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Using drones to quantify beach users across a range of environmental conditions

Euan J. Provost[1] · Paul A. Butcher[1,2] · Andrew P. Colefax[1,2] · Melinda A. Coleman[1,2] · Belinda G. Curley[3] · Brendan P. Kelaher[1]

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Abstract

Beaches are economically and socially important to coastal regions. The intensive use of beaches requires active management to mitigate impacts to natural habitats and users. Understanding the patterns of beach use can assist in developing management actions designed to promote sustainable use. We assessed whether remotely piloted aerial systems (commonly known as drones) are an appropriate tool for quantifying beach use, and if beach activities are influenced by environmental conditions. Novel drone-based methods were used to quantify beach use. Drone flights recorded 2 km of beach, capturing video footage of the beach from the dune to water interface and the breaker zone. Flights were undertaken during three school holiday periods at four popular beaches in New South Wales, Australia. These videos were later analysed in the laboratory to categorise beach users. Of the total users sampled, 45.0% were sunbathing, 22.8% swimming, 21.2% walking, 10.6% surfing, and less than 0.5% were fishing. Participation in walking, surfing and fishing was similar throughout the sampling periods. However, sunbathing and swimming significantly increased during the austral spring and summer sampling periods. Usage patterns varied significantly among beaches, and during the different sampling periods, suggesting that adaptive management strategies targeted to specific areas are the most appropriate way to protect beach habitats and users. Furthermore, we demonstrate that drones are an effective assessment tool to improve coastal management decisions.

Keywords Drones · Remotely piloted aerial systems · Coastal management · Beach attendance · Beach use

Introduction

Beaches are an economically valuable asset that attract people (Dwight et al. 2012; Lucrezi et al. 2016). Beach tourism is an important economic contributor for coastal regions and drives developments to facilitate recreational involvement (e.g. hotels, surf tourism) (Alexandrakis et al. 2015; Barbieri and Sotomayor 2013; Papageorgiou 2016; Pérez-Maqueo et al. 2017). However, intensive human use of beaches can be unsustainable and result in degradation to habitat quality (i.e. water pollution) (Botero et al. 2017; Juhasz et al. 2010; Semeoshenkova and Newton 2015). Furthermore, there are risks to beach users, including, drowning, sun exposure and interactions with dangerous wildlife, that often require careful management (Attard et al. 2015; Chapman and Mcphee 2016; Mckay et al. 2014; Warton and Brander 2017).

The active management of beaches is essential to mitigate threats to habitats and users, and to maximise their economic and recreational potential (Chen and Teng 2016; González and Holtmann-Ahumada 2017; Papageorgiou 2016). An understanding of the human aspects (e.g. usage and values), in addition to physical beach characteristics (e.g. morphology and environmental influences), can ensure that beach habitats are managed effectively (Lucrezi et al. 2016; Semeoshenkova et al. 2017). By understanding patterns of recreational beach use, such as the quantity of users and the specific activities being undertaken, tailored management actions that enhance community use and the long-term ecological and economic sustainability of these areas can be developed (Jiménez et al. 2007; King and McGregor 2012).

✉ Euan J. Provost
euanjprovost@gmail.com

1 National Marine Science Centre and Marine Ecology Research Centre, Southern Cross University, Coffs Harbour, NSW, Australia

2 New South Wales Department of Primary Industries, National Marine Science Centre, Coffs Harbour, NSW, Australia

3 New South Wales Department of Primary Industries, Port Stephens Fisheries Centre, Taylors Beach, NSW, Australia

Despite the high value of beaches, patterns of recreational use in Australia are not well known (James 2000; Maguire et al. 2011). Conventional tools to assess beach use include manned aerial surveys using spotters and digital imagery (Blackweir and Beckley 2004), shore-based surveys using fixed video cameras and photography (Huamantinco et al. 2016; Ibarra 2011; Jiménez et al. 2007), manual counting (King and McGregor 2012) and community surveys (Dwight et al. 2007; Zhang et al. 2015). Remotely piloted aircraft systems (hereafter called drones, see Chabot 2018; Chapman 2014) may provide a novel method for cost-effective assessments of beach use, but their value is yet to be rigorously assessed.

Recent technological improvements (e.g. rechargeable long-life batteries, compact electric motors and light-weight high definition digital cameras) have increased the utility of drones and their potential as a tool for data collection and environmental monitoring (Anderson and Gaston 2013; Anweiler and Piwowarski 2017). Higher resolution digital video imagery can be collected using drones compared to other remote sensing platforms (e.g. civilian satellites) (Di Felice et al. 2018), allowing them to intensively sample areas over scales <10 km^2 (Colefax et al. 2018). Drone technology has been used successfully to monitor marine wildlife (Hodgson et al. 2013; Kelaher et al. 2019) and to survey coastal morphology (Gonçalves and Henriques 2015; Turner et al. 2016). Compared to manned aerial surveys, drone techniques are likely to provide cost (financial, staff), logistical (deployment, maintenance, storage) and safety benefits (Nishar et al. 2016; Goebel et al. 2015). Further applications benefiting coastal management include subtidal and intertidal habitat mapping (Casella et al. 2017; Konar and Iken 2018; Ventura et al. 2016), beach litter detection (Martin et al. 2018) and assisting fisheries and marine park compliance (Jiménez López and Mulero-Pázmány 2019; Nyman 2019).

The present study aimed to determine whether drones are an effective tool to quantify human use on popular beaches. Drone surveys were used to; (i) quantify and categorise beach users; (ii) test differences in patterns of use among different beaches and time periods; and (iii) determine if beach activities are influenced by a range of environmental variables, such as wind, humidity and temperature.

Methods

Drones were used to survey the recreational use at four popular beaches in New South Wales (NSW), Australia during the NSW summer (27/12/16–29/01/17), winter (30/06/17–17/07/17) and spring (23/09/17–08/10/17) school holiday periods in 2017. Drone flights were undertaken daily during the sampling periods, except when weather conditions were unsuitable (e.g. raining or wind over 20 km/h). The beaches surveyed during the summer holiday period included Lennox Head (*n* = 29 flights) (28.7850°S, 153.5943°E–28.8009°S, 153.5961°E), Ballina (*n* = 19 flights) (28.8598°S, 153.5976°E–28.8741°S, 153.5898°E) and Evans Head (*n* = 20 flights) (29.1032°S, 153.4329°E–29.1161°S, 153.4448°E). The survey locations during the winter and spring holiday periods included Evans Head (*n* = 18 and 14 flights, respectively), Ballina (*n* = 18 and 13 flights, respectively), Lennox Head (*n* = 16 and 14 flights, respectively) and Byron Bay (*n* = 16 and 16 flights, respectively) (28.6395°S, 153.6100°E–28.6367°S, 153.6284°E) (see Fig 1). These locations had seasonal Surf Life Saving flagged areas (designated areas considered safe for swimming and are monitored by trained personnel) during the spring and summer holiday periods, although these services were not provided at Ballina, Lennox Head and Evans Head during the winter holiday period.

Flights

At each beach flights began at 10:30 am and surveyed the beach and water section 1 km north and south of the local Surf Life Saving Club, resulting in a 2 km transect being sampled. The drone used was the DJI Phantom 4, which is a small (1380 g) commercially-available quadcopter aircraft, with a high-resolution camera.

During each flight, a commercially licensed drone pilot flew the drone at a speed of 8 m.s^{-1} over the water at 60 m altitude. During the flight the camera was facing towards the beach to capture beach users from the dunes to water interface. The drone was then moved further seaward, and returned flying a parallel flight path to capture water users. Flights were undertaken in this manner to avoid flying directly over people. Video data was recorded in UHD resolution (3840 × 2160) at 25 frames per second. Cameras were equipped with circular polarising filters (ND4) to reduce glare.

Environmental data

Environmental variables measured for each flight included wind speed (km h^{-1}), wind direction (compass point), air temperature (°C), humidity (%), air pressure (hectopascal), cloud cover (eights) and Beaufort Sea state (0–5). Water temperature (°C) and surf rating (1–10) were obtained from Coastalwatch Networks.

Video review

Videos were reviewed in the laboratory and individual beach-goers counted manually, using a 58.5 cm (diagonal) LED

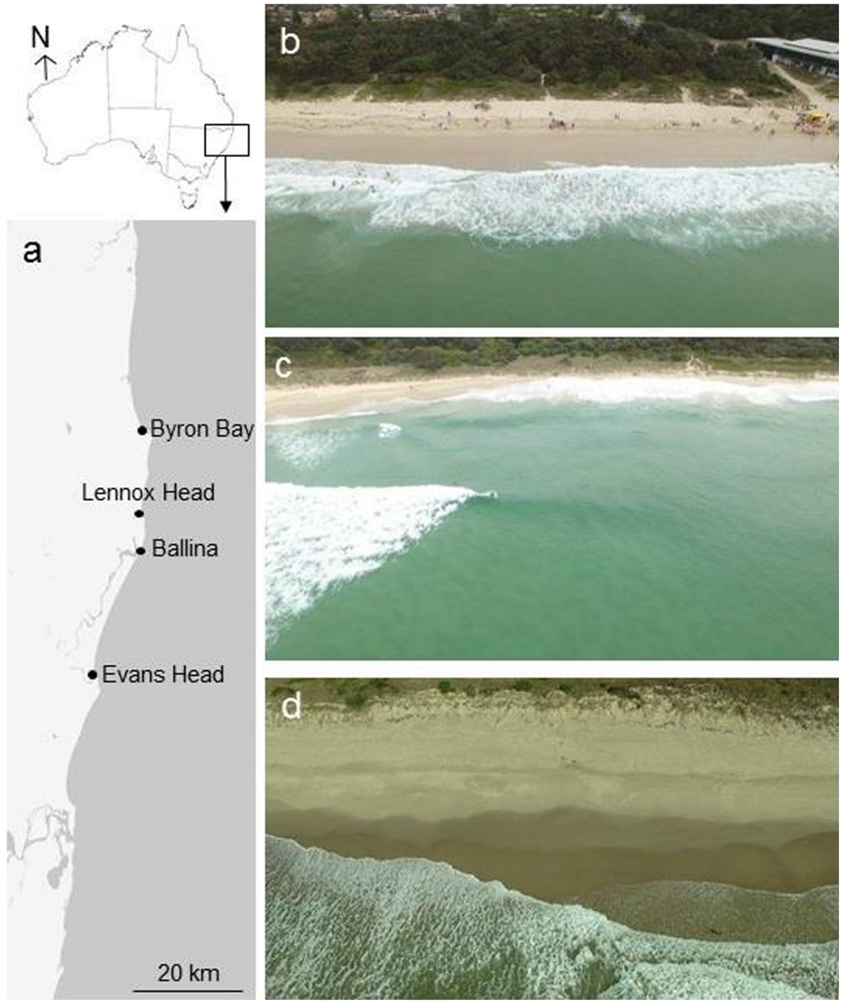

Fig. 1 **a** Location of beaches studied on the north coast of New South Wales, Australia. Examples of the footage collected with drones of recreational beach use: (**b**) moderately-high usage, swimmer and sunbathers at Ballina; (**c**) small number of surfers at Ballina; (**d**) a beach fisher at Evans Head

display with a pixel resolution of 1920 × 1080. Individual beachgoers were classified into one of the following user categories: sunbathing (those sitting, laying, standing still, engaged in beach games, lifesavers, junior lifesavers and officials), walking (walking, running and dog walking), swimming, surfing (surfing, stand-up paddle boarding and bodyboarding) and fishing. The user categories jet skis, snorkelling, surf ski/kayaking, wind/kite surfing and cycling were noted but not included in analysis due to very low rates of participation.

Statistical analysis

Permutational analyses of variance (PERMANOVA, Anderson et al. 2008) was used to test whether participation in the six key beach user categories (sunbathing, walking, swimming, surfing and fishing) and a multivariate combination of these groups differed between the beaches sampled, sampling periods and weekdays versus weekends/public holidays. All PERMANOVA analysis were based on 4999 permutation. Univariate and Multivariate analyses were based of Euclidean Distance and Bray-Curtis resemblance measures, respectively. Data was Log $(x + 1)$ transformed prior to analysis to reduce any variance heterogeneity and to downscale the influence of more popular groups in multivariate analyses. Pair-wise post hoc tests were used to evaluate significant main effects with 3 or more levels and interaction terms.

Generalized Linear Models (GLM) were used to determine the relationship of environmental variables to participation in the main activity categories (sunbathing, walking, swimming, surfing and fishing). The associations with key predictor variables (beach location, wind direction, wind speed, air temperature, humidity, sea state, cloud cover, surf rating and water temperature) with participation rates were tested using the lme4 package with R (R Development Core Team 2008). For these analyses, predictor variables were not co-linear (Pearson r's all <0.5) and the data was not zero inflated. Given the GLMs were consistently over dispersed using the Poisson distribution, the analyses were carried out using a negative binomial distribution (see Zuur and Ieno 2016).

Results

Overview

During the study period, 193 flights were completed with 36, 618 beach users documented. Rain or strong wind resulted in 28 of the 221 planned flights being cancelled. Of the total users sampled, 45.0% were sunbathing, 22.8% swimming, 21.2% walking, 10.6% surfing, and < 0.5% were fishing.

Participation in walking did not differ significantly among sampling periods, however there was significantly more walkers at Byron Bay compared to the other beaches, and significantly more walkers at Lennox Head than at Ballina and Evans Head (Fig. 2). During the winter holiday period, walking was the most popular activity undertaken, apart from at Lennox Head where surfing (34.7% of total users) and Byron Bay where sunbathing (35.6%) were marginally more popular. During the summer and spring holiday periods, sunbathing (45.4%) and swimming (30.0%) were the most popular activities undertaken, with significantly greater participation than during the winter holiday period (Fig. 2). During the summer holiday period, swimming was more popular than sunbathing at Ballina (swimming 38.4%) and Evans Head (44.4%). Participation in surfing remained constant over the sampled periods, and during the winter holiday period became the third most popular activity due to fewer people swimming (Fig.2). At each location and every holiday period sampled, fishing was by far the least popular activity (Fig. 2).

Patterns of use among beaches, holiday periods and weekdays vs weekends

Multivariate analysis comparing beach users found a significant interaction between beach location and sample period (Table 2). Pairwise tests revealed during the summer and winter holiday periods, all the beaches were significantly different from each other, and during the spring holiday period Byron Bay was significantly different from all others (Fig. 3).

There was a significant difference in the number of people swimming at the different beaches (Fig. 2), and a significant interaction between sample period and weekend versus weekday use (Fig. 4). Pairwise tests revealed Byron Bay to have significantly more swimmers than all other beaches. Lennox Head had significantly more swimmers than Ballina but not Evans Head, and Ballina was not different to Evans Head (Fig. 2) There was significantly more swimming on weekdays than on the weekends during the winter and spring holiday periods (Fig. 4).

Sunbathing varied significantly among sample periods and beaches (Table 1, Fig. 2). During the summer and spring holiday periods, participation in sunbathing did not differ significantly, but there was significantly less participation during the winter holiday period (Fig. 2). Pairwise tests among beaches showed participation in sunbathing at Evans Head and Ballina were not significantly different. There was, however, significantly more sunbathing at Lennox Head, and participation significantly increased again at Byron Bay (Fig. 2).

The number of walkers varied significantly among beaches, and also interacted significantly between sample period and weekend versus weekdays (Table 1, Fig. 2). Pairwise tests showed that Byron Bay was significantly different to all other beaches, with around three times as many walkers (Fig. 2). The significant interaction was a result of increased participation on weekends during the summer and winter holiday periods (Fig. 1).

During the summer holiday period participation in surfing at Lennox and Evans Head was greater than Ballina (see significant B × P interaction in Table 1, Fig. 2). However, during the winter sampling period, Lennox Head and Byron Bay had significantly more surfers than Evans Head and Ballina (Fig.

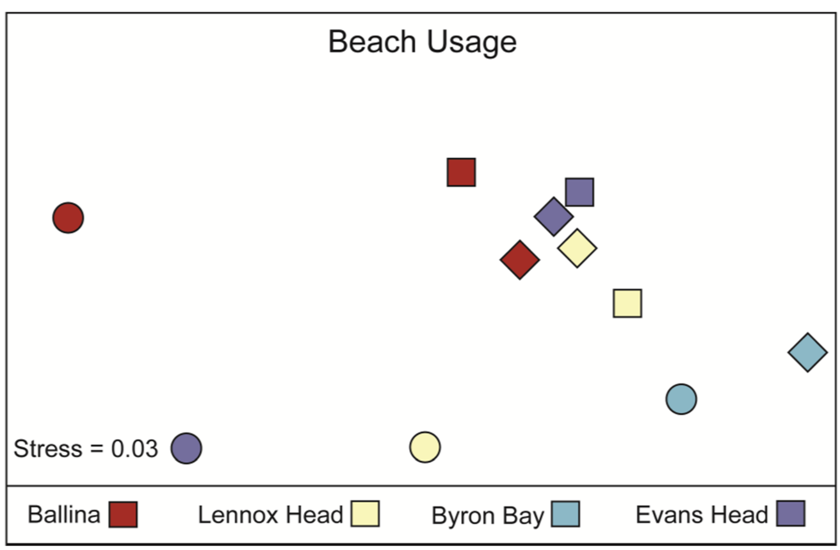

Fig. 2 Multidimensional scaling (MDS) plot comparing overall beach usage at the sampled beach locations at each of the sampling periods. Squares, circles and diamonds symbols represent summer, winter and spring holidays sampling periods, respectively

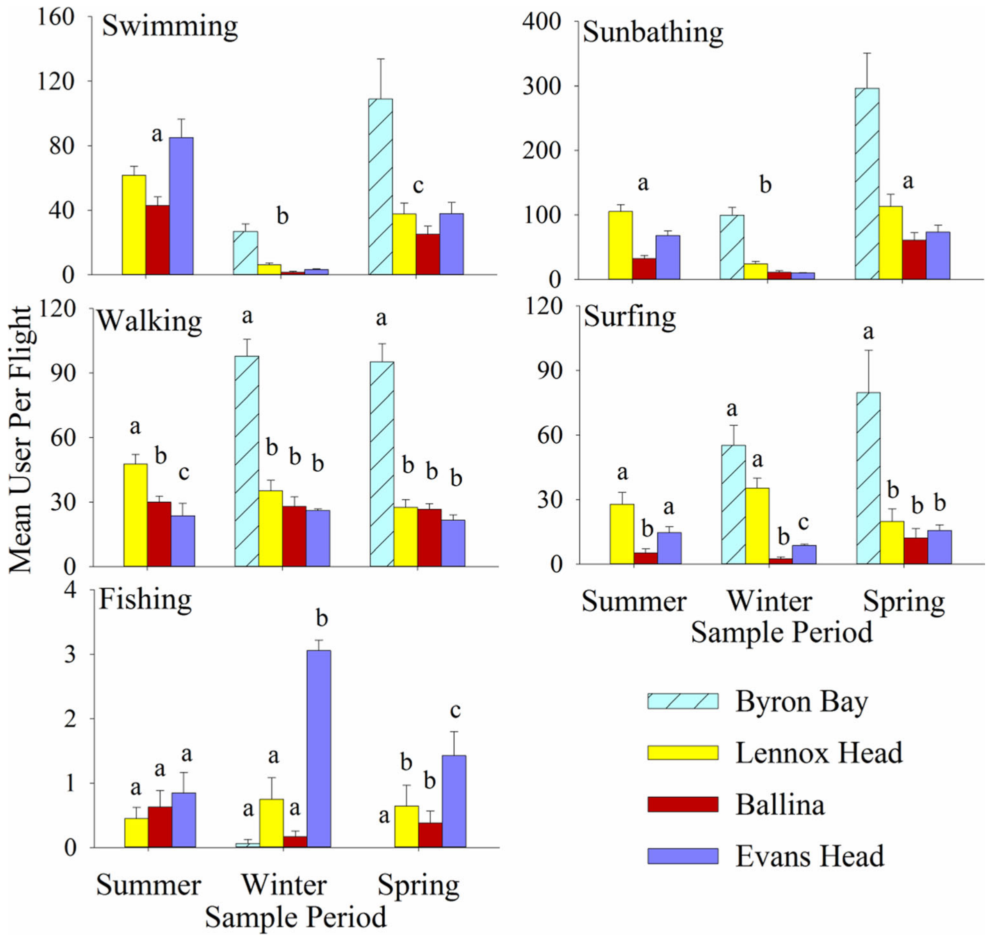

Fig. 3 Comparison of beach users engaged in the user categories of swimming, sunbathing, walking, surfing and fishing, over the sampling periods. Figures display average users observed per flight (± SE). Different letters indicate significant differences at $P < 0.05$

2). During the spring sampling period, participation in surfing at Byron Bay was significantly greater than all other locations, with the number of surfers at Byron Bay 95% greater than the other beaches combined (Fig. 2).

Participation in fishing was small, <0.5% of total users sampled, though there was significantly more participation on weekends (Table 1). A significant interaction of beach and period was also found, and was the result of fishing

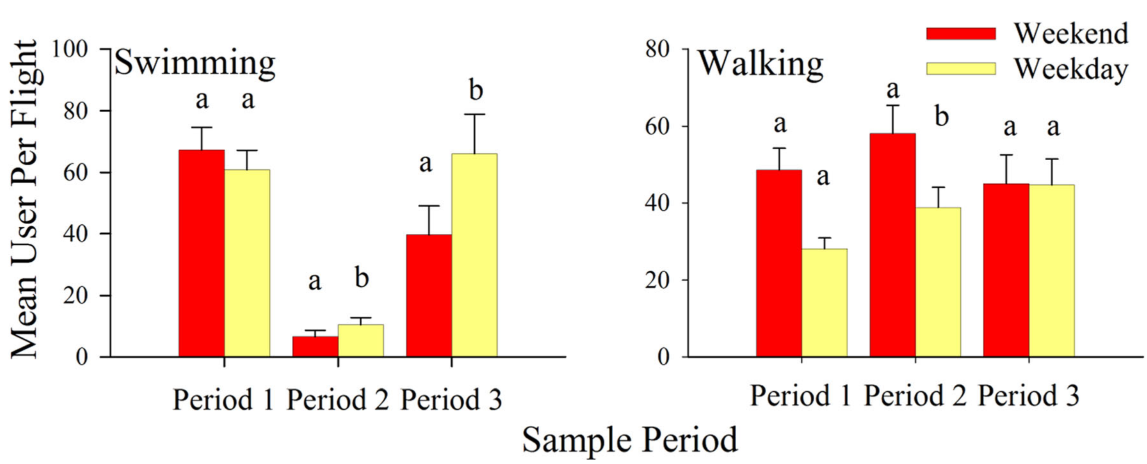

Fig. 4 Difference in the participation on weekend and public holidays compared to weekdays for the user categories of swimming and walking. Figures displays average users observed per flight (± SE). Different letters indicate significant differences at $P < 0.05$

Table 1 PERMANOVA analysis results of beach users; all users (all user categories combined), sunbathing, surfing, swimming, and fishing. Significance indicated in bold.

	df	(a) All Users			(b) Sunbathing			(c) Walking		
		MS	p-*F*	*P*	MS	p-*F*	*P*	MS	p-*F*	*P*
Beach = B	3	4850.20	28.97	**< 0.001**	25.68	42.49	**< 0.001**	13.95	49.33	**< 0.001**
Period = P	2	6748.50	10.23	**< 0.05**	39.45	36.07	**< 0.01**	0.69	1.29	0.35
Weekend = W	1	621.29	3.39	0.127	0.24	2.09	0.2588	4.28	24.64	**< 0.05**
B × P	5	650.28	3.88	**< 0.001**	1.08	1.78	0.12	0.53	1.88	0.10
B × W	3	181.77	1.08	0.38	0.11	0.19	0.91	0.17	0.61	0.62
P × W	2	285.86	2.56	0.14	1.41	2.66	0.16	1.15	10.85	**< 0.05**
B × P × W	5	111.17	0.66	0.80	0.52	0.87	0.49	0.10	0.37	0.86
Residual	171	167.44			0.60			0.28		
		(a) Swimming			**(b) Surfing**			**(c) Fishing**		
		MS	**p-*F***	***P***	**MS**	**p-*F***	***P***	**MS**	**p-*F***	***P***
Beach = B	3	21.34	27.38	**< 0.001**	34.63	32.18	**< 0.001**	4.44	18.25	**< 0.001**
Period = P	2	113.54	63.49	**< 0.001**	0.81	0.28	0.75	0.63	0.66	0.64
Weekend = W	1	6.08	5.70	0.10	1.43	0.59	0.48	0.27	36.11	**< 0.05**
B × P	5	1.76	2.26	0.05	2.88	2.68	**< 0.05**	0.94	3.86	**< 0.01**
B × W	3	1.06	1.35	0.26	2.44	2.27	0.08	0.007	0.03	0.99
P × W	2	2.12	15.26	**< 0.01**	0.55	0.78	0.50	0.42	1.83	0.25
B × P × W	5	0.14	0.17	0.96	0.72	0.67	0.64	0.23	0.94	0.45
Residual	171	0.78			1.08			0.24		

Beach sampled locations; *Period* sampling period; *Weekend* weekends and public holidays

mostly being undertaken at Evans Head during winter and spring holiday periods (Fig. 2).

Relationships between patterns of use and environmental variable

GLM analysis found that participation in all categories (sunbathing, swimming, walking, surfing and fishing) varied significantly among beaches (Table 2). Wind direction was significantly related to participation in sunbathing and swimming, with greater participation during on-shore wind conditions (wind moving from the sea towards land, Table 2). Wind speed had a significantly negative influence on surfing participation (Table 2), reducing surfing numbers with increased wind speed. Air temperature had a significantly positive relationship to participation in sunbathing and swimming, but had a significantly negative influence on the number of surfers (Table 2). Humidity was significantly negatively associated with participation in sunbathing and swimming (Table 2). Sea state was negatively related to the participation in surfers (Table 2), with lower sea state rating indicating flatter conditions, and as sea states increased the conditions become rougher with more wind chop (less favourable for surfing). Cloud cover had a significantly negative association with beach walkers, displaying a

Table 2 Results from Generalized Linear Model analysis, displaying the effect of predictor variables on the participation in different beach user categories.

Predictor	df	Sunbathing	Walking	Swimming	Surfing	Fishing
Beach location	3	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**	**< 0.001**
Wind direction	1	**< 0.01**	0.95	**< 0.01**	0.21	0.3
Wind speed	1	0.12	0.66	0.84	**< 0.05**	0.51
Air temperature	1	**< 0.001**	0.08	**< 0.001**	**< 0.05**	0.09
Humidity	1	**< 0.01**	0.33	**< 0.001**	0.22	0.09
Sea-state	1	0.32	0.43	0.19	**< 0.05**	0.94
Cloud cover	1	0.53	**< 0.001**	0.06	0.99	0.29
Surf rating	1	0.78	0.10	0.38	0.89	0.56
Water temperature	1	**< 0.05**	0.16	0.18	0.52	0.18

Significant variables are in bold and represent a variable that influenced the participation in these activities preference for walking during days that were finer (less clouds). Water temperature was related negatively with the number of sunbathers. No environmental variables were found to affect participation in fishing (Table 2).

Discussion

Beaches are important assets and require management based on a sound understanding of unique beach characteristics including patterns of use (Brown and Hausner 2017; James 2000). In the present study, the capacity for aerial drones to undertake cost-effective quantification of beach usage was demonstrated. Generally, participation in walking, surfing and fishing was similar throughout the sampling periods, however, during warmer periods there was significantly more participation in sunbathing and swimming. Despite similarities in general patterns of usage among seasons, we found that attendance at each location and period sampled tended to be unique. These results demonstrate that while sampling of random locations is probably adequate to inform planning at a regional scale, the collection of data at individual beaches is required to develop effective site-specific beach management strategies.

Despite the differences in levels of beach use among sites (i.e. higher attendance at Byron Bay), general seasonal patterns were still apparent and are common for beaches globally (e.g. Dwight et al. 2007; Guillén et al. 2008; Ibarra 2011). The pattern of increased attendance during the spring and summer period was driven in this study by greater participation in sunbathing and swimming. Environmental conditions commonly experienced during these warmer seasons, increased air temperature and on-shore wind, were found to be significant influences on the participation in these user groups. At all locations, the seasonal increase in attendance was accompanied by the provision of Surf Lifesaver flagged areas. For regional based planning of beach services, sampling several random beaches is probably adequate to assess the general patterns of use in beaches within management areas.

Visitor numbers can be a good indicator of beach attendance, as tourists travel to coastal areas with the intention to use beach habitats (Zhang et al. 2015). Byron Bay experienced more usage than the other beaches sampled, probably due to its popularity as a tourist location (Wray et al. 2010). Visitor statistics shows Byron Bay shire (includes, Byron Bay beach; total day visitors ~4 million) receives substantially more visitors compared to Ballina shire (includes Ballina, Evans and Lennox Head beaches; total day visitors ~1.4 million), which likely contributed to the higher beach attendance found in this study. Although visitor statistics can guide managers on the expected attendance within a local government area, they do not provide insight into the distribution of people and beach usage within the areas. This study demonstrates that drones can be used to effectively collect this type of data, which can then be used by management authorities to better manage services. For example, drones documented most swimmers at Byron Bay outside of the flagged areas (~260% more swimmers outside flags) suggesting that more services such as education or lifesavers may be required.

Higher beach attendance on weekends is well documented in the primary literature (Dwight et al. 2007; Guillén et al. 2008). In contrast, we did not observe peak attendance during weekends, most likely as a result of surveys occurring exclusively during holiday periods (Blackweir and Beckley 2004). This study indicates when sampling during holiday periods, day of week is not an important factor. Further, the study suggests for the daily management of these beaches during holiday periods, similar levels of services should be provided at these beaches. This may have implications for the management arrangements currently implemented in these areas during holiday periods.

Although surfing was a popular activity year-round, participation was highest when air temperature and sea states were lowest, typically experienced during winter when surfing conditions are often of higher quality (Espejo et al. 2014; Scott and Rogers 2018; Tauro et al. 2016). Surfing was more popular at Lennox Head and Byron Bay, which are both marketed as quality surf destinations, and Lennox Head being an important cultural site for Australian surfing (Orchard 2017). Participation at Ballina may have been lower than expected due to community concerns surrounding recent shark-human interactions in the area (Hannam 2017). The relatively high participation in surfing occurred during the winter holiday period, when lifesaving services are not operating (Attard et al. 2015). While the need for lifesaver assistance for surfers is less than swimmers (see Surf Life Saving New South Wales 2017), other risks may require consideration (i.e. shark mitigation strategies, water quality monitoring) when planning seasonal beach services at locations popular for surfing.

While drones were effective for quantifying and classifying users on the beach and in the water, they could also be used to add detail to current webcam based methods of beach monitoring. Using webcam techniques to quantify beach attendance is common because it is cost-effective (Guillén et al. 2008), but can lack detail when assessing beach attendance, generally categorising attendance as low, medium or high (Balouin et al. 2014; Guillén et al. 2008). Due to automated counting techniques focused on pre-defined sections of the beach, these techniques do not categorise attendees into discrete user groups, and are unable to quantify swimmers (Zhang and Wang 2013; Balouin et al. 2014). This limitation may lead to: an underestimation of beach attendance rates; more challenging user-based management; and inadequate provision of services (King and McGregor 2012).

Drones can provide rapid and detailed quantification of beach usage, and easily survey multiple beaches simultaneously allowing for real comparisons of usage between locations. Compared to webcams, which requires installation, maintenance and provide data only at a specific location, drones are mobile and can sample any beach of interest with little setup and without the need for a permanent structure. Further improvements for utilising drones could arise from the use of ground control points or RTK GPS allowing for geographic information system and mapping applications (Agüera-Vega et al. 2017), predetermined flight paths and autonomous operations. Autonomous flights and the development of automatic analysis of images would allow for large amounts of data to be collected and analysed quickly. Further, drones can undertake additional tasks, such as assisting with search and rescue (Claesson et al. 2017), shark detection (Colefax et al. 2018) and monitoring morphological change (Gonçalves and Henriques 2015). Consequentially, drones are likely to be a valuable addition to the coastal manager's toolbox in coming years.

In conclusion, drones provided a rapid assessment of beach habitats and their usage in high resolution. The drone surveys clearly highlight that beach usage patterns vary among popular beaches and holiday periods, suggesting that locally adapted beach management strategies may be required. While drone surveys detected well known patterns of beach use (e.g. such as increased beach use during warmer seasons), they also revealed less obvious patterns, such as the lack of difference in usage between weekends and weekdays during holiday periods. Such detailed information provides a strong basis for delivering effective evidence-based management strategies to minimise impacts and maximise the experience of beach users (e.g. safety, recreational facilities). Overall, we contend that drone technology can provide management with a rapid and cost-effective assessment tool to assist in decision making, and inform management on spatial and temporal habitat use.

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Compliance with ethical standards

Ethics NSW DPI ACEC Proposal 16/09 – Coastal aerial surveys.

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References

Agüera-Vega F, Carvajal-Ramírez F, Martínez-Carricondo P (2017) Assessment of photogrammetric mapping accuracy based on variation ground control points number using unmanned aerial vehicle. Measurement 98:221–227 http://www.sciencedirect.com/science/article/pii/S026322411630700X

Alexandrakis G, Manasakis C, Kampanis NA (2015) Ocean & Coastal Management Valuating the effects of beach Erosion to tourism revenue. A management perspective. Ocean Coast Manag 111: 1–11. https://doi.org/10.1016/j.ocecoaman.2015.04.001

Anderson K, Gaston KJ (2013) Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Front Ecol Environ 11(3):138–146

Anderson M, Gorley R, Clarke K (2008) PERMANOVA+ for PRIMER: guide to software and statistical methods. Plymouth, UK.

Anweiler S, Piwowarski D (2017) Multicopter platform prototype for environmental monitoring. J Clean Prod 155:204–211

Attard A, Brander RW, Shaw WS (2015) Rescues conducted by surfers on Australian beaches. Accid Anal Prev 82:70–78. https://doi.org/10.1016/j.aap.2015.05.017

Balouin Y, Rey-Valette H, Picand PA (2014) Automatic assessment and analysis of beach attendance using video images at the lido of Sète Beach, France. Ocean Coast Manag 102(PA):114–122. https://doi.org/10.1016/j.ocecoaman.2014.09.006

Barbieri C, Sotomayor S (2013) Surf travel behavior and destination preferences : an application of the serious leisure inventory and measure. Tour Manag 35:111–121. https://doi.org/10.1016/j.tourman.2012.06.005

Blackweir DG, Beckley LE (2004) "Beach usage patterns along the Perth metropolitan coastline during shark surveillance flights in summer 2003 / 04." (December 2003)

Botero CM, Anfuso G, Milanes C, Cabrera A, Casas G, Pranzini E, Williams AT (2017) Litter assessment on 99 Cuban beaches: a baseline to identify sources of pollution and impacts for tourism and recreation. Mar Pollut Bull 118(1–2):437–441. https://doi.org/10.1016/j.marpolbul.2017.02.061

Brown G, Hausner VH (2017) An empirical analysis of cultural ecosystem values in coastal landscapes. Ocean Coast Manag 142:49–60 http://www.sciencedirect.com/science/article/pii/S0964569117302831

Casella E, Collin A, Harris D, Ferse S, Bejarano S, Parravicini V, … Rovere A (2017) Mapping coral reefs using consumer-grade drones and structure from motion photogrammetry techniques. Coral Reefs 36(1):269–275

Chabot D (2018) Trends in drone research and applications as the journal of unmanned vehicle systems turns five. J Unmanned Vehicle Systems 6(1):vi–xv. https://doi.org/10.1139/juvs-2018-0005

Chapman A (2014) It's okay to call them drones. J Unmanned Vehicle Systems 02(02):iii–iiv. https://doi.org/10.1139/juvs-2014-0009

Chapman BK, Mcphee D (2016) Ocean & Coastal Management Global Shark Attack Hotspots : identifying underlying factors behind increased unprovoked shark bite incidence. Ocean Coast Manag 133: 72–84. https://doi.org/10.1016/j.ocecoaman.2016.09.010

Chen CL, Teng N (2016) Management priorities and carrying capacity at a high-Use Beach from tourists' perspectives: a way towards Sustainable Beach tourism. Mar Policy 74(June):213–219. https://doi.org/10.1016/j.marpol.2016.09.030

Claesson A, Svensson L, Nordberg P, Ringh M, Rosenqvist M, Djarv T, Samuelsson J, Hernborg O, Dahlbom P, Jansson A, Hollenberg J (2017) Drones may be used to save lives in out of hospital cardiac arrest due to drowning. Resuscitation 114:152–156. https://doi.org/10.1016/j.resuscitation.2017.01.003

Colefax AP, Butcher PA, Kelaher BP (2018) The potential for unmanned aerial vehicles (UAVs) to conduct marine Fauna surveys in place of manned aircraft. ICES J Mar Sci 75(1):1–8. https://academic.oup.com/icesjms/article-lookup/. https://doi.org/10.1093/icesjms/fsx100

Di Felice F, Mazzini A, Di Stefano G, Romeo G (2018) Drone high resolution infrared imaging of the Lusi mud eruption. Mar Pet Geol 90(December 2016):38–51 http://www.sciencedirect.com/science/article/pii/S0264817217304269

Dwight RH, Brinks MV, SharavanaKumar G, Semenza JC (2007) Beach attendance and bathing rates for Southern California beaches. Ocean Coast Manag 50(10):847–858

Dwight RH, Catlin SN, Fernandez LM (2012) Amounts and distribution of Recreational Beach expenditures in Southern California. Ocean Coast Manag 59:13–19. https://doi.org/10.1016/j.ocecoaman.2011.12.010

Espejo A, Losada IJ, Méndez FJ (2014) Surfing wave climate variability. Glob Planet Chang 121:19–25 http://www.sciencedirect.com/science/article/pii/S0921818114001192

Goebel ME, Perryman WL, Hinke JT, Krause DJ, Hann NA, Gardner S, LeRoi DJ (2015) A small unmanned aerial system for estimating abundance and size of Antarctic predators. Polar Biology 38 (5): 619-630

Gonçalves JA, Henriques R (2015) UAV photogrammetry for topographic monitoring of coastal areas. ISPRS J Photogramm Remote Sens 104: 101–111. http://www.sciencedirect.com.ezproxy.scu.edu.au/science/article/pii/S0924271615000532 . Accessed (November 10, 2017)

González SA, Holtmann-Ahumada G (2017) Quality of tourist beaches of northern Chile: a first approach for ecosystem-based management. Ocean Coast Manag 137:154–164 http://www.sciencedirect.com/science/article/pii/S0964569116304653

Guillén, J, García-Olivares A, Ojeda E, Osorio A, Chic O, González R (2008) Long-term quantification of beach users using video monitoring. J Coast Res 246:1612–1619. http://www.jcronline.org . https://doi.org/10.2112/07-0886.1

Hannam P (2017) "Shark nets: Ballina surfers Back in water after confidence-boosting six-month trial." https://www.smh.com.au/environment/conservation/shark-nets-ballina-surfers-back-in-water-after-confidenceboosting-sixmonth-trial-20170428-gvuqhb.html . Accessed: 16/07/2018

Hodgson A, Kelly N, Peel D (2013) Unmanned aerial vehicles (UAVs) for surveying marine Fauna: a Dugong case study. PLoS One 8(11): 1–15

Huamantinco CMA, Revollo SNV, Delrieux CA, Piccolo MC, Perillo GME (2016).Beach carrying capacity assessment through image processing tools for coastal management. Ocean Coast Manag 130:138–147 http://linkinghub.elsevier.com/retrieve/pii/S0964569116301193

Ibarra EM (2011) The use of webcam images to determine tourist-climate aptitude: Favourable weather types for sun and beach tourism on the Alicante coast (Spain). Int J Biometeorol 55:373–385

James RJ (2000) From beaches to beach environments: linking the ecology, human-use and Management of Beaches in Australia. Ocean Coast Manag 43(6):495–514

Jiménez López J, Mulero-Pázmány M (2019) Drones for conservation in protected areas: present and future. Drones 3(1):10

Jiménez JA, Osorio A, Marino-Tapia I, Davidson M, Medina R, Kroon A, Archetti R, Ciavola P, Aarnikhof SGJ (2007) Beach recreation planning using video-derived coastal state indicators. Coast Eng 54(6–7):507–521

Juhasz A, Ho E, Bender E, Fong P (2010) Does use of tropical beaches by tourists and island residents result in damage to fringing coral reefs? A case study in Moorea French Polynesia. Mar Pollut Bull 60(12): 2251–2256. https://doi.org/10.1016/j.marpolbul.2010.08.011

Kelaher BP, Colefax AP, Tagliafico A, Bishop MJ, Giles A, Butcher PA (2019) Assessing variation in assemblages of large marine Fauna off ocean beaches using drones. Mar Freshw Res

King P, McGregor A (2012) Who's counting: an analysis of beach attendance estimates and methodologies in Southern California. Ocean Coast Manag 58:17–25. https://doi.org/10.1016/j.ocecoaman.2011.12.005

Konar B, Iken K (2018) The use of unmanned aerial vehicle imagery in intertidal monitoring. Deep-Sea Research Part II: Topical Studies in Oceanography 147(April 2017):79–86. https://doi.org/10.1016/j.dsr2.2017.04.010

Lucrezi S, Saayman M, Van der Merwe P (2016) An assessment tool for Sandy beaches: a case study for Integrating Beach description, human dimension, and economic factors to identify priority management issues. Ocean Coast Manag 121(1–22):1–22. https://doi.org/10.1016/j.ocecoaman.2015.12.003

Maguire GS, Miller KK, Weston MA, Young K (2011) Being beside the seaside: beach use and preferences among coastal residents of south-eastern Australia. Ocean Coast Manag 54(10):781–788. https://doi.org/10.1016/j.ocecoaman.2011.07.012

Martin C, Parkes S, Zhang Q, Zhang X, McCabe MF, Duarte CM (2018) Use of unmanned aerial vehicles for Efficient Beach litter monitoring. Mar Pollut Bull 131(April):662–673. https://doi.org/10.1016/j.marpolbul.2018.04.045

McKay C, Brander RW, Goff J (2014) Putting tourists in harms way - coastal tourist parks and hazardous unpatrolled surf beaches in New South Wales, Australia. Tour Manag 45:71–84. https://doi.org/10.1016/j.tourman.2014.03.007

Nishar A, Richards S, Breen D, Robertson J, Breen B (2016) Thermal infrared imaging of geothermal environments and by an unmanned aerial vehicle (UAV): a case study of the Wairakei - Tauhara geothermal field, Taupo, New Zealand. Renew Energy 86:1256–1264. https://doi.org/10.1016/j.renene.2015.09.042

Nyman E (2019) Techno-optimism and ocean governance: new trends in maritime monitoring. Mar Policy 99(September 2018):30–33 https://linkinghub.elsevier.com/retrieve/pii/S0308597X18303750

Orchard S (2017) Lessons for the Design of Surf Resource Protection – the Australasian experience. Ocean Coast Manag 148:104–112 http://www.sciencedirect.com/science/article/pii/S0964569117301783

Papageorgiou M (2016) Ocean & Coastal Management Coastal and marine tourism : a challenging factor in marine spatial planning. Ocean Coast Manag 129:44–48. https://doi.org/10.1016/j.ocecoaman.2016.05.006

Pérez-Maqueo O, Martínez ML, Nahuacatl RC (2017). "Is the protection of beach and dune vegetation compatible with tourism?" Tour Manag 58: 175–183. http://www.sciencedirect.com/science/article/pii/S0261517716301972 . Accessed (November 6, 2017)

R Development Core Team (2008) "R: A Language and Environment for Statistical Computing"

Scott SQ, Rogers SH (2018) Surf's up? How does water quality risk impact surfer decisions? Ocean Coast Manag 151(October 2017): 53–60. https://doi.org/10.1016/j.ocecoaman.2017.10.025

Semeoshenkova V, Newton A (2015) Overview of Erosion and beach quality issues in three southern European countries: Portugal, Spain and Italy. Ocean Coast Manag 118:12–21. https://doi.org/10.1016/j.ocecoaman.2015.08.013

Semeoshenkova V, Newton A, Contin A, Greggio N (2017) Development and application of an Integrated Beach quality index (BQI). Ocean Coast Manag 143:74–86. https://doi.org/10.1016/j.ocecoaman.2016.08.013

Surf Life Saving New South Wales (2017) New South Wales coastal safety report 2017. SLSNSW: Sydney

Tauro F, Porfiri M, Grimaldi S (2016) Surface flow measurements from drones. J Hydrol 540:240–245. https://doi.org/10.1016/j.jhydrol.2016.06.012

Turner IL, Harley MD, Drummond CD (2016) UAVs for coastal surveying. Coast Eng 114:19–24. https://doi.org/10.1016/j.coastaleng.2016.03.011

Ventura D, Bruno M, Lasinio GJ, Belluscio A, Ardizzone G (2016) A low-cost drone based application for identifying and mapping of coastal fish nursery grounds. Estuar Coast Shelf Sci 171:85–98. https://doi.org/10.1016/j.ecss.2016.01.030

Warton NM, Brander RW (2017) Improving Tourist Beach safety awareness : the benefits of watching Bondi rescue. Tour Manag 63:187–200. https://doi.org/10.1016/j.tourman.2017.06.017

Wray M, Laing J, Voigt C (2010) Byron Bay: an alternate health and wellness destination. J Hosp Tour Manag 17(1):158–166 http://www.sciencedirect.com/science/article/pii/S1447677000000759

Zhang F, Wang XH (2013) Assessing preferences of beach users for certain aspects of weather and ocean conditions: case studies from Australia. Int J Biometeorol 57(3):337–347

Zhang F, Wang XH, Nunes PALDLD, Ma C (2015) The recreational value of Gold Coast beaches, Australia: an application of the travel cost method. Ecosystem Services 11:106–114. https://doi.org/10.1016/j.ecoser.2014.09.001

Zuur AF, Ieno EN (2016) A protocol for conducting and presenting results of regression-type analyses. Methods Ecol Evol 7(6):636–645. https://doi.org/10.1111/2041-210X.12577

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