Continuous wildlife monitoring using blimps as an aerial platform: A case study observing marine Megafauna

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Abstract

© 2020 Royal Zoological Society of New South Wales. All rights reserved. Aerial surveys are a powerful means of collecting ecological data in terrestrial and marine systems that may otherwise be difficult to acquire. Increasingly aerial observations are made with Unmanned Aerial Vehicles (UAVs), such as drones. As this technology has improved in reliability and affordability it has replaced the traditional use of fixed-wing aircraft and helicopters. Drones do, however, have limitations; primarily in their limited flight duration, potential to disturb wildlife and concerns over safety. Here we introduce an aerostat, a ground tethered blimp, as a logistically simple and economical alternative to drones and other aircraft. Blimps differ from drones by using helium for lift, thereby conserving battery life. This technology offers the advantage of near-continuous coverage of locations, as well as providing a safe and accessible alternative aerial platform for a range of applications. We demonstrate the viability of blimp-mounted cameras in a notoriously difficult area to conduct research: the high-energy nearshore marine zone. Specifically, we sought to determine the likelihood of encountering marine megafauna using real-time video and whether their presence was correlated with the occurrence of baitfish. Stingrays were observed more often than other species and the occurrence of seals was correlated with the presence of baitfish. The continuous coverage allowed the observation of foraging behaviour in sharks and seals for extended periods. This demonstrates the utility of this novel technique to improve human safety and enhance ecological research.

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ABSTRACT

Aerial surveys are a powerful means of collecting ecological data in terrestrial and marine systems that may otherwise be difficult to acquire. Increasingly aerial observations are made with Unmanned Aerial Vehicles (UAVs), such as drones. As this technology has improved in reliability and affordability it has replaced the traditional use of fixed-wing aircraft and helicopters. Drones do, however, have limitations; primarily in their limited flight duration, potential to disturb wildlife and concerns over safety. Here we introduce an aerostat, a ground tethered blimp, as a logistically simple and economical alternative to drones and other aircraft. Blimps differ from drones by using helium for lift, thereby conserving battery life. This technology offers the advantage of near-continuous coverage of locations, as well as providing a safe and accessible alternative aerial platform for a range of applications. We demonstrate the viability of blimp-mounted cameras in a notoriously difficult area to conduct research: the high-energy nearshore marine zone. Specifically, we sought to determine the likelihood of encountering marine megafauna using real-time video and whether their presence was correlated with the occurrence of baitfish. Stingrays were observed more often than other species and the occurrence of seals was correlated with the presence of baitfish. The continuous coverage allowed the observation of foraging behaviour in sharks and seals for extended periods. This demonstrates the utility of this novel technique to improve human safety and enhance ecological research.

Key words: drones, “Unmanned Aerial Systems” (UAS), “Unmanned Aerial Vehicles” (UAV), sharks, surveillance, aerostats, airship, behaviour, “movement ecology”

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Introduction

Aerial surveys are commonly used to sample in both terrestrial and marine ecology. Usually aerial surveys are used to obtain population estimates (Schlossberg et al. 2016; Colefax et al. 2018) but they can also be used as a tool to assess behaviour (Rieucau et al. 2018). When compared to land-based sampling methods, aerial techniques have several advantages; they can provide access to remote areas (Koh and Wich 2012) or environments that are difficult or dangerous to access due to obstructions. Elevated observing platforms can also improve the sightability of animals, particularly in marine environments (Torres et al. 2018, Colefax et al. 2018). Traditionally, such surveys have been conducted from fixed wing aircraft and helicopters that can be costly, noisy, and pose a risk to human safety (Torres et al. 2018). Drones, which are self-propelled (either single-rotor, multi-rotor or fixed wing) unmanned aerial vehicles (UAVs) (Domínguez-Sánchez et al. 2018), are increasingly being used as a tool to conduct and enhance ecological research (Bevan et al. 2018; Colefax et al. 2018; Colefax et al. 2019). UAVs are proving to be an increasingly viable alternative to traditional aerial techniques.

Aerial video-surveillance is an emerging field with great potential and several key advantages for providing new insights into both terrestrial and marine ecology. Drones are highly mobile, easily deployable, and can be pre-programmed to collect imagery in an automated fashion. The increasing popularity and use of UAVs are likely attributable to the emergence, and increasing affordability, of a wide variety of commercial platforms which can provide high-quality real-time observations and imagery that rival or surpass data collected through traditional means (Colefax et al. 2018; Hodgdon et al. 2018). In addition, drones offer the advantage of high spatial and temporal resolution and provide a systematic and permanent record (Linchant et al. 2014). Thus, drone
usage in ecology is burgeoning with a multitude of relatively affordable sensors and platforms available for scientists needing to conduct ecological surveys.

As with any tool, the use of drones in ecological research has limitations. A major limitation is their endurance in circumstances that require continuous surveillance. Smaller, affordable drones have limited flight duration that averages 30 minutes (Hassanalian and Abdelkefi 2017), reducing capabilities for observation (Rauolt et al. 2018). Further, researchers are required to have experience in operating and manoeuvring drones and they must constantly monitor the field of view while keeping the drone within line of sight. Importantly, this can further reduce observational competencies by inducing observer fatigue (Rauolt et al. 2018). Safety concerns for wildlife and humans also limits the use of drones in ecological research. Birds, such as Wedge-tailed eagles Aquila audax, (and other birds) have been observed attacking drones (Lyons et al. 2017), which raises the potential for injury to wildlife and the destruction of costly sampling equipment. The safety of researchers, and the public in populous locations, is also a consideration (Fox 2017) which requires detailed safety planning, training and reporting to mitigate the risk of injury. The final key constraint is one which drones share with helicopters and fixed-wing aircraft, which is the potential to disturb wildlife through the noise that they produce (Erbe et al. 2018; Mulero-Pázmány 2017). The minimum approach distance and altitude that elicits disturbance when using a drone varies by taxon, as does the response of each taxon (Bevan et al. 2018). Due, in part, to these species-specific effects, there are few scientifically justified guidelines for minimum approach distances to minimize disturbance to wildlife (Bevan et al. 2018). Although speculative, there are some indications that disturbance by drones may trigger short-term (physiological) and long-term effects (Mulero-Pázmány 2017). Some animals, however, have been shown to habituate to repeated exposures (Dittmer et al. 2019). Despite limitations, drones are a new platform for aerial monitoring, which offers a wide range of possibilities. Ultimately the aerial platform (and sensors) chosen by researchers depends on study requirements, but should be fit for purpose.

To overcome some of the limitations of drones, aerostats (powered or unpowered aerial platforms using a buoyant gas for lift) may be considered more suitable aerial systems for particular applications. Aerostats have been used extensively since the early 1900s because of their long endurance and relatively low operating costs. Historical use includes military surveillance as well as intercontinental passenger transportation prior to the emergence of fixed-wing passenger aircraft (Althoff 1990). Their use as a scientific research tool on which to mount sensors is a more recent development. Balloons are routinely used for atmospheric monitoring (Hain and Harris, 2004) and have also been used for monitoring wildlife, including whales, dugongs and sharks (Hain 2004; Hodgson, 2007; Nosal et al. 2012). As for other UAVs, key advantages that aerostats offer are high spatial and temporal resolution data with reduced operational costs, especially compared to planes and helicopters (Table 1). Some of the key advantages over drones include extended flight times and silent, non-invasive operation. Camera batteries deployed on blimps or balloons can last over eight hours, compared to the 20 to 30 minutes on a drone (Table 1). They are also easy to operate safely in proximity to both wildlife and humans with minimal disturbance to the animals being observed, probably less than drones, helicopters and other aircraft. These advantages ensure insights into patterns of movement of the target species within its habitat as well as the likelihood of observation of interactions with other organisms.

This case study aims to demonstrate the capability of aerostats (in this case a blimp) as a low-cost aerial monitoring platform that can be used for near-continuous research surveillance and the assessment of human safety. Nearshore beach environments are dynamic, high-energy systems which creates accessibility and safety issues when conducting research. As a consequence, patterns of movement and the behaviour of animals in these areas is poorly understood and largely unquantified. In addition, beaches represent areas of overlap between human usage and potentially dangerous animals, most notably sharks. Therefore, a platform able to continuously monitor these zones is advantageous for public safety, as well as acquiring ecological data. In this research, we conducted an aerial survey with the purpose of quantifying the coverage achieved by a blimp-mounted camera in time and space. We also provide data on the occurrence and behaviour of marine animals in the nearshore environment. Specifically, we aim to determine if certain species of marine megafauna are observed more frequently in the study area than others and whether their presence is correlated with the occurrence of baitfish. We demonstrate the application of blimps for ecological research, and the information obtained using them has important implications for public safety as well as for scientists considering ecological survey techniques.

**Methods**

This study took place in December 2017 to January 2018 in the Austral summer at Surf Beach in Kiama, on the south coast of New South Wales (NSW), Australia (Fig. 1). This beach is within a small (~250 m long), sandy coastal embayment enclosed by two rocky headlands.

Our aim was to detect and study the behaviour and beach usage of marine megafauna. We used a 5 m long and 1.8 m in diameter commercially available blimp to provide a stable platform for a high definition camera with 10 x optical zoom (Tarot Peeper) (Fig. 2; Fig. 3). The blimp was...
Continuous wildlife monitoring using blimps as an aerial platform: a case study observing marine megafauna

Table 1 - Comparisons of a range of aerial survey devices and their associated features. Values are ranges based on general estimates in $AUD (note: these may vary with the specifications of the device, conditions and vary across countries). Fixed wing (based on a single engine airplane). Fuel costs are based on an 8 hour day.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Fixed Wing</th>
<th>Helicopter</th>
<th>Rotary Drones</th>
<th>Aerostat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flight time</td>
<td>4 to 6 hours</td>
<td>~ 2.5 hours</td>
<td>20-30 mins</td>
<td>8 hours</td>
</tr>
<tr>
<td>Operator requirements</td>
<td>Commercial pilot license</td>
<td>Commercial pilot license</td>
<td>Experienced pilot</td>
<td>Trained operator</td>
</tr>
<tr>
<td>Equipment cost (Aerial device)</td>
<td>$75K - $300K</td>
<td>$250K – $1.7M</td>
<td>$2K - $250K</td>
<td>$5K-10K</td>
</tr>
<tr>
<td>Fuel costs</td>
<td>~$1,600 /day</td>
<td>~ $2,400 /day</td>
<td>NA</td>
<td>NA(^a)</td>
</tr>
<tr>
<td>Staffing costs</td>
<td>Two staff: spotter and pilot</td>
<td>Two staff: spotter and pilot</td>
<td>Typically two staff but possible with one operator</td>
<td>Possible with one operator</td>
</tr>
<tr>
<td>Safety</td>
<td>Risk of serious collision with humans and wildlife</td>
<td>Risk of serious collision with humans and wildlife</td>
<td>Risk of serious collision with humans and wildlife</td>
<td>Soft, small risk of rope burn during deployment and retrieval</td>
</tr>
<tr>
<td>Storage requirements</td>
<td>Airport or airfield</td>
<td>Airport or airfield</td>
<td>Minimal</td>
<td>Preferably under cover (e.g. one car garage or shipping container)</td>
</tr>
<tr>
<td>Operational restrictions</td>
<td>Airport or airfield</td>
<td>Airport or airfield</td>
<td>120 m and restricted in no-fly zones</td>
<td>Approval required from aviation authority in operations above 120 m and/or in no-fly zones</td>
</tr>
<tr>
<td>Mobility</td>
<td>Highly mobile</td>
<td>Highly mobile</td>
<td>Highly mobile</td>
<td>Tethered (mobile if tethered to a boat or vehicle)</td>
</tr>
<tr>
<td>Sampling method</td>
<td>Transect (or area based if hovering)</td>
<td>Transect</td>
<td>Transect (or area based if hovering)</td>
<td>Area based (or transect if towed)</td>
</tr>
</tbody>
</table>

\(^a\) Inflation costs: depends on the length of deployment but ~$85/day (assuming 1 week deployment)

Figure 1 - Kiama Surf Beach, a small sandy coastal embayment on the South East coast of New South Wales, Australia.
tethered at 70 m above sea-level with deployment being simple and safely achieved by a single operator. Between deployments, the blimp was stored fully inflated in a garage in order to minimise helium usage and costs. Stored in this manner, helium loss is typically less than 1% a day so a small top-up of helium was required when the blimp lost rigidity (~ twice a week). Initial inflation required 8000 L of helium which provided approximately 2 kg of lift and was adequate to lift the camera system.

Daily surveys were conducted between 11 am to 5 pm, with some periods of sampling curtailed due to winds forecasted to exceed our 40 km/hr safety threshold. The camera sent live footage directly to a monitor on the ground using a broadcaster (DJI Lightbridge 2). The live stream was constantly monitored by an observer who controlled the camera direction and zoom (Fig. 3). Species identification was undertaken by qualified marine scientists using visual assessment of animal morphology and known species ranges. The position in which the blimp was placed depended on the wind direction and strength. Its placement alternated between the southern, middle and northern end of the beach with the field of view comparable for all three positions.

To quantify whether the encounter rate of marine megafauna was influenced by species, we binned the data into hourly presence and absence for each species. We then used a generalized linear mixed model fit by maximum likelihood (Laplace approximation) in the logit binomial family using the lme4 package in R (R Development Core Team 2008; Bates et al. 2012) to determine if hourly encounter rate differed between species. Species was included in the model as a three-level fixed factor and sampling date was included as a random effect. To quantify whether the encounter rate of marine megafauna was influenced by the presence of baitfish (e.g. Australian salmon, *Arripis trutta*), we again used generalized linear mixed models) to test for correlations in hourly encounter rate between each species and the presence of baitfish. Baitfish presence was included in the models as a two-level fixed factor and sampling date was included as a random effect.

**Results and Discussion**

**Animal observation and risk prevention**

The blimp was deployed on approximately 70% of days over the study period. For the other 30% of days the system could not be deployed due to high winds (> 40 km/hr) or rainfall (as the camera was not waterproof). In total, 16 aerial surveys were completed with a mean daily flight time of 4 h 16 min ± 15 min and a total of
68 h 32 min. The deployment and observation window of the blimp was determined by the work hours of lifeguards and daily flights of a shark patrol helicopter at 11 am. Grey nurse sharks *Carcharias taurus*, Australian fur seals *Arctocephalus pusillus doriferus*, and smooth Stingray *Bathypteros brevicaudata* or Black Stingray *Dasyatis thetidis*, were the common marine megafauna observed in our study. It was not possible to distinguish between the stingray species or among individuals of any taxon from the video recordings. The average hourly encounter rate of marine megafauna in the nearshore area of approximately 18,500 m² was dependent on the species (Fig. 4) and also influenced by the presence of baitfish (Fig. 5). Stingrays were observed in the study area significantly more often than both sharks and seals ($z = 5.451, p < 0.001$, Fig. 4).

Seals were much more likely to be encountered if baitfish were present in the bay ($z = 2.666, p = 0.008$, Fig. 5) whereas Shark ($z = 0.777, p = 0.437$) and Stingray ($z = 1.571, p = 0.116$) occurrence did not appear to be influenced by the presence of baitfish (Fig. 5). It seems likely then that seals use this particular beach to forage. Further, our findings suggest that the occurrence of sharks at this particular beach was very rare, and this low encounter rate may have made any correlation with baitfish activity difficult to detect. Although the seals and shark species observed here are not seen to be highly threatening, our

Figure 4 – the average hourly encounter rate in the nearshore beach environment for three mega-fauna as observed from a blimp mounted camera. The species were identified as Australian fur seals, *Arctocephalus pusillus doriferus*, Grey nurse sharks, *Carcharias taurus*, and Smooth Stingray *Bathypteros brevicaudata* or Black Stingray *Dasyatis thetidis*. Error bars are 95% CI.

Figure 5 – The average hourly encounter rate of three megafaunal taxa associated with the presence of baitfish in the nearshore beach environment as observed from a blimp mounted camera. The species were identified as Australian fur seals, *Arctocephalus pusillus doriferus*, Grey nurse sharks, *Carcharias taurus*, and Smooth Stingray *Bathypteros brevicaudata* or Black Stingray *Dasyatis thetidis*. The baitfish are likely Australian salmon, *Arripis trutta*. Error bars are 95% CI.
findings have implications for humans who use these areas for recreation and adds to the recommendation by Curtis et al. (2014) to avoid entering the water when baitfish are present. An unquantified number of seabirds including silver gulls *Larus novaehollandiae* and cormorants *Phalacrocorax* spp. were also observed. These observations, when viewed together, paint a picture of a diverse and functional ecosystem just offshore from a populated beach. Furthermore, the insights into animal habitat usage and behaviour highlight the applicability of aerostats, including blimps, as novel tools for ecological research.

Unsurprisingly, our surveys observed people engaging in a variety of recreational activities including surfing, swimming, snorkelling and kayaking. One notable incident that demonstrates the application of the platform for beach safety was the observation and intervention of a bodyboarder who came close to a foraging shark (Fig. 6). The video observer alerted lifeguards to the proximity of the shark to the bodyboarder, so they were then able to signal to the bodyboarder, who could then exit the water safely. Only later, with the acquisition of additional footage, was the species identity of the shark confirmed. Our findings highlight an important application for aerial platforms, which could indeed be used for preventing shark-human incidents, especially given that shark incidents are known to be increasing globally (Curtis et al. 2012; McPhee 2014). Prior to implementation of such a platform for targeted shark detection, it would be imperative to quantify the ability of such a system to reliably detect sharks, given the limited effectiveness of other aerial shark patrols (Robbins et al. 2014).

**Behavioural observations**

In addition to data on animal occurrence, continuous aerial video-surveillance can provide an opportunity to collect information about the interactions of target animals with their habitat and with other organisms. One key behaviour we observed was predator-prey interactions between apex predators (sharks and seals) and their baitfish prey in the nearshore zone. On occasions, up to two grey nurse sharks were seen to be foraging on a baitball (Fig. 7). Seals were observed herding fish into the shallows and surfing waves to aid with capture of their prey. Indeed, a seal was observed to demonstrate this shallow-water herding behaviour and video recordings identified it successfully capturing a fish (Fig. 8). This represents the first evidence, of which we are aware, that Australian fur seals may use shallow nearshore environments as foraging grounds as Wilson et al. (2014) speculated for a different species of seal. Importantly, due to the nature of the blimp, we were able to make these behavioural observations silently and remotely. When using other aerial platforms such disturbances have the potential to lead to increased energy expenditure and changes in behaviour (Mulero-Pázmány 2017). This is particularly relevant and needs consideration if repeated sampling is required at one site, or sampling is focused on tracking individual animals (Raoult et al. 2018).

**Shortcomings of blimp usage**

As with any technique there are limitations that need to be considered if using a blimp or balloon for research. The first relates to the costs associated with inflation of the device, as helium is quite expensive for a one-off inflation. Inflation quickly becomes economical if the blimp or balloon can be stored on site, either in a garage, shipping container or trailer. Another consideration is stability in variable winds; the blimp tends to ‘fishtail’ when close to the ground if winds are gusty and variable. We compensated for this movement by having a self-stabilising gimbal for the camera, including 360-degree rotation; this camera set up automatically sustained the field of view of interest no matter which direction the blimp was orientated. In marine systems Hodgson (2007), Robbins et al. (2014) and Westgate et al. (2014) have consistently demonstrated that the maximum visible depth of large marine fauna extends 4 – 5 metres

*Figure 6* - A bodyboarder in close proximity to a bait ball (grey mass) and associated grey nurse shark *Carcharias taurus* (top - black circle), before being alerted by lifeguards to the shark (middle-head turned towards shore) and catching the next wave into shore (bottom). The location of the shark is indicated by the black circle.
Continuous wildlife monitoring using blimps as an aerial platform: a case study observing marine megafauna

Figure 7 - Two grey nurse sharks Carcharias taurus attempting to feed on a baitfish school of Arripis trutta in shallow (approximately 2-3 m deep) water as observed from a blimp mounted camera.

Figure 8 - An Australian fur seal Arctocephalus pusillus doriferus chases a baitfish school (Arripis trutta) (top left), before herding them into shallow water and splitting the school into two (top right). The seal uses the shallow sandbank to its advantage, and wounds (bottom left) and consumes (bottom right) an unfortunate salmon.

beneath the surface, which is in agreement with our animal sightings, suggesting that this technique may be limited to surface waters or nearshore areas.

Prospects for continuous aerial monitoring

In the marine realm, we envision a network of such blimps, with a focus on shark detection for human safety but also acting as a means for collecting continuous ecological data that would be highly valuable to researchers and coastal managers alike. Current aerial shark-spotting patrols provide highly sporadic coverage with low spotting rates (Robbins et al. 2014), and blimp platforms may have the capacity to improve shark detection. Automated detection algorithms would likely play a key role in such a network (Gonzalez et al. 2018) and could be extended to cover a variety of fauna. Further detail about animal movement patterns in this high energy environment would be ascertainable if the movement paths were georeferenced, as has been done previously (Raoult et al. 2018; Ruiz-Garcia et al. 2018), although such analyses are beyond the scope of this current study.
Conclusions
We provide new insights into the behaviour of marine fauna in high-energy surf areas, which likely apply broadly to other beaches. Continuous aerial video-surveillance is a novel technique, which could provide information on the fine-scale movement patterns and behaviour of a variety of animals in both marine and terrestrial habitats. In our case study, the key advantage of using a blimp are the continuous coverage it provides, which enables observers to detect fauna for the full day. Our platform is particularly useful in high-energy environments where other techniques may be unsuitable (Bicknell et al. 2016). They may also have the capacity to serve as an alternative to aerial shark spotting patrols following additional research on their efficacy for this purpose. In addition, the blimp operates with zero licensing and minimal training, so it can be deployed without reference to the aviation authority and without needing a drone pilot. The costs of running such a surveillance program could also be offset by the sale of advertising space on the blimp itself. This case study adds support for the use of aerostats as an aerial monitoring platform providing insight into animal habitat usage and behaviour. Our intention has been to showcase an emerging tool for research and human safety.

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Continuous wildlife monitoring using blimps as an aerial platform: a case study observing marine megafauna


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