Camping and groundwater quality on the eastern beach of Fraser Island: a smoking gun

[1][2]RW (Bill) Carter, [2]Peter Brooks, [2]Neil Tindale, [2]Daryle Sullivan, and [2]Nikita Tully

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Abstract

Concern for the maintenance of water quality of the lakes on Fraser Island has attracted research attention but the impact of beach camping on freshwater beach-flows has been poorly considered. The assumption has been that the natural assimilative capacity of the foredune ecosystem is sufficient to dissipate any negative environmental impact. An exploratory study of nutrients, faecal coliforms and faecal sterols in the watertable and beach flows associated with camping and non-camping zones reveals concerning and, in some cases, extreme differences. The study suggests nutrient levels in the watertable are enriched in camping zones and that, in some areas, faecal coliforms persist in beach flows. The link to a human cause is supported by the presence of strong faecal sterol signals in soil samples from the watertable interface.

The risk implications for human health are significant although the biological impact implications remain unexplored. It will be important to clarify the temporal and spatial nature of the variables measured to inform the management decision making process, because the groundwater pollutants may be localised and short-term seasonal. If this is the case, then management strategies of camp area rotation and health warnings may be appropriate. If the human waste signals are more widespread and persistent, then a major change in human waste disposal will be essential.

Keywords: beach camping, watertable, coprostanol, nutrients, faecal coliforms

Introduction

Fraser Island, in southeast Queensland, Australia, is the largest sand island in the world (Hockings, 1998). In 1992, the island received World Heritage status because it exhibits important ongoing geological and biological processes, natural phenomena and exceptional natural beauty (Hockings & Twyford 1997). The Great Sandy Region Management Plan identifies Fraser Island as a place where "tourists from Queensland, interstate, and overseas can enjoy Fraser Island's splendour and tranquillity and return home without having marred their priceless inheritance" (EPA 2005). The island attracts over 350 000 visitors per year (Burns & Howard 2003) for sightseeing, walking, four-wheel driving, picnicking, fishing, boating, bait collecting, commercial tours and beach camping. Beach camping alone attracts approximately 90 000 visitors each year (Thompson & Schlacher 2008) or 390 000 camping nights. Tourism on Fraser Island is highly seasonal with December - January (Christmas) and March - April (Easter) being the most popular times (Hadwen 2002).

Compared with the nearby sand areas of the mainland (Cooloola National Park), Fraser Island's biophysical character has attracted considerably less research attention. Much of the understanding of the dynamics of Fraser environments comes from extrapolation of mainland studies. Fraser Island's oligotrophic freshwater dune lakes have been the focus of most research, and tourist attention. In 2000, 90% of the 331 652 tourists to the island visited the perched lakes in the central part of the island (FIDO 2006). These low nutrient, highly oxygenated lakes support a limited number of aquatic organisms and algal species (Hadwen 2002), and even low levels of nutrient addition has the potential to affect their overall health (Arthington *et al*. 1990). Based on changes in nutrients and chlorophyll a concentrations, these lakes have become slightly more biologically productive and less pristine since 1990 (Hadwen 2002). The large numbers of tourists swimming in the lakes is a probable cause of nutrient additions and the shift towards eutrophication; a process, if it continues, that would greatly diminish the lakes' aesthetic appeal

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[1] Sustainability Research Centre, University of the Sunshine Coast, bcarter@usc.edu.au

[2] School of Science and Education, Faculty of Science, Health and Education, University of the Sunshine Coast

(Hadwen 2002). In 2003, the campground at one of the lakes (Lake Mackenzie) was permanently closed due to the threat posed by tourist numbers, and elevated nutrient levels (EPA 2005). Direct human waste additions were thought to be the main source of enrichment, although burial of camping waste may have also contributed (Hadwen 2002).

Four-wheel driving is permitted on 98% of the Fraser Island's eastern beach (Thompson & Schlacher 2008) and concern exists for impacts of this activity on foredune vegetation and dune stability (Thompson & Schlacher 2008; Hockings & Twyford 1997). In areas where camping is permitted, 235 vehicle tracks pass through the foredune, resulting in the erosion of 20% of the dune in these areas, which may take two or more years to recover (Thompson & Schlacher 2008). Recreational four wheel driving has also been shown to be detrimental to migrating birds, marine turtle hatchings and endobenthic invertebrates such as crabs (Moss & McPhee 2006; Schlacher & Thompson 2006; 2007), which could to lead to further ecological consequences (Schlacher *et al.* 2008).

Beach camping remains one of the greatest environmental management concerns for the island (Hockings & Twyford 1997). Thompson & Schlacher (2008) estimate that the dune area devoted to beach camping is approximately 23% (28.7km) of Fraser's ocean exposed foredunes. The recreational activity causes dune disturbance by four-wheel drives, direct attrition of vegetation (see McAtee & Drawe 1980; Cole 1992; Anna *et al*. 2000; Marion & Farrel 2002) and the introduction of human waste and litter into the system. Despite widespread acknowledgement of the potential for environmental harm from human waste in natural areas, little research has been conducted to inform management on how to address the issue (Cilimburg *et al.* 2000). Nevertheless, in response to a camping review (Q.PWS 2004), the managing authority for recreational use of the island, the Queensland Parks and Wildlife Service, restricted beach camping to defined zones, a shift in policy from the previous unrestricted camping approach that had been in place for a considerable number of years.

The introduction of human faeces and urine to the dune system has the potential to alter the nitrogen and phosphorus status of dunes, shifting the ecological balance away from species that can withstand low nutrient levels. In addition, there is the health risk of human pathogens (Anna *et al*. 2000; Campbell & Bate 1998; Bridle & Kirkpatrick 2003). Based on Seyed *et al.* (2000), Q.PWS (2004) and Thompson and Schlacher (2008), it is estimated that an average of 4.3 kgs of faeces and 18.3 litres of urine are added each year to every lineal metre of camping zone on Fraser Island's eastern beach. The assumption has been that in silica sand dunes, nutrients and pathogens will quickly pass through the dune to the watertable to be diluted and transported safely to shoreline beach flows with limited ecological effect or risk to human health. However, faecal indicator bacteria have been found to be relatively more concentrated in sand than in water (Alm *et al.* 2003) and, like nutrients, can attach to organic material concentrated at the watertable interface (see Craig *et al.* 2000).

This exploratory study sought simply to verify if human waste from beach camping on the foredunes of the eastern beach of Fraser Island is likely to be ecologically benign as assumed, and if the risk to human health was within acceptable limits.

Methods

Camping intensity

As a surrogate for the level of human faecal matter entering different beach camping zones, campsites were counted in each 100m of the camping zones on Fraser Island and converted to an average per 100m. The count was undertaken during Easter (March) 2009; one of the known peak visitation periods. It was assumed that this measure of camping intensity would be a reasonable surrogate for annual faecal input, given that campers have preferred camping zones based on access to various attractions and services of the island. Some zones were counted on more than one occasion because additional campers had arrived during the study period.

Faecal indicators

Faecal coliforms, soluble nutrients and faecal sterols were selected as indicators of human waste contamination (see Prieto *et al.* 2001; Mwashote 2000; Sullivan 2006) of the watertable below the beach camping zones. Faecal coliforms are heat tolerant bacteria that live in the gut of warm-blooded animals. They survive under the same conditions as many faecal derived pathogens and high levels of faecal coliforms suggest faecal contamination and human pathogens (Prieto *et al.* 2001; Fujioka 2001). The decomposition of faecal matter and urine results in compounds high in phosphorus and nitrogen; therefore, water samples were tested for total phosphorus, phosphates, total nitrogen, nitrates, nitrites, and ammonia. Elevated faecal coliform and nutrient levels in camping zones, when compared to matched non-camping zones, were expected to reflect faecal input.

Soil samples were tested for faecal sterols, as they are by-products of digestion of sterols (e.g. cholesterol) in the diet of animals. Animals ingest sterols according to their food source (carnivore, herbivore, and omnivore) (Leeming *et al.* 1996) to be metabolized resulting in by-products that are organism specific. Coprostanol is the major by-product of human digestion of cholesterol (Leeming *et al.* 1996). The native animals on Fraser Island produce very little coprostanol, thus the presence of coprostanol is strong evidence of human faecal contamination.

Sampling

Samples were collected from Ocean Lake to One Tree Rocks in January, and from Guruman to Cornwell camping zones in February 2009 to coincide with a peak visitation period and rain events expected to induce increased flushing (see Krogh & Robinson 1996; Ackerman & Weisberg 2003). Thirteen sites were sampled (across ten camping/non-camping zones) in January and 17 sites (across six camping/non-camping zones) in February. Samples were taken from creeks, groundwater and beach flows in January largely to confirm the suitability of methods, and in February from paired groundwater and beach flows in camping and non-camping zones (Figure 1). For the purpose of this paper, the data sets were combined for analysis.

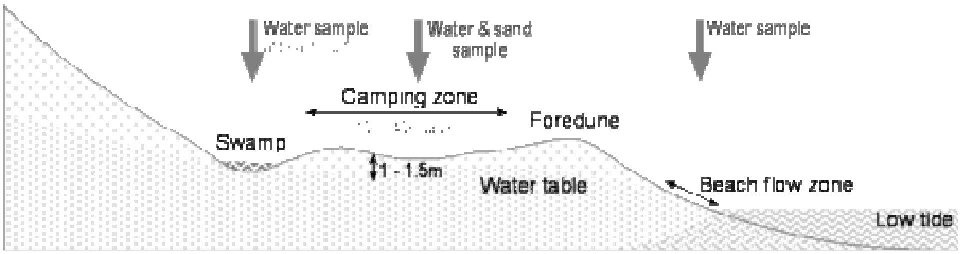

Figure 1 Sampling locations

All sample sites were selected by convenience. Groundwater and soil samples were taken from an auger hole dug at the low point behind the foredune(s). Upon reaching the water table (at around 1 to 2m), a soil sample was collected from the auger bit for sterol analysis, and water was extracted from subsequent auger liftings for coliform and nutrient analysis. Soil samples were collected in plastic zip-lock bags, while water samples were decanted from the moist soil into a 250ml sterile bottle. All samples were stored on ice until analysed.

Beach flow water samples were collected at low tide, between the tidal levels. A shovel was used to make a y-shaped depression in the sand, into which the groundwater outflow was collected and handled similarly to the groundwater samples.

Analyses

Faecal coliforms

The chilled water samples were processed in the field within 6 hours for faecal coliforms using standard methods (see Clesceri *et al.* 1998; Eaton *et al.* 2005). Briefly, using aseptic techniques, the water samples were vacuum filtered through a 0.45 µm milllipore filter membrane, then the filters were placed on coliform-specific agar containing rhizolic acid and incubated at 45°C for 24 hours. After incubation, the number of blue-coloured Colony Forming Units (CFU/100ml) was counted. Where the samples contained a significant amount of organic material, and smothering was a concern, 20ml or 50ml was plated as well as the 100ml. This method proved useful as the low volume plate often gave results higher than the 100ml plate, due to the masking or inhibition of coliform forming units on the 100ml plate by the organic matter.

Nutrients and faecal sterols

Water samples were analysed (see Clesceri *et al.* 1998; Eaton *et al.* 2005) for total nitrogen, nitrates, nitrites, ammonia, total phosphorus and phosphates using the Flow Injection Analyzer in the laboratory at the University of the Sunshine Coast. All standard curves had a 0.999 correlation co-efficient. The 100µg/L and 500µg/L standards were used as internal quality checks; and tested again as unknowns at the end of the sample run and analysed values came within ±5 µg/L of the standard concentration.

Faecal sterols were removed from soil samples by methanol and hexane extraction (Sullivan 2006) and analysed in the laboratory using a Gas Chromatography Mass Spectrometer (Sullivan 2006).

Results

Camping pressure

Camping intensity indicated uneven dispersal of campers in the beach camping zones (Figure2), although, as predicted, there were more intensely used zones (e.g. around Eli and Cornwells) that provide convenient access to attractions of the island. While the zones with the highest camping intensity recorded elevated levels of all groundwater parameters measured, and hence likely higher levels of faecal inputs, camping intensity had no direct correlation with any of the water quality parameters. This parallels the findings of Graziano *et al.* (2005) and suggests that groundwater quality is not related simply to contaminant input levels.

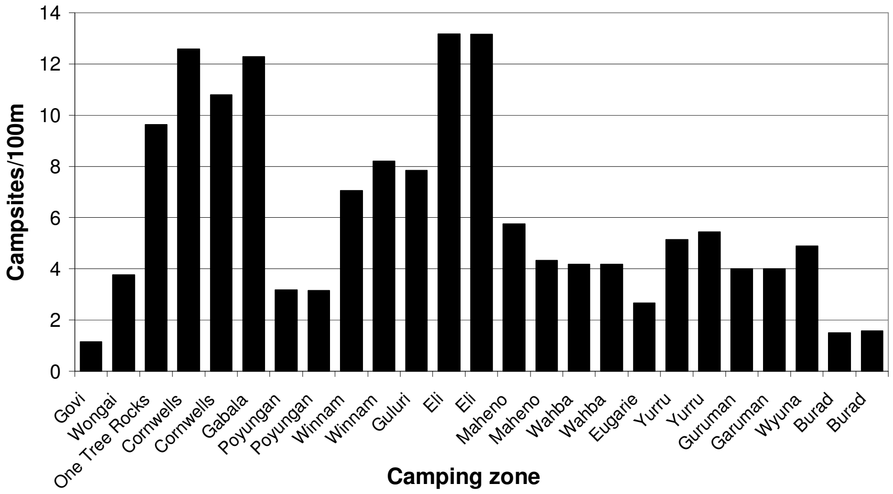

Figure 2 Camping intensity in beach camping zones at Easter 2009

Creeks

Four of the five creeks sampled had no evidence of faecal coliforms, while the Happy Valley sample had thermotolerant coliform counts that exceeded water quality standards for recreational activity (EPA 2006). All creeks sampled, except Kurrnung Creek, recorded total nitrogen levels that exceeded the EPA standard for total nitrogen in open coastal waters. All other water quality variables measured from all creeks sampled were well below Queensland's water quality standards. Hence, the creeks sampled on the east coast of Fraser Island are in acceptable condition (except for the one with high faecal coliforms presumed to be associated with poorly maintained nearby septic systems), and probably reflect the low-nutrient aquifer under the island.

Groundwater

The mean value of all water quality parameters measured from groundwater samples showed marked differences between non-camping and camping zones. Values for water quality parameters from camping zones exceeded the non-camping zones by an order of 1.5 to more than 30 times (Table 1). However, all parameters exhibited extreme variation in values, both from camping and non-camping zones.

Table 1 Groundwater quality parameters for non-camping and camping zones
Figures in bold indicate levels exceeding Queensland water quality standards (EPA 2006)

	Non-camping (n=7)				**Camping** (n=18)				**Times the average non-camping level**
	Mean	**Std dev.**	**Max**	**Min**	**Mean**	**Std dev.**	**Max**	**Min**	
Thermotolerant coliforms (cfu/100ml)	12.9	34.0	90	0	**399.7**	438.2	**999**	0	31.1
PO_4-P (µg/L)	49.0	35.8	110	21	69.9	93.2	**415**	<10	1.4
Total P (µg/L)	**52.4**	33.1	**110**	21	**170.2**	366.8	**1597**	28	3.2
NH_3-N (µg/L)	**328.7**	166.5	**658**	**135**	**529.8**	569.4	**2191**	**77**	1.6
NO_3 (µg/L)	106.1	91.7	248	<10	778.6	884.7	2706	39	7.3
NO_2 (µg/L)	12.3	17.2	51	<10	19.0	30.7	133	<10	1.5
Total N (µg/L)	**1461.0**	471.5	**2284**	**944**	**2430.9**	983.9	**4252**	**907**	1.7
Coprostanol (ngms/100g)	88.4	184.5	493	0	305.5	993.2	4209	0	3.5

For inorganic chemicals, all groundwater samples exceeded Queensland water quality standards (Table 2); most by a considerable amount. No sample from the non-camping zones had unacceptable levels of coliforms, while most of the camping zone samples recorded unacceptable levels.

Table 2 Groundwater quality parameters against Queensland water quality standards (EPA 2006)

	Non camping (n=7)	**Camping** (n=18)
Thermotolerant coliforms	No sample exceeded the EPA standard.	56% of sample sites exceeded the EPA standard.
Total P	100% of sample sites exceeded the EPA standard for open coastal waters (20µg/L); 43% exceeded the standard for lowland streams (50µg/L).	100% of sample sites exceeded the EPA standard for lowland streams (50µg/L).
NH_3-N	100% of sample sites exceeded the EPA standard for upper estuarine (30µg/L).	
Total N	100% of sample sites exceeded the EPA standard for lowland streams (500µg/L).	

Groundwater in non-camping zones

Thermotolerant coliforms were recorded (but at an acceptable level) only in one of the seven groundwater sample sites in the non-camping zone. This site was near a group camping site and may reflect campers moving into the non-camping zone for toilet use. However, sites where coliforms were recorded did not match the two sites where the human faeces signal coprostanol existed, and only coincided with the highest level of ammonia recorded in non-camping zone samples. This lack of correlation exists between all water quality parameters measured, suggesting different rates of degradation, retention and loss to the system. Total phosphorous, ammonia and total nitrogen levels were consistently high (exceeded Queensland water quality standards (EPA 2006) in all samples).

Groundwater in camping zones

In camping zones, thermotolerant coliforms were recorded in the groundwater of 13 of the 18 sample sites; 10 were at levels that exceeded Queensland's water quality standards (EPA 2006). Coprostanol was recorded at only four sites, and while three of these were associated with high coliform values, the other was associated with a zero coliform value. All other water quality parameters measured were extremely high, with the exception of nitrite, which was in low concentrations in 10 of the 18 sample sites. Again, correlation between parameters is weak.

Beach flows

The mean value for coliforms and total phosphorus from beach flow samples showed marked differences between non-camping and camping zones (camping zone mean values are more than double those from non-camping zones) (Table 3). Less extreme differences exist for phosphate and nitrite, although the maximum recorded value for all water quality parameters measured is much higher in the camping zone samples. However, all parameters exhibit extreme variation in values, both from camping and non-camping zones.

Table 3 Beach flow water quality parameters for non-camping and camping zones
Figures in bold indicate levels exceeding Queensland water quality standards (EPA 2006)

	Non-camping (n=10)				**Camping** (n=18)				**Times the average non-camping level**
	Mean	**Std dev.**	**Max**	**Min**	**Mean**	**Std dev.**	**Max**	**Min**	
Thermotolerant coliforms (cfu/100ml)	3.7	8.8	28	0	9.6	22.7	76	0	2.6
PO_4-P (µg/L)	39.4	33.5	125	10	48.9	50.0	237	<10	1.2
Total P (µg/L)	**53.9**	53.9	**178**	11	**153.1**	307.3	**1272**	<10	2.8
NH_3-N (µg/L)	**71.5**	51.0	**130**	<10	**70.2**	57.9	**185**	<10	1.0
NO_3-N (µg/L)	170.1	187.7	480	<10	173.3	190.4	558	<10	1.0
NO_2-N (µg/L)	9.6	6.2	19	<10	11.3	8.0	32	<10	1.2
Total N (µg/L)	**726.4**	436.8	**1775**	305	**752.5**	418.5	**2008**	335	1.0

For inorganic chemicals, most beach flow water samples exceeded Queensland water quality standards (Table 4), but not to the extent of the groundwater samples. However, total nitrogen levels were high in most of the samples. While thermotolerant coliforms were recorded in both the non-camping (40%) and camping (33%) samples, levels were well below the widely accepted standard of 150 cfu/100ml.

Table 4 Beach flow water quality parameters against Queensland water quality standards (EPA 2006)

	Non camping (n=10)	**Camping** (n=18)
Thermotolerant coliforms	No sample exceeded EPA standards.	
Total P	80% of sample sites exceeded the EPA standard for open coastal waters (20µg/L); 20% exceeded the standard for lowland streams (50µg/L)	94% of sample sites exceeded the EPA standard for open coastal waters (20µg/L); 11% exceeded the standard for lowland streams (50µg/L)
NH_3-N	70% of sample sites exceeded the EPA standard for upper estuarine (30µg/L)	62% exceeded the EPA standard for upper estuarine (30µg/L)
Total N	100% of sample sites exceeded EPA standard for open coastal waters (140 µg/L).	
	70% exceeded the EPA standard for lowland streams (500 µg/L).	72% exceeded the EPA standard for lowland streams (500 µg/L).

Beach flows from non-camping zones

Like the groundwater data, there is little correlation between any of the beach flow water quality parameters measured from non-camping zones; again suggesting different rates of degradation, retention and loss to the system, as well as mobility. In some samples only, total phosphorous and ammonia were high, while total nitrogen levels were consistently high (exceeded Queensland water quality standards (EPA 2006) in all samples). The low-level presence of thermotolerant coliforms in some samples may be attributable to shorebird activity; however, the low mean (9.2 cfu/100ml), when coliforms are present, compared with camping zone levels (28.8 cfu/100ml) suggests a possible residual relationship with past camping activity.

Beach flows from camping zones

Again, there is little correlation between camping zone beach flow water quality parameters measured. Total nitrogen and total phosphorus are consistently high in all samples, but only total phosphorus exceeds levels recorded from the non-camping area. Ammonia levels show a distinct difference between the January and February sampling periods (14.0µg/L versus 105.9µg/L), suggesting a time-related influence on this parameter.

Groundwater and beach flow relationships

Using the paired groundwater and beach flow data from the February samples, there is no strong correlation between any of the water quality variables measured for camping zones or non-camping zones, other than the beach flow values are generally lower. The exceptions (total phosphorus in both the camping and non-camping data, and nitrite in the non-camping data) can be explained by the small sample and high variability in recorded values. However, assuming the data are reliable, then the results suggest either a simple dilution effect along with a delay in the water quality parameters reaching the beach flows, loss of some inorganic chemicals to plant uptake and as gas, or retention in the organic-rich upper part of the watertable.

Discussion

The high variability in the data and the lack of correlation between variables suggest that measured water quality parameters disperse, degrade and transport differentially, temporally and spatially, through the sand above the watertable during rain events, as well as when under the influence of groundwater flow to the beach (Figure 2).

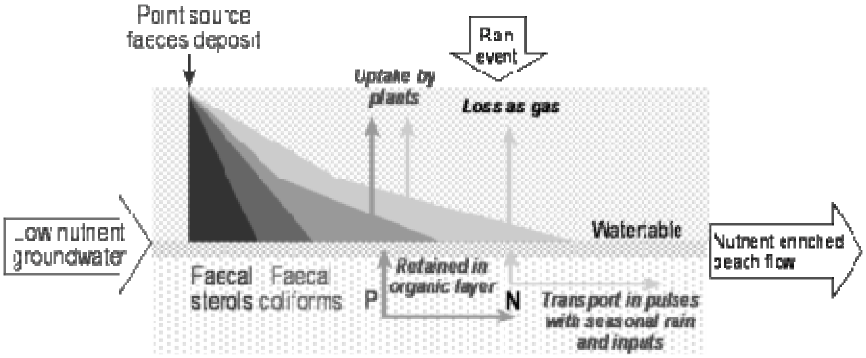

Figure 2 Model of the distribution of water quality parameters measured

The human faecal sterol coprostanol is a 'hotspot marker', and remains stable for weeks to months, binding to sand. Therefore, it is spatially contained. The presence of thermotolerant coliforms indicates faecal contamination; however, coliforms normally survive for little more than a fortnight in sand, although it has been shown that they can have extended lives, and indeed multiply, in brackish sands (Fujioka 2001; Gabutti *et al.* 2000; Desmarais 2002; Hartz et al. 2008), with longevity further enhanced by small particle size and high organic carbon (Craig *et al.* 2000). This makes them available for transport within groundwater, although temporally constrained. Dissolved nutrients are more permanent in soil systems than coliforms and more labile, and hence can travel further in groundwater. However, they can also be diluted, transformed or lost to the system through uptake by plants or conversion to gaseous forms. In addition, they can attach to organic matter and therefore remain 'locked' within the system. These temporal, spatial and transformative characteristics of the measured water quality parameters go some way to explain the variability in results. For example, if sampling occurs near the point, and shortly after the time of faecal contamination, nutrients, coliforms and sterols are likely to be detected. If sampled a few meters away, a short time after contamination, only nutrients and coliforms that have travelled further than the sterols are likely to be detected. However, if sampling occurs at the point of contamination, a month after the event, then possibly only sterols and nutrients that have not been transported from the point source will be detected. The three types of indicator have the same root cause; however, depending on the time and location of the sampling in relation to the point source of contamination, different indicators will be found.

Based on all water quality variables measured, there is a clear difference in the quality of the groundwater between camping and non-camping zones. This persists, but to a much lesser extent, in the beach flows from these areas. The variation from the 'pristine', caused by human waste disposal is amplified if the data are compared with the water quality of creeks whose source is the watertable cut by 'up-stream' swales behind the camping areas (Table 5). Because of their location and the source of water, these creeks probably reflect the baseline groundwater condition under the island. Water quality parameters in the groundwater below non-camping zones are considerably higher than creek values, with the camping zones being an order of magnitude higher again. The beach flows show a similar degraded state when compared with the creeks, although the difference between the non-camping and camping zones is less distinct (Table 5).

Table 5 Groundwater and beach flow water quality parameters for non-camping and camping zones times compared with values recorded in creeks

	Groundwater		**Beach flows**	
	Non-camping	**Camping**	**Non-camping**	**Camping**
Thermotolerant coliforms	3	107	1	3
PO_4-P	5	7	4	5
Total P	4	14	4	13
NH_3-N	66	106	14	14
NO_3-N	15	111	24	25
NO_2-N	2	4	2	2
Total N	7	12	4	4

The presence of elevated water quality parameters in the groundwater of non-camping zones suggests that a residual of pollutants exists in the watertable from past camping, permitted by a previous unrestricted beach camping management policy. While the change in policy appears to have had a considerable effect in improving groundwater quality, high levels of inorganic nutrients remain in the system, possibly bound to organic material at the surface of the watertable. The sand both above and below the watertable appears not to be acting as an inert sieve through which rainwater and groundwater flows freely flush dissolved nutrients and solids out of the dunes to the sea. Instead, organic solids are being filtered and act as a base to which inorganic nutrients and coliforms attach to form a sink of nutrient enriched subsurface soil, whose nutrients are available for use by plants. The implications for plant floristics and structure with the shift from low nutrient status foredune sands to sandy soils, where nutrients are freely available, may be profound (see Schlacher *et al.* 2008).

However, the effects of elevated groundwater nutrients probably extend beyond the dunes. Where groundwater meets the sea, watertable levels are affected by the tides, as salt water at high tide acts as a bund to freshwater flow (Emery & Foster 1948). At low tide, the bund is removed and a pulse of nutrient rich groundwater is discharged across the beach (see Uchiyama *et al.* 2000;

Boehm *et al*. 2006; Connors 2007). Such nutrient inputs can result in changes to the composition of marine algal communities (see Campbell & Bate 1998) and other meiofauna that live in the sand (Mosisch & Arthington 2001). On Fraser Island, the seasonality of beach camping and rainfall means that the effect of nutrient rich pulses of groundwater on the littoral sand biota may be exacerbated. But like the effects on terrestrial biota, this can currently only be speculated.

Conclusion

The Great Sandy Region Management Plan acknowledges the threat that beach camping may pose to the long-term ecological health of the foredunes of Fraser Island. By 2010, management aims to "achieve ecological sustainability by reducing the environmental impacts of camping and beach camping in particular" (EPA 2005). This study suggests that the achievement of this aim is unlikely because of potentially chronic changes in the nutrient status of the foredune watertable. Beach camping and associated dune disposal of human waste appears to be closely associated with elevated faecal coliform levels and persistent elevated nutrient levels in the groundwater. This association extends to beach flows from camping zones. While the risk to human health is probably acceptable, the extent of the ecological threat and the spatial and temporal dynamics of the system remain speculative.

Given the economic, recreation and tourism significance of beach camping to Fraser Island, a ban on beach camping is probably politically and socially untenable. Equally, the capital cost of providing appropriate toilet facilities, when the level of ecological risk is uncertain, makes this option difficult to justify; especially when such action would have significant aesthetic impacts and shifts in recreation opportunities. However, the requirement for campers to bring and use portable toilets is a management intervention that has been applied to nearby mainland beach camping areas (e.g. Noosa North Shore). Application of this approach, like elsewhere, would probably attract short-term public and political outcry and create long-term compliance issues for management. So none of these approaches to responding to the apparent threat identified in this study are easily justified.

The option of 'resting' some camping zones, with part or complete temporary closures during off-peak periods, may have some merit in possibly arresting further decline in these areas, while loading nutrient inputs into sacrificial zones. With the high level of ecological uncertainty surrounding the dynamics of nutrients in the watertable and ecological effects, selection of suitable rest and sacrificial areas is problematic. The no-change to management practice option assumes that dilution is the solution, but this appears to be wishful thinking.

Which approach or combination of approaches is applied needs to be supported by evidence of efficacy of action to mitigate further deterioration and remediate existing deterioration. With pristine, closed, intensely used and low use camping zones, as well as intermittent use, beach camping on Fraser Island represents an ideal case for an experimental adaptive management approach to gain information to inform decisions. Armed with a better understanding of the nutrient dynamics of the dune system and ecological effects, ammunition will exist to defend whichever management approach is ultimately applied and target achievement of management aims for camping.

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