VEHICLE-BASED RECREATION AND COMPLIANCE FOR THREE BEACHES IN NORTHERN NEW SOUTH WALES

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ABSTRACT

Vehicles can be a serious vector for human recreation disturbance to beach-nesting birds because they enable people, often with their dogs, to disperse over greater distances than they would typically walk. The objective of this study was to quantify vehicle-based recreation and compliance with regulations and codes of conduct for Seven Mile (Lennox Head), South Ballina and Airforce (Evans Head) beaches, N New South Wales, Australia. South Ballina and Airforce supported remnant beach-nesting Australian pied oystercatcher *Haematopus longirostris* populations. Vehicle-based recreation and compliance varied among beaches. The most frequent activities observed were picnics (31–50%), driving (14–30%) and fishing (5–16%). Picnics can be intensely disturbing for beach-nesting birds because they typically occur on the super-tidal zone and are long-duration events. Compliance was high for beach driving zones and driving below the high tide limit but variable for speed limits (33–79%) and dog zones (6–100%). The Discussion argues that regulations and codes of conduct are not effective for managing the social and environmental impacts of beach driving if they do not limit the numbers of vehicles.

INTRODUCTION

Australia has a hedonistic beach culture that values beaches as ‘playgrounds’ and includes driving on the beach (James 2000). Growing human populations, increased four-wheel-drive (4WD) ownership and more capable 4WD technology can increase vehicle-based recreation pressures on beaches. Intense vehicle-based recreation can result in negative social and environmental impacts.

For shorebirds, it’s not vehicles that are the problem *per se* but also the people and their dogs. BirdLife Australia (2018) have stated that the greatest conservation threat to beach-nesting birds is disturbance from people visiting the beach. Vehicles can be a serious vector for human recreation disturbance because they enable people, often with their dogs, to disperse over greater distances than they would typically walk.

Evidence for vehicle-based recreation impacts on beach-resident oystercatchers in Australia includes: vehicle-strike mortalities and lowered survival (Harrison 2009, Totterman 2020a), a long-term decline in oystercatcher counts on 75 Mile Beach, Fraser Island, Queensland (Fisher *et al.* 1998, Totterman 2020b) and near zero oystercatcher breeding success on Stockton Beach, New South Wales (NSW) (Russell & George 2012). Totterman (2020a)

reviewed 21 years of oystercatcher conservation data from the Richmond River area, N NSW and contrasted the negative breeding population size trend and lower breeding success for South Ballina Beach, where public beach driving was allowed, with the positive trend and higher success for Bombing Range Beach, which was closed to the public. Internationally, Williams *et al.* (2004) also reported evidence for population impacts where breeding pair counts and breeding success for five species (two shorebirds, two terns and a cormorant) increased after beach driving was banned in South Africa in 2001.

To paraphrase Manfredo and Dayer (2004), it is the thoughts and actions of land managers that ultimately determine the course and resolution (if any) of human-wildlife conflicts. The prevalence of beach driving along the E Australian coast indicates that management authorities have prioritised social and political interests in maintaining the *status quo* for 4WD access. Then, they pretend that they can manage the impacts of vehicle-based recreation with regulations, codes of conduct and occasional enforcement. However, evidence is accumulating that ‘pro-environmental’ behaviour is uncommon on beaches and that compliance with rules is low (e.g. Weston *et al.* 2014, Maguire *et al.* 2019).

This study doesn’t concern beach-nesting birds directly. Instead, the objectives of this study were to quantify vehicle-based recreation and non-compliance for three beaches in N NSW for land managers and conservationists to better understand the problem.

METHODS

Study sites

Vehicle-based recreation was studied on three beaches in the Richmond River Area, N NSW, during Oct–Dec 2020 (Figure 1). Seven Mile is an 8.4 km long semi-urban beach, South Ballina is a 23 km long rural beach and Airforce is a 5.8 km long semi-urban beach (Table 1). The ‘coffee rocks’ interval between Airforce and South Ballina was not included because it is often impassable to 4WDs.

South Ballina and ‘Broadwater Beach’ (which was defined for management purposes as the coast from Boundary Creek south to Evans Head; Figure 1) are Key Management Sites for the Endangered in NSW Australian Pied Oystercatcher *Haematopus longirostris* (NSW Government 2016, NSW Department of Planning, Industry and Environment 2019).

Observations

Beaches were visited on weekends, during fine weather and at low tide. Many people have time for recreation on weekends, fine weather encourages outdoor recreation and the firm intertidal zone sand at low tide suits beach driving. There were no school holidays during the study. The Covid-19 pandemic was ongoing, however the NSW-Queensland border was open.

Beaches were visited once per day. Separate activity and speed passes were made on each visit. A 4WD was driven along the entire length of 4WD zones. When others were spotted

outside of 4WD zones, those sections were covered with a bicycle. Groups of 4WDs (*e.g.* a picnic or a convoy) were recorded as one observation, to avoid pseudoreplication. Any management and enforcement 4WDs and professional fishers present were not recreational 4WDs and were not recorded. 4WDs arriving or leaving the beach via official access tracks were also not recorded (4WDs on informal tracks through the dunes were classified as dune driving).

The objective of the activity pass was to record a ‘snapshot’ of 4WD locations and activities. Activities were recorded while driving along the beach quickly (≥ 30 km/h), slowing down in crowded areas and when recording observations but avoiding stopping. Observations were recorded to a voice log (on a smart phone) and video recordings were made for reference (mini digital video camera mounted on the left or right door mirror, when driving N or S respectively). Data recorded for each activity observation were date, time (Australian Eastern Standard Time (AEST), *i.e.* without daylight saving), location (using a Garmin GPSmap 62s Global Positioning System (GPS) satellite receiver), count of 4WDs in a group (driving 4WDs were counted as a convoy if approximately < 10 s apart, which is equal to a 83 m gap at 30 km/h), registration plate State (majority if $> two$ 4WDs; a coin was flipped to select one if there were equal numbers of different States; plates that were not visible were recorded as NA), tidal zone on which the 4WDs were observed (swash, which moves up and down the beach face with the tide; intertidal, to the high tide mark (drift line); supertidal, to the base of the front dune or vegetation line, and; dunes), recreational activity (Table 2) and counts of people and dogs outside the 4WDs. Areas of coffee rock above the high tide limit were classified as supertidal because they underlie the dunes. The Salty Lagoon inlet was closed and the northern side was classified as dune because it was distant from the high tide limit with some vegetated patches between. Voice logs and video recordings were merged in video editing software and data were transcribed from those records. The activity sample size objective was 100 to allow reasonably precise estimates of activity frequencies (resolution = $1/100 = 1$ per cent).

The objectives of the speed pass were to record the speeds of driving 4WDs and count oystercatchers; this required frequent stopping. Speed observations were recorded to a voice log only. Data recorded for each speed observation were date, time, GPS location, count of 4WDs in a group, registration plate State, tidal zone on which the 4WDs were driving, whether the 4WDs were passing any people or shorebirds on the same tidal zone and speed (with a Bushnell Velocity radar gun). The radar gun performance specification was 16–320 km/h for a car at 457 m. Speeds < 16 km/h were recorded as 8 km/h (the midpoint of 0–16). For 4WDs in convoy, the speed of the leading or tailing 4WD was recorded, whichever was convenient to measure. Radar speed measurements are affected by ‘cosine error’: when the observer is not directly in line with the moving object, the measured speed is less than the actual speed. Measurements were usually made at distances of some hundreds of metres to avoid alerting drivers and to reduce cosine error. The speed sample size objective was 50 to allow reasonably precise estimates of mean speed ($SE = s/\sqrt{n}$).

‘Adult’-plumage oystercatchers were counted including second immature plumage attained at approximately one year old, which looks the same without close inspection (Marchant & Higgins 1993). Birds outside of 4WD zones were not counted. Other data recorded on the beach were the GPS locations of 4WD access points, 4WD and dog zone limits and Broadwater National Park and Richmond River Nature Reserve boundaries. Weather observations were obtained from the Australian Bureau of Meteorology, Ballina Airport AWS (station 058198) (<http://www.bom.gov.au/climate/data/index.shtml>). Morning (0900h) or afternoon (1500h) observations were used, whichever were closest to the observation times.

Driving quickly, there were few other 4WDs overtaking the observer, which would inflate the number of driving 4WD observations. However, encounters of 4WDs driving in the opposite direction will decrease towards the end of a pass. To counter this spatial bias, the direction (N/S) of activity and speed passes was alternated between visits (a coin was flipped to choose the direction of the first pass on the first visit).

Data quality control included checking observation times against GPS times, deleting observations where the activity was uncertain (*e.g.* 4WDs just-arrived or about to leave), deleting speed observations where the 4WD was changing speed (*e.g.* slowing to a stop) and reviewing any zero counts of people for non-driving observations. Given that the occupants of a 4WD might exit at some time or that absent persons will return, the few zero counts for people-out were ignored in the analysis.

If 4WD groups act independently (starting from planning their beach trip) and are sampled once per visit, observations within visits are expected to be independent. However, if regular beach users are sampled on multiple visits, those repeated observations (between visits) are expected to be correlated. Activity pass video recordings were reviewed to identify repeated observations of 4WDs (which can be uniquely identified by their make, model, colour scheme, registration plates, accessories and modifications). 377 of a total of 491 4WDs could be identified. Four repeated observations of 4WD groups were deleted at random for Seven Mile and three for Airforce. Two were deleted for South Ballina as well as one extreme observation of 24 4WDs on what appeared to be a 4WD club outing. There were no video recordings for speed passes and, based on the activity pass data, repeated observations were assumed to be negligible for that dataset.

4WD and dog rules were defined by signage at official beach access points (Table 1). The NSW National Parks and Wildlife Service had installed a new sign at South Ballina in mid-2020 which explicitly prohibited driving and parking above the high tide limit in Richmond River Nature Reserve and Broadwater National Park. The purpose of this sign was presumably to discourage dune driving and it was ignored. There had been no known enforcement against 4WDs driving or parking on the supertidal on any of the study beaches. Moreover, prohibiting driving or parking above the high tide limit was not well supported by the legislation. The supertidal zone could be considered to be a ‘road-related area’ as defined in S. 4 of the NSW Roads and Transport Act 2013 (NSW Government 2013) and S. 632 Cl. 2A of the NSW Local Government Act 1993 (NSW Government 1993) does not, in general,

allow Councils to ‘prohibit or regulate the taking of a vehicle into, or the driving, parking or use of any vehicle in, any public place that is a road or road related area within the meaning of section 4 (1) of the Road Transport Act 2013.’

Statistical analysis

Further to the preceding discussion of independent observations, spline correlograms (Bjørnstad & Falck 2001) were computed to check for spatial dependence (spatial autocorrelation) in group sizes and speeds. These correlograms were essentially flat with zero y-intercepts. The weak spatial autocorrelation also indicates that there were no clear spatial trends or patterns for these variables. Temporal autocorrelation was not relevant for ‘snapshot’ observations. Temporal autocorrelation was ignored for total count densities because those time series were short and irregular.

The statistical analysis then focussed on comparisons among beaches. Count models were assumed for count data. Generalised linear models (GLMs) were fitted to total counts:

$$total\ count = 1 \times \log(length) + beach$$

where the coefficient of one for 4WD zone length indicates that it is an offset (*i.e.* $\log(count/length) = \log(count\ density)$). A negative binomial error distribution was assumed for 4WD, people- and dogs-out counts. A poisson distribution was assumed for oystercatcher counts.

There were no zero 4WD counts and few zero people-out counts. Zero-truncated count models were fitted to those data:

$$count = beach$$

A negative binomial error distribution was assumed for 4WD and people-out counts. There were many zero dogs-out counts and a ‘hurdle model’ (Martin *et al.* 2005), with a binomial component for zero counts and a zero-truncated negative-binomial component for positive counts, was fitted. This model separately estimates the probability that dogs are out and then, given that dogs are present, estimates the mean number of dogs.

An ANOVA model was fitted for speeds:

$$speed = beach + class + beach: class$$

where the classes (people/bird/neither) were mutually exclusive because shorebirds generally move away when approached by people and *beach:class* is an interaction term.

Model assumptions were checked using common diagnostic plots and, where relevant, overdispersion estimates. GLM diagnostics used Dunn-Smyth randomised quantile residuals (Dunn & Smyth 1996). Fitted models were compared with null, overall mean models (*i.e.* with no *beach* effect or other predictors) using likelihood ratio tests or, for the ANOVA model, *F*-tests.

Spatial distributions of observations were examined using along-shore distances, zeroed at the southern end of each 4WD zone. The beaches studied are practically straight-lines and Euclidean along-shore distances were calculated from Universal Transverse Mercator (UTM) coordinates. The maximum error for Euclidean 4WD zone lengths (using only the S and N end points), compared to along-shore distances from maps or GPS surveys, was 0.1 km. One sample Kolmogorov-Smirnov tests were used to test uniformity of spatial distributions.

4WD and dog zone compliance was calculated by classifying observations as inside/outside of the respective zones using UTM y coordinates. Speed compliance focussed on the 30 km/h limit and speeds were classified according to NSW speeding offense bands for Class A license (for cars and motorcycles) holders: 0) under the speed limit; 1) 1–10 km/h over; 2) 11–20 km/h over; 3) 21–30 km/h over; 4) 31–45 km/h over, or; 5) >45 km/h over (<https://www.rms.nsw.gov.au/roads/safety-rules/demerits-offences/speeding-offences.html>). Speeds in band one, between 30–39 km/h, were considered to be within the ‘range of discretion’ and not classified as speeding. Speeds ≥ 40 km/h were classified as speeding.

Activities and States are nominal data for which comparisons between beaches used chi-squared tests. Infrequent activities (expected count < 1) were combined to achieve an average expected frequency > 10 (Roscoe & Byars 1971). Chi-squared tests were also used to compare compliance results (instead of more GLMs). Confidence intervals for compliance results (proportions) were estimated using Wilson score intervals (Newcombe 1998).

All statistical analyses were performed using the software R version 3.5-2 (R Core Team 2018). Spline correlograms were computed using *ncf* version 1.2-6 (Bjørnstad 2018). Zero-truncated and hurdle models were fitted with *VGAM* version 1.1.1 (Yee 2015) and *pscl* version 1.5.2 (Zeileis *et al.* 2008). Randomized quantile residuals were computed using *statmod* version 1.4.32 (Dunn & Smyth 1996). Confidence intervals for model coefficients were computed using *emmeans* version 1.5.3 (Lenth 2020). Confidence intervals for proportions were computed using the *prop.test* function without continuity correction. Figures were prepared using *ggplot2* version 3.1.0 (Wickham 2016).

RESULTS

Seven Mile Beach was visited on 12 weekend days, between 24 Oct and 6 Dec 2020, South Ballina Beach on six weekend days, between 25 Oct and 29 Nov and Airforce Beach on 11 weekend days, between 24 Oct and 6 Dec. Final sample sizes (after deleting repeated activity observations) were 105 activity and 52 speed observations for Seven Mile, 105 and 55 for South Ballina and 97 and 55 for Airforce. Weather conditions were mostly fine, with median daily rainfall 1.5 mm (range 0–8.8), mean temperature 26 °C (range 21–30), median cloud cover 0/8 (range 0–8), mean wind speed 19 km/h (range 9–31) and the most frequent wind direction was N–NE. Observations occurred broadly through the middle of the day (median 1129h AEST, interquartile range 0906–1359).

Seven Mile, the shortest beach, had the highest mean 4WD, people- and dogs-out total count densities (3.4, 7.4 and 1.5 /km respectively), although counts were variable and sample sizes

were small (Figures 2a–c). South Ballina and Airforce, where there are established oystercatcher breeding populations, had the highest mean oystercatcher count densities (1.7 and 1.4 /km respectively) (Figure 2d).

South Ballina had larger mean 4WD and people-out counts per observation (1.8 and 5.4 respectively) than did Seven Mile (1.3 and 3.4) and Airforce (1.4 and 3.3) (Figure 3). However, mean dogs-out was similar for all three beaches (overall mean 1.5, 95% CI 1.2–2.6) as were proportions of positive counts (overall 31%, 95% CI 26–37%).

Vehicle-based recreation was dispersed along 4WD zones on all three beaches (Figure 4). Spatial distributions for 4WDs and people-out were approximately uniform for Airforce (Figures 4c1,2) but the distribution of dogs-out was skewed towards the dog zone (Figure 4c3). Dogs-out were widespread along South Ballina even though the dog zone was only 500 m N and S of the Patch’s Beach access (Figure 4b3).

Picnics, swimming and playing were more frequent for Seven Mile (combined 65%) compared to South Ballina and Airforce (53 and 43% respectively) (Figure 5a). Driving and fishing were more frequent for South Ballina and Airforce (combined 42 and 46% respectively) compared to Seven Mile (19%). NSW registration plates were most frequent on Seven Mile (73%) and Airforce (71%), while South Ballina was popular with Queenslanders (52%) (Figure 5b). There were Victorians and others in a few observations but they were outnumbered by NSW and Queensland plates.

Mean speeds were higher for South Ballina and Airforce (45 and 41 km/h respectively) than for Seven Mile (33), where there often were high count densities of walkers and dogs on the intertidal zone (Figure 6). Mean speeds within-beaches were not substantially slower near people or shorebirds (Table 3) although speeds near people were less variable for Airforce (Figure 6c). The relevant 15 km/h speed limit was almost completely ignored.

4WD zone compliance was high for all beaches (range 93–100%; Figure 7). However, unobserved non-compliance was evident from wheel tracks north of the 4WD zones on Seven Mile and South Ballina. Tidal zone compliance was also high (overall 88%, 95% CI 78–93) however parking above the busy intertidal zone was common (overall 79%, $n = 234$, 95% CI 74–84). Following from mean speed results, speed compliance was lower for South Ballina (33%) and Airforce (49%) than for Seven Mile (79%). Following from spatial distributions results, dog zone compliance was very low for South Ballina (6%), moderate for Airforce (65%) and high for Seven Mile (100%).

DISCUSSION

This study accumulated observations from three beaches on multiple weekend days in a six week period. Reasons for the small number of repeated observations could be that observation passes were fast and regular beach drivers did not stay for long, the population of beach drivers was large and many 4WDs were weekend visitors. Observations occurred broadly through the middle of the day and it is suggested that the data were reasonably

representative of early-summer, weekend, low-tide 4WD activity on Seven Mile, South Ballina and Airforce beaches. There was substantial variation among beaches and readers are cautioned not to overgeneralise the results of this study. Rather, it is recommended that similar studies be performed for other beaches.

Observed characteristics of vehicle-based recreation for Seven Mile included: a short 4WD zone, higher densities of 4WDs compared to the other two beaches, mostly NSW registration plates, smaller 4WD group sizes, mostly passive recreation activities (picnics, sunbathing, swimming and playing), lower speeds and high compliance with beach driving and dogs rules. High count densities of walkers and dogs were observed towards the southern end of the 4WD zone. It is suggested that many of the 4WDs on Seven Mile drive to access less-crowded areas along the beach. Compliance with beach driving and dogs rules was high because responsible drivers reduce speed in areas of high pedestrian activity and because the dog zone completely overlapped the 4WD zone

Characteristics of vehicle-based recreation for South Ballina included: a long 4WD zone, lower densities of 4WDs (but high total counts over the beach length), mostly QLD plates, larger 4WD group sizes, a mix of passive and active recreation activities (picnics, driving and fishing), higher speeds and low compliance with beach driving and dogs rules. It is suggested that many of the 4WDs on South Ballina were visitors, who come to enjoy the freedom and adventure and that they plan their visits together with other 4WD owners. Compliance was low because the beach was not crowded, signage was inadequate (for dog rules especially) and enforcement patrols have been rare (pers. obs.). Two additional and common non-compliant activities were dune driving and camping in the back dunes. However, only 4WDs visible from the beach were recorded in this study.

Characteristics of vehicle-based recreation for Airforce included: a short 4WD zone, intermediate densities of 4WDs, mostly NSW registration plates, smaller 4WD group sizes, a mix of passive and active recreation activities (picnics, driving, fishing and swimming), higher speeds and moderate compliance with beach driving and dogs rules. Beach walkers were few, even though the dog zone was mostly within the 4WD zone. It is suggested that many people preferred to drive onto the beach with their dogs rather than walk.

Vehicles are serious vectors of human recreation disturbance. 4WDs were dispersed along 4WD zones on all three beaches. Mean along-shore distances of 2.0–7.7 km (note that distances on Seven Mile were limited by the short 3.3 km 4WD zone length) were at least twice the mean 0.8 km for beach walkers and dog walkers combined in Totterman (2019b). Mean counts of 3.3–5.4 people/group were at least twice the mean 1.4 persons/group for non-driving beach users in Totterman (2019b). The mean 1.5 dogs/group was similar to 1.4 dogs/group in Totterman (2019b). Also, the 31% of non-driving observations with dogs was similar to 27% in Totterman (2019b). The 31–50% frequency of picnics was at least six times the 5% for non-driving beach users in Totterman (2019b). Picnics can be intensely disturbing for beach-nesting birds because they typically occur on the supertidal zone, closer to nesting habitat, and are long-duration events.

Reasons for low compliance with beach driving and dogs rules can include: impracticable rules, socially unacceptable rules, driver ignorance, prevailing driver behaviour and a lack of enforcement (Schlacher *et al.* 2013). The northern two km of South Ballina had been closed to 4WDs for about two decades, there was adequate signage on the beach and yet 7% of activity observations were from this zone, including picnics. It is suggested that these drivers ignored the signs because they knew that the enforcement risk was low.

High tidal zone compliance (overall 88%) was expected for observations made around low tide. However, Schlacher and Thompson (2007) reported, for beaches in SE Queensland, that beach traffic was highest between the late-morning to mid-afternoon and not always synchronous with low tide. Between 16–67% of 4WDs in that study were driving on the supertidal. Tidal zone rules are impracticable and, as noted in the Methods, may also be unenforceable.

Speed compliance was lower for the longer and less crowded South Ballina and Airforce beaches (33 and 49% respectively). Regular patrols of Airforce by the NSW Police (pers. obs.) had evidently done little to change driver behaviour on that beach. Mean speeds were not substantially lower when passing shorebirds. Weston *et al.* (2014) similarly reported, for beaches in SE Queensland, that 66% of individual drivers did not slow down and/or change course near shorebirds and evasive actions for the other drivers were modest and ineffective in reducing disturbance. It is suggested that the 30 and 15 km/h speed limits were not compatible with prevailing driver behaviour and were socially unacceptable. Schlacher *et al.* (2013) suggested that large setback distances (> 25 m) and low speeds (< 30 km/h) could reduce disturbance to shorebirds but also recognised that these targets would result in very low compliance. Petch *et al.* (2018) surveyed beach drivers in South Australia and found that recreation was more important to those people than protection of wildlife and their habitats.

Dog zone compliance was higher for beaches with relatively long dog zones. The 4.4 km long dog zone for Seven Mile overlapped the entire 3.3 km 4WD zone and dog zone compliance was 100% for that beach. The 1.0 km long dog zone for South Ballina was short relative to the 21.0 km 4WD zone length and compliance was 6%. Enforcement patrols by Richmond Valley Council Rangers for Airforce had been regular (pers. obs.) yet dog zone compliance was 65% for that beach. It is suggested that rules for dogs on beaches are socially unacceptable (also see Guinness *et al.* 2020).

Beach driving and dogs rules cannot be effective in controlling social and environmental impacts if they do not limit numbers of 4WDs. Rules can be designed to suit the interests of drivers and dog owners, *e.g.* the ‘dog friendly’ Seven Mile Beach. Rules could also be relaxed to improve compliance (‘shifting the goal posts’), *e.g.* higher speed limits. Beach driving permits have not been used to limit numbers of 4WDs on beaches along the E Australian coast, rather they have encouraged the commercialisation of beach driving, *e.g.* Fraser Island and Teewah (Cooloola), Queensland, and Stockton and Nine Mile (Belmont), NSW (Totterman 2020).

Land managers need to balance human recreation and social and environmental impacts and it would be prudent for the authorities to prohibit beach driving where there is evidence for serious impacts (Celliers *et al.* 2004). It is not acceptable to allow beach driving within Key Management Sites for threatened beach-nesting birds. Drivers will defend the privilege to drive on the beach and to bring their dogs. They commonly argue that individually they have minimal impacts (pers. obs.). They are correct, although their individual concerns are selfish and ignore the ‘tragedy of the commons’ that results from the combined impacts of numerous 4WDs.

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447 **Table 1.** Study beaches and 4WD and dog rules from signage at official 4WD beach access points. The 4WD
 448 zone on South Ballina spans two Local Government Areas. Intertidal zone (ITZ) widths are from Totterman
 449 (2019b).

Beach	Seven Mile	South Ballina		Airforce
Length	8.4 km, Lennox Head to Jews Point	23 km, Broadwater Headland to Richmond River	49 m	5.8 km, Evans R. to the 'coffee rocks'
ITZ width	42 m	Ballina	Richmond Valley	56 m
Local Gov. Area	Ballina (S 6.2 km)	Ballina (N 16.9 km)	Richmond Valley (S 6.1 km)	Richmond Valley
4WD permits	Yes	No		No
4WD zone	3.3 km N of the 4WD access to the Ballina/Byron Shire boundary.	21 km S of the South Ballina 4WD access (continues through the 'coffee rocks').		4.6 km N of the 4WD access (continues through 'coffee rocks').
Tidal zone	Use only approved 4WD access points. Below HTM, not within 10 m of the vegetated dune and not in the dunes.	Use only approved 4WD access points Below HTM .	No stopping at oystercatcher nests between Aug-Mar. Below HTM.	
Speed limits	30 km/h 15 km/h within 50 m of other beach users	30 km/h 15 km/h near people and shorebirds	30 km/h 15 km/h near pedestrians, shorebirds and horses.	
Road rules	NSW road rules	Not specified.	Australian road rules Other beach users have right of way over motor vehicles.	
Dog zone	3.3 km off leash N of the 4WD access and 1.1 km S.	500 m N and S of the Patchs Beach access.	No dogs.	1.3 km off leash N of the 4WD access and 150 m S. Intertidal zone only.
Motorcycles Camping & fires	No No	No		No

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Table 2. Vehicle-based recreation activities that were observed in this study (this table of activities is not exhaustive), grouped into four general classes (Petch *et al.* 2018) and then ordered by overall frequency.

Activity	Description
General Recreation (REC)	
Picnic (PC)	Picnics generally involved multiple persons and a variety of general recreation activities. Temporary shelters (awnings and/or gazebos) were a nearly universal feature of picnics plus chairs and sometimes tables.
Playing (PL)	Generally young children playing on the beach. These groups were not setup like picnics, usually did not stay long and adults present were supervising the children.
Sunbathing (SB)	These groups were not setup like picnics, there were usually fewer people and the activity was exclusively sunbathing (<i>e.g.</i> one or two people laying on the sand beside their vehicle).
Dog exercise (DG)	‘Playing for dogs.’ Dog walking was not common for drivers.
Parked (PK)	Parked, with people sitting in the vehicle or no people about.
Camping (CA)	Beach front camping or overnight staying. Campers commonly used ‘hit-and-run’ tactics, setting-up around dusk and moving in the morning (<i>pers. obs.</i>).
Drone-flying (FL)	Person outside 4WD flying a drone. Not driving with a drone following.
Off-road Driving (ORD)	
Driving (DV)	Beach driving. The destination and purpose were unknown.
Fishing (FISH)	
Fishing (FI)	Recreational line fishing and beach worm and shellfish collection. The activity was exclusively fishing, unlike picnics, and 4WDs were usually parked on the intertidal zone, closer to the water.
Water-based Recreation (WATER)	
Swimming (SW)	Includes wading above knee depth.
Surfing (SF)	Mostly on surfboards.
Jet-skiing (JS)	Jet-skis launched from the beach.
Kite surfing (KS)	A vehicle followed the kite surfers along the beach on one occasion.
Boating (BT)	Boat launched from the beach.

454 **Table 3.** Nested speed models. ANOVA tests are sequential by rows (*i.e.* row two vs one, three vs two and four
 455 vs three). The minimal adequate model was *speed ~ beach*.

Speed model	<i>F</i> (d.f.)	<i>P</i>
~ overall mean (null)		
~ <i>beach</i>	11.9 (2, 156)	< 0.001
~ <i>beach</i> + <i>class</i>	0.5 (2, 154)	0.62
~ <i>beach</i> + <i>class</i> + <i>beach: class</i>	0.6 (2, 152)	0.57

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Figure 1. Map of Seven Mile, South Ballina and Airforce beaches. Blue lines indicate 4WD zones. The ‘coffee rocks’ (dotted blue line) was not included in this study. Green lines indicate dog zones. Black circles are official 4WD access points. Light grey areas are National Parks and Nature Reserves. Dark-grey areas are urban. The inset map (top-left) shows the location of the Richmond River area in Australia.

Figure 2. Total count densities for 4WDs (a) people-out of 4WDs (b), dogs-out of 4WDs (c) and oystercatchers within the 4WD zone (d). Grey points are individual densities, with a small amount of random horizontal ‘jitter’. Black points are mean densities and error bars are 95% confidence intervals from GLMs. Likelihood ratio test statistics compare fitted models (density $\sim$ beach) with null models (density $\sim$ overall mean).

Figure 3. 4WD (1), people-out (2) and dogs-out (3) group size distributions (in columns) for Seven Mile (a), South Ballina (b) and Airforce (c) beaches (in rows). People- and dogs-out counts are for non-driving 4WD observations. Means (vertical, dotted lines) are for positive counts (positive count sample sizes are in parentheses). Horizontal error bars are 95% confidence intervals for the means from zero-truncated (for 4WDs and people-out) and hurdle (for dogs-out) models. Proportions of zero counts (grey-filled bars) and 95% confidence intervals from hurdle models are included in column (3). Likelihood ratio test statistics in row (b) compare fitted models ($count \sim beach$ and, for hurdle models, $[count > 0] \sim beach$) with null models ($count \sim overall\ mean$ and proportion $[count > 0] \sim overall\ mean$). One large count of 26 people in (b2) is not plotted but was included in the analysis. Column (2) is scaled 0–45 ($2 \times$).

Figure 4. 4WD (1), people-out (2) and dogs-out (3) along-shore spatial distributions (probability densities) (in rows) for Seven Mile (a), South Ballina (b) and Airforce beaches (c) (in columns). 4WD distributions include those driving ‘Rug plots’ at the bottom of the figures show the distributions of individual observations. Smooth lines overlaying histograms are kernel densities (‘smoothed histograms’). Coarser resolution figures are presented for smaller sample sizes in (b3) and (c3). Mean $\pm$ sd distances are reported in row (1). The South Ballina mean distance refers to the South Ballina 4WD access (b1). Dashed, horizontal lines are uniform distributions (density = $1/(4WD \text{ zone length})$). One-sample Kolmogorov-Smirnov test statistics and P -values are reported in (c) (the null hypothesis was that the observed distributions are uniform and small P -values indicate non-uniformity). Thick, grey lines below the graphs are 4WD and dog zones and Broadwater National Park (BWNP) and Richmond River Nature Reserve (RRNR) sections. The location of the South Ballina (SB) and Boundary Creek (BC) 4WD access tracks is also indicated in (b1) (the Seven Mile and Airforce 4WD access tracks were at distance zero). Column (b) is scaled 0–0.125 (4 $\times$).

Figure 5. Vehicle-based recreation activities in six (a) and four (b) classes and 4WD registration States (c). The chi-squared test for (a) compared counts in nine classes (d.f. = 2 × 8). The chi-squared test for (b) compared counts in those four general classes (Petch *et al.* 2018; Table 2). The chi-squared test for (c) compared counts in two classes (NSW/QLD) (d.f. = 2 × 1).

Figure 6. 4WD speeds. There were no observations of 4WDs passing shorebirds for Seven Mile (a) and only three of 4WDs passing people for South Ballina, which were ignored (b). Grey points are individual speeds, plotted with a small amount of random horizontal ‘jitter’. Black points are mean speeds and error bars are 95% confidence intervals from ANOVA models. Overall means and 95% confidence intervals are reported at the top of each figure. ANOVA tests are reported in Table 3.

Figure 7. Compliance results and 95% confidence intervals (SM = Seven Mile; SB = South Ballina; AF = Airforce). ‘Driving > HTM’ means driving above the High Tide Mark (above the intertidal zone). Chi-squared statistics compare all three beaches (d.f. = 2).