Changes to dunes caused by 4WD vehicle tracks in beach camping areas of Fraser Island.

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ABSTRACT Although dunes are known to have very low tolerance to human disturbance and provide irreplaceable ecosystem services (e.g. erosion control, critical habitat and nesting sites), in dunes serve as campsites for large numbers of people (~ 90,000 p.a.) on the ocean-exposed shores of Fraser Island, Australia. On the island, camp sites are located in the established dunes and can only be accessed with 4WD vehicles along tracks cut directly from the beach through the foredunes. We quantified the extent of physical damage to foredunes caused by this practice, and tested whether human-induced physical changes to foredunes translate into biological effects. Of the 124 km of ocean-exposed, east-facing beaches, 122 km (98%) are open to vehicles, and camping zones cover 28.7 km or 23% of the dunes. A total of 235 vehicle tracks are cut across the foredunes at an average density of 8 tracks per km of beach. These tracks have effectively destroyed one-fifth (20.2%) of the dune front within the camping zones, deeply incising the dune-beach interface. There is evidence of accelerated erosion and shoreline retreat centred around vehicle tracks, resulting in a "scalloping" of the shoreline. No dune vegetation remains in the tracks and the abundance of ghost crabs (*Ocypode* spp.) is significantly reduced compared with the abutting dunes. Because current levels of environmental change caused by dune camping may not be compatible with the sustainable use of coastal resources and conservation obligations for the island (listed as a World Heritage Area and gazetted as a National Park), restoration and mitigation interventions are critical; these will require prioritisation of effort, and we present a multi-criteria ranking method to objectively target rehabilitation and conservation measures. Ultimately, coastal management needs to develop and implement strategies that reconcile demands for human recreation, including beach camping, with the conservation of dune ecosystems in the region.

1. INTRODUCTION

Foredunes form the land-ocean boundary of beaches. By absorbing storm energy, dunes slow erosion - a critical function in all urban and periurban areas of SE-Queensland. Dunes provide unique habitats for plants, numerous invertebrate species, as well as nesting and feeding sites for birds and turtles (Hosier et al., 1981; Baird and Dann, 2003; Groom et al., 2007; Van Dam and Van Dam, 2008).

Almost all dunes are sensitive to human disturbance (Rust and Illenberger, 1996). Frequent or continuous anthropogenic disturbance to foredunes usually leads to loss of habitat, threatens native vegetation species, reduces seed sources, lowers the resilience of plant communities, and increases the risk of dune erosion by storms (Nordstrom et al., 2000; Roze and Lemauviel, 2004; Feagin et al., 2005).

In southern Queensland camping in coastal dunes is highly popular on the offshore barrier islands (North Stradbroke, Moreton Island, Fraser Island) and some mainland locations (e.g. Noosa North Shore). On most beaches with dune camping, a four-wheel-drive (4WD) vehicle is required to access camping zones. However, driving of vehicles is the most damaging form of human beach and dune use (Godfrey and Godfrey, 1980): dunes have virtually zero tolerance to vehicles, and this activity can have massively detrimental effects on dune vegetation (Hosier and Eaton, 1980; Anders and Leatherman, 1987; Rickard et al., 1994; Groom et al. , 2007) and animals (Van Dam and Van Dam, 2008).

As currently practiced in southern Queensland, campsites in coastal dunes can usually only be reached via vehicle tracks cut directly from the beach through the foredunes, causing physical habitat changes. Possible ecological impacts would be manifested as reduced vegetation cover, lower plant species richness and decreased habitat quality for the dune fauna. Yet, neither the extent and distribution of such physical dune damage nor any of the putative ecological impacts have been quantified in the region; consequently, this is the primary objective of this study where we use Fraser Island as test region to assess these changes.

Fig. 1
Examples of damage to dune fronts on Fraser Island caused by vehicle tracks cut through the frontal dunes to access camp grounds located in the mature dunes further inland.

2. METHODS

All tracks in 19 beach camping zones along the east coast of Fraser Island were geo-referenced and assessed for physical damage, measuring track width at the dune front (i.e. the beach-dune boundary near the drift line), and at the height of the first crest inland as well as the second dune crest. We also tested whether physical habitat modifications resulting from vehicle tracks caused biological effects by contrasting the density of ghost crab (*Ocypode* spp.) burrows between vehicle tracks and the adjacent foredunes. Crab burrows were counted and their diameter measured in 2 x 1 m quadrat frames. We counted burrows at two levels: where the first and second dune crest intersected the tracks. Each level encompassed two replicates inside the track and two replicates on both sides of the dunes abutting the tracks. Inside the tracks, the centres of the quadrat frames were positioned in line with the centre of the tyre ruts. On the adjacent dunes, each quadrat was positioned randomly within 10 m from the edge of the tracks. We also took a digital, plan-view photograph of each quadrat frame to record vegetation cover, species composition and diversity, using Coral Point Count (Kohler and Gill, 2006); for each individual image, 60 points, spread randomly within a grid of five columns and two rows overlaid over the image, were analysed.

A multi-criteria ranking system to prioritize camping areas for dune rehabilitation was developed. This was based on physical dune damage and biological attributes: physical criteria included the proportion of dune front destroyed by vehicle tracks and the density of tracks in camping zones; these are direct measures of the intensity of human use (i.e. track density) and the resulting magnitude of physical impact (e.g. percent dune front destroyed). Biological criteria included cover and species richness of dune plants and the density of ghost crabs in the foredunes. The basic rationale here is that areas with lower plant cover have lower resilience against erosion and provide lower-quality habitats for invertebrates; these are directly measured as the abundance of ghost crabs and used as the fifth criterion in the site rankings. Thus, camping zones with currently low values of these biological attributes will receive higher priority for restoration interventions. Each of the five criteria was weighted equally, and the final prioritisation of camping zones is based on the summed ranks across all five criteria.

3. RESULTS

3.1. Physical Dune Damage

Of the 124 km of ocean-exposed beaches on the eastern shores of Fraser Island, 122 km (98%) are open to vehicles, and camping zones cover 28.7 km or 23% of the coastal dunes. Camping zones range from relatively short stretches (636 m - Duling) to long sections of the dune system (3498 m - Burad). A total of 235 vehicle tracks are cut across the foredunes in the camping zones, with individual zones having up to 30 tracks. Mean spacing between tracks is 101 m, but adjacent tracks can be as close as 6 m: in some camping zones the median along-shore distance between tracks reduces to 54 – 61 m. Across all camping zones, 8.2 tracks incise the dunes per kilometre of beach, but track densities can be as high as 14.9 tracks km^{-1} in individual camping zones (Table 1).

Physical dune damage caused by vehicle access tracks in camping zones is substantial: one-fifth (20.2%) of the dune front has effectively been destroyed in the camping zones (Figs. 1&2). For all the exposed beaches on the island, including non-camping zones, vehicle tracks incise 5.8 km of dune frontage. Physical damage is most pronounced at the boundary between the dune and unvegetated beach, often causing hot spots of erosion centred around track entrances which produce a distinct “scalloping” of the shoreline.

3.2. Impacts on ghost crabs

Physical habitat disturbance by vehicle tracks significantly reduces the density of ghost crabs in the foredunes. Fewer ghost crab burrows occurred in vehicle tracks at the height of the second dune crest compared with the adjacent dunes (ANOVA, Effect: Crest x Impact

Fig. 2 Physical damage to foredune fronts caused by vehicle tracks cut from the beach across the dunes to access camping zones further inland on Fraser Island.

$F_{(1,1687)}$ = 145.7, $P < 0.001$; Fig. 3). The number of zero count samples (i.e. no visible burrows) was significantly ($P<0.05$) higher in the vehicle tracks compared with the adjacent dunes on both the first dune crest (22% vs. 15%) and the second crest (56% vs. 12%). At the second dune crest, no ghost crab burrows were found in the vehicle tracks in one camping zone, and 70-90% of quadrats contained no burrows in five other zones.

3.3. Dune vegetation

A total of 14 plant species were recorded in the foredunes of camping zones. The grass *Spinifex sericeus* dominated the vegetation communities at an average ground cover of 27%. All other species had comparatively low cover (max. 5.8% for *Zoyasia macrantha* on the second crest), with five species (*Isolepis nodosa, Canavalia rosea, Acacia sophorae, Banksia integrifolia, and Casuarina equisetifolia var. incana*) being rare at <0.1% cover. Live vegetation cover rests was highest (51.3%) in the Dulling camp zone and lowest (22.9%) in

Winnam. Wyuna had the highest species richness with a total of 9 plant species recorded, whereas only 3 plant species were recorded at Govi and Poyungan.

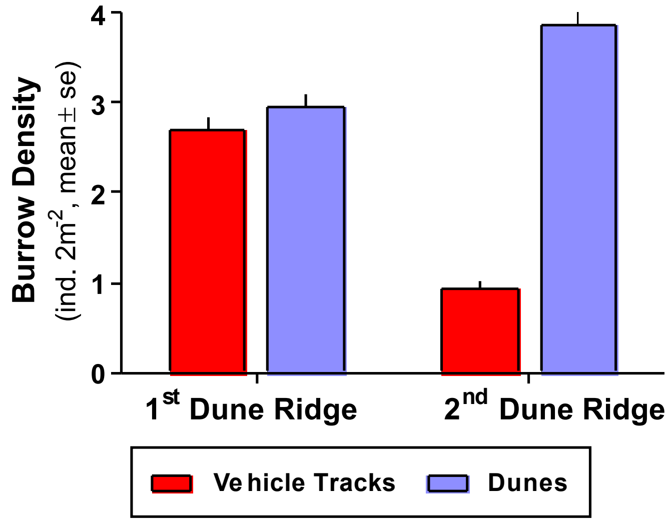

Fig. 3
Comparison of burrow densities of ghost crabs between vehicle access tracks (solid bars) cut through the foredunes and abutting dune areas (open bars) at two positions (1st and 2nd ridge) in the foredune field of Fraser Island.

3.4. Dune Restoration - Site Prioritisation

Closure of all camping zones is not a politically acceptable option. Restoration efforts will therefore have to target a subset of camping zones, which will require some objective method to prioritize sites. Here we provide a relatively simple, objective, ranking of camping zones in terms of their restoration priorities, based on physical damage measured and biological attributes. The top three camping zones ranked as priority areas for restoration are Marloo, Maheno, and Poyungan (Table 1, Fig. 5). The next three zones which ranked highly in terms of rehabilitation needs were the Yurru, Guluri and Eli camping zones (Table 1, Fig. 5). Marloo ranked consistently in the top 5 for three of the four criteria, including sparse vegetation cover and comparatively low plant species richness, as well as the third highest density of access tracks. Similarly, Maheno also had sparse vegetation cover and low plant species richness, but physical damage was intermediate. The third priority camping zone, Poyungan recorded the second lowest plant species richness and low abundances of ghost crabs (Table 1, Fig. 5).

4. DISCUSSION

Increased storminess due to climate change is likely to exacerbate anthropogenic disturbances to dune systems (Slott et al., 2006): more frequent and stronger storm events are predicted which will reduce the ability of dune systems to recover from anthropogenic impacts (Harley et al., 2006). On Fraser Island, dune camping was found to reduce vegetation cover and causes scalloping of the dune-beach interface. This effectively breaches the dune-beach barrier and is likely to lower the foredunes' ability to act as a barrier against storms, possibly contributing to accelerated shoreline retreat in the future.

Shorebirds and turtles use dunes as feeding and nesting sites (Hosier et al. , 1981; Watson et al., 1997; Bouchard and Bjorndal, 2000), and many dune species are threatened by human activities (e.g. 4WDs) affecting their behaviour, reproductive success, survival and population sizes (Burger, 1994; Watson et al., 1996; Williamset al., 2004; Bonte, 2005; Van Dam and Van Dam, 2008). On Fraser Island, beach camping significantly lowered the abundance of dune biota: in vehicle tracks vegetation cover was dramatically reduced to the point of barren sand and densities of ghost crabs were significantly lower.

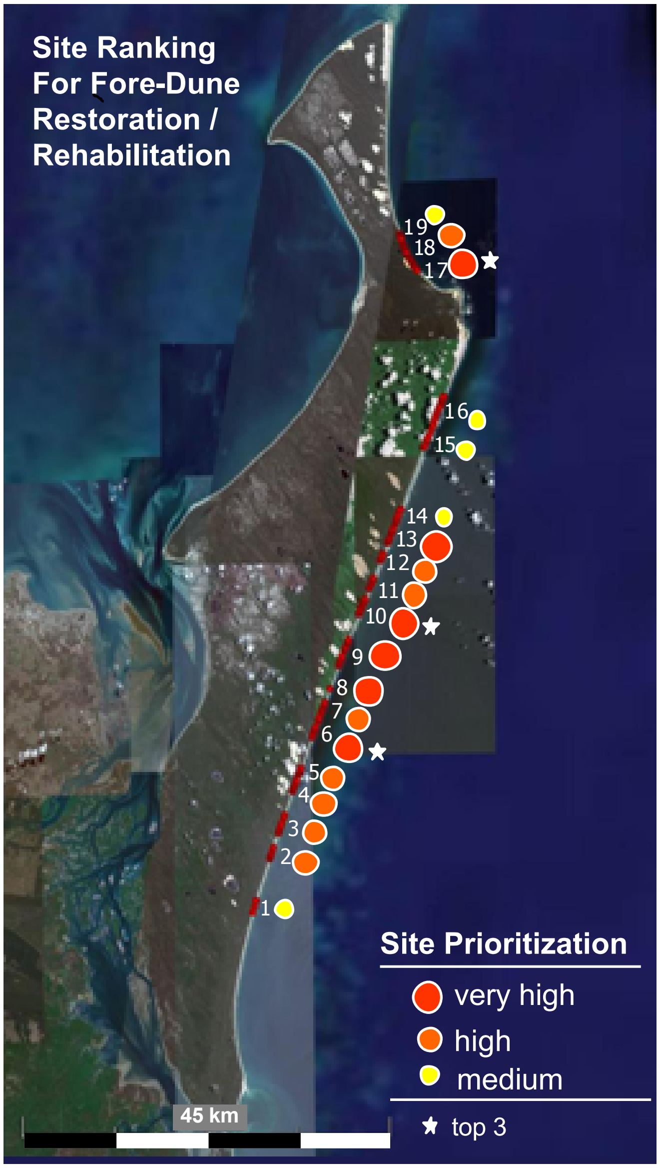

Fig. 5
Prioritization of camping zone for dune restoration and rehabilitation based on the extent of physical habitat damage (proportion of dune front destroyed), human pressure intensity (vehicle track density) and biological attributes (vegetation cover, plant species richness, ghost crab abundance). Graphical categorisation (medium, high, very high) is based on the 33 and 66 percentiles of total scores summed over the five variables above (cf. Table 1).

Arguably, damage to dunes will require restoration measures. These need to be underpinned by systematic conservation planning (Margules and Pressey, 2000) which provides explicit criteria for site selection (Sarkar et al., 2006). We have therefore provided a relatively simple but objective method to prioritise camping sites for rehabilitation (Table 1). The criteria encompass both physical aspects of the dune habitats as well as biological dimensions, but complementary criteria may be used if they can be accurately quantified. Also, it is important that bio-physical aspects will need to be matched by socio-cultural and economic considerations to achieve balanced conservation outcomes.

5. Take Home Message

It can be questioned whether environmental damage caused by recreation in its current form (including beach camping and 4WD traffic) is truly compatible with conservation obligations for Fraser Island. It may therefore be timely to restore dune areas, limit future environmental impacts, and formulate management plans that reconcile demands for recreation with conservation measures that protect the ecological integrity of the irreplaceable coastal dune ecosystems on Fraser Island and other beaches of SE-Queensland.

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Table 1 Prioritization of camping zones for dune restoration and rehabilitation based on physical habitat damage caused by vehicle tracks cut through the foredunes and biological attributes. Camping zones are ranked according to 3 biological (vegetation cover, plant species richness and burrow density of ghost crabs) and 2 physical criteria of habitat damage (proportion of dune front destroyed, vehicle track density). Ranks in bold denote zones within the top 5 for individual criteria, and * symbols indicate zones within the top 3.

	Dune Vegetation Cover		**Plant Species Richness**		**Ghost Crab Burrow Density**		**Physical Damage - Dune Front**		**Vehicle Track Density**		**Combined Score**	**Overall Rank**
Camping Zone	Rank	($\bar{x}$, %)	Rank	($\bar{x}$, S)	Rank	($\bar{x}$, n $2m^{-2}$)	Rank	(%)	Rank	(n km^{-1})		
Marloo	**2***	(27)	**5**	(1.4)	11	(3.0)	8	(24)	**3***	(13.1)	29	1
Maheno	**3***	(28)	**4**	(1.3)	7	(2.6)	9	(23)	13	(7.0)	36	2
Poyungan	8	(31)	**2***	(1.2)	**4**	(2.1)	7	(25)	16	(5.6)	37	3
Yurru	**4**	(28)	11	(1.6)	16	(4.3)	**5**	(27)	**5**	(10.4)	41	4
Guluri	9	(31)	16	(2.0)	9	(2.8)	**2***	(33)	6	(10.2)	42	5
Eli	7	(30)	13	(1.7)	**3***	(2.1)	11	(21)	8	(9.3)	42	5
Gabala	13	(35)	19	(2.4)	10	(3.0)	**1***	(36)	**1***	(14.9)	44	7
Wongai	6	(29)	7	(1.4)	17	(4.6)	**3***	(30)	11	(8.2)	44	7
One Tree Rocks	**5**	(29)	**3***	(1.3)	**5**	(2.4)	13	(17)	18	(4.3)	44	7
Ocean Lakes	14	(36)	**1***	(1.2)	13	(3.5)	14	(16)	**4**	(11.1)	46	10
Wahba	11	(33)	12	(1.7)	8	(2.6)	**4**	(27)	12	(7.8)	47	11
Cornwells	17	(42)	15	(2.0)	**2***	(2.0)	10	(23)	8	(9.3)	52	12
Eugarie	10	(32)	8	(1.5)	6	(2.5)	15	(14)	14	(6.9)	53	13
Winnam	**1***	(23)	6	(1.4)	12	(3.2)	17	(10)	17	(5.1)	53	13
Govi	12	(33)	8	(1.5)	**1***	(1.9)	19	(4)	19	(2.1)	59	15
Gur uman	18	(44)	17	(2.0)	14	(3.7)	**5**	(27)	6	(10.2)	60	16
Dulling	19	(51)	8	(1.5)	19	(6.9)	18	(8)	**2***	(14.2)	66	17
Bur ad	16	(39)	18	(2.1)	18	(5.4)	12	(20)	10	(8.6)	74	18

Wyuna	15	(37)	14	(2.0)	15	(3.8)	16	(11)	15	(5.7)	75	19