maximum distance from the base station.

When comparing one UAV scoping flight with one manned flight, the UAV maintained the desired altitude and trackline (average 0.04 m and 5 m deviance respectively) better than the manned aircraft (average 4.5 m and 158 m deviance respectively) under the same low-wind conditions. During our over-water scoping flight, the wind speed reached 15 knots and the UAV deviated more heavily from the trackline under these conditions.

The Warrigul could transmit images in real-time back to the base station and its flight path could be diverted at any time. However the video images obtained had limited resolution. We were able to depict two dolphins (which were sighted by land-based spotters first) and a manta ray using the real-time footage.

The Warrigul gave the advantage of providing records of the field of view and angle of the camera, together with the exact altitude, pitch, roll, heading and GPS track. These records could be used to determine the exact proportion of the survey area sampled more precisely than can be obtained from manned flights, and consequently provided more accurate population estimates.

(b) <u>Using manned planes mounted with UAV systems</u>

The Australian Research Centre for Aerospace Automation (ARCAA) assisted us in conducting manned flights using a Partenavia mounted with their UAV data acquisition system. Images were captured at 1 frame per second and at a resolution of 1024 × 768 pixels, with the camera angle being changed during flight according to where the animals were located.

One flight was conducted over a large dugong herd in shallow water in Moreton Bay. At all altitudes tested (1000, 750 and 550 ft) the dugongs were visible in the images captured. However we felt we could only reliably count the dugongs visible because they were in a large herd and we had prior knowledge that they were dugongs. If surveying animals in deeper water where they might be more obscured by the water, we felt this camera system would not be reliable.

We also conducted scoping flights over humpback whales in Moreton Bay and the results were similar to dugongs. In images captured at 1000 ft we could depict whales but couldn’t have identified them to species. At 1500 ft, whales could not be reliably depicted.

The combination of the typical UAV imaging system we used and the altitudes we trialled did not provide images of high enough resolution to reliably detect dugongs or whales. Rather than continuing with this system and conducting further trials at lower altitudes, we converted to with higher resolution imaging systems.

Objective 3: Comparison between humans and imaging systems

We used a manned aircraft to directly compare the sighting rates of dugongs from three observation platforms: (1) four human observers, (2) two high definition video cameras, and (3) a digital still camera capturing 4 megapixel images. A small line-transect survey was conducted at Shark Bay, Western Australia, where there is a high density of dugongs which offers a good opportunity to compare these platforms.

The overall sighting rate per platform was analysed within a log-linear model framework. This analysis showed that the still platform's sighting rate was significantly better than the human observers by 251% at the altitude of 900 ft. However, at 500 ft the performance of the still camera was reduced by 42% to be equivalent to the human observers. The video system performed relatively worse than human observers across both altitudes with a sighting rate of 60% that of human observers. More data would be needed to investigate this result further.

Two possible explanations for the different relative performance of stills and observers at the different heights are: (1) the poor sea-state conditions experienced at the low altitude flight may have been better compensated for by the human observers who could spend more time viewing each sighting compared to the single snapshot obtained from the stills, or (2) the observers' sighting rate may have been poorer at 900 ft than at 500 ft because they had a greater search area to observe in a limited time frame.

The poor performance of the video platform was because of the low resolution these images compared to the stills, but may be improved if flying lower and pointing the cameras vertically downwards rather than obliquely. Video should not be discounted as it produces a higher frame rate than the stills providing benefits such as: (1) increasing the probability of capturing animals surfacing, (2) providing some information about the animal movement (e.g. multiple surfacing of dolphins or the white-water produced when dugongs exhale), and (3) increasing the probability of capturing animals outside of the zone of glare within the images.

Overall, if capturing one image per second, each kilometre of survey takes 3.2 min to analyse post-flight. With the aid of ARCAA we tested an image analysis computer algorithm which has the potential to automate this process. The algorithm showed promising results but requires more development to reduce the false-positive detections and most importantly decrease the animals missed to a rate equal to or better than human observers. If this algorithm could at least limit the number of images needing manual analysis, it would reduce the time for analysing images substantially.

In conclusion, it is apparent, just by the UAV developments that have occurred in Australia during the course of this project, that the capabilities of UAVs will continue to improve. There are companies, such as *CyberTech* and *Insitu Pacific* who have UAVs capable of the range and endurance needed to conduct full marine mammal survey trials. The next step forward for the development of this technique for monitoring marine mammal populations would be to hire one of these companies and trial a range of UAV payload systems to determine the most efficient imaging system for each type of marine mammal surveyed in Australia. As there are currently fewer limitations in Australia than in the US for flying UAVs in civilian airspace, we have strong potential to research and develop UAVs for aerial surveys in Australia.

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PROJECT OUTLINE

The conservation and management of many marine mammal species is largely dependent on monitoring population status by conducting aerial surveys from manned aircraft. For example, dugong populations in Australia have been regularly surveyed since the 1980s in Queensland and the Torres Strait (e.g. Marsh et al. 2004; Marsh and Lawler 2006), and since the 1990s in Shark Bay and Exmouth (Marsh et al. 1994; Preen et al. 1997; Gales et al. 2004; Holley et al. 2006). Aerial surveys of whales, particularly humpbacks (*Megaptera novaeangliae*), have been conducted in Australia since the 1980s (Chittleborough 1965; Bannister 1985; Bryden 1985; Bannister 1994; Bannister and Hedley 2001; Noad et al. 2008). Pinniped populations, such as the Australian sea lion (*Neophoca cinerea*), have also been monitored using aerial surveys (e.g., Shaughnessy et al. 2005). In the US, the *Marine Mammal Protection Act (MMPA) of 1972*, requires an annual stock assessment of all marine mammal species in US waters. Many of these stock assessments and the consequential management actions to conserve marine mammals are based on minimum population estimates from aerial surveys. Abundance estimates of cetaceans in European (e.g., Hammond et al. 2002) and Canadian (e.g., Kingsley and Reeves 1998) waters have also relied on aerial surveys. The datasets produced from aerial surveys form the basis of many studies to determine the ecological requirements of species such as manatees (*Trichechus manatus latirostris*) (e.g., Craig and Reynolds 2004), North Atlantic right whales (*Eubalaena glacialis*) (e.g., Keller et al. 2006), harbour porpoises (*Phocoena phocoena*) (e.g., Sonntag et al. 1999), and Risso's dolphins (*Grampus griseus*) (Baumgartner 1997). Aerial surveys are also used to assess the effectiveness of marine mammal sanctuaries (e.g., Marsh 2000; Slooten et al. 2006).

Recent developments in the technical capacity and civilian use of Unmanned Aerial Vehicles (UAVs) have led to some investigations into the potential use of these systems for aerial surveys of marine mammals (Jones et al. 2006b; Buck et al. 2007; Koski et al. 2007b; Koski et al. 2009). UAVs operating under autopilot and mounted with GPS and imaging systems have the potential to replace traditional manned aerial surveys and provide an improved method for monitoring marine mammal populations through: (1) reduced cost, (2) reduced human risk, (3) increased accuracy of detection, location and identification of species, and/or (4) provision of a permanent record of the survey. UAVs may reduce the personnel needed for aerial surveys, thereby decreasing costs. If the permanent visual records of sightings obtained are of high enough resolution, they should increase the accuracy of detection and identification of species, and allow more immediate localisation of animals, thereby increasing the accuracy of distribution data. Manned aerial surveys pose a risk to the observers with at least four aircraft crashes having killed nine marine mammal researchers during aerial surveys (Stone 1988; Cosens et al. 2000; Wells 2003; ASFC 2008). The UAV will eliminate this risk to researchers.

This project uses a number of approaches to determine the efficacy of using UAVs for marine surveys, largely focussing on surveying dugongs, with a lesser focus on humpback whales and dolphins. The study had three main objectives as follows.

Objective 1: **Provide a review of current UAV capabilities and potential use for marine fauna surveys**, particularly in Australia, including a summary of:

- The companies currently providing UAV operations in Australia and UAVs available for purchase
- The pros and cons of a research group hiring UAV operators or purchasing and operating their own UAV.

Objective 2: **Test the basic capabilities of UAVs for viewing and surveying marine mammals** using both (a) small UAVs, and (b) manned planes mounted with UAV systems by determining:

- Whether UAVs are capable of flying transects with enough accuracy and stability to provide the appropriate survey coverage to replace manned aircraft.
- If the imaging platforms commonly used on UAVs provide high resolution and stable still or video images that allow observers / image analysis programs to detect and identify dugongs and whales.
- Whether images can be transmitted in real-time to a base station and be monitored so that the UAV's flight path can be altered where necessary, e.g., if large groups are sighted and need to be circled and counted, or an individual animal needs to be circled to be identified.

Objective 3: **Directly compare the capabilities of UAV imaging systems with human observer marine mammal counts from a manned plane**, specifically determining:

- The optimal height and camera type/system for each of the test species.
- How much post analysis (i.e., video / image analysis) time is required and whether this still allows the UAV surveys to be cost-effective compared with traditional manned flights.
- If the video analysis to obtain counts of marine mammals can be fully or partially automated

To be appropriate for surveying dugongs and humpback whales in Australia, the UAV systems will need to be capable of covering relatively large areas in remote regions. For example, previous surveys for dugongs in Shark Bay covered an area of 10,900 km^2 (Hodgson 2007) and in Torres Strait covered 30,560 km^2 (Marsh et al. 2004). Surveys of migrating humpback whales have tended to be smaller, for example the survey off Stradbroke Island in Queensland covered approximate 2,500 km^2. However, large areas of humpback whale habitat have never been surveyed, such as the Great Barrier Reef. These large, remote areas offer challenges if UAVs have limited range capabilities and require runways or even roads to be launched or recovered. The general system requirements of a UAV for completing humpback whale or dugong surveys cannot yet be specified because each requirement is dependent on one another. For example, endurance is dependent on speed and range. Launch and recovery site requirements are dependent on endurance and range. However, the overall aim of investigating UAVs for aerial surveys of dugong and humpback whales is to find or develop systems that can operate in the remote regions of Australia where manned surveys are currently the most logistically challenging.

REVIEW OF UAVS

Globally, the development of UAVs (also referred to as Unmanned Aerial Systems, UAS) has centred on their military application. The civilian application of these systems, by comparison, is at a very early stage of development. Some examples of the civilian applications of UAVs that have been investigated to date include farm management (Lelong et al. 2008; Schmale et al. 2008), cyclone observation (Beven and Cobb III 2006), coastal zone remote sensing (Delacourt et al. 2009), fire management (Wu et al. 2006; Phan and Liu 2008), search and rescue (Doherty and Rudol 2007), atmospheric research (Abrahamsson et al. 2003; Ramana et al. 2007) and pollution monitoring (Corrigan et al. 2008), traffic monitoring (Puri et al. 2007), maintenance assessments for structures such as bridges (Metni and Hamel 2007), gas pipelines (Hausamann et al. 2005) or powerlines (Jones et al. 2006a; Campoy et al. 2009), and monitoring open environments such as rangelands (Hardin and Jackson 2005) and ice conditions (Curry et al. 2004). In Europe, 15 countries have signed an MOU on “unmanned aerial systems (UAS) in atmospheric research” (European Cooperation in the field of Scientific and Technical Research (COST) Action ES0802) under which the development and application of UAVs will be coordinated. This MOU recognises that “unmanned aerial systems (UAS) will be of large and increasing importance for environmental monitoring in the future, e.g. under the aspects of climate change and sustainable development”.

In Australia there are at least four research groups specifically involved in the research and development of UAV systems. The Australian Research Centre for Aerospace Automation, Queensland University of Technology and CSIRO, is currently focussed on two main areas of UAV development: (1) aerospace separation management (collision avoidance), and (2) the application of UAVs in power line monitoring. The School of Aerospace, Mechanical and Mechatronic Engineering, University of Sydney (USyd) is working on various UAV airframe designs, including the 30kg T-Wing Tail-Sitter VTOL (vertical take-off and landing) UAV, tube-launched UAVs (air, ground or even submersible-launched), biomimetic airframes and systems, morphing airframe UAVs, and mini-UAV designs weighing less than 200 grams. Also at USyd is the Australian Centre for Field Robotics (ACFR), where most of the research relates to sensors, navigation, data fusion, using airframes (some originally developed from designs within the other USyd group) for applications in defence and various innovative civilian applications. The ACFR have funded projects investigating navigation without a-priori maps (simultaneous localisation and mapping or SLAM), detection of weeds, and surveillance of locust migration. Finally, the Visual and Sensory Neuroscience Group at the Queensland Brain Institute, University of Queensland, is designing guidance systems for UAVs that use passive sensing (such as vision, for example see Srinivasan et al. 2004; Soccol et al. 2007; Thurrowgood et al. 2007). To date, there have been no formal investigations in Australia into the potential for using UAVs in wildlife research.

However, there are a number of other research programs around the world investigating the use of UAVs in wildlife research, and in particular, marine mammal monitoring (Stark et al. 2003; Jones et al. 2006b; NOAA 2006; Buck et al. 2007; Ireland et al. 2007; Koski et al. 2007a; Dähne et al. 2008; Grenzdorffer et al. 2008; Schoonmaker et al. 2008; Watts 2008, uas.noaa.gov). All of these research programs are in the relatively early stages of research and development. A review has recently been conducted of the potential use of UAVs for aerial surveys and monitoring of marine mammal, sea turtles and sea birds during offshore oil and gas exploration and production in the Arctic and Subarctic (Koski et al. 2009). This review investigated the UAV systems available and the successes and limitations encountered by the various research projects on UAVs for marine mammal research around the globe. The review concluded that more testing was needed before we are able to replace manned surveys with UAVs. The main limitations currently include: (1) the quality and reliability of the imagery to identify animals, particularly small marine mammals (it was recommended that high definition video be used), (2) stabilisation of the imaging platforms is needed to produce high quality images and reliably survey the area of interest, but to date most stabilising systems are prohibitively heavy and/or expensive, and (3) permitting requirements include collision avoidance methods such as autonomous sense and avoid systems, however these methods are still in the research and development stage.

The review presented here focuses on UAV activities within Australia. There are currently fewer limitations in Australia than in the US for flying UAVs in civilian airspace. This emphasises the importance of continuing to investigate the use of UAVs for marine fauna surveys in Australia as there is stronger potential to research and develop UAVs here than there is in the US.

We consider two options for further development of UAVs for marine mammal research in Australia: (1) hire the services of an established UAV company who can conduct the surveys and simply provide researchers with the data, and (2) purchase UAVs custom built for marine mammal surveys and develop the technique within a research group. In reviewing these options, we consider the companies and UAVs available, the permitting, approvals and insurance requirements, maintenance, reliability and safety considerations, and the current status of sense and avoid systems.

UAV Company Hire

Currently in Australia, there are a number of companies who provide commercial small UAV services. Table 1 provides information about the UAV systems they operate and the services they provide.

During the undertaking of this project, *V-TOL Aerospace* was the only company we could contract, at a rate within our budget, to conduct UAV trial flights without purchasing a complete system. The CropCam UAV used by *Skyview Solutions* does not have the range required for marine mammal surveys. According to *UAV Systems'* website, the standard operations they provided target aerial photography of particular locations. They are currently advertising that "special operations" will be available soon, and the range and endurance quoted suggest that this company may be capable of aerial surveys in the future. However, we could not get confirmed specifications of the systems they use.

Insitu Pacific, Cyber Technology and *Aerosonde* are examples of companies that, at the time of writing this report, have UAVs with suitable capabilities but mostly design UAVs for use in the military. *BAE Systems* and *Air Affairs Australia* also design UAVs for the military but we were unable to confirm details about the systems or services they provide. Hiring the services of any of these companies is relatively costly. Their commercial focus is to provide UAV services for situations where manned aircraft are not suitable, such as long-endurance, turbulent or dangerous missions. For these scenarios, customers (such as Defence) are prepared to pay high costs. For the relatively small-scale, one-off missions required for most inshore marine mammal surveys, hiring these companies would not be cost-effective. However, for large-scale, regular surveys, offshore and/or remote surveys (where landing sites or fuel availability is limited), hiring these companies may become cost-effective because their UAVs have longer endurance times than manned aircraft (e.g. they could conduct full-day flights), they can operate multiple UAVs from one ground-station, and they eliminate the human risk involved in flying offshore.

Both *Insitu Pacific* and *Cyber Technology*, however, are interested in developing the civilian applications for their UAVs. A potential niche market for them is monitoring marine fauna as part of the regulatory and/or environmental impact assessment requirements for the oil and gas industry. *Insitu Pacific* have approached *Woodside Energy* and confirmed their interest in UAV technology, particularly for eliminating human risk in aerial surveys.

Cyber Technology offered this project some low cost trials. However, these trials were stalled by the permitting requirements of the Civil Aviation Safety Authority (CASA), and the long wait time for CASA to issue their UAV Operators Certificate.

Surveys of large, remote areas may require the use of a fleet of UAVs, where information can be transmitted in relay between UAVs. Most of the UAVs we have reviewed can be customised to have this capability. This would improve the coverage range and greatly increase the efficacy of using UAVs. This ability needs to be explored in future projects.

UAVs for Purchase

Internationally, there are a number of UAV systems available for purchase. These vary in their capabilities and there are a number of factors to consider in purchasing these systems. We do not attempt to review all systems here, but have focused on UAVs developed in, or imported into, Australia. These systems are summarised in Table 2.

Silvertone Electronics produce Flamingo UAVs, which became available in mid-2008, and offer promising endurance and range capabilities. The standard cost of the airframe is provided in Table 2. *Silvertone* provided us with an example quote for a complete system, where they provided the airframe and a separate company in Chile provided the payload (stills camera), autopilot, data-link, ground control station, testing and training, all of which amounted to under $AU100,000.

The Bat UAV produced by *MLB*, is a successor of the FoldBat assessed by Jones et al. (2006b) for its potential in wildlife research. *V-TOL Aerospace* (referred to in Table 1) own a Bat UAV, which they purchased for a total of approximately $AU100,000 including the ground station, training in the US and importation costs. The Bat's payload includes a still camera (with images stored onboard), and a video camera from which real-time images are transmitted back to the ground station for navigation purposes. One limitation of the Bat is that its recovery requires 50 m of cleared land and approximately 200 m of glide path for the final approach. Although the Bat operates autonomously, its landing system is not suitable for all terrain as mentioned by Jones et al. (2006b). *V-TOL Aerospace* prefers to land theirs manually, as they have had some stress fractures occur between the under carriage and the fuselage following hard landings. As *MLB* are located in the US, all damages need to be repaired there, and therefore maintenance costs include sending this UAV to the US.

Table 1. Outline of the UAV systems used by operators who hire their services in Australia.

Company	UAV system	Use	Wing Span (m)	Length (m)	Gross Weight (kg)	Power Source	Flight Control	Altitude (ft)	Cruise Speed (kn)	Dash Speed (kn)	Payload Options	Control Range	Endurance	Launch and Recovery
Aerosonde	Mark 4.4	Ecological and biological surveys, meteorological and military missions	3.45		16.8	Fuel engine (4-stroke)	Fully autonomous with manual flight an option	15000	50	62	EO/IR, Comms Relay, Chem/Bio, MET and Atmospheric Sensors		14-24 hrs	vehicle roof/hydraulic launchers and belly landing
Cyber Technology	CyberEye II	surveillance/surveying (eg: shark / coastline monitoring, mines, development sites, animal, farming, fire, search and rescue, border security, mail delivery to remote areas)	4.5	2.8	60	100cc twin cylinder horizontally opposed two stroke engine		Up to 15000	54	86	Sony Video camera , pan, tilt, zoom fully stabilised, 360 degree rotation camera system	100 km (video 30 km)	10 hrs	standard takeoff and landing on a suitable runway (bitumen, short grass, clay, etc)
Insitu Pacific	Scan-Eagle	Reconnaissance & surveillance	3.11	1.22	20	2 stroke petrol engine	Fully autonomous	Max 19500ft, operating 2000-3000ft	48-55	75	EO, IR, Radio Relay, SAR	100 km (line of sight)	20+ hrs	catapult and skyhook (no runway required)
Skyview Solutions	CropCam	Natural resource management, agriculture, emergency response, carbon accounting	2.44	1.22	2.72	Fuel or electric	Fully autonomous with manual flight an option	400			Still or video, colour or infrared	5km	60 min	hand and belly
V-TOL Aerospace	Warrigul	Marine and urban environmental monitoring	1.5	1.2	5	Battery to electric motor	Fully autonomous with manual flight an option	200-1500	30	90	Colour/infrared/hi-res still photography	6-9km standard, 50km+ optional	60-90 minutes	catapult and belly landing

Table 2. Outline of some UAV systems available for purchase that are suitable for marine mammal surveys.

Company	UAV system	Price	Use	Wing Span (m)	Length (m)	Gross Weight (kg)	Power Source	Flight Control	Max Altitude (ft)	Cruise Speed (kn)	Dash Speed (kn)	Payload Options	Control Range	Endurance	Launch and Recovery
Silvertone Electronics	Flamingo	$29,500 (incl. Saito FG-36 motor, 5.6 litre fuel tank, Hitec digital servos, wired ready to accept a modern 2.4GHz radio	Training, survey, aerial photography	4	2.9	20	Fuel motor (23cc-50cc)	Various (up to customer)	16000	70	90	Wide range on a demountable pannier	Depends on choice of avionics	Depends upon motor fitted but typically between 5 - 10 hrs	Fixed undercarriage or drop off dolly. Suitable for catapult or roof top launch
MLB	Bat	$US42,000 (ready-to-fly aircraft with standard sensor payload and complete ground station)	Short range surveillance and aerial mapping	1.83		6.8	2-stroke engine (23cc)	Autonomous from launch to landing. Waypoint changes can be made.	9000	22-43		Colour CCD video camera. Three-axis stabilized gimbal mount colour cameras. IR video and still cameras.	11km	2.5 hrs nominal, 6 hrs maximum	Autonomous using bungee-powered catapult and automatic return-to-base with autonomous GPS landing on wheels

Approvals, Permits and Insurance

The Civil Aviation and Safety Authority (CASA) govern the use of UAVs in Australia under the regulation CASR101. “Small” UAVs are classified as < 150 kg for fixed wing, or < 99 kg for rotary wing, and are the category we have been investigating in this project. The approvals and permits needed to own and operate a small UAV are:

- CASA approval to operate above 400 ft for any particular mission
- aircraft radiotelephone operator’s certificate of proficiency to operate in controlled airspace or if directed to use radiotelephone by CASA
- certificate of airworthiness for the UAV to operate over a populated area
- approval to operate a certificated UAV over a populous area at a height less than the height from which, if any of its components fail, it would be able to clear the area
- a UAV Operator’s Certificate that authorises the person to operate the UAV for hire or reward (but also requires a radio operator’s certificate of proficiency, passing of an aviation license exam, passing of an instrument rating theory exam, completion of a UAV training course, and 5 hours of experience flying in controlled airspace)

Currently there are no routine UAV operations in Australia and any operations that do occur are assessed on a case by case basis. Obtaining approval from CASA to conduct a specified mission is somewhat easier if the company has a UAV Operator’s Certificate as this means CASA already recognises the company as having the required safety standard. Approvals to operate a UAV above 400 ft depend on the amount and type of air traffic in the area. Remote areas are more likely to have personal aircraft used by pilots who haven’t issued notifications of their flight plans (NOTAMS) or checked other pilots’ notices, and this makes it difficult to ensure the safety of UAV operations in remote areas. This can be overcome by contacting local airspace users through media, advertising and direct phone-calls to re-enforce the impending UAV mission.

In our experience, UAV operations also require council approval, particularly when launching and recovering the UAV on council land. Safety officers need to be appointed to ensure the safety of bystanders. It should also be noted that special approval needs to be obtained to fly any aircraft within 1000 ft (300 m) of whales in all State and Commonwealth waters, and in our experience, UAVs were considered aircraft in this context.

Insurance is also assessed on a case by case basis, but cannot be economically obtained for UAV with a wingspan > 5 m in Australia. Insurance for operations over remote areas costs approximately $10,000, and this cost increases (to many tens of thousands) if operating over populous areas, or if the operator is inexperienced (Rodney Walker, ARCAA, personal communication).

Maintenance, Reliability and Safety

If a research group is to purchase as UAV, there are more risks and ongoing costs involved than purchasing the data off a UAV company. Not only do UAVs require ongoing maintenance, there is still a high risk of crashing UAVs and lost aircraft are the responsibility of the operator. UAV “accidents” are quite common, and in the US, occur at a rate of approximately 100 times that of commercial aircraft (Weibel and Hansman 2005). Human error is a significant causal factor, however, the majority of accidents occur as a result of equipment failure, so that full UAV autonomy is not yet a fail-safe solution (Hing et al. 2008). Landing, known as 'recovery', is a particularly difficult part of a mission, and unless operators are very experienced, it is very likely that the recovery of UAVs such as the BAT will result in major airframe damage or loss of the vehicle (Rodney Walker, ARCAA, personal communication). Ideally, during autonomous flight, operators still need to be able to override with manual control of the aircraft in emergency situations. This relies on good ground station controls and the ability of the pilot to have clear situational awareness while the UAV is in operation (Hing et al. 2008). Training of operators is essential, and therefore a research group would need to maintain a capable flight crew in order to make the purchase of a UAV a cost-effective option. "The quality of the data obtained is usually directly related to the operation of the UAV platform", (www.mlbuav.com).

Sense and Avoid Systems

Sense and avoid systems, which allow either the UAV or other planes to detect and avoid one another in flight, are not currently required on UAVs by CASA when operating in remote areas under 400 ft. However operations departing from this are assessed on a case by case basis. The ARCAA research group is leading the development of sense and avoid systems in Australia and the following information was provided by the leader of this team, Rodney Walker:

For operations in remote areas, aircraft separation assurance is maintained through procedural techniques (e.g. not flying in areas or altitudes where other aircraft are expected to be, through monitoring radio calls and by educating the local aviation community about the operation).

There is research and development underway to develop the sense and avoid systems required to allow more accessible operation of UAVs. There are three primary methodologies:

1. **Onboard Radar** –Onboard radars can be used to detect other airborne traffic in the same manner as air traffic controllers make use of radar systems. However this approach is only applicable to the larger UAVs (several hundred kg class) and is quite expensive.

2. **Onboard Vision and Acoustic** – These approaches are much more experimental, however, they are applicable to the cheaper and smaller UAVs. Whilst there are some systems advertised as commercially available, they are still not recognised by the safety regulators as meeting the required performance. It is an active research area and systems are expected to be available on the market within 3-5 years.

3. **Transponder based** – These systems rely on all aircraft transmitting their GPS-derived position information via communications links to nearby traffic. In this manner, all aircraft (manned and unmanned) are made aware of the surrounding traffic and can manoeuvre to avoid collision. The difficulty with this approach is that all aircraft must be equipped and this is not currently the case in Australia. Recently, a mandate to equip all Australian aircraft with the required technology (in this case ADS-B) was overturned. This has pushed the realisable date for a transponder-based sense and avoid system for UAVs back at least 10 years.

Future Directions for Purchase or Hire

We approached the research and development of UAVs for marine mammal surveys with the aim of hiring a company that operates UAVs to conduct the flights. There are a number of benefits to this approach: (1) the relatively costly outlay for purchasing, insuring and maintaining a technology that has not been proven for marine mammal surveys is avoided, (2) all risk of system failure or loss is borne by the operator, and (3) hiring multiple operators means you can trial different UAVs. However, there are currently very few operators within Australia. *Insitu Pacific* and *Cyber Technology* are the only operators using developed UAV systems capable of the range and endurance required for marine mammal surveys. Neither company was hiring their services for civilian applications during the timeframe of our project.

Considering the limited UAV operators is Australia, further UAV development for marine mammal surveys may rely on purchasing a UAV system. This approach would mean that a system could be designed to specifically meet the needs of a marine mammal survey, and flights could be conducted at the researcher's discretion. New UAV systems with the capabilities we require for these surveys emerged in Australia during the course of our project (e.g. the Flamingo by *Silvertone Electronics*) that may enable the direct UAV survey trials that we were unable to achieve. This option would require a large commitment to the development of UAVs by a single research institute, due to the ongoing maintenance costs, permitting requirements and the need to retain personnel with the skills to operate the systems.

UAV SCOPING FLIGHTS

UAV System: "Warrigul"

We conducted our scoping flight using a small UAV (the "Warrigul") that, at the time of this project, was the most suitable and cost-effective system available for use in Australia. The plane was designed and operated by *V-TOL Aerospace*. The specifications of this aircraft are provided in Table 3. The model is currently a prototype version being used as a concept demonstrator for a larger version that will have a 5 kg payload and 6 hr endurance capability allowing it to be used for long distance offshore applications, and thus will eventually be suitable for marine survey work (Figure 1).

Table 3. Specifications of the UAV

Prototype	Under development 76 hrs flown in test flights
Name	Warrigal (4 x airframes)
Class	Light Unmanned Aircraft System (LUAS)
Use	Marine and urban environmental monitoring
Wing Span	1500mm (60 inches)
Length	1200mm (47 inches)
Weight	5kg all up weight with payload
Power Source	Battery to electric motor
Flight Control	Fully autonomous with manual flight an option
Altitude	200ft – 1,500ft
Cruise Speed	30 knots
Dash Speed	90 knots
Payload Options	Colour/infrared/hi-res still photography
Control Range	6-9km standard, 50km+ optional
Endurance	60-90 minutes

The Warrigul fuselage and wings are manufactured from impact optimised energy absorption extruded polypropylene materials. This material is very forgiving and high-impact resistant, protecting the on-board systems from heavy impacts, particularly in combination with the retractable camera payloads and electric tail pusher power plant. During *V-TOL Aerospace's* previous flight testing, several 20+ G impacts were performed. In each instance the airframe was flyable after recovery. The UAV will also float if landed in water which is essential for marine survey work. The Warrigul is launched via bungee cord and during this development phase, needs ~200 m of flat ground, relatively clear of surrounding trees, buildings or power poles, to be recovered. As shown in Figure 2, the UAV is operated from a van equipped with a laptop computer used to control the aircraft, LCD monitors and video recording systems, and all transmitter aerials.

Figure 1. The UAV ("Warrigul") used for scoping flights.

Figure 2. Base-station van fitted with all operating equipment and transmitter antennas.

Scoping Flight 1: Preliminary test

The aim of the preliminary scoping flight was to understand how the UAV system worked and was operated. We also used the flight to get a first look at how well this particular UAV model performed when flying between set GPS locations at a desired altitude and air speed, as well as the kind of video footage that could be obtained. The specifications for the payload are provided in Table 4. As shown in Figure 3, the UAV appeared to fly extremely accurately to the limited number of set locations we used during this flight, and was able to repeatedly follow the same paths.

Table 4. Camera and transmission system used during both the first and second scoping flights.

Camera	
Scanning area	Colour CCD image sensore
Illumination	0.9 lux
Resolution	752 (H) x 582 (V)
Focal length	4 mm
Electronic iris	1/50s – 1/100s
Panning range and speed	400° max, 0.72°/s
Tilting range and speed	90° max, 0.18°/s
Dimensions	54 x 38 x 89 mm, ball (dome) diameter 40 mm
Weight	65 g
Transmitter	
Wireless modem	Maxstream 9Xtend with NTSC/PAL video
Command input link	900 MHz
Video downlink	2.4 GHz
Video recording	
Receiver	NTSC/Pal commbox
Recorder	Sony Digital Recorder (8mm tape cassette)

Locations were added and deleted while the UAV was in flight and Figure 3 shows the UAV changing flight paths. Real-time footage was transmitted to the base-station (Figure 4) and therefore this flight showed that the UAV has the capacity to be diverted from a set survey flight path to investigate sightings of interest such as large dugong herds, in real-time.

The average difference between the desired airspeed and realised airspeed was only 2 km/hr (Table 5). The realised altitude throughout the flight was also relatively accurate. The maximum difference between the desired and realised altitudes was 50 m, however the standard deviation of the difference was only 4 m, and the average proportional error in the desire altitude was 2% (Table 5). Pitch and roll of the aircraft is important for video footage stability. It appears that there was less than 0.2° pitch and roll while the aircraft was on the straight line paths which should give good camera stability (Table 5).

Figure 3. Flight path of the UAV when flying between set GPS locations (several flight paths depicted by different coloured dots) during scoping flight 1.

Figure 4. An example still frame from the video footage obtained during UAV scoping flight 1. This footage was transmitted back to the base and recorded remotely.

Table 5. Difference between desired and realised flight parameters during UAV scoping flight 1.

Flight Parameter	Desired value	Difference of realised from desired			
		Average	Minimum	Maximum	St Dev
Altitude (m)	various 60-150	1.91	0.00	49.17	3.85
Proportion of Altitude	0	0.018	0.000	0.395	0.033
Air Speed (km/hr)	50	2.05	0.00	24.8	2.34
Roll (degrees)	0	0.15	0.00	0.54	0.13
Pitch (degrees)	0	0.16	0.03	0.29	0.05

Scoping Flight 2: Over-water tests

The two over-water flights were conducted from Point Lookout on Stradbroke Island. The aim of these flights was to determine the capabilities of the UAV in flying over water, and obtain images of humpback whales as they were passing through the area.

The main limitations of these flights were (1) finding a suitable site as a base-station that was large enough to launch, and in particular, recover the UAV, and (2) the range capabilities of the UAV. *V-TOL Aerospace* had not yet tested their capacity to change the location of the base-station following the launch and prior to retrieval, which would extend the area within which the UAV could be flown beyond the area that is within range of the landing site. At the time of this flight, we were limited to flying the UAV within 2 km of the launch and retrieval site, which was not the most likely path of migrating humpback whales, but an area they occasionally pass through. During the first test flight, no marine fauna were sighted. To maximise our potential to fly over whales during the second flight, we employed three experienced whale survey volunteers to keep watch over the focal area from an elevated vantage point and radio the base station when any marine fauna entered the area. Although whales were within the area upon our arrival and during set-up of the UAV, no more whales passed through during the time we had available. However, we were able to launch the UAV and capture video of dolphins reported by the spotters, and could distinguish a manta ray identified solely from the real-time UAV footage (Figure 5). This ability to distinguish dolphins and a ray was encouraging given that we consider the video system currently used on the Warrigul to be of much lower resolution than we would expect to use for future surveys. It should be noted that although Figure 5 does not clearly depict dolphins, their movement in the video made it possible to identify these animals, however we could not identify them to species.

Figure 5. Two dolphins (above) and a manta ray (below), both circled in red, captured by the UAV camera during the second scoping flight.

The over-water test flights also provided the following insights:

1. During retrieval of the UAV following the first flight, the wind direction was misjudged and the Warrigul was crash-landed into a pole. For other UAVs that we have knowledge of, it would have been expensive and time-consuming to repair the damage caused to the wing of the UAV. The robustness of this UAV was exemplified by the fact that it was fixed within 24 hours at minimal cost and neither the payload nor autopilot was damaged. Our second over-water test flight was conducted only one week later and the UAV flew perfectly. The potential to damage UAVs (particularly during landing) is a major limitation in using this technology. The Warrigul therefore offers significant advantages over other UAVs being tested for marine mammal surveys throughout the world.
2. The maximum wind speeds during the second over-water flight averaged 15 knots, but the UAV maintained a stable position in the air (Table 6) and the video footage appeared stable enough to conduct surveys, suggesting that it is feasible to expect the UAV to be able to fly in at least the same wind conditions in which we currently conduct manned surveys.
3. The camera system would need to have a continuous pan and tilt system with digital vertical flip in order to maintain a view of animals of interest. Some systems have the ability to automatically maintain the camera view on a particular GPS location, which would be an advantage.

Although the pitch and roll of the plane was minimal during this flight (Table 6), Figure 6 shows that the UAV did not always maintain a straight heading. This reduced heading accuracy was likely due to the higher winds in comparison the first over-land flight scoping flight.

Table 6. Difference between desired and realised flight parameters during UAV scoping flight 2.

Flight Parameter	Desired value	Difference of realised from desired			
		Average	Minimum	Maximum	St Dev
Altitude (m)	Various 100-150	1.63	0.00	32.50	2.48
Air Speed (km/hr)	50	1.48	0.00	19.8	8.93
Roll (degrees)	0	0.14	0.00	0.34	0.11
Pitch (degrees)	0	0.13	0.00	0.34	0.07

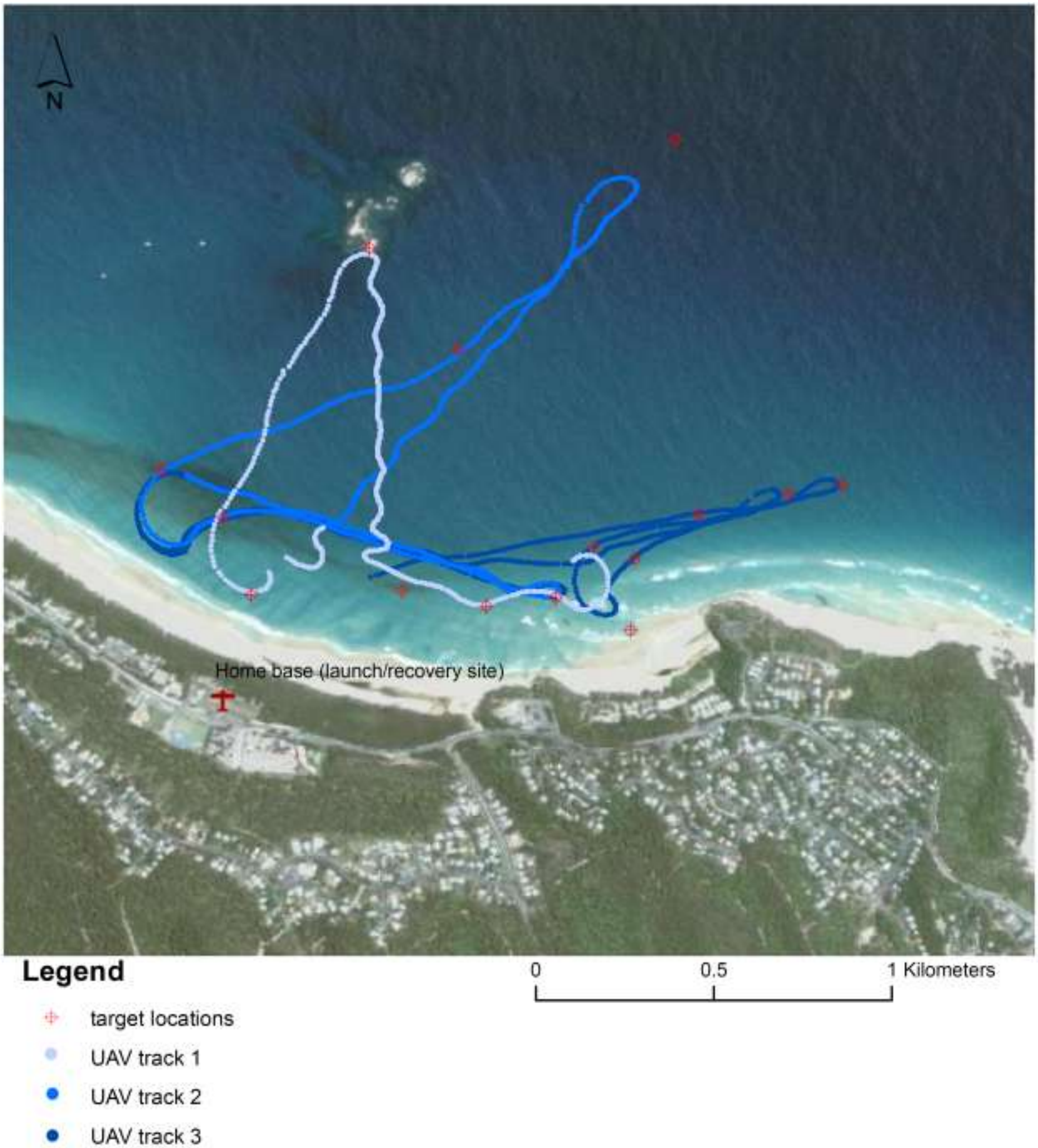

Figure 6. UAV tracks during second over-water flight off Stradbroke Island. UAV track 2 represents the current range limit of the Warrigul at this location.

Scoping Flight 3: Flying transects test

Through the final scoping flight we aimed to determine whether the Warrigul could fly a precise, transect-style flight path to at least the accuracy of a manned aircraft. The test was conducted over open fields in Haigslea near Brisbane, as the Warrigul was not at the development stage where it could be flown to this extent over water. Ten transects were flown of approximately 2 km in length and spaced an average of 120 m apart (Figure 7). The set altitude for the test was 328 ft (100 m) and the set speed was approximately 27 knots (50 km/hr). The average wind speed during this flight was only 1 kn (maximum 2 kn), which is much lower than for scoping flight 2 and represents ideal wind conditions. The results of this flight are presented in Table 7. The Warrigul flew extremely accurately along this relatively fine-scale transect pattern maintaining an average distance from the trackline of less than 5 m (excluding transect 1 which was preceded by circling around the beginning point of the transect which meant the Warrigul was off the start point when it began the transect, see Figure 7). The largest degree of error in maintaining the flight path occurred during the turns. This can be very simply overcome by slightly lengthening the transects to give the UAV room to turn, as occurs during manned flights. The turns were very quick relative to a manned flight.

Comparison with manned flight

For comparison to commonly conducted manned surveys, we used an example flight from an aerial survey in Shark Bay, Western Australia. This flight was conducted in June 2007 with the standard methods and aircraft (Partenavia 6-seater aircraft) used for aerial surveys of dugongs (for the full report and description of methods see Hodgson 2007). Ten consecutive transects were selected from the survey where Beaufort sea-state was recorded as 0 or 1 so that the conditions were comparable to the UAV fight. The transects ranged from 24 to 41 km in length and were spaced at 4.6 km apart. The only data recorded in relation to flight accuracy was altitude (recorded by the flight leader approximately every 2 minutes from the cockpit display dial) and distance from the desired transect line. As shown in Table 7, this larger scale flight had much greater errors than the UAV flight, particularly in relation to the deviance of the aircraft from the trackline (average of 158 m).

The greatest advantage of using the UAV rather than conducting manned flights is that the UAV system produces precise records of the flight parameters. Knowing the field of view and angle of the camera, together with the exact altitude, pitch, roll, heading and GPS track provides the opportunity to determine the exact area surveyed and therefore the proportion of the survey area sampled. This then allows a more accurate population estimate to be calculated.

Figure 7. Final scoping flight testing the Warrigul's precision in flying transects.

Table 7. Desired and realised flight parameters during UAV scoping flight 3 with some data from an example 10 transects of a manned aerial survey.

Flight Parameter	Aircraft	Desired value	Realised value			
			Average	Minimum	Maximum	St Dev
Altitude (m)	UAV	100	99.96	94.17	104.00	1.24
	Partenavia	137.2	141.71	106.68	167.64	9.55
Air Speed (km/hr)		50.4	50.39	43.74	58.5	1.81
Roll (degrees)		0	0.08	0.00	0.69	0.12 (from 0)
Pitch (degrees)		0	0.09	0.00	0.37	0.10 (from 0)
Distance from trackline (m)	UAV[1]	0	4.77	0.03	26.62	5.87 (from 0)
	Partenavia	0	158.06	0.55	765.45	226.94 (from 0)

[1] Excludes transect 1

UAV DATA ACQUISITION SYSTEMS

Manned flights with UAV Data Acquisition Systems

To complete Phase II: **Testing the basic capabilities of the UAV for viewing and surveying marine mammals** we focused on assessing the feasibility of using a typical UAV data acquisition system to survey marine mammals. We were assisted by the Australian Research Centre for Aerospace Automation (ARCAA) in order to conduct manned flights using a Partenavia mounted with their UAV data acquisition system. This system consisted of a compact IEEE-1394 digital camera (Point Grey Research “Flea”) with a 3.5 mm lens (Figure 8a), a GPS receiver (Novatel OEMV-1), a typical UAV inertial sensor (Crossbow MicroNav), and a battery box to power the system (Figure 8b, for a full description of this system see Gurtner et al. 2009). All data and images were received on a laptop computer (Figure 8c). Images were captured at 1 fps (frames per second) and at a resolution of 1024 × 768 pixels. The camera-mount was designed so that the lateral angle of the camera could be rotated during flight from downward pointing to up to 85 degrees pointed starboard. As this lateral angle was adjusted manually during each flight it could not be recorded and therefore the actual field of view for each image could not be calculated.

We commissioned the ARCAA team to design a bracket to be fitted to a Partenavia that already had a hole in the fuselage for mounting cameras. We were able to view the footage from the camera during flight so that we could adjust the camera angle to capture images of the animals. Two members of the ARCAA group were with us during each flight to operate the computer programs related to each component of the data acquisition system. We conducted four manned aircraft scoping flights, each of which are described below.

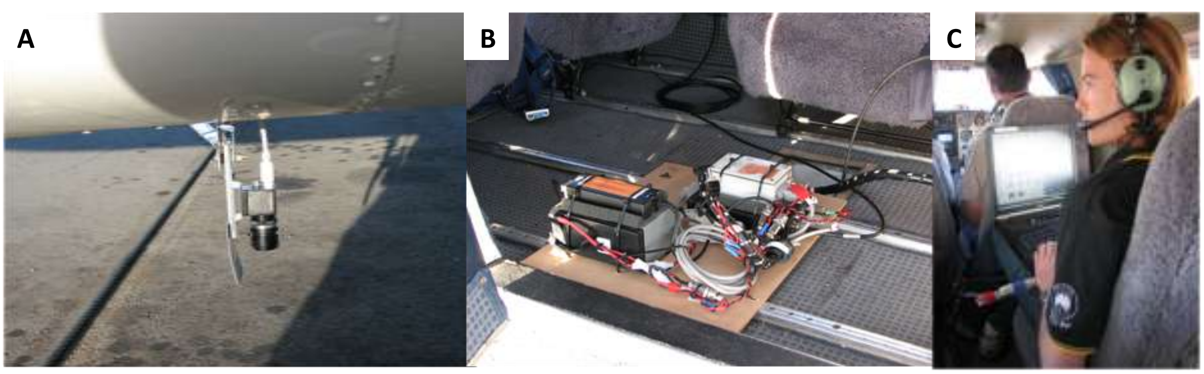

Figure 8. Camera set-up on the Partenavia aircraft during UAV payload scoping flights. A. Camera mounting. B. Data acquisition system. B. Operation of the camera system by an ARCAA group member.

Scoping Flight 1: Validate camera system

This initial flight was conducted on 26th September 2008 with the following objectives:

- Validate the camera bracket mounting, including investigation of any adverse effects such as vortex shedding, which could lead to undesirable vibration, or even failure of the bracket.
- Validate the data collection system for the surveys.

During this initial flight the images were out of focus when the camera focus was set to the infinity. Winding the focus back towards the 'far focus' setting and retesting improved the images when flying at altitudes of 300-400 feet, however the quality was still not high enough to continue the flight. It was determined post-flight (by testing the camera on the ground) that the appropriate focus setting for the camera was just back of infinity focus.

Scoping Flight 2: Dugong trial

This flight was conducted on 1st October 2008 and validated the on-the-ground test for the appropriate focus of the camera. The primary objective of this flight was to film dugong herds at various heights to validate the lens selection and system settings for a dugong survey. We undertook a flight over an area where large dugong herds are known to regularly occur on shallow sand banks off the southwest tip of Moreton Island, near Brisbane (Figure 9). Dugongs were successfully located by an observer looking out the same side of the aircraft as the camera was pointed. The observer directed the pilot to conduct several passes of the dugong herd so that images could be captured. Passes were made at altitudes of approximately 1000, 750 and 550 ft and images were captured of the herd at each of these heights.

Dugongs could be counted in the images captured from 1000 ft (Figure 10) but only because there was a large herd and they were known to be dugongs. The results of the post-flight image analysis are provided in Table 8. At this altitude the image resolution was not high enough to reliably identify individual dugongs or distinguish dugongs from dolphins if the images had been capture remotely. Dugongs could be identified and counted more reliably in images obtained at 750 ft (Table 8, Figure 11), however we felt the image resolution would still need to be higher than in the camera we used, to reliably identify individual dugongs and distinguish them from dolphins throughout the survey area, particularly in deeper waters where the dugong may not be so clearly visible from the surface. At 550 ft the field of view of the images was compromised and it was difficult to manoeuvre the aircraft past the dugongs at the exact distance that would provide images suitable to critique. In all images captured at 550 ft, the angle of the camera was too acute to reliably identify and count the dugongs (Table 8, Figure 12).

Figure 9. Locations of dugong herds for which images were collected using the UAV payload on a Partenavia.

Table 8. Dugong sightings during scoping flights using the UAV payload on a Partenavia.

Pass No.	Altitude (ft)	Image	No. Additional Dugongs	Total Dugongs
1	1048	1	29	
1	1054	2	6	
1	1073	3	51	
1	1085	4	29	
1	1094	5	20	
1	1098	6	4	
1	1096	7	1	140
2	759	1	too far off to side	
3	752	1	3	
3	754	2	15	
3	757	3	23	
3	759	4	33	
3	763	5	4	
3	769	6	7	
3	769	7	13	
3	764	8	27	125
4	578	1	too far off to side	
5	565	1	~58	
5	562	2	too far off to side	~58

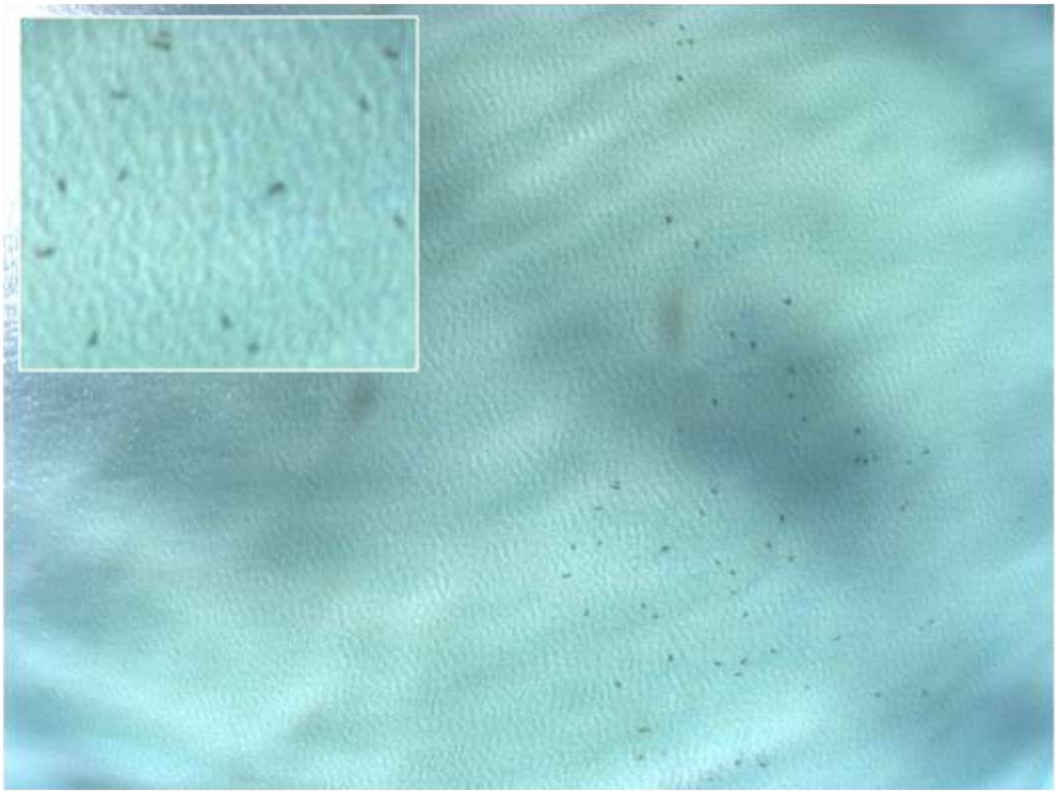

Figure 10. Example images obtained of a dugong herd using the UAV payload on a Partenavia at 1000 ft (inset is an enlarged section of the image).

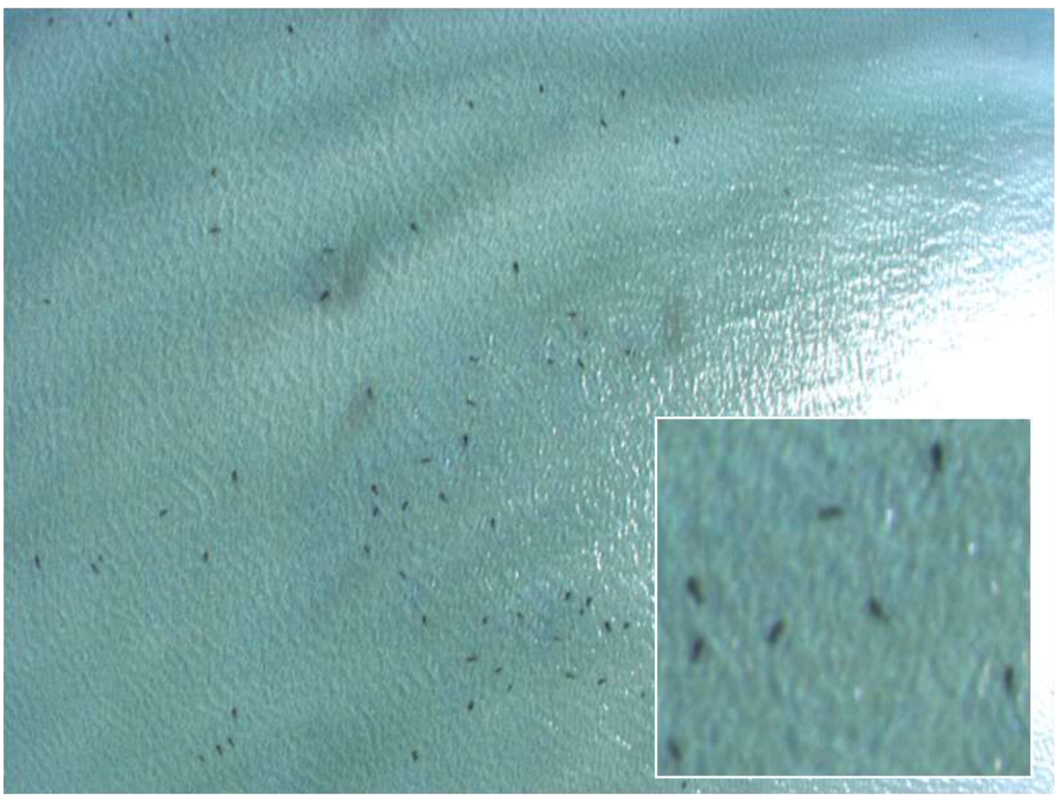

Figure 11. Example images obtained during a pass over a dugong herd using the UAV payload at on a Partenavia at 750 ft (inset is an enlarged section of the image).

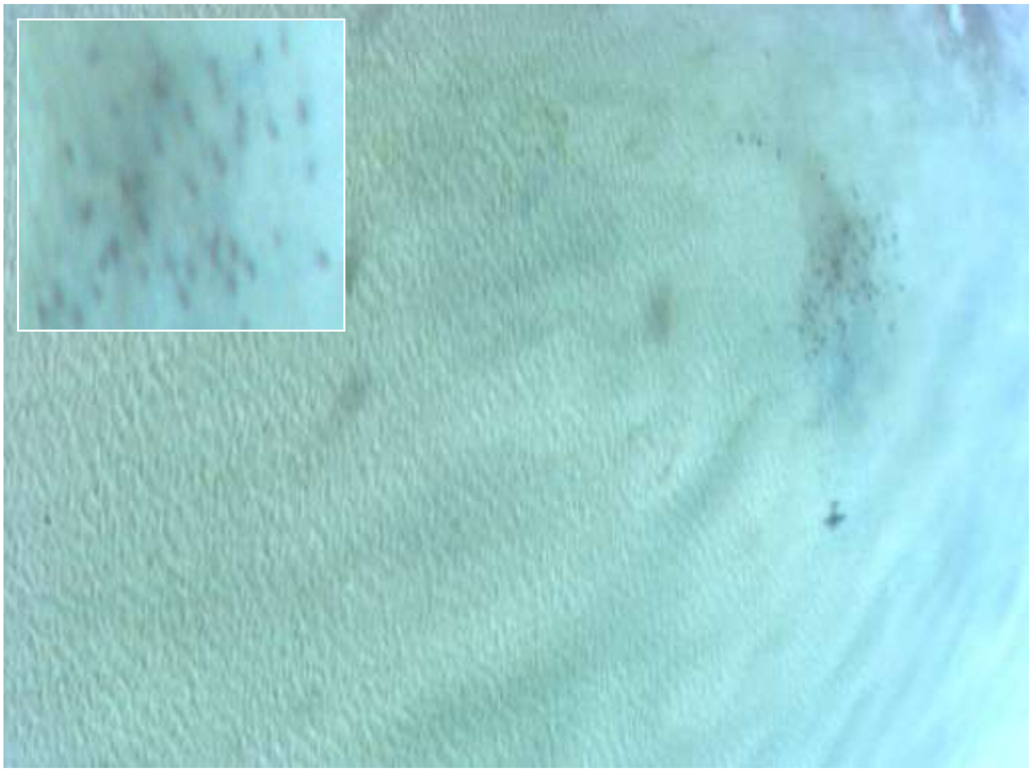

Figure 12. Example images obtained during a pass over a dugong herd using the UAV payload at on a Partenavia at 550 ft (inset is an enlarged section of the image).

Scoping Flights 3 and 4: Whale trials

The objective of these scoping flights was to capture images of whales from various heights to determine whether the camera system and lens selected provided sufficient resolution to identify whales from the images. In both flights, two experienced observers were seated on the same side of the aircraft as the camera was pointed, and they directed the pilot to keep the whales on that side of the aircraft. The first of these flights was conducted on 14th October 2008 in conjunction with humpback whale research being conducted at Peregian Beach on the Sunshine Coast by Noad and his team during the whales' southern migration. Their research included spotters tracking the whales using theodolites from Emu Mountain, and during our flight we were in contact with the spotters to get positions of the whales in the area. This enabled us to quickly locate a whale and fly past it a number of times. However, we had difficulty obtaining images of the whale due to: 1. glare, 2. insufficient image storage space on the hard-drive, and 3. time constraints on the aircraft charter. As a result, no images of whales were obtained during this flight.

A second whale trial flight was conducted on 21st October 2008 in Moreton Bay, near Brisbane. We did not have land-based spotters during this flight but conducted a random transect style search off Point Lookout, North Stradbroke Island, where whales are known to funnel through a narrow section of the coast. Four pods of humpback whales were sighted, one during transit across Moreton Bay, and three off Point Lookout. We collected multiple images of two of these pods (a mother-calf pair and a single individual), locations for which are provided in Figure 13. The first whale pod was passed at approximately 1000 ft, while the second was passed at approximately 1500 ft. At 1000 ft the field of view was relatively narrow and the image resolution was high enough to depict the presence of whales, but not high enough to identify whale species (Figure 14). Capturing the images at 1500 ft provided greater coverage, however the image resolution was too poor to reliably depict the presence of whales (Figure 15).

Figure 13. Locations of humpback whale pods for which images were collected using the UAV payload on a Partenavia.

Figure 14. Example images obtained during two passes over a humpback whale mother-calf pair using the UAV payload at on a Partenavia at 1000 ft.

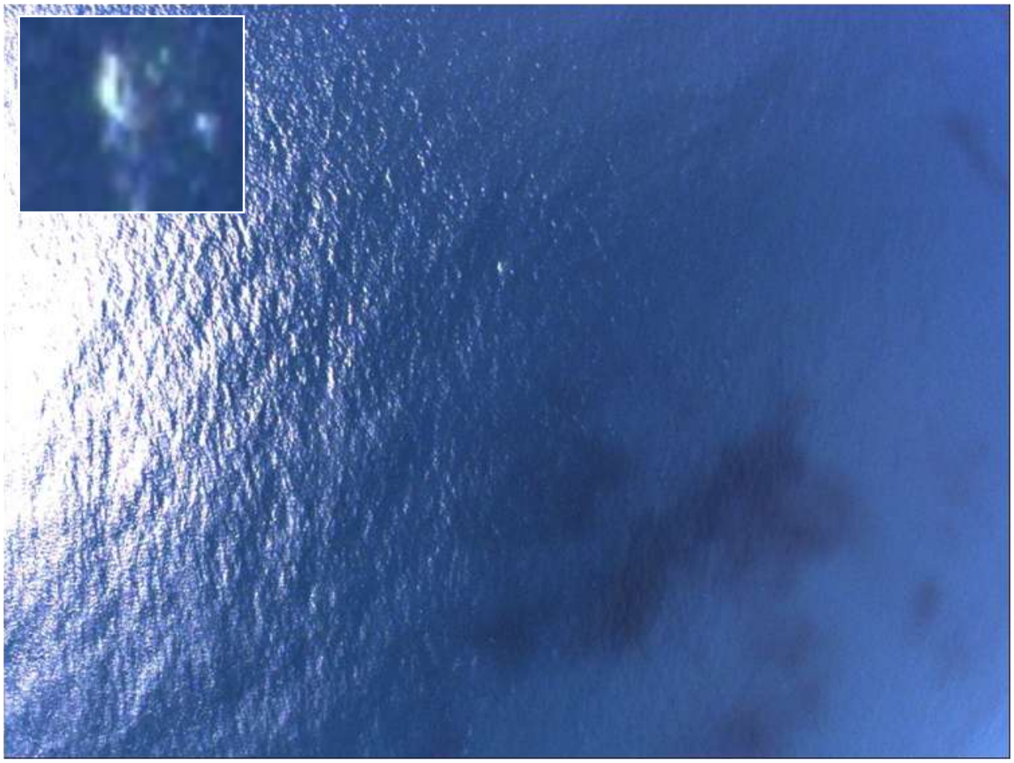

Figure 15. Example images obtained during a pass over a humpback whale using the UAV payload at on a Partenavia at 1500 ft.

Conclusions

The combination of the typical UAV imaging system we used and the altitudes we trialled did not provide images of high enough resolution to reliably detect dugongs or whales. Rather than continuing with this system and conducting further trials at lower altitudes, we converted to higher resolution imaging systems, the results of which are provided in the next section.

MANNED VERSUS UNMANNED OBSERVATIONS

Background

During the summer of 2008-09 the Australian Antarctic Division conducted preliminary aerial surveys of minke whales (*Balaenoptera bonaerensis*) in the Antarctic region (Kelly 2009). The aircraft used was a CASA 212-400, which was equipped to provide three observation platforms: (1) real-time human observers, (2) video recordings, and (3) still image captures (Pyper 2007). We took the opportunity to use the CASA aircraft with the same imaging systems installed to conduct trial dugong surveys evaluating the three observation platforms to determine whether either video or still images (which the UAV survey technique relies upon) could replace human observers and provide comparable survey results.

Aim

The aim was to assess if there were any significant differences in the sighting rate of dugongs between the three aerial observation platforms: human observers, digital still camera and the high definition video camera.

Methods

Observation Platforms

The aircraft used throughout this project was a CASA 212-400 (CASA). This is a twin turboprop military transport aircraft which has been certified for civil operations by the Civil Aviation Safety Authority of Australia to carry 15 passengers. It is a high-wing aircraft providing an unobstructed view of the survey transect strip. The aircraft has an electrical power supply system consisting of two DC generators with AV inverters from which the computers, video cameras and digital audio recorders were powered.

The three observation platforms were:

1. Human observers – the survey team consisted of four dedicated observers (two on each side of the aircraft), and a survey leader. Details of the methods the observers used are provided in the following sections. Each observer was looking out a single window which was flat and approximately 25 x 25 cm with rounded corners. When the observers sat so their eyes were close to the window, animals at the surface were visible for 6-10 sec (at an altitude of 900 ft) depending whether the animal was sighted at the narrowest (top and bottom) or widest (middle) part of the window.

2. Video cameras – two high definition video cameras (GC1350C Prosilica GigE) were mounted within the fuselage of the CASA. These were set at a 38° angle so that they covered the observers' field of view on each side of the plane. These cameras were controlled during flight

via a computer program (StreamPix High Speed Video Recording Software V3.0). Images were captured at approximately 5 frames per second and at a resolution of 1036 x 1024 pixels.

3. Still camera – one digital SLR Nikon D200 10 megapixel with a Computar 5mm F1.4 MP Manual Lens was mounted within the fuselage of the CASA. The camera was set to capture images at 4 megapixels every 2 sec when flying at an altitude of 900 ft and every 1 sec at 500 ft. This provided complete coverage of the transect line directly under the plane with approximately 5% overlap between photographs at a ground speed of 110 knots.

Study Sites

This trial was conducted at Shark Bay in Western Australia (25°30'S, 113°30'E). This site was chosen because there is a high density of dugongs in the Bay found in relatively shallow clear waters. Therefore we expected a high animal sighting rate which would allow us the best opportunity to test the three platforms. Previous surveys of Shark Bay have produced dugong population estimates of approximately 10,000 dugongs (Marsh et al. 1994; Preen et al. 1997; Gales et al. 2004; Holley et al. 2006; Hodgson 2007). There is also a large population of bottlenose dolphins and a humpback dolphin population of unknown size (Preen et al. 1997; Hodgson 2007).

Survey Design

Two survey flights were conducted at Shark Bay on 16-17 March 2009. The flights were conducted in an eastern section of the Bay where high densities of dugongs are known to occur in summer (Holley et al. 2006). The flight plan followed seven parallel line transects previously flown during surveys in Shark Bay, spaced at intervals of 2.5 nm (4.6 km, Figure 16). The aerial survey methodology followed the transect strip design used regularly for dugongs (Marsh and Sinclair 1989b; Marsh and Sinclair 1989a; Pollock et al. 2006), except that the altitude of the first flight was 900 ft and the second was 500 ft. The coverage (strip width) for each observation platform at the two heights is provided in Figure 17.

For the two observers on each side of the aircraft, the transect strip was delineated using markings on the aircraft windows and the observers maintained a consistent eye height by aligning their eye with the wing/wheel hub of the plane so they were reliably surveying the correct transect strip. These markings were calibrated on the ground to account for observer height. All sightings within the demarcated transect strip recorded from all four observers were used in the comparison between observation platforms.

Although all dugongs are assumed equally visible across the 400 m or 222 m wide strip (900 and 500 ft respectively) for the observers, this was not the case with the video image. Dugongs were not observed beyond 386 m or 198 m (calculated according to number of pixels of the dugongs from trackline edge of video as proportion of total of field of view). That provided a maximum of 252.5 m or 148 m overlap with the observers (i.e. 63% or 67% of the transect strip). Consequently the width of the video transect was truncated to this maximum distance of sightings for all post-survey analysis.

For all dugong sightings the observers recorded the total number of animals visible and the turbidity (see Appendix 1 for scale). Periodically during each transect, and whenever conditions changed, the team leader (who was additional to the four observers and was not announcing sightings) recorded

Beaufort sea-state, turbidity and glare on each side (scored by the front observers, see Appendix 1 for scales).

Post Flight Image Analysis

Post flight, Hodgson (also the team leader), reviewed all video and still images. All dugongs that could confidently be identified within the still and video images were recorded without referring to the observer data. It should be noted that Hodgson had prior knowledge of the observer sightings as she recorded the data at the time of the survey. This may have caused some bias in assessing the images, however, dugongs reasonably well distributed throughout the survey area which minimised this bias (see Results). From each still image or video frame containing dugongs, scores were also recorded for turbidity, glare, and Beaufort sea-state (the latter being recorded from stills only).

The time taken to analyse the stills images was calculated by dividing the total number of images analysed by the total time taken to view all images, which included the time taken to save the images showing animals in a separate folder and note the position and number of animals sighted. This time did not include assessment of the conditions for each still (turbidity, glare and sea state).

The video footage only recorded properly on the left side of the aircraft for the first flight (at 900 ft) and the right side of the aircraft for the second flight (at 500 ft), and therefore, only the observer data from the matching side was used in the comparison. For the first flight, some sections of the transects were missed by the video, so that only the sections recorded by the video were used from stills and observer data for the comparison.

Comparison Analysis

The aim of this analysis was to assess if there were any significant differences in the sighting rate between the three observation platforms: human observers, the digital still camera and the high definition video camera. In the survey the three platforms did not cover equivalent distances from the trackline (Figure 17) so a direct comparison on duplicate individual sightings, as per double platform distance sampling techniques, was not possible. However, making a few reasonable assumptions, the overall sightings rate per platform could be analysed within a log-linear model framework with platform as a term. The model was fitted with a treatment-wise contrast, where the human observer was taken as the reference level. Hence, the performance of the platforms could be quantitatively compared and the differences between each platform and the human observer assessed for statistical significance.

Letting N_i denote the number of animals seen by a platform P_i on a transect *i* with strip width area A_i (length *times* strip width) and altitude D_i then the general framework of our log-linear model was,

$$\log(\mathrm{E}(N_i)) \sim P_i + \log(A_i) + P_i \times D_i \,.$$

The distribution around the expected value of *N* is taken to be Poisson. The coefficient of the log(*A*) term is fixed at one so that transect strip area is simply an offset in the model. Hence, the rate of sightings per area is what is being modelled. The two flights were each conducted at different heights: 900ft (274m) and 500ft (152m), respectively. Therefore, the altitude term D_i is equivalent to date. The

$P_i \times D_i$ interaction is to include the effect of altitude on the comparative performance of the three platforms. If the relative sightability performance of the platforms was independent of the aircraft's altitude then all the data could be pooled, since the differences in strip width (area) due to altitude are offset in the model. However, we felt that it was possible that the platforms relative performance could change with altitude; hence a platform-altitude interaction effect was included for investigation.
A number of assumptions have been made in the analysis:

- Since the platforms' fields-of-view are not equivalent, and in some cases have no overlap, it must be assumed that different areas are covered by each. However, as we are assuming an identical uniform random distribution of animals across all areas covered, the numbers of animals observed by each platform can be considered to be arising from the same sampling population. This would seem a reasonable assumption and is a fundamental assumption of distance sampling.
- As stated, the distribution of counts is assumed to be Poisson. This assumption corresponds to a one-to-one mean-variance relationship. In some cases this relationship has not held. For example, when there is over-dispersion or excess zero data. The model diagnostics (see Appendix 2) show that the mean-variance relationship assumption is reasonable and hence the Poisson assumption would seem valid.
- The human and video platforms are positioned obliquely, and the still camera is not. If human or video sightings very distant from the track-line were included in the comparison to the still platform, such an analysis would be invalid due to sightability naturally reducing at further distances. For such a comparison to be valid, sightability must be reasonably constant across the strip width. Fortunately, this survey was conducted as a strip width survey so all sightings are within a narrow strip and this assumption is reasonably valid.
- It is assumed that strip width has a constant linear effect. For example, if you double the strip width (ignoring increasing sighting distance effects) you should observe twice as many animals. This may not be completely true as human observers may miss fewer animals in a smaller search region, i.e., if the observers concentrated on a very small area the sighting rate per area unit may increase.

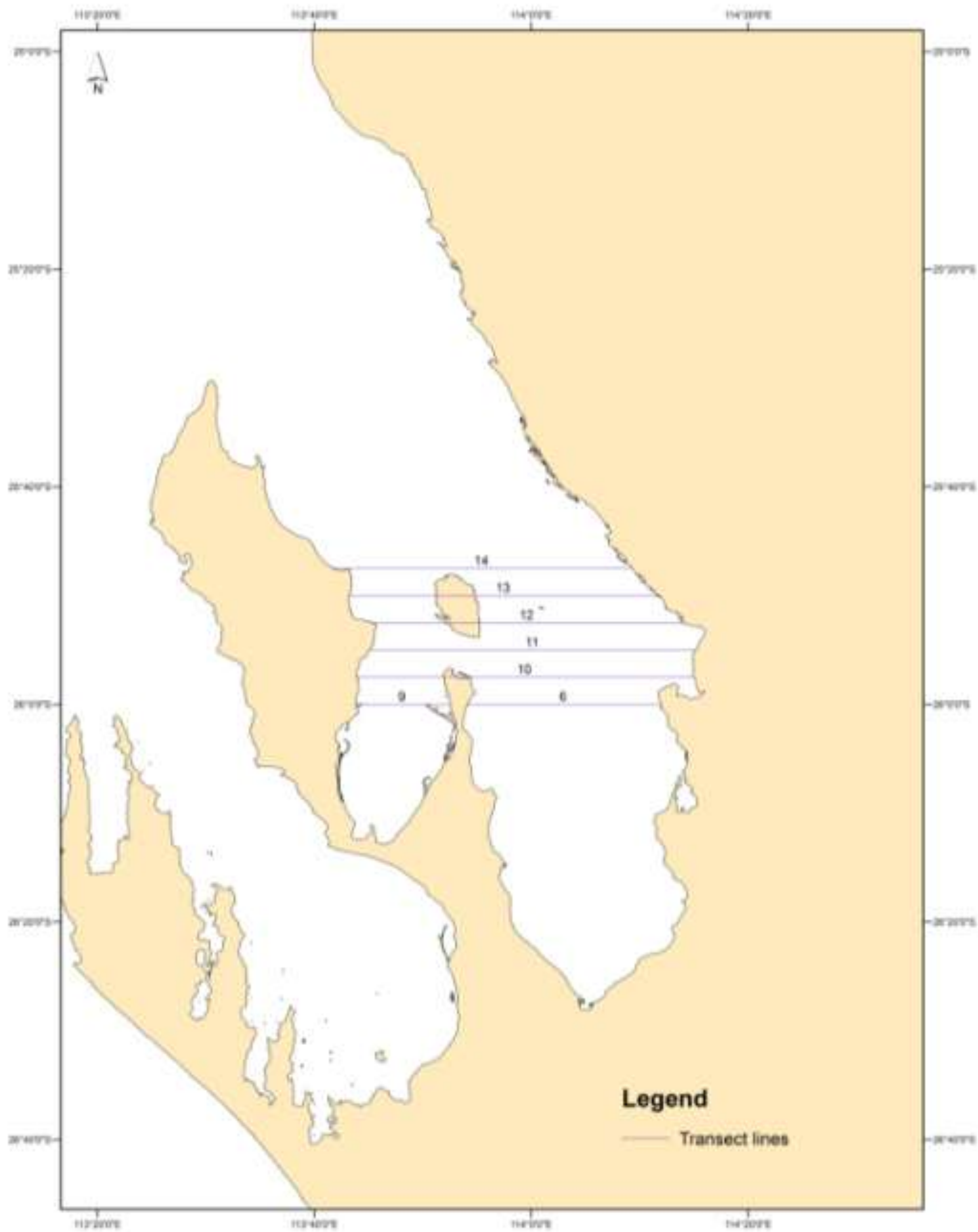

Figure 16. Transects lines flown in Shark Bay.

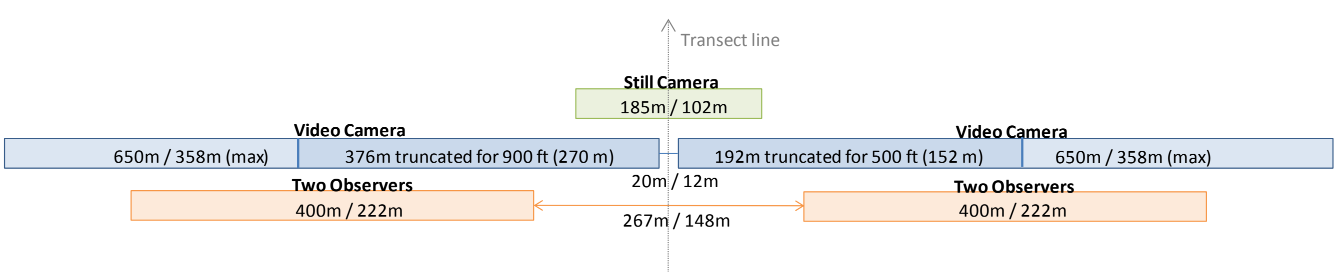

Figure 17. Transect strip width for each observation platform at altitudes of 900 / 500 ft. The video strip with was truncated post-survey according to the maximum distance of sightings from the transect line.

Results

Image analysis rate

The still images were analysed at an average rate of 6 images per minute. In our Shark Bay survey, the transects were an average of 41 km long. The images were collected at 1 s^{-1} at 900 ft and 2 s^{-1} at 500 ft. Manned dugong surveys are flown at 100 kn or 3.1 km / min. Therefore, for the average 41 km transect we would obtain 794 and 1587 images which would take 4.4 and 2.2 hours to analyse if captured at 900 and 500 ft respectively.

Overall, when capturing one image per second, each kilometre of survey took 3.2 min to analyse post-survey.

Platform comparison

The environmental conditions for the surveys were excellent during the first survey (16th March, 900 ft) but there were higher winds during the second survey (17th March, 500 ft) causing poorer sighting conditions (Table 9). The number of dugongs sighted by each observation platforms is provided in Table 10).

Table 9. Summary of environmental conditions recorded by the observers during both flights.

Environmental Condition	Summary	16/03/2009	17/03/2009
Beaufort sea state	Min	1	1
	Max	3	4
	Mean of Modes	1.00	1.43
Turbidty[1]	Min	1	1
	Max	4	4
	Mean of Modes	1.43	1.43
Glare South[1]	Min	0	0
	Max	3	2
	Mean of Modes	1.80	1.17
Glare North[1]	Min	0	0
	Max	2	3
	Mean of Modes	0.80	1.20

[1] For reference scales see Appendix 1.

Table 10. Number of dugongs recorded from each observer platform during the two flights in Shark Bay.

Transect	Observers	Stills	Video
16/03/2009[1]			
6	1		1
9	4	1	
10	17	3	1
11	21	12	3
12	29	34	14
13	39	21	17
14	2	2	1
Total	113	73	37
17/03/2009[2]			
6	8		
9	2		2
10	23	1	6
11	22	3	4
12	40	26	21
13	42	2	5
14	4		3
Total	141	32	41

[1] Only partial data from the left observers left video and stills are presented, flight altitude was 900 ft
[2] Only data from the right observers and right video are presented, flight altitude was 500 ft

Figure 18 and Figure 19 are box plots of the sighting rate per km^2 at the two different survey altitudes. Initial examination found the environmental covariates (turbidity, glare and sea-state) to generally be insignificant, so they are not included in the final analysis. The exclusion of these covariates seems reasonable since all platforms would be covering similar conditions overall. To maximise the similarity of environmental conditions, in particular the glare, the observer data was configured to match the side/direction of the platform it was being compared to. So, for the still platform analysis the observer data from both sides was pooled and the strip width adjusted accordingly. The video platform was only active on one side at a time so only the observer sightings from the sides of the aircraft where video was present were considered (port on the 16/03/2009 at 900 ft and starboard on the 17/03/2009 at 500 ft). Distributing the data in this way meant that we are able to get a comparison between the still and video platforms and the human observers, but no direct comparison between the still and video platforms.

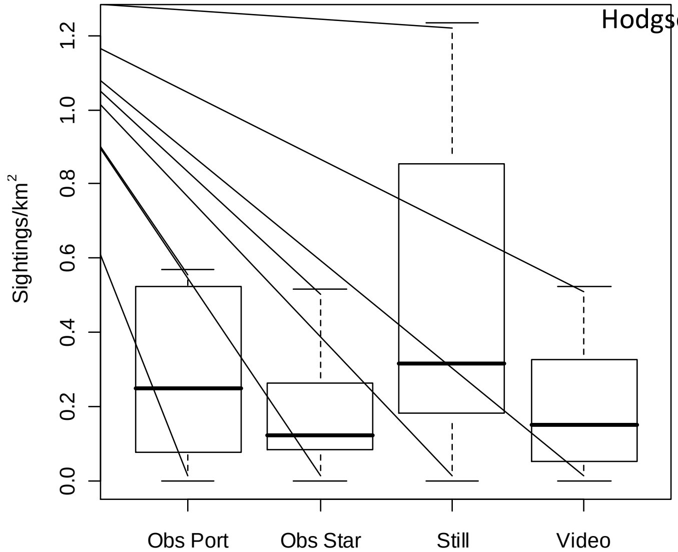

Figure 18. Number of sightings per strip area (in km^2), replicated over transects, for each platform at an altitude of 900ft (270m).

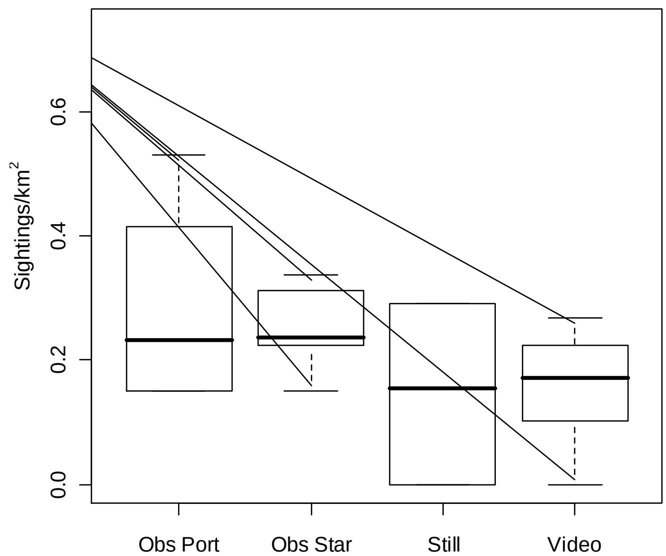

Figure 19. Number of sightings per strip area (in km^2), replicated over transects, for each platform at an altitude of 500ft (152m).

The results from the examination of the still and observer platforms are given in Table 11. A significant interaction term Still x Altitude was found so the different days (altitude) were analysed separately (results given in Table 12 and Table 13). This analysis showed that the still platform at 900 ft (274 m) had superior performance over the observers' platform with a sighting rate of 251% that of the pooled observers. Even if the starboard observers on the 16/03/2009 (900 ft) are removed from the comparison due to their low sighting rate the difference is still 210%. At the lower altitude of 500 ft (152 m) the still platform sighting rate was not significantly different to the observers. The still platform performance deteriorates at the lower altitude by 42% to be equivalent to the observer sighting rate which is not significantly different between the two altitudes. More data would be needed to investigate this result further. Examples of the still images obtained at the two altitudes are provided in Figure 20.

Table 11. Estimates for additive log-linear model of sightings per transect for the still and human observer platforms

Term	Estimate	SE	z-value	P-value
Intercept i.e. Observer 900ft (270m)	-15.0821	0.1270	-118.756	**<0.001**
Still i.e. 900ft (270m)	0.9206	0.2095	4.394	**<0.001**
Altitude i.e Observer 500ft(152m)	*0.1265*	*0.1803*	*0.701*	*0.4831*
Still x Altitude i.e. 500ft (152m)	-0.9957	0.3704	-2.688	**0.0072**

Table 12. Estimates for additive log-linear model of sightings per transect for the still and observer platforms on the 16/03/2009 at an altitude of 900 feet

Term	Estimate	SE	z-value	P-value
Intercept i.e. Observer	-15.0821	0.1270	-118.756	**<0.001**
Still	0.9206	0.2095	4.394	**<0.001**

Table 13. Estimates for additive log-linear model of sightings per transect for the still and observer platforms on the 17/03/2009 at an altitude of 500 feet

Term	Estimate	SE	z-value	P-value
Intercept i.e. Observer	-14.95561	0.1280	-116.807	**<0.001**
Still	*-0.07507*	*0.3055*	*-0.246*	*0.806*

The video model results are given in Table 14. No significant difference was found in the video sighting rate in relation to altitude. However, the model showed that the video platform performs significantly worse than the human observers across both altitudes, with a sighting rate of 60% that of human observers.

Table 14. Estimates for additive log-linear model of sightings per transect for the video and observer platforms

Term	Estimate	St. error	z-value	P-value
Intercept i.e. Observer 900ft (270m)	-14.9660	0.1240	-120.660	**<0.001**
Video i.e. 900ft (270m)	-0.5193	0.2097	-2.477	**0.01**

An analysis was done with a mixed-effect framework too (treating both transect and day as random effects), but there were issues with the way the mixed-effects models were being fitted. In particular, the difference in AIC between the model without a mixed effects (approx. 296) and with (approx. 105) was too big and this indicates a problem (Mark Bravington, personal communication).

Figure 20. Still images captured in Shark Bay at the two different altitudes. Dugongs are outlined in red boxes.

Discussion

In summary, the still platform's sighting rate was significantly better than the human observers by 251% at the altitude of 900 ft. However, at 500 ft the performance of the still camera was reduced by 42% to be equivalent to the human observers. The video system performed relatively worse than human observers across both altitudes with a sighting rate of 60% that of human observers.

A possible explanation for the decrease in still camera performance at the low altitude could be the relatively high wind speeds during this flight compared to the 900 ft flight. The sighting conditions could be expected to affect all platforms, and a model with sea-state was examined, however it was problematic to extract information as altitude and sea-state are confounded. Whether sighting conditions affect the sighting rates in the still images more than for observers needs further investigation.

A second explanation for the poor performance of observers compared to the stills at 900 ft is the potential that the sighting rate drops off towards the outside edge of the transect. Marsh and Sinclair (1989b) showed no different between dugong sightings rates at 900 ft with a 400 m wide transect compared to 450 ft with a 200 m wide transect. However, an equal sighting rate throughout the transect has only been shown for the lower altitude and smaller transect (Pollock et al. 2006). The observers' disadvantage in comparison to the stills is that they have a limited search time. This may only be a significant issue at 900 ft where the search area is much large than for 500 ft.

The poor performance of the video was mainly a result of the low resolution of each image in comparison to the still images. The resolution was further affected by the angle of the video and the resulting large area covered in each image. Animals appeared much smaller and were harder to zoom in on in the video compared to the still images. The angle of the video was set in an attempt to maximise the overlap of the video with the observers transect strip. However, post-survey we decided to truncate the video strip to the maximum distance of sightings, which were much closer to the transect line than what the observers could see. The performance of the video platform may be improved if the cameras were set to point either straight down, providing a direct comparison with the stills, or at less of an angle than we had them. This would increase the resolution of the images per survey area covered and therefore increase the quality of the images. The video platform should not be discounted as it produces a higher frame rate that the stills providing benefits such as: (1) increasing the probability of capturing animals surfacing, (2) providing some information about the animal movement (e.g. multiple surfacing of dolphins or the white-water produced when dugongs exhale), and (3) increasing the probability of capturing animals outside of the zone of glare within the images.

AUTO-ANALYSIS OF UAV IMAGES

Background

Using the still images obtained during the comparison between manned and unmanned observations, we aimed to determine whether animals could be detected automatically in the images using a computer algorithm in order to reduce the post-flight analysis time. Within the overall time and scope of this project, and with the limited images available, it was not possible to develop a complete and robust algorithm to process the images and produce counts of animals. However, we pursued the initial stages of developing an algorithm with the view of determining the potential for automating the counting process.

In addition to the images obtained in Shark Bay (as described in the previous section) we used images captured using the same equipment and survey methods at a second location, Site B. This was along an undisclosed part of the coastline where formal marine mammal surveys have not previously been conducted, but where dugongs and dolphins were expected to be found. At Site B, the marine environment is much more turbid; according to our turbidity scale where 1 was “shallow and sea floor clearly visible” and 4 was “deep and turbid”, the average turbidity recorded was 3.7 (refer to Appendix 1 for full turbidity scale). Therefore, at Site B we expected most animals to only be captured on still images when they were at, or very close to, the surface, and the sea floor to be rarely visible. This provided an alternative scenario in which to assess the accuracy of the algorithm.

Development of the Algorithm

We hired Dr Luis Mejias from ARCAA to develop an image analysis algorithm that could batch process a file of images and present the images with potential animal candidates highlighted. Of the still images obtained during the manned flights in Shark Bay and Site B, we manually checked a total of 6035 and 9672 images respectively for animals. Of those, a total of 142 images were found to contain animals (dugongs, dolphins or turtles). Half of the images containing animals were provided to develop the algorithm. The remaining half we retained for testing the algorithm.

The detailed methodology for the development of the algorithm is outlined in Appendix 3. The approach used to detect animals within the images consisted of four processing layers:

1. Morphological operations – simplifying the image using two mathematical operations called erosion and dilation.
2. Adaptive thresholding – identifying all pixels above a threshold light intensity
3. Blob detection – detecting points and/or regions in the image that are either brighter or darker than those surrounding.
4. Colour analysis – using colour thresholds to determine which blobs are potential animals.

Analysis of selected images from the “development” subset of images showed that, as expected, the number of false detections increased as the complexity (measured as the level of texture or clutter) of the image increased. This analysis is presented in Appendix 3, and it was recognised that a large number of false detections occurred overall, but that there was an “acceptable level” of missed detections. The “acceptable level” was not defined. However, if we consider that the aim is to replace human observers on the aircraft, as well as eliminate the need to manually check all images, we can set the minimal acceptable level of detections according to the probability of a dugong being detected by a human observer on an aircraft, estimated as 0.72 empirically by Marsh and Sinclair (1989a). The detection rate obtained during the analysis of the “development” subset of images was 41%. A large number of missed detections were accounted for by two images each containing 11 animals. If eliminating these two images, the detection rate was 62%. Therefore, during this initial analysis conducted by Mejias, the positive detection rate was lower than we would consider acceptable.

Testing the Algorithm

We used the “test” subset of images containing animals (N = 69 images), none of which were used to develop the algorithm, together with a total of 375 images containing no animals, to conduct a more rigorous test of the algorithm. The results of this analysis are presented in Table 15 and Table 16. It should be noted that the algorithm was developed based on the shape of a dugong, and therefore correct detections of turtles were not necessarily expected.

The algorithm successfully detected 53% of the dugongs in the Shark Bay images and only 17% in the Site B images. There were more images of animals from Shark Bay used to develop the algorithm than from Site B, which may explain the higher successful detection rate at Shark Bay. This suggests that at this stage, the algorithm needs to be adjusted to the particular environmental conditions (and subsequent characteristics of images obtained) at different sites.

Assuming that the number of missed detections could be reduced to an acceptable level (less than 28%, see previous section), the algorithm would be considered successful if it could reduce the amount of time needed to manually check images, i.e., if it could refine the number of images, and locations within the images, that need to be checked. This was the case for the images obtained at Site B. The algorithm reduced the number of images needing to be checked by almost 50%. However, the images from Shark Bay were much more complex as the ocean floor could often be seen and there was a large amount of variation in bottom-type in most images. This resulted in a high proportion of Shark Bay images (91%) containing false detections. An example of an image with a uniform bottom-type and successful detection of a dugong is provided in Figure 21, while an image with a highly varied bottom-type a large number of false detections is provided in Figure 22.

Table 15. Results of image analysis using an algorithm to detect potential animals using images previously manually checked.

Animal in Image	Images	Total Animals	Correct detections	Animals Missed	Total Incorrect Detections	Images with Incorrect Detections
			Shark Bay			
Dugong	30	51	27	24	567	22
None	158				5564	150
Total	**188**	**51**	**27**	**24**	**6131**	**172 (91%)**
			Site B			
Dolphin	1	2	0	2	0	0
Dugong	5	6	1	5	15	2
Turtle	33	45	0	45	66	9
None	217				1670	125
Total	**256**	**53**	**1**	**52**	**1751**	**136 (53%)**

Table 16. Results of image analysis using an algorithm to detect potential dugongs, separated according to the altitude at which the image was captured.

Altitude	Images	Total Dugongs	Correct detections	Animals Missed	Total Incorrect Detections	Images with Incorrect Detections
900 ft	22	37	20	17 (46%)	397	16
500 ft	8	14	7	7 (50%)	170	6
Total	**30**	**51**	**27**	**24**	**567**	**22**

Figure 21. Example of image analysis results with a relatively uniform bottom where a dugong is correctly detected.

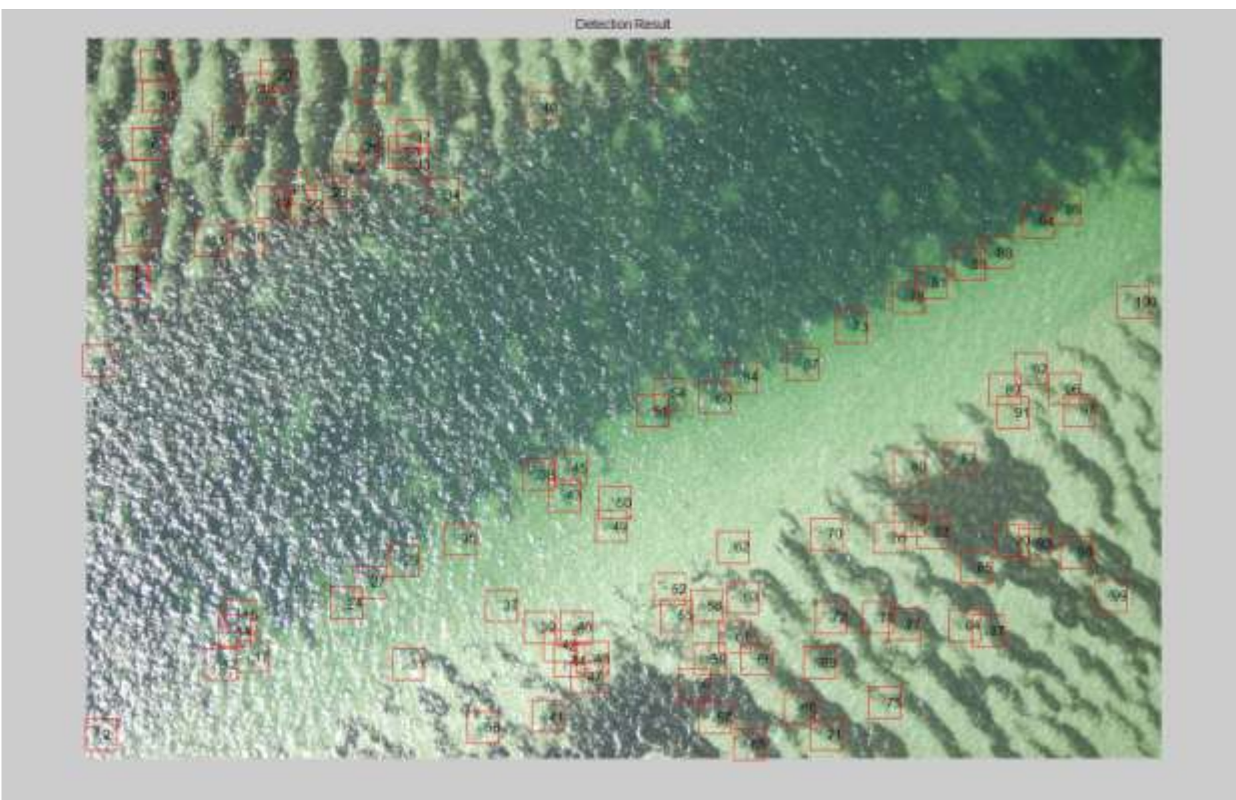

Figure 22. Example of image analysis results where the variation in bottom-type results in a lot of false detections.

SUMMARY

To summarise the results of this project, we review our findings against the objectives stated in the first section (Project Outline) of this report.

Objective 1: **Provide a review of current UAV capabilities and potential use for marine fauna surveys**

Within the timeframe and budget of this project there was no single UAV available to purchase or hire that could fulfil our requirements and meet our budget for conducting a trial survey of either dugongs or humpback whales. However, *Insitu Pacific* and *CyberTech* have expressed interest in developing the civilian applications for their UAVs. A potential niche market for them is monitoring marine fauna as part of the regulatory and/or environmental impact assessment requirements for the oil and gas industry. *Insitu Pacific* have approached *Woodside Energy* and confirmed their interest in UAV technology, particularly for eliminating human risk in aerial surveys. *Cyber Technology* offered this project some low cost trials. However, these trials were stalled by the permitting requirements of the Civil Aviation Safety Authority (CASA), and the long wait time for CASA to issue their UAV Operators Certificate.

Silvertone Electronics has the most promising UAV airframe for purchase. Researchers would then need to source their own payload, autopilot, data link and ground station. The option of purchasing a UAV would require a large commitment to the development of UAVs by a single research institute, due to the permitting requirements, maintenance costs and the need to retain personnel with the skills to operate the systems. Hiring UAVs for trials at this stage in the development of this methodology for aerial surveys provides the option of testing multiple systems. Different species may require different UAV capabilities and hiring systems for trials would provide some flexibility to investigate this variation of needs.

Objective 2: **Test the basic capabilities of UAVs for viewing and surveying marine mammals**

(c) Using small UAVs

We used the Warrigul UAV operated by *V-TOL Aerospace* to conduct scoping flights over both land and water. This UAV had limited endurance and control range so flights were restricted to within 10 km maximum distance from the base station. The scoping flights showed that UAVs can maintain the desired altitude and trackline more accurately than manned aircraft when compared under the same low-wind conditions. During our over-water scoping flight, the wind speed reached 15 knots and the UAV deviated more heavily from the trackline under these conditions. This UAV could transmit images in real-time back to the base station and its flight path could be diverted at any time. However the video images obtained had limited resolution. We were able to depict two dolphins (which were sighted by land-based spotters first) and a manta ray using the real-time footage. The UAV had the advantage of providing records of the field of view and angle of the camera, together with the exact altitude, pitch, roll, heading and GPS track. These records could be used to determine the exact proportion of the survey area sampled more precisely than can be obtained from manned flights, and consequently provide more accurate population estimates.

(d) Using manned planes mounted with UAV systems

We were assisted by the Australian Research Centre for Aerospace Automation (ARCAA) in order to conduct manned flights using a Partenavia mounted with their UAV data acquisition system. Images were captured at 1 fps (frames per second) and at a resolution of 1024 × 768 pixels, with the camera angle being changed during flight according to where the animals were located. One flight was conducted over a large dugong herd in shallow water in Moreton Bay. At all altitudes tested (1000, 750 and 550 ft) the dugongs were visible in the images captured. However we felt we could only reliably count the dugongs visible because they were in a large herd and we had prior knowledge that they were dugongs. If surveying animals in deeper water where they might be more obscured by the water, we felt this camera system would not be reliable.

We also conducted scoping flights over humpback whales in Moreton Bay and the results were similar to dugongs. In images captured at 1000 ft we could depict whale but couldn't have identified them to species. At 1500 ft, whales could not be reliably depicted.

The combination of the typical UAV imaging system we used and the altitudes we trialled did not provide images of high enough resolution to reliably detect dugongs or whales. Rather than continuing with this system and conducting further trials at lower altitudes, we converted to with higher resolution imaging systems.

Objective 3: **Directly compare the capabilities of UAV imaging systems with human observer marine mammal counts from a manned plane**

We used a manned aircraft to directly compare the sighting rates of dugongs from three observation platforms: (1) four human observers, (2) two high definition video cameras, and (3) a digital still camera capturing 4 megapixel images. A small line transect survey was conducted at Shark Bay, Western Australia, where there is a high density of dugongs which offers a good opportunity to compare these platforms.

The overall sighting rate per platform was analysed within a log-linear model framework. This analysis showed that the still platform's sighting rate was significantly better than the human observers by 251% at the altitude of 900 ft. However, at 500 ft the performance of the still camera was reduced by 42% to be equivalent to the human observers. The video system performed relatively worse than human observers across both altitudes with a sighting rate of 60% that of human observers. More data would be needed to investigate this result further.

Two possible explanations for the different relative performance of stills and observers at the different heights are: (1) the poor sea-state conditions experienced at the low altitude flight may have been better compensated for by the human observers who could spend more time viewing each sighting compared to the single snapshot obtained from the stills, or (2) the observers' sighting rate may have been poorer at 900 ft than at 500 ft because they had a greater search area to observe in a limited time frame.

The poor performance of the video platform was because of the low resolution these images compared to the stills, but may be improved if flying lower and pointing the cameras vertically downwards rather than obliquely. Video should not be discounted as it produces a higher frame rate than the stills providing benefits such as: (1) increasing the probability of capturing animals surfacing, (2) providing some information about the animal movement (e.g. multiple surfacing of dolphins or the white-water produced when dugongs exhale), and (3) increasing the probability of capturing animals outside of the zone of glare within the images.

Overall, if capturing one image per second, each kilometre of survey takes 3.2 min to analyse post-flight. With the aid of ARCAA we tested an image analysis computer algorithm which has the potential to automate this process. The algorithm showed promising results but requires more development to reduce the false-positive detections and most importantly decrease the animals missed to a rate equal to or better than human observers. If this algorithm could at least limit the number of images needing manual analysis, it would reduce the time for analysing images substantially.

In conclusion, it is apparent, just by the UAV developments that have occurred in Australian during the course of this project, that the capabilities of UAVs will continue to improve. There are now companies, such as *CyberTech* in Western Australia, who have UAVs capable of the range and endurance needed to conduct full marine mammal survey trials. The next step forward for the development of this technique for monitoring marine mammal populations would be to hire a range of companies and trial a range of UAV systems to determine the UAVs requirements specific to each type marine mammal surveyed in Australia. As there are currently fewer limitations in Australia than in the US for flying UAVs in civilian airspace, we have strong potential to research and develop UAVs for aerial surveys in Australia.

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APPENDICES

APPENDIX 1: Turbidity and Glare Scales

Table A1. Turbidity scale.

Turbidity	Water Quality	Depth Range	Visibility of Sea Floor
1	Clear	Shallow	Clearly visible
2	Variable	Variable	Visible but unclear
3	Clear	>5m	Not visible
4	Turbid	Variable	Not visible

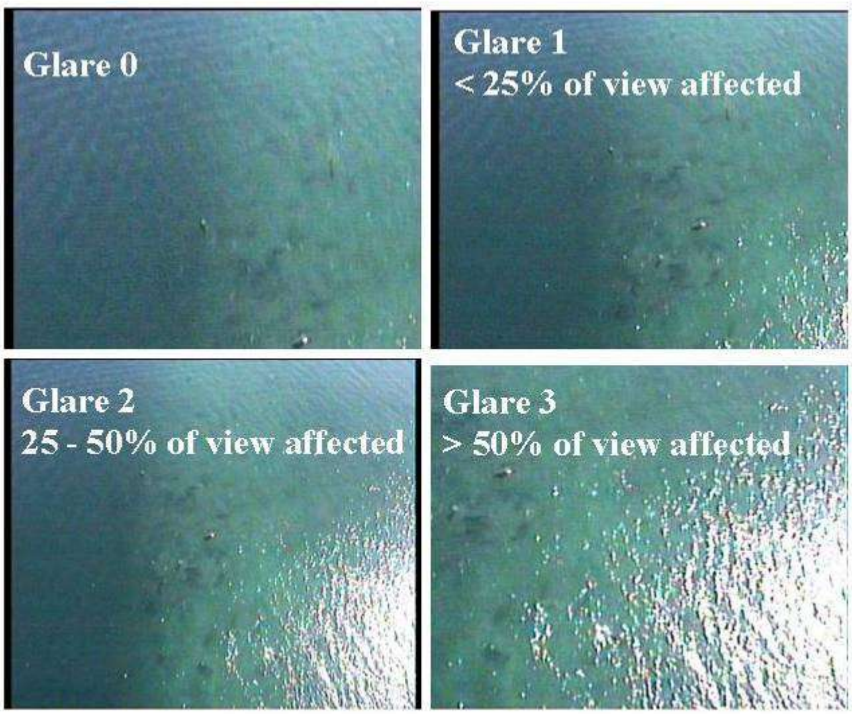


Figure A1. Glare scale.

APPENDIX 2:

Model Diagnostics for Log-Linear Models Comparing Three Observation Platforms

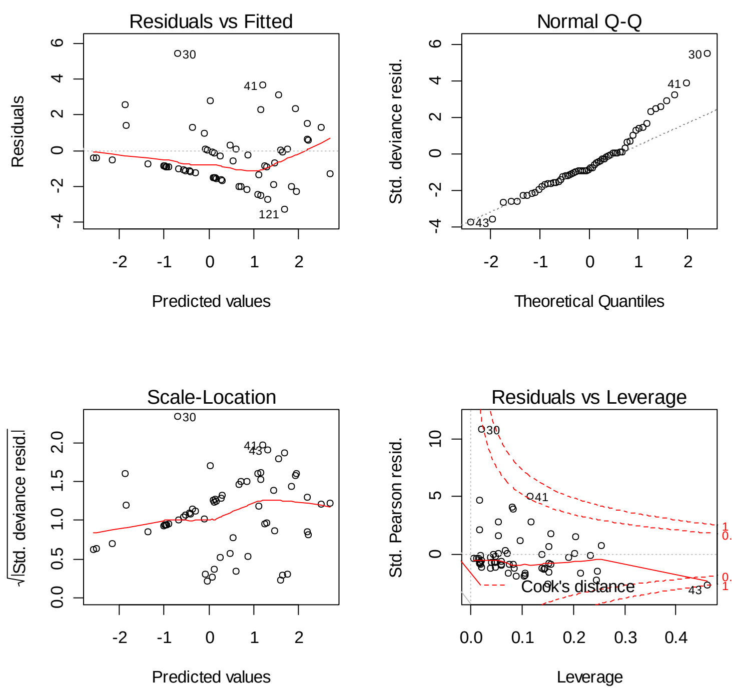


Figure A2. Model fit diagnostics still and observer model, with platform * date interaction

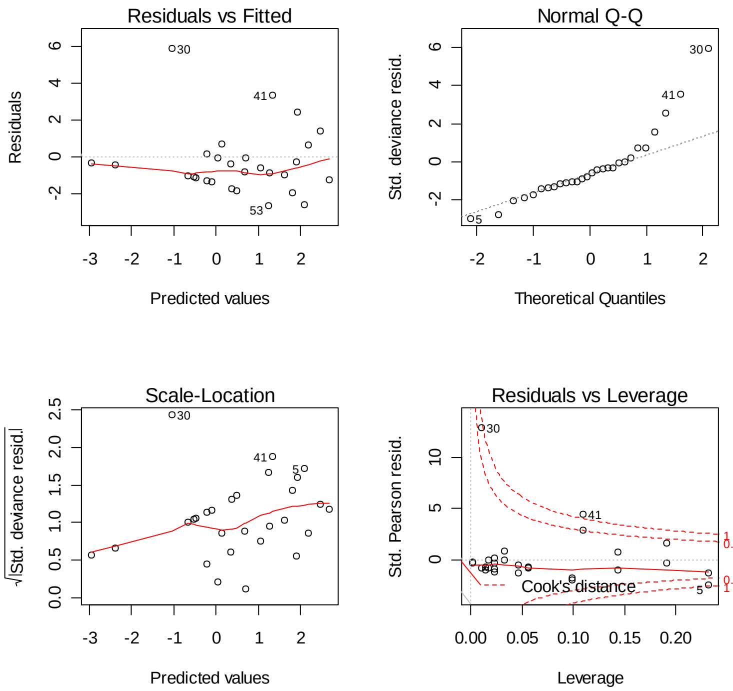


Figure A3. Model fit diagnostics still and observer platform model for 16/03/2009 altitude at 900 feet

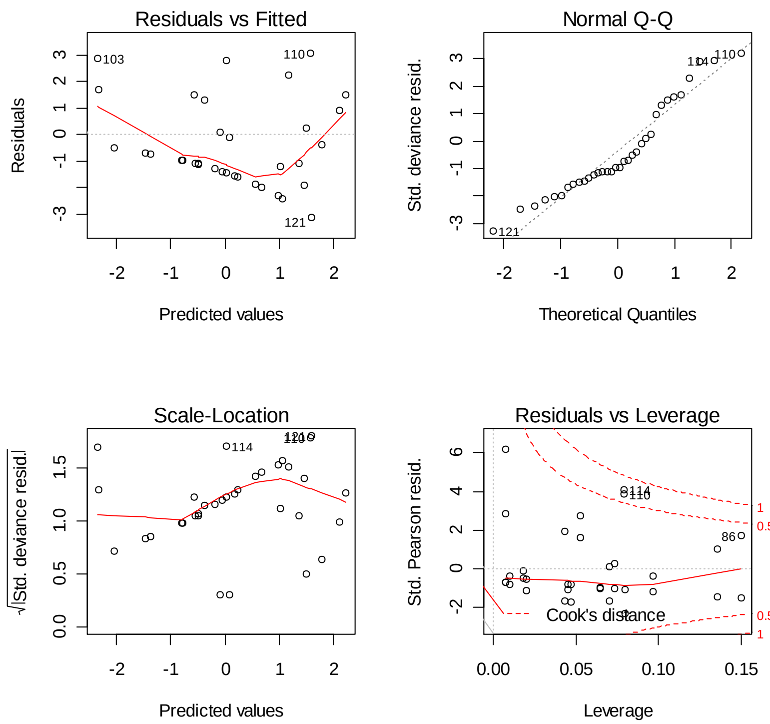


Figure A4. Model fit diagnostics still and observer platform model for 17/03/2009 altitude at 500 feet

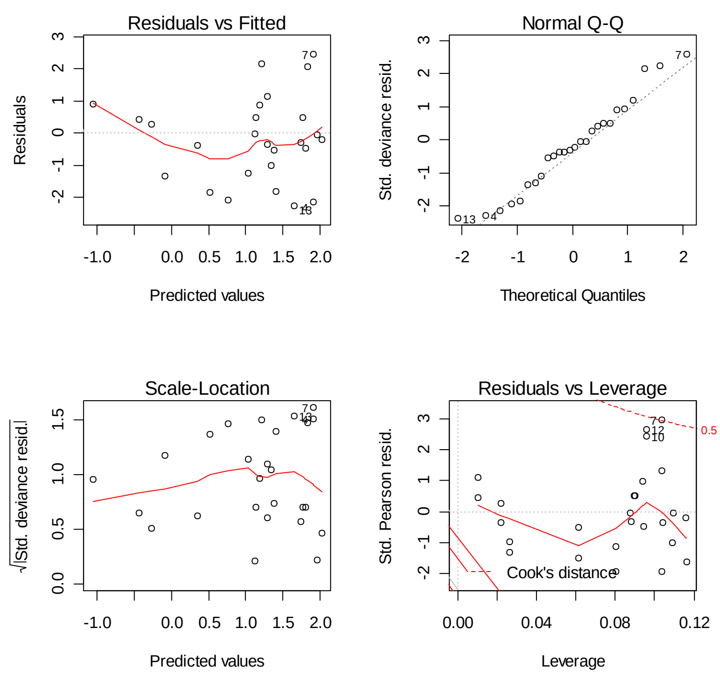


Figure A5. Model fit diagnostics video and observer platform

APPENDIX 3:

Automatic Detection of Marine Mammal from Aerial Imagery

Report provided by **Luis Mejias**

Abstract

The following technical report describes the approach and algorithm used to detect marine mammals from aerial imagery taken from manned/unmanned platform. The aim is to automate the process of counting the population of dugongs and other mammals. I have developed an algorithm that automatically presents to a user a number of possible candidates of these mammals. I tested the algorithm in two distinct datasets taken from different altitudes. The analysis and discussion are presented in relation to the complexity of the input datasets and the detection performance.

Detection Approach

Detection of features in images involves generally accurate modelling of geometrical and textural properties. The choice of a specific feature detector depends on both the observations we obtain from the scene and the level of modelling we seek. In this section, I assess several image processing techniques, such as opening and closing, adaptive thresholding, blob detection, and colour analysis with the aim of developing an approach to detect marine mammals in high-resolution aerial imagery. I have built an algorithm consisting of several processing layers, in which each layer is responsible for analysis and/or extracting a specific set of properties from the image. **Figure A6** shows the sequential stages of this algorithm and following this I describe the processing stages.

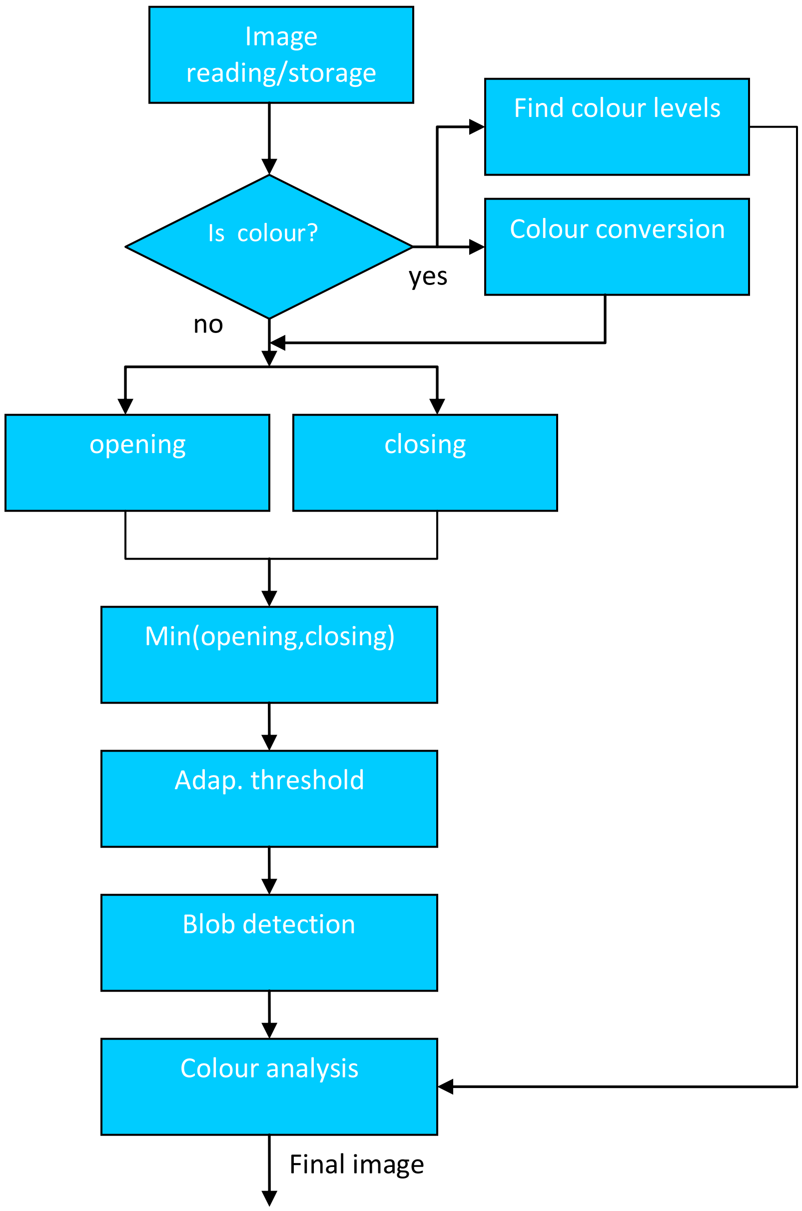


Figure A6. Algorithm processing stages.

Morphological operations

This algorithm starts applying two fundamental operations in image processing called opening and closing by combining two mathematical operations called erosion and dilation. The opening of A by B is defined by the erosion of A by B, followed by the dilation of the resulting image by B. The closing of A by B is obtained by the dilation of A by B, followed by the erosion of the resulting image by B. The mathematical representations of these operations are provided in the following.

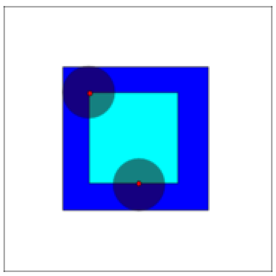
Erosion, of a binary image A by the structuring element B is defined by

$$A \ominus B = \{z \in E | B_z \subseteq A\}$$

where Bz is the translation of B by the vector z, i. e,

$$B_z = \{b + z | b \in B\} \; \forall z \in E$$

When the structuring element B has a centre (e.g., B is a disk or a square), and this centre is located on the origin of E, then the erosion of A by B can be understood as the locus of points reached by the centre of B when B moves inside A. For example, the erosion of a square of side 10, centred at the origin, by a disc of radius 2, also centred at the origin, is a square of side 6 centred at the origin.



Example: The erosion of the dark-blue square by a disk, resulting in the light-blue square.

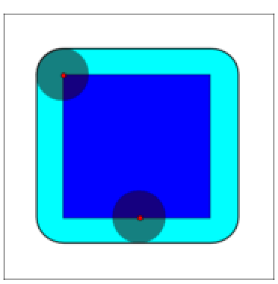
Dilation, of A by the structuring element B is defined by

$$A \oplus B = \{z \in E | (B^s)_z \cap A \neq \varnothing\}$$

where B^s denotes the symmetric of B, that is,

$$B^s = \{x \in E | -x \in B\}$$

If B has a centre on the origin, as before, then the dilation of A by B can be understood as the locus of the points covered by B when the centre of B moves inside A. In the above example, the dilation of the square of side 10 by the disk of radius 2 is a square of side 14, with rounded corners, centred at the origin. The radius of the rounded corners is 2.

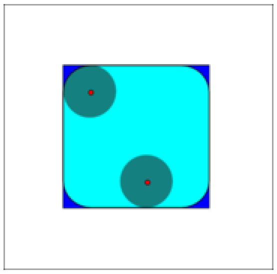


Example: The dilation of the dark-blue square by a disk, resulting in the light-blue square with rounded corners.

The opening of A by B is defined by

$$A \circ B = (A \ominus B) \oplus B$$

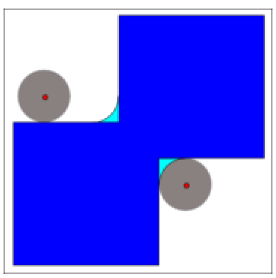
In the case of the square of radius 10, and a disc of radius 2 as the structuring element, the opening is a square of radius 10 with rounded corners, where the corner radius is 2.



Example: The opening of the dark-blue square by a disk, resulting in the light-blue square with round corners.

The closing of A by B is defined by

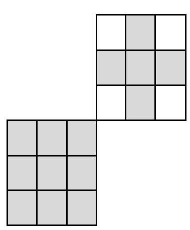
$$A \bullet B = (A \oplus B) \ominus B$$



Example: The closing of the dark-blue shape (union of two squares) by a disk, resulting in the union of the dark-blue shape and the light-blue areas.

Figure A7 and **Figure A8** shows the result of applying the operation described above in a sample image. I used a disk-shape structuring element of radius 25 pixels.

A structuring element is defined as a spatial distribution of pixels under a certain level of connectivity. The standard structuring elements are provided in the following example:



a) b)

where a connectivity of 4 is shown in (a) and a connectivity of 8 in (b). Generally, shaded pixels have a value ranging from 0 (0) to 255 (1). Additional to these elements, any shape can be formed by combining any spatial pixel distribution. An example of the morphological operations is shown below is shown in Figure .

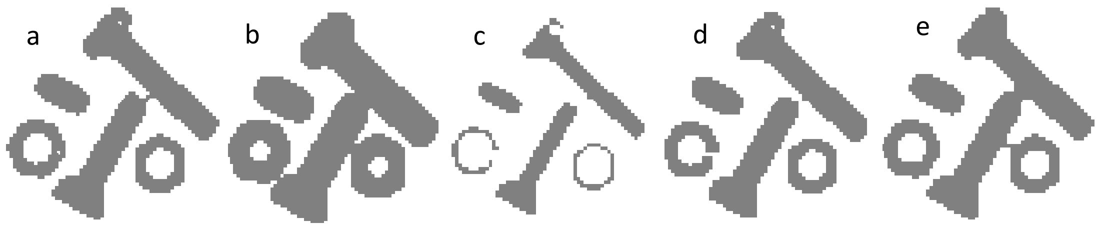
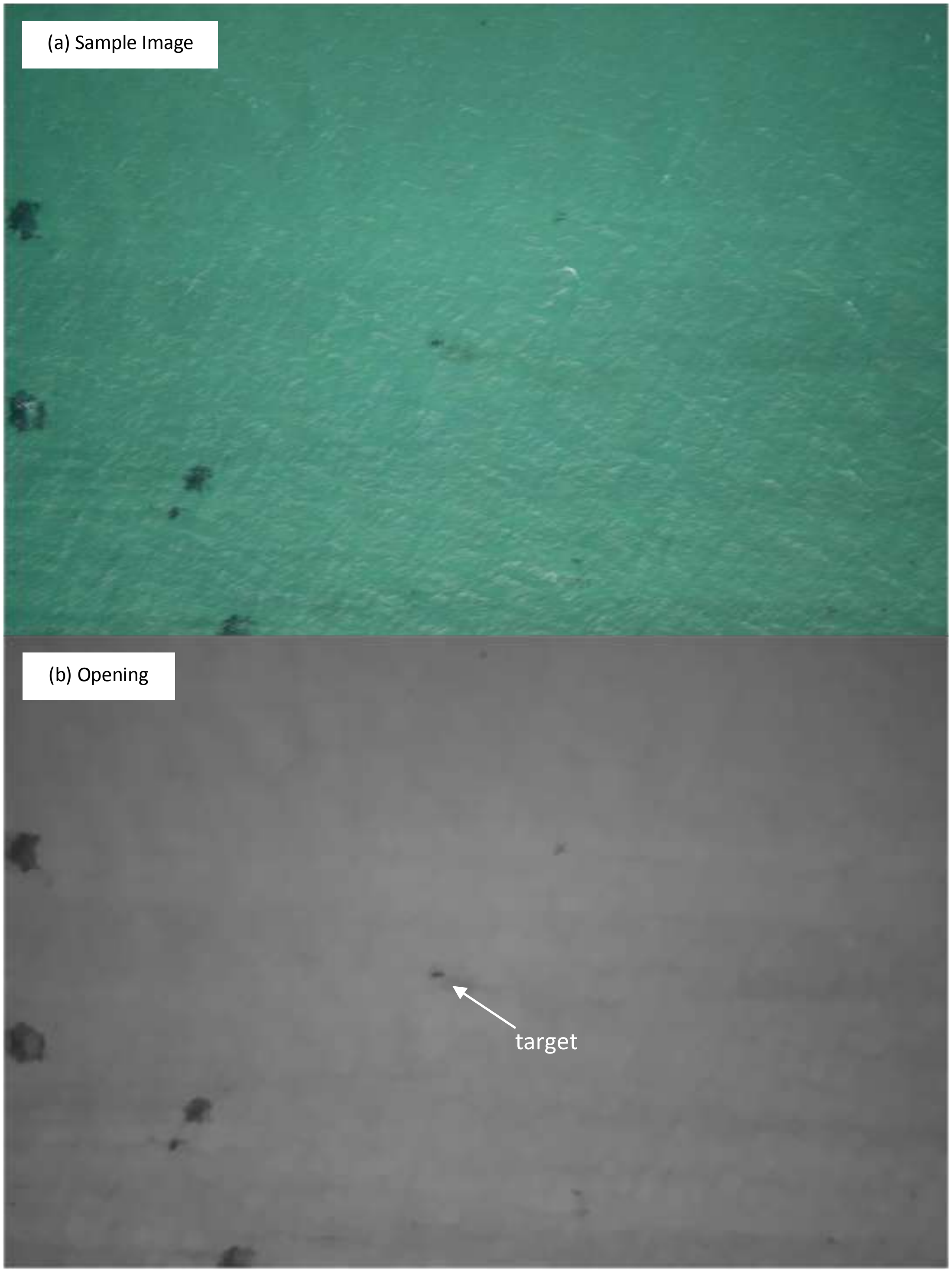


Figure A7. Example of the morphological operations, where (a) is the original image, (b) is the result of applying dilation (expansion), (c) is the result of applying erosion (edge thinning), (d) is the result of opening, and (e) is the result of closing.

The *opening* operation can separate objects that are connected in a binary image. The *closing* operation can fill in small holes. Both operations generate a certain amount of smoothing on an object contour given a "smooth" structuring element. The *opening* smoothes from the inside of the object contour and the *closing* smoothes from the outside of the object contour.


(a) Sample Image
(b) Opening
target

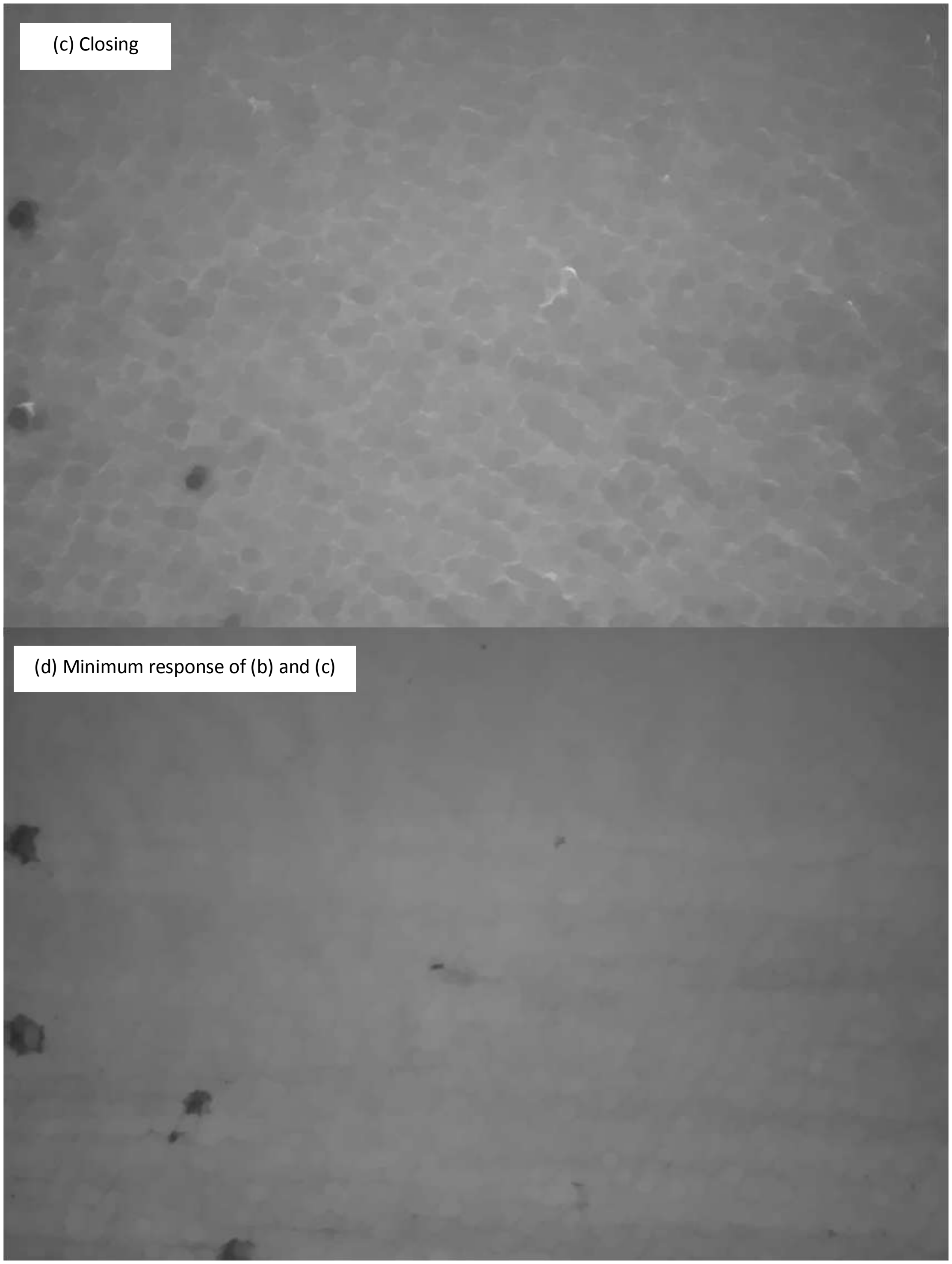


Figure A8. Example of opening and closing operations where (d) is the final result.

Adaptive thresholding

Thresholding is used to segment an image by setting all pixels whose intensity values are above a threshold to a foreground value and all the remaining pixels to a background value. Whereas the conventional thresholding operator uses a global threshold for all pixels, adaptive thresholding changes the threshold dynamically over the image. This more sophisticated version of thresholding can accommodate changing lighting conditions in the image, e.g. those occurring as a result of a strong illumination gradient or shadows. The operations involved in this stage are:

Operation	**Pseudo code**
Perform the convolution of the image with a suitable statistical operator, i.e. the mean, median or average.	Compute the average pixel value on a 10x10 window, and perform the convolution, where *n* and *m* are set to 10 $c[m,n] = a[m,n] \otimes b[m,n] = \sum_{j=-\infty}^{+\infty} \sum_{k=-\infty}^{+\infty} a[j,k]b[m-j,n-k]$
Subtract the convolved image from original and a constant K.	I_{result}=c[m.n]-$I_{original}$-K
Invert the resulting image.	I=invert(I_{result})

It was more efficient to threshold the image with the statistical operator minus K (e.g. mean-K), instead of just the statistical operator. Using this statistic, all pixels which exist in a uniform neighbourhood (e.g. along the margins) are set to background. The value of K (0.09) was found by visual inspection using the whole dataset. The statistical operator was computed locally on a window of 10x10 pixels using the average pixel values.

Figure A9 shows the advantages of this thresholding approach compared with the traditional method.

Blob Detection

Blob detection refers to an algorithm aimed at detecting points and/or regions in the image that are either brighter or darker than the surrounding. There are two main classes of blob detectors (i) differential methods based on derivative expressions and (ii) methods based on local extremer in the intensity landscape. In our case, we use a blob detector of class (i). The following are the operations necessary for detection and extraction:

1. Create a region counter (i.e. the blob has to between a minimum and maximum area of 400-2000 pixels), and a certain shape (ellipsoid), the values of which were derived experimentally.

2. Scan the image (for example, from left to right and from top to bottom):

    a. For every pixel check the north and west pixel (when considering 4-connectivity) or the northeast, north, northwest, and west pixel for 8-connectivity for a given region criterion (i.e. intensity value of 1 in binary image, or similar intensity to connected pixels in gray-scale image). In this case, 8-connectivity was used. This process ensures that only blobs that are uniform are selected.

   b. If none of the neighbours fit the criterion then assign to region value of the region counter. Increment region counter.
   c. If only one neighbour fits the criterion assign pixel to that region.
   d. If multiple neighbours match and are all members of the same region, assign pixel to their region.
   e. If multiple neighbours match and are members of different regions, assign pixel to one of the regions (it doesn't matter which one). Indicate that all of these regions are the equivalent.

3. Scan image again, assigning all equivalent regions the same region value.

Once, the regions have been labelled then the moment of each region can be extracted in order to find parameters such as area, centroid, etc. From the set blobs detected, we use criteria such as area and shape to filter those blobs that don’t fit in an iptical shape corresponding to the body shape of our target (dugongs and/or dolphins, see **Figure A10**).

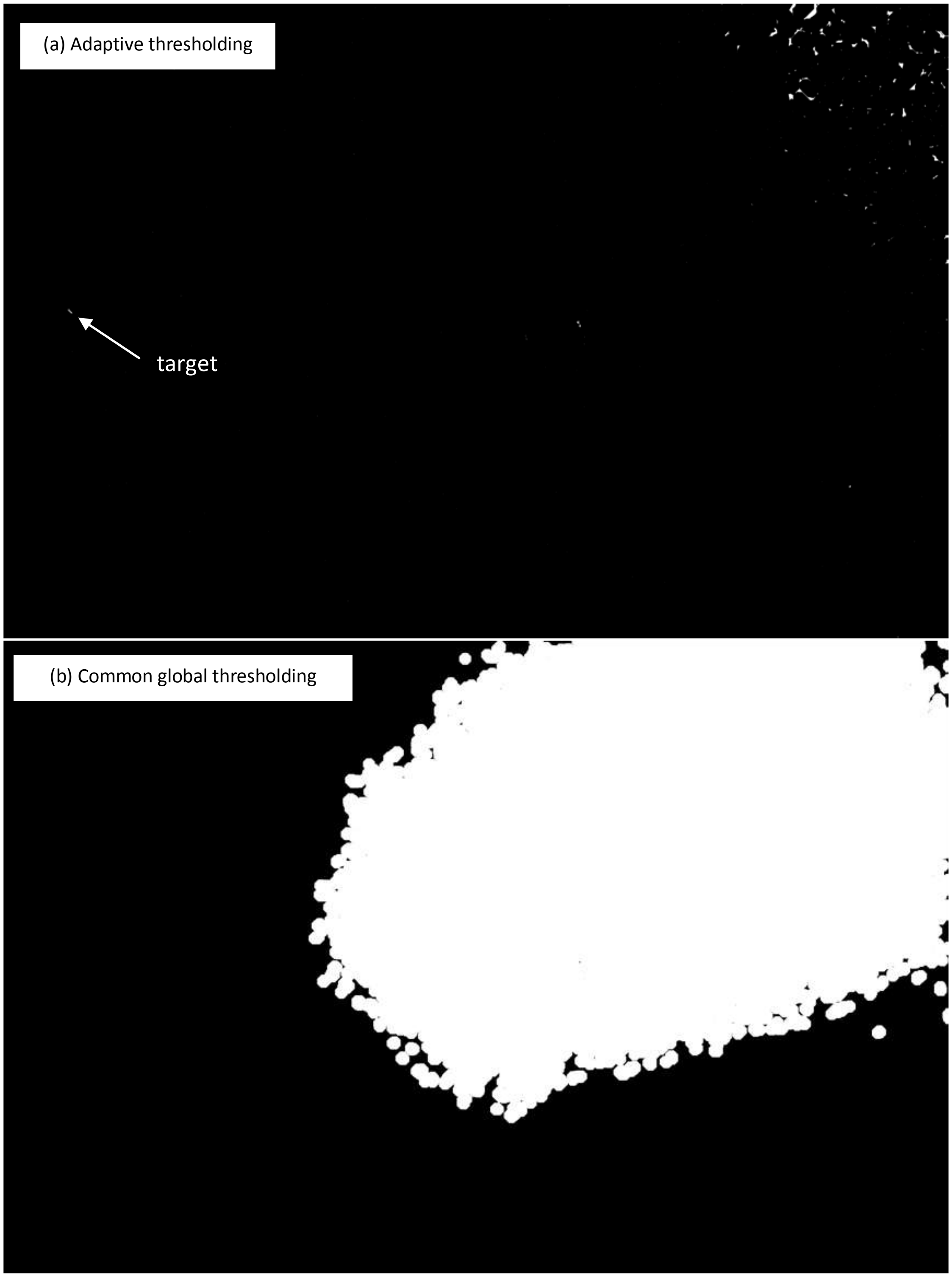
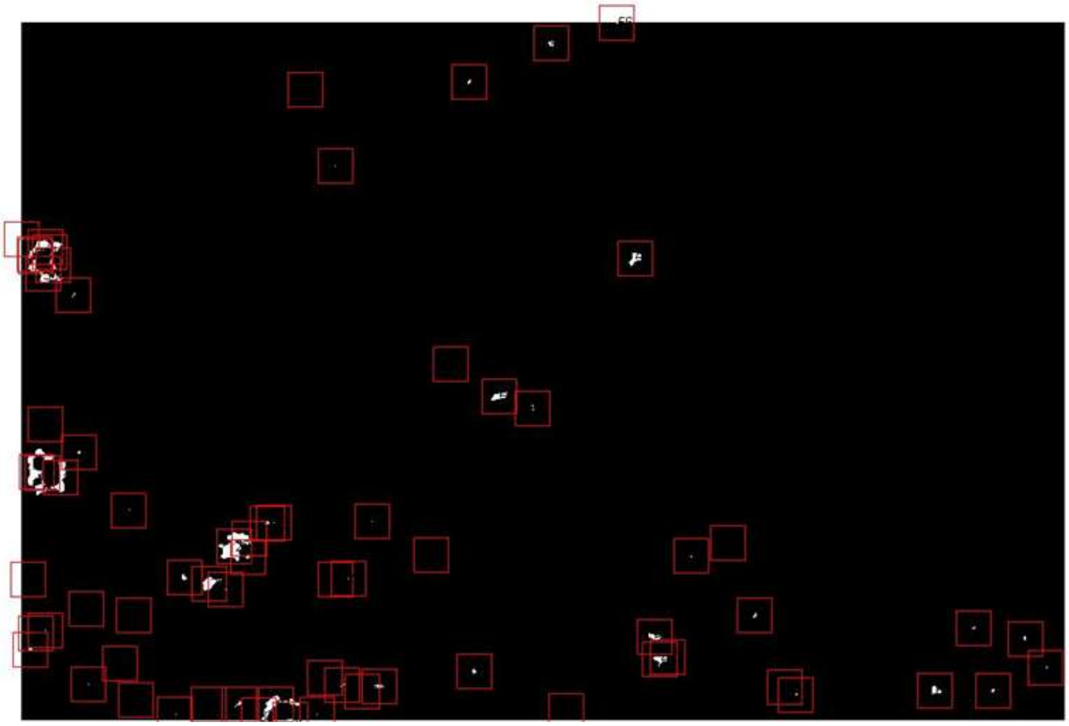
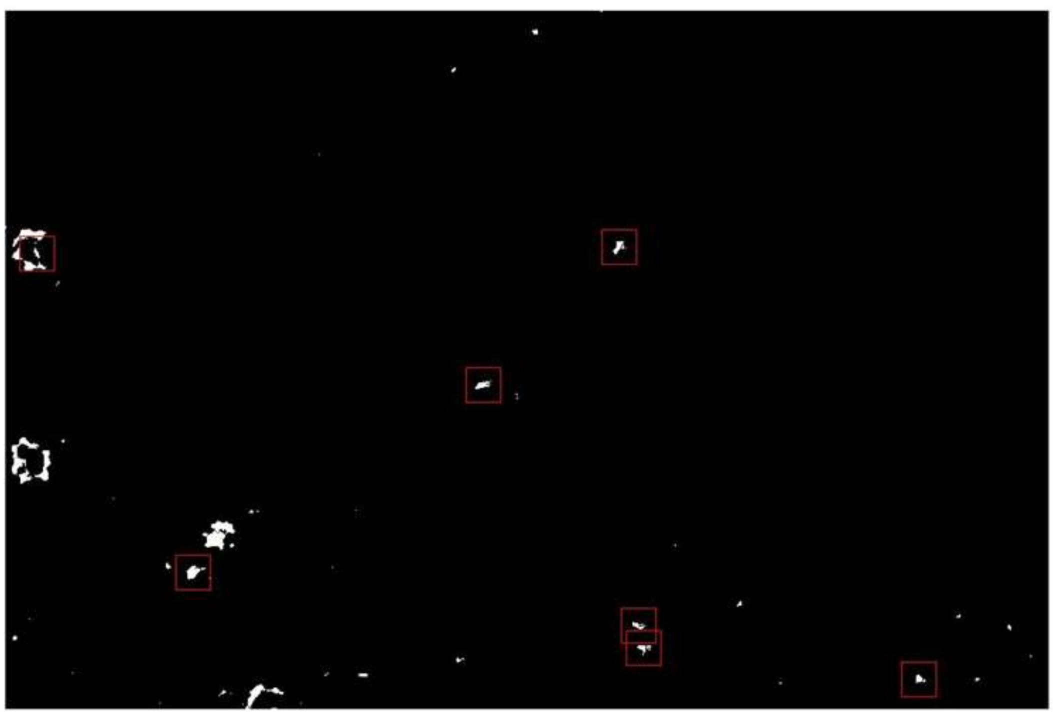


Figure A9. Differences between our implemented thresholding approach and the commonly used global thresholding approach



(a) Blob detection without area and shape criteria



(b) Blobs filtered after considering area and shape criteria criteria

Figure A10. Blob detection results in binary images: (a) blobs detected before filtering, (b) blobs detected after filtering.

Colour Analysis

Automatic colour description

In order to perform a better analysis and colour thresholding of the images, the amount of colour in the HSV (hue, saturation, value) colour space is determined in each image. A close relationship was found between the amounts of colour, e.g, blue, yellow, brown and the colour level in which each animal appears in the image. This value was used to determine the appropriate colour level thresholding described in the next section. **Figure A11** shows the close relationship between the saturation and the amount of blue/yellow-brown in the images. From examples in **Figure A12**, the left image lies in the range h < 30 and the middle and right in h > 30.

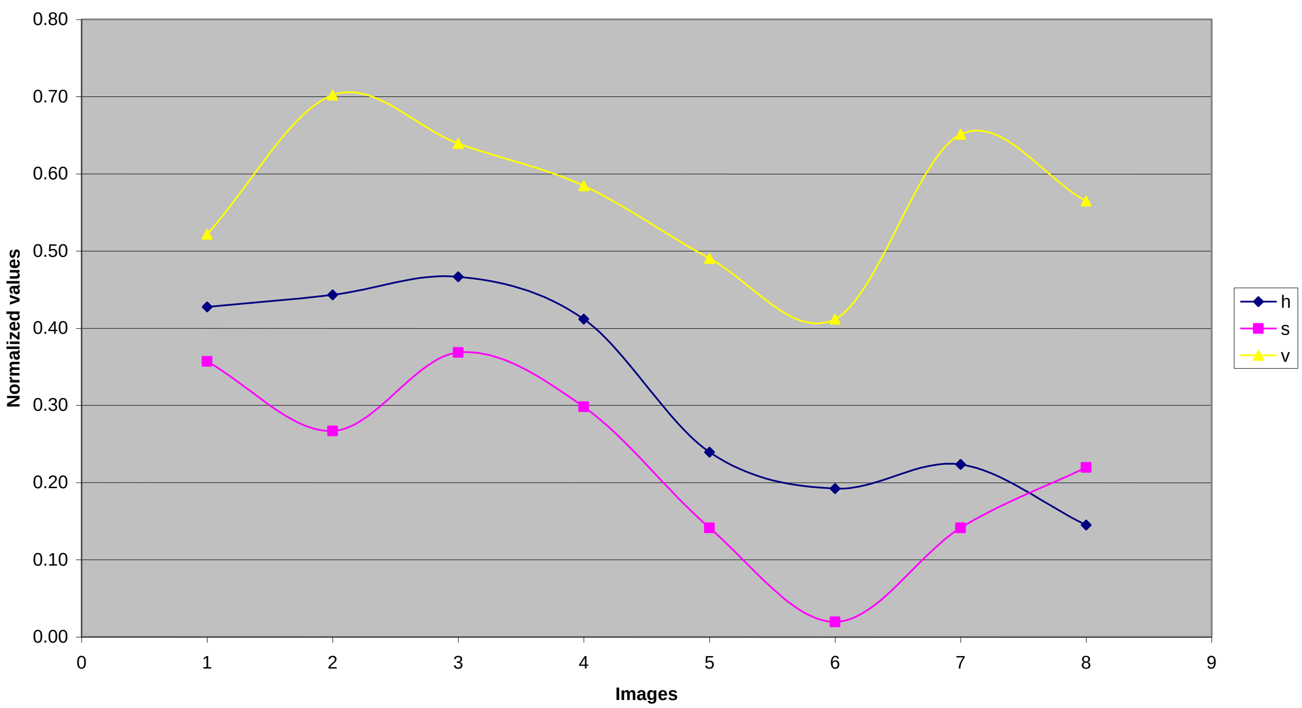
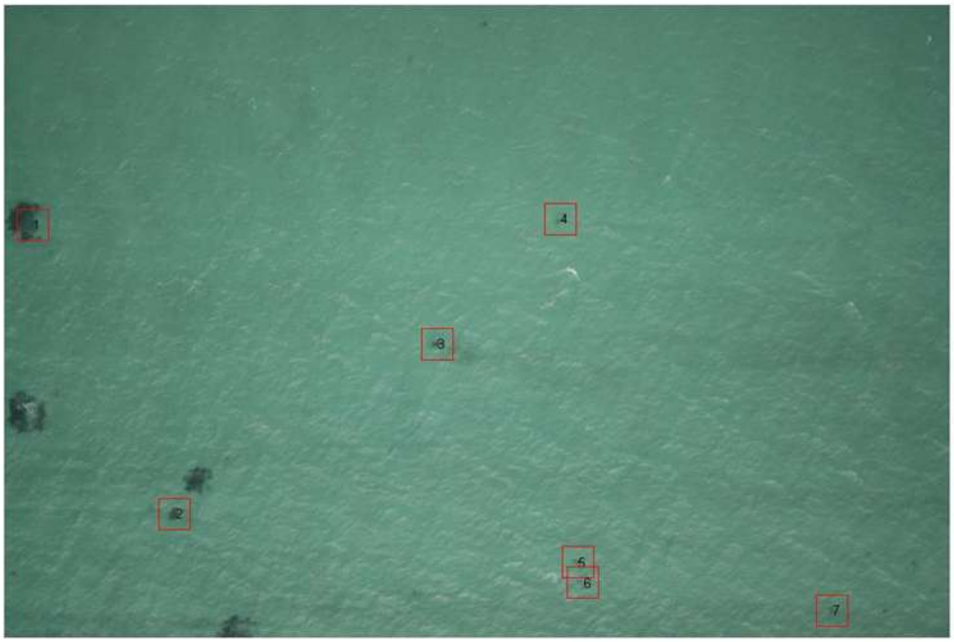


Figure A11. Level of Hue, Saturation and Value for set of images

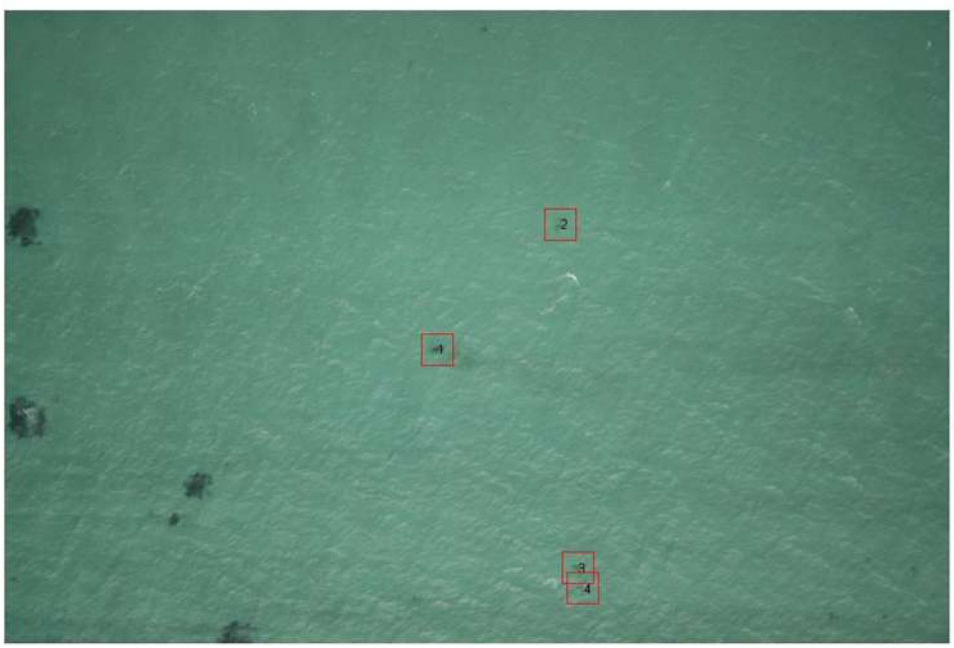
Figure A12. Three examples of images with different colour properties

Colour thresholding

Using a training data set, we found the colour range for how each target (animal) appears in the images. In other words, several images with known targets were analysed to build a colour threshold data set. Then, this data set was used analyse each blob detected to determine if was a target (animal) or not (for example see **Figure A13**).



(a) Detected features without colour



(b) Detected features with colour thresholding criteria

Figure A13. Example of colour thresholding result. The number of false positives is reduced from 6 to 3 (approximately 50%) after analysing the colour of each blob.

Analysis and results

A total of 33 images captured from 2 different altitudes (500 ft – dataset 1 and 900 ft – dataset 2) were analysed. The images ranged from high complexity (highly cluttered, highly textured) images to moderate complexity, according to the image entropy as a complexity measure for an image. Entropy is a measure of image information content, and can be used as a statistical measure of randomness to characterize the texture of the input image (for examples see **Table A2**). In highly textured (cluttered) images the number of false positive will be high. As shown in **Table A3**, when entropy values are higher than 6.5 the number of false positives rapidly increases. The same pattern can be observed in **Table A4**, where the level of complexity of the images is much higher than dataset 1, and therefore the false positive values are higher.

Table A2. Examples of various ranges of image entropy.

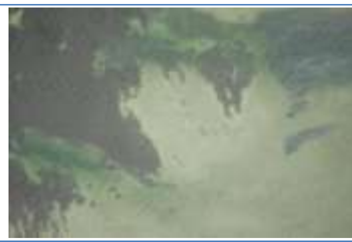
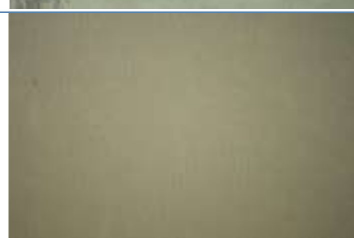
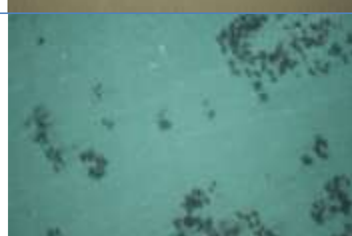
Image	Entropy Value
	6.7277
	6.25
	6.7615
	6.5025
	7.1366

Table A3. Resulting analysis for images taken from Set 1: altitude 500ft

Image Number	Known targets	Detected target	False positives	Missed detection	Image complexity
1	1	4	3	0	6.5025
2	1	22	21	0	6.7177
3	1	4	3	0	6.7615
4	1	20	19	0	6.5677
5	1	1	0	0	6.235
6	1	11	10	0	6.8222
7	11	3	3	11	6.7277
8	1	1	0	0	6.25
Average	na	na	7.375	1.375	6.5730
Standard deviation			8.3996	3.8890	

Table A4. Resulting analysis for images taken from Set 2: altitude 900ft

Image Number	Known targets	Detected target	False positives	Missed detection	Image complexity
1	1	29	28	0	7.2216
2	1	20	19	0	7.2408
3	1	23	22	0	7.3999
4	1	80	79	0	7.4326
5	1	88	87	0	7.1366
6	4	0	0	4	6.6818
7	na	0	na	na	7.3336
8	1	0	0	0	7.3516
9	11	1	0	10	7.3391
10	1	11	10	0	7.6083
11	2	6	4	0	7.6427
12	1	2	1	0	7.6198
13	1	4	3	0	7.4257
14	1	6	5	0	7.3483
15	1	7	6	0	6.7663
16	1	1	0	0	6.7496
17	1	6	5	0	6.4717
18	1	0	0	0	6.4227
19	3	1	0	2	6.3872
20	1	0	0	1	6.5796
21	1	0	0	1	6.6283
22	3	0	0	3	6.4903
23	2	0	0	2	7.2156
24	1	0	0	1	6.8872
25	1	0	0	1	6.6919
Average			10.76	0.84	7.042912
Standard deviation			23.054	2.16024	

Overall, the false positive values were high in both datasets. However, the missed detection remains at an acceptable value. Therefore, any future effort should be focused in reducing the number of false positives. A more comprehensive colour analysis and with the use of multispectral information could be highly beneficial in order to reduce false detections.