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Review Article

The potential for unmanned aerial vehicles (UAVs) to conduct marine fauna surveys in place of manned aircraft

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Unmanned aerial vehicles (UAVs) are increasingly used in marine wildlife research. As technological developments rapidly advance the versatility and functionality of affordable UAVs, their potential as a marine aerial survey tool is quickly gaining attention. Currently, there is significant interest in whether cost-effective UAVs can outperform manned aircraft in aerial surveys of marine fauna at sea, although few empirical studies have compared relative sampling efficiency, accuracy and precision. Civil aviation restrictions, and subsequent available civilian technologies, make it unlikely that UAVs will currently be more effective than manned aircraft for large area marine surveys. UAVs do, however, have the capacity to fill a niche for intensive smaller spatial scale sampling and for undertaking aerial surveys in isolated locations. Improvements in UAV sensor resolutions and alternative sensor types, such as multispectral cameras, may increase area coverage, reduce perception error, and increase water penetration for sightability. Additionally, the further development of auto-detection software will rapidly improve image processing and further reduce human observer error inherent in manned aerial surveys. As UAV technologies and associated methodology is further developed and becomes more affordable, these aircraft will be increasingly adopted as a marine aerial survey tool in place of traditional methods using manned aircraft.

Keywords: aerial survey, drone, remotely piloted aerial systems, RPAS, unmanned aerial vehicle, UAV.

Introduction

Unmanned aerial vehicles (UAVs), also known as remotely piloted aerial systems (RPAS) or "drones", comprise as a minimum, an unmanned aircraft, a ground control station, and a communications link between the two (Colomina and Molina, 2014). Recently available technological developments, such as component miniaturization, lithium batteries, and high resolution image capture, have made UAVs more versatile and affordable in the civilian market. Their use in ecological research is a relatively new concept, owing to rapid developments in available UAV technology over the last ten years. UAVs now commonly host an array of sophisticated sensors and processors that can provide high quality real-time observations and imagery. Thus, they are becoming increasingly utilized in wildlife research, specifically in aerial survey applications (Koh and Wich, 2012; Vermeulen *et al.*, 2013; Kiszka *et al.*, 2016; Sweeney *et al.*, 2016). Furthermore, their decreasing costs, increasing flight times and improving capacity for easy launch and retrieval at sea is rapidly expanding the utility of UAVs for surveys of marine life.

Aerial surveys using manned aircraft, such as airplanes or helicopters are commonly used to obtain population estimates of large mammals (Pollock *et al.*, 2006). Such aerial surveys have been used extensively in marine systems for distribution and abundance counts on marine fauna including whales (Keller *et al.*, 2006; Fearnbach *et al.*, 2011), dolphins and porpoises (Gilles *et al.*, 2009; Alves *et al.*, 2013; Hammond *et al.*, 2013), manatees (Craig and Reynolds, 2004), dugongs (Holley *et al.*, 2006), sea turtles (Fuentes *et al.*, 2015), sharks (Cliff *et al.*, 2007; Rowat *et al.*, 2009; Westgate *et al.*, 2014), seals (Conn *et al.*, 2012), and birds (Kemper *et al.*, 2016). Although they can

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efficiently cover large survey areas (Alves *et al.*, 2013), they are limited to the vicinity of airfields, are costly, and are subject to sightability errors (particularly when sighting fauna at sea) (Marsh and Sinclair, 1989; Pollock *et al.*, 2006; Robbins *et al.*, 2014; Lubow and Ransom, 2016). These errors are a function of not all animals being detected in the area being observed, and are caused by external factor biases (availability), and biases inherent in the sampling methodology (perception bias). It is argued these biases are less of an issue when comparing trends of relative abundance. However, for population assessments, sightability errors are often estimated and applied to the abundance data using correction factors to increase data reliability (Marsh and Sinclair, 1989; Pollock *et al.*, 2006; Melville *et al.*, 2008; Fuentes *et al.*, 2015; Lubow and Ransom, 2016).

Due to the functional and logistical limitations of manned aerial surveys, some studies have suggested that UAVs may provide better sampling efficiency and data quality (Koski *et al.*, 2009; Watts *et al.*, 2010; Lisein *et al.*, 2013; Durban *et al.*, 2015; Kiszka *et al.*, 2016; Sweeney *et al.*, 2016). In the marine fauna context, it is probable that UAVs will be readily adopted if the methodology and technology are demonstrated to improve on data reliability (precision and accuracy) and overall cost-effectiveness relative to surveys by manned aircraft. While there are currently no published empirical comparisons between marine fauna surveys by manned aircraft and UAVs, we use published literature to contrast these two marine aerial survey approaches and compare benefits and limitations through sampling efficiency and errors that affect data reliability, particularly for fauna at sea.

UAV overview

The use of UAVs in ecological research has typically utilized small UAV units ($<$20 kg) due to lower procurement and operating costs, and fewer operational legislative restrictions, which vary between countries (Anderson and Gaston, 2013). Fixed-wing and multirotor (copter) are two main types of small UAVs currently suitable for aerial surveys, requiring usually one or two people for operation. Fixed-wing UAVs are typically utilised for speed and energy efficiency, covering comparatively longer distances and flight durations (Evans *et al.*, 2015; Linchant *et al.*, 2015). Due to fixed-wing aerodynamics and assisted take-offs requiring less energy (than multirotors), they typically stay airborne from 20 min to several hours (depending on aircraft design, and whether it’s battery or fuel powered). Fixed-wing UAVs, usually need a larger cleared area for take-off and retrieval. They normally require assistance with taking off (“throwing” by hand or catapult) and a capture system or smooth ground for retrieval (Anderson and Gaston, 2013; Vermeulen *et al.*, 2013; Linchant *et al.*, 2015). However, some recent accessible fixed-wing UAVs are more compact and transportable, and require less take-off and landing space than previous airframes (Seymour *et al.*, 2017).

Multirotor UAVs are a comparatively new technology and have only appeared in the marine literature in the last few years (Durban *et al.*, 2015; Goebel *et al.*, 2015; Hodgson *et al.*, 2016; Sweeney *et al.*, 2016). They have been often utilised for vertical take-off and landing capabilities, requiring no additional landing equipment, making them also suitable for launching and retrieving from small vessels (Durban *et al.*, 2015; Casella *et al.*, 2017). Whilst still uncommon, some recent consumer level fixed-wing UAVs are designed to be hand launched, and retrieved by automated water landings, which may also appeal to small vessel based UAV surveys.

Multirotors are more dynamic and responsive in movement positioning than fixed-wing UAVs, and can sometimes provide better image stability and more accurate georeferencing capability regarding a specific target (Anderson and Gaston, 2013; Linchant *et al.*, 2015; Sweeney *et al.*, 2016). Consequently, they are aerodynamically unstable and have shorter flight durations of typically 12–40 min. Despite the potentially longer flight times and ability to cover large distances offered with fixed-wing UAVs, civil aviation regulations in many countries restrict typical usage to “line-of-sight,” effectively reducing potential range to a few kilometres. Whilst line-of-sight restrictions can currently be negated theoretically in certain locations and situations (on a case-by-case basis), in most operations it would likely be unfeasible. Specialized training would have to be obtained and proven safety countermeasures would have to be accepted by aviation authorities, such as collision avoidance with other aircraft, event of loss of signal or control, and systems failure. This may reduce potential benefits of fixed-wing UAVs, leaving multirotors as often the preferred option for UAV aerial surveys in scenarios where the survey area is relatively small, and where better manoeuvrability (including at launch and retrieval) and hovering capabilities are attractive (Durban *et al.*, 2015; Kiszka *et al.*, 2016; Sweeney *et al.*, 2016; Casella *et al.*, 2017).

As launch and retrieval systems for fixed-wing UAV improve and become more versatile, their longer flight times in other circumstances may have more appeal than benefits offered with multirotors. The inclusion of on-board GPS (for both aircraft types) and real-time kinematic (RTK) GPS systems to UAV platforms may make fixed-wing UAVs better suited for many mapping (creation of orthomosaics) applications over spatial scales of a few square kilometres, taking advantages of the longer flight times over multirotor platforms (Koski *et al.*, 2009; Hodgson *et al.*, 2013; Seymour *et al.*, 2017). Ultimately, the cost of set-up, the effective flight time and manoeuvrability requirements, the ease of launch and retrieval, and the flight servicing requirements (refuelling or replacing batteries and equipment checks) are important considerations in ascertaining the most effective UAV type and model for surveys of marine fauna.

In contrast to UAVs, manned aircraft in marine fauna surveys generally operate for longer durations and cover greater area (Table 1). For example, marine surveys at sea using fixed-wing aircraft usually sample over a hundred kilometres of transect, operating at an altitude of around 137–286 m and at speeds of 46.3–51.4 m s^{-1} (167–185 km h^{-1}) (1st and 3rd quartiles from online Supplementary Material). Altitude and speed specifications of a survey are often selected to maximize sightability of target fauna, with a minimum height dictated by safety requirements (Rowat *et al.*, 2009; Alves *et al.*, 2013; Fuentes *et al.*, 2015). In many surveys, two sets of observers sit on either side of the aircraft and sight within a predefined transect width (often around 200 m) on each side (Gales *et al.*, 2004; Holley *et al.*, 2006; Hammond *et al.*, 2013). Voice recordings are commonly used during the survey and later analysed in post-processing. Helicopters (such as Robinson R44) have also been used for aerial surveys, improving sightability in some circumstances (Robbins *et al.*, 2014). They have also been used as the preferred aircraft type for digital manned aerial surveys where georeferenced imagery or photogrammetry is required (Perryman and Westlake, 1998; Pitman *et al.*, 2007; Fearnbach *et al.*, 2011). As with UAV comparisons, this is due to improved manoeuvrability of helicopters compared with fixed-wing aircraft (Fearnbach *et al.*, 2011; Durban *et al.*, 2015).

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Table 1. Comparison of median flight specifications (and min, max) for UAVs and manned aircraft surveys cited in this review (see online Supplementary Material).

Flight Variable	UAV	Manned Aircraft
Elevation (m)	120.0 (12.0, 305.0)	152.0 (46.0, 731).0)
View/transect width (m)	102.8 (10.0, 600.0)[a]	400.0 (147, < 1600)
Average flight time (min)	15.8 (7.0, 60.0)	163.5 (30.0, 480.0)
Average Speed (m/s)	13.2 (2.0, 27.5)	51.4 (9.7, 66.5)
Distance covered (km)	14.9 (1.0, 99.0)	370.0 (26.3, 990.0)
Area covered (km^2)	1.1 (0.1, 39.5)	211.5 (4.8, 525.0)

Table does not include photogrammetry studies.

[a] Transect width was achieved by panning the camera during flights.

Sampling cost-effectiveness

Compared to UAVs, the use of manned aircraft for marine surveys are relatively expensive due to costs associated with aircraft hire and staffing, sometimes costing >$1000 US per survey hour. Regardless, manned aircraft are often deemed efficient for sampling large areas, and arguably provide the greatest area sampled per-unit-cost (Koski *et al.*, 2009; Watts *et al.*, 2010). To sample an equivalent area with current available UAV technology and regulations, many separate flights would likely be required, demanding either much longer sampling windows or multiple pilots and UAVs (Table 1).

Hodgson *et al.* (2013) tested a fixed-wing UAV for dugong aerial surveys in Shark Bay, Western Australia, and compared its efficacy to a similar survey using manned fixed-wing aircraft (Holley *et al.*, 2006). The UAV took 25 min at 25 m s^{-1} to complete ten transects of 1.8 km. At an altitude of 305 m, the transect width obtained was 144 m (online Supplementary Material). Although transect width from the UAV could be widened by adopting a wider focal lens and a higher resolution camera, UAVs are still mostly limited by reduced range, slower speeds, and shorter flight times. Even though the survey area covered was significantly less by UAV than that covered by Holley *et al.* (2006), the sampling area by UAV was much more intensively surveyed (Hodgson *et al.*, 2013). Similarly, Sweeney *et al.* (2016) also used a UAV (multirotor hexacopter) in place of manned aircraft. The multirotor UAV was used as a supplement method for obtaining abundance estimates of Steller sea lions (*Eumetopias jubatus*) along the Aleutian Island chain, as accessibility by manned aircraft was limited due to frequent inclement weather and scarcity of airfields. They were able to launch the UAV on days manned aircraft would have been unable to operate, proving UAVs to be efficient and effective for the remote areas. Unfortunately, due to the size of the survey area, sole reliance on UAV to complete the survey would be unfeasible (Sweeney *et al.*, 2016).

An additional consideration regarding aerial sampling efficiencies between manned aircraft and UAV is the time involved in post-processing (Chabot and Francis, 2016). Unless spotting in real-time from a UAV ground control station [such as in Koski *et al.* (2009)], manual processing of aerial images from UAV is likely much more time consuming than analysing audio recordings from manned aerial surveys (Pollock *et al.*, 2006; Hodgson *et al.*, 2013; Seymour *et al.*, 2017). While the height and lens parameters of many UAV studies are governed by image clarity derived from ground pixel resolution (see online Supplementary Material), high resolution cameras that enable larger sampling swaths also increase manual post-processing time per image. Thus, in scenarios where timely reporting is a major consideration (particularly for "one-off" surveys), or the survey area is vast, established survey methods using manned aircraft are likely to be a preferred option.

While manually post-processing digital aerial imagery can be a bottleneck in the data collection to reporting process, research investment into the development of image analysis and auto-recognition software is beginning to improve UAV post-processing efficacy (Schoonmaker *et al.*, 2011; Chabot and Francis, 2016; Seymour *et al.*, 2017). This may include abundance counts of species from data that comprises still images for mosaics, collection of images for fine-scale analysing, or video recordings of transects. Computer automated post-processing for obtaining abundance counts has been most successful for certain species of birds, such as snow geese [see review by Chabot and Francis (2016)]. This is due primarily to high spectral contrast between the fauna and their surrounding background environment. Additionally, individuals being of similar size to their cohorts allows for cleaner algorithm parameters in automation programming (Chabot and Francis, 2016). To facilitate this, trials are being done to analyse the utility of alternative sensors on UAVs, such as thermal infrared and multispectral to aid the differentiation of target fauna from background noise (Schoonmaker *et al.*, 2011; Gonzalez *et al.*, 2016; Seymour *et al.*, 2017).

Seymour *et al.* (2017) used a portable fixed-wing UAV equipped with a 12 MP sensor and an additional thermal infrared sensor (provided effective ground pixel resolution of 8 cm) to test the efficacy of a computer automated post-processing approach to manual counts of two breeding colonies of grey seals (*Halichoerus grypus*) in Nova Scotia, Canada. Automated processing was achieved by object recognition and edge detection algorithms based on size, shape and temperature of thermal spatial indices. The automated model showed similar results to manual human counts, displaying the highest reliability where large thermal differences were present between seals and their surrounding landscape. In another study, Schoonmaker *et al.* (2011) demonstrated a proof of concept for a real-time automatic detection algorithm for detecting submerged humpback whales (*Megaptera novaeangliae*) by using multispectral sensor technology to reduce sea surface spectral noise and allow better edge classification of target fauna.

Detection and counting algorithms for machine-based processing also have potential to improve data processing time and precision (Seymour *et al.*, 2017). Currently, algorithms seem most effective for single aggregating species that can be easily differentiated from the background image or where spectral information can be used to differentiate and classify objects. When applied to such imagery, processing times are significantly reduced compared to manual counting (Kobryn *et al.*, 2013; Chabot and Francis, 2016; Gonzalez *et al.*, 2016; Seymour *et al.*, 2017).

Availability errors

In aerial surveys of marine fauna at sea, external factor biases that compose availability errors are mainly caused by turbidity and the depth of a target animal in relation to the maximum depth of sightability (Marsh and Sinclair, 1989). Thus, in clear shallow water there are few availability errors (Figure 1) (Kessel *et al.*, 2013). Where water depth is beyond depth of sightability, availability bias is determined by calculating the localized depth of sightability (given the average turbidity) at which the target animal can be readily sighted, and estimating the portion of time the animal is likely to spend in the available depth portion. A correction factor

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can then be calculated and applied to adjust the count data (Marsh and Sinclair, 1989; Pollock *et al.*, 2006). The higher portion of time the target species spends near the surface will ultimately render more accurate and precise population estimates. Ultimately the sightability of a species will be linked to its size, morphological attributes and behaviour (Hammond *et al.*, 2013). Thus, where the target species does not congregate on land, marine aerial surveys at sea are typically performed on fauna that surface regularly, congregate on the surface, or are located in shallow depths (Gruber *et al.*, 1988; Pollock *et al.*, 2006; Rowat *et al.*, 2009; Alves *et al.*, 2013; Kessel *et al.*, 2013).

The use of UAVs in marine aerial surveys relies on imaging sensor technologies, typically using red, green, and blue (RGB) spectral bands in the 400–700 nm spectrum. These digital representations of what human eyes see is digitally stored as still images (currently 12–15 MP up to 80 MP), or video (HD of 2.1 MP or 4k at 8.3 MP) (Kemper *et al.*, 2016). Although the level of detail changes according to data resolution, water penetration is usually comparable to what is obtained with the naked eye from manned aircraft. This is typically a number of meters, depending on turbidity (Veenstra and Churnside, 2012). Availability biases in the marine context are, therefore, theoretically similar between UAVs and manned aerial surveys.

Alternative sensor technologies are, however, becoming more readily available to UAV platforms which may lead to enhanced sightability and reductions in error. Thermal infrared sensors have been used successfully to detect sea lions (*Eumetopias jubatus*) at night, feeding on the water surface (Thomas and Thorne, 2001), and have been attached to a fixed-wing UAV to allow easier detection of grey seals (*Halichoerus grypus*) on land (Seymour *et al.*, 2017). The sensors capture heat signatures in the range of 3–5, or 7–14 μm wavelength bands. Infrared, however, does not effectively penetrate water (Veenstra and Churnside, 2012), and were generally not capable of being able to confidently different individuals in close proximity to each other (Sweeney *et al.*, 2016). Higher resolution infrared sensors are now becoming available and are proving effective for detecting individuals in colonies of marine-associated fauna on land, particularly when combined with shape recognition and discriminating algorithms (Seymour *et al.*, 2017).

Multispectral sensor systems use four or more spectral bands with narrow wavelengths compared with RGB sensors. Hyperspectral systems utilise over 30 spectral bands at even narrower wavelengths. There are a number of micro-multispectral and hyperspectral arrays suitable as payload for UAVs, with much of their research and focus on precision agriculture (Torres-Sanchez *et al.*, 2013; Rey-Caramés *et al.*, 2015).

In marine survey scenarios, near-infrared reflectance has been measured from satellite imagery and manned aircraft to determine abundance of kelp, off the coast of California and the Gulf of Alaska (Stekoll *et al.*, 2006; Bell *et al.*, 2015). Stekoll *et al.* (2006) used a multispectral camera on a manned fixed-wing aircraft and surveyed 4.8 km^2 of kelp habitat area. Using post-processing Normalized Difference Vegetation Index (NDVI) algorithms, often utilized as an indicator of plant health in agriculture and terrestrial applications, they detected subsurface plants to 3 m by utilizing the additional spectral bands (451 and 551 nm)

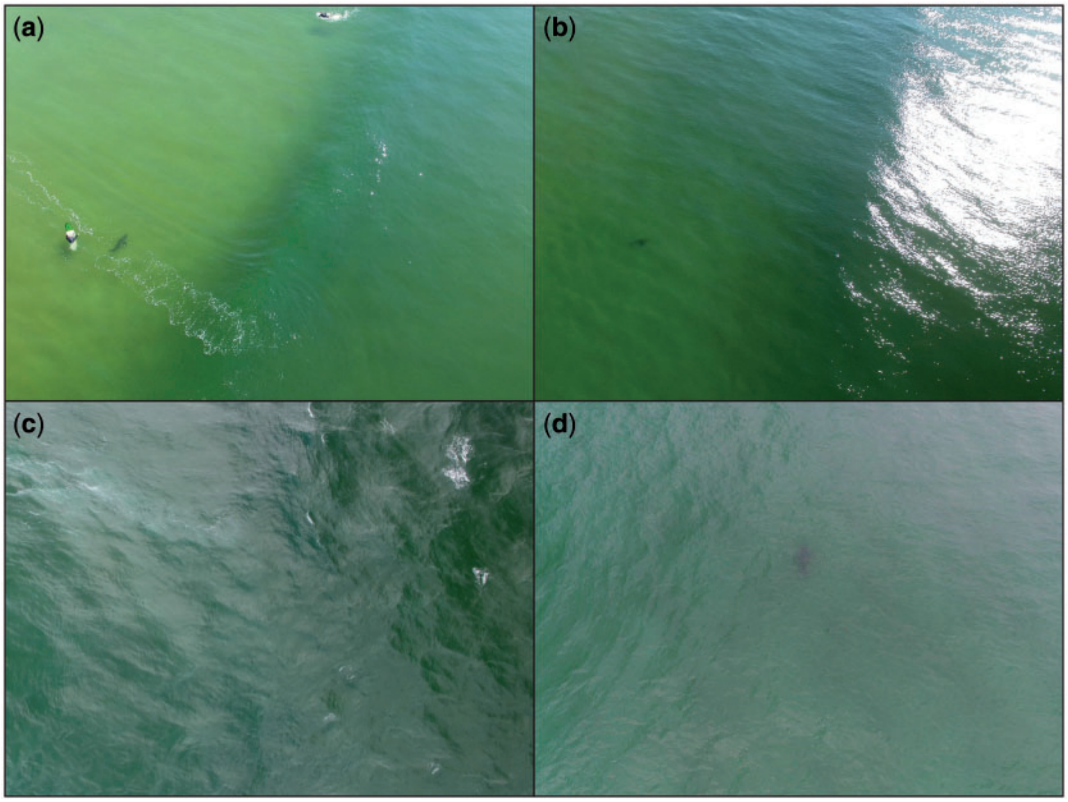

Figure 1. Comparison of shark images captured from a multirotor UAV at 60 m under different environmental conditions. (a) Clear shallow (< 5m depth) water, (b) effects of sun glare, (c) effects of sea state (no shark sighted), and (d) turbid water. Photos taken by New South Wales Department of Primary Industries.

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from the multispectral sensor. This improved upon previous near-infrared aerial photography that could only detect the portions of kelp that were at the surface. In marine applications, in-water reflectance is comparatively much less than terrestrial and is centred across a relatively narrow blue-green spectral band (Veenstra and Churnside, 2012), thus the way multispectral and hyperspectral cameras would be used to improve in-water marine fauna sighting will be fundamentally different from terrestrial mapping and classification. This becomes evident when using multispectral NDVI in marine scenarios, as depth penetration tends to be very limited.

Other multispectral and hyperspectral sensors have also been trialled in other shallow marine environments for habitat mapping, such as for determining reflectance of coral reef benthic communities (Karpouzli *et al.*, 2004; Kobryn *et al.*, 2013) and for shallow (< 5 m) benthic macroalgal mapping (Vahtmäe *et al.*, 2006). In Kobryn *et al.* (2013), seabed habitats in the Ningaloo Reef, Western Australia, were mapped and classified by discrimination of spectral attenuation, using airborne narrow band hyperspectral imaging. Using this approach, they successfully obtained relatively accurate, detailed spatial bathymetry and habitat information per spectral classification, to a depth of 20 m. Multispectral sensors have also been trialled as a means of improving sightability of whales from the air, as a proof-of-concept, which could also be used from a UAV (Schoonmaker *et al.*, 2011). The authors used spectral band width combinations of blue (∼486 nm), green (∼529 nm), and red (∼600 nm) to eliminate much of the spectral reflectance at the sea surface and residual sea surface interference, such as from the effects of clouds. This enabled possible sighting of whales in clear waters of up to 50 m deep.

It may be reasoned that finer selection and isolating of spectral bands via hyperspectral sensor technology, based on spectral characteristics of the water body, could merit improvements to in-water fauna sightability beyond what is most commonly achieved by eyesight or RGB sensors. The theory of eliminating sea surface spectral reflectance and thus achieving greater sightability by utilizing certain spectral bands warrants further scientific investigation.

Perception biases

Perception biases occur when an animal is theoretically available for detection, but is not sighted due to factors inherent with the sampling methodology. These include biases associated with observers, flight characteristics, or variable environmental conditions (Marsh and Sinclair, 1989; Pollock *et al.*, 2006; Fuentes *et al.*, 2015). In manned aerial surveys, detectability bias is generally minimized or quantified by developing repeatable statistical sampling methods, having multiple observers, and selecting favourable weather parameters for sampling. Perception biases in traditional manned aerial surveys are typically minimized by maintaining constant aircraft speed, altitude, and transect widths. Observer error can be estimated by using multiple observers and testing sighting efficacy of cut-out analogues at known depths, and calculating differences in detectability between observers (Marsh and Sinclair, 1989; Rowat *et al.*, 2009; Robbins *et al.*, 2014). This requires additional trained observers on each flight and longer post-processing time, however, has been described as a minimal cost compared with the overall cost of conducting aerial surveys (Marsh and Sinclair, 1989). In contrast, UAVs can fly pre-programmed courses maintaining relatively precise speeds and altitudes. They can also either stream video in real-time to the ground control station for observer counts, or provide a permanent high resolution digital record of "what is seen" within the sampling area for post-processing, or both. This reduces or eliminates biases associated with between-observer biasing (Koski *et al.*, 2009; Hodgson *et al.*, 2013). The advent of functional auto-detection algorithms and software for different species may also contribute to reducing issues associated with observer error.

Weather variables that influence detectability may include time of day, surface irradiance (glare), cloud cover, and sea state (examples in Figure 1). Whilst these may have significant effects on the number of animals detected, successfully modelling or factoring data adjustments to compensate is largely impossible (Pollock *et al.*, 2006; Hammond *et al.*, 2013; Fuentes *et al.*, 2015). Surveys instead are usually conducted in sea-state conditions of Beaufort < 3, and timed to reduce sun reflectance of glare and "sun glitter" off the water surface (Rowat *et al.*, 2009; Alves *et al.*, 2013; Westgate *et al.*, 2014). The detectability of marine fauna from UAV surveys is also potentially influenced by sea state, however not to the same extent as aerial surveys, particularly if taking overlapping still images for post analysis (Koski *et al.*, 2009; Hodgson *et al.*, 2013). The degree of perception bias for a given sea state may depend on the data capture method (stills or video), camera resolution, aircraft speed and altitude, and camera angle. Koski *et al.* (2009) tested the effectiveness of a fixed-wing (3.1 m wingspan) UAV with a 640 × 480 resolution video camera to spot whale-like analogues in 2006. Sightability was highly influenced by sea state, which was comparable to manned aerial surveys. In each case, sightability decreased significantly in sea states of Beaufort > 2. Hodgson *et al.* (2013), however, found that even in sea states of Beaufort 4–5, sea state had no significant influence on detectability when analysing still images captured from a digital SLR camera on a fixed-wing UAV. It was postulated that a still image reduced potential distraction of moving white caps to the observer.

Minimizing image distortion effects from the water surface and improving the level of detail able to be surveyed in shallow environments is also currently being developed using algorithm approaches to UAV-collected aerial imagery (Chirayath and Earle, 2016; Casella *et al.*, 2017). In Casella *et al.* (2017), Structure-from-motion (SfM) algorithms were applied to georeferenced imagery to remove optical refractive distortion effects created by motion at the water surface. Such distortion can produce warping effects on images and cause significant errors in attempts at creating orthomosaics of underwater habitats from aerial imagery (Casella *et al.*, 2017). For the algorithms to function effectively, sampling was confined to very calm conditions with minimal sun glare (early morning), however, results produced accurate high resolution (0.78–1.56 cm pixel^{-1}) orthomosaic bathymetry maps of shallow coral reef habitats in French Polynesia. "Fluid lensing" is a developmental, more advanced approach, which can obtain even higher levels of detail and accuracy (Chirayath and Earle, 2016). It uses a model and a complex set of algorithms to allow post-processing distortion correction of UAV collected imagery. A recent trial used a specialized UAV (multirotor) to collected imagery from a coral reef site in American Samoa and at a stromatolite colony in Western Australia (Chirayath and Earle, 2016). The fluid lensing proved a potential to create effective underwater 3d imaging from UAV collected aerial images, of which can depict corals, fish, and invertebrates.

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Although these techniques are also very limited by the water surface wave conditions and sun glare, it can allow fine scale measurements of fauna and assess their habitat preferences in shallow water ecosystems, effectively broadening the utility of UAV-based marine surveys and eliminating some potential visibility bias created by the water surface refractive optical distortion.

Conclusions

As technological developments enhance the versatility and functionality, and decrease the cost of commercially available UAVs, their potential as a marine aerial survey tool will also improve. Based on the literature, it is currently unlikely that UAVs would prove more efficient than manned aircraft for large area surveys (with basic data output requirements), with civil aviation restrictions ultimately limiting obtainable flight parameters and available technologies in most applications. Likewise, surveys requiring a quick turn-around for reporting that are of medium to large scale are likely to find traditional methods currently more efficient, due to comparatively straight forward project planning and established methodology for data processing and analysis.

For sampling spatial scales of a few square kilometres, or in isolated locations, UAVs may be the more efficient approach. This will become more evident as improvements in UAV sensor resolutions allow increases to sample area coverage, and as evolving auto-detection software improves post-processing efficiencies. Currently, computer automated streamlining of data processing can enhance post-processing efficiency and provide more precise results, eliminating human biases such as fatigue and differing interpretations between individuals. Automatic post-processing is mostly limited to single species aggregations or broad identification types (habitat mapping), and although more precise, are often not as accurate as human processing. Although automated data processing can be achieved on digital imagery, whether collected by manned aircraft or UAV, the benefits are likely to appeal to ongoing monitoring programs over on-off investigations, with the aircraft type (manned or UAV) dependent on scale and location.

Although technology is currently available for very long endurance fixed-wing UAV platforms (which could sample significantly larger areas), they are often either military-based craft or custom built, which results in a much higher cost. However, if civil aviation regulations change to allow beyond line-of-sight operations, consumer grade UAVs with extended flight will be more common, and the use of UAVs (particularly fixed-wing) will expand utility into larger area surveys.

Overall, UAVs and associated developing technologies, have the potential to improve on current data reliability offered with manned aircraft in marine fauna surveys. UAVs and associated methodologies are able to remove much of the observer bias, and can improve on perception biases encountered. Developments in multispectral and hyperspectral sensors for marine fauna surveys may also further improve on current sightability errors and limitations, and post-processing image correction algorithms may reduce surface water optical distortion and provide clearer visuals. Empirical testing of UAVs and associated technologies aimed at increasing sampling and post-processing efficiencies, and reducing sightability errors will ultimately enable UAVs to fill a niche of delivering efficient and reliable marine aerial survey data on smaller spatial scales. More freedom with civil aviation restrictions for marine surveys may further widen applicability into the wildlife survey domain currently dominated by manned aircraft.

Author contributions

All authors conceived the research and contributed to development of concepts. AC researched the literature and wrote the initial manuscript. All authors critically reviewed multiple drafts of the manuscript, as well as commented on and approved the final version.

Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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