MSc Land and Ecological Restoration

Research Project

The effect of dog waste on the sand dune habitats of Upton Towans, St Gothian Sands and Lethlean Towans.

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Abstract

1. There is a conflict between the use of the sand dune system between Hayle and Godrevy for recreation purposes, primarily dog walking, and its conservation due to substantial amounts of dog waste being left in the environment. This is thought to negatively impact dune soil and its vegetation altering conditions to favour invasive vegetation, stabilising dune soils and threatening the loss of dune habitat through succession to scrub.
2. Soil nitrogen, phosphorus, pH and vegetation were compared across areas of high and low activity and between soil samples collected beneath dog waste and without dog waste.
3. There were significant differences between levels of soil phosphorus in all areas but not with levels of soil nitrogen. pH varied significantly between dog waste and non-dog waste soil samples but not between high and low activity areas.
4. Leaching rates of phosphorus from dog waste increased over time but did not increase for leached nitrogen.
5. There were significant differences in sward height between high and low activity areas but no significant differences in desirable and undesirable dune vegetation. High activity areas showed a higher proportion of taller vegetation and pathway whilst low activity areas showed a higher proportion of short (grazed) vegetation and bare ground.
6. Synthesis and applications: Substantial amounts of dog waste are altering the sand dune habitat threatening its loss to scrub from invasive vegetation. Information gained from this study can be used to improve public awareness with educational campaigns to reduce levels of dog waste left in the environment whilst informing improved management practices to prevent or mitigate issues from recreational use.

Keywords

Nutrients, Nitrogen, Phosphorus, pH, Sward height, Dog, Dog waste, Vegetation, Dune soil, Leaching, High/low activity, Disturbance, Invasive

1 Introduction

Coastal dune habitats are a complex habitat type (JNCC, 2007) that in the UK cover between 11-14% of the land (Natura 2000) with many designated as SSSIs (Site of Special Scientific Interest) or SACs (Special Area of Conservation) due to their rarity and hosting rare or threatened species. They provide a habitat to one of the UK's rarest vertebrates, the Sand Lizard (*Lacerta agilis* L.*)* which require bare sand to lay their eggs (House and Spellerberg, 1983), and are protected under the Wildlife and Countryside Act as well as being classified as a Priority Species in the UK Biodiversity Action Plan. The habitat is also important for many nationally scarce invertebrates such as the Silver-studded blue butterfly (*Plebejus argus* L.) (Howe *et al.,* 2010). They also play a role in coastal flood defenses providing a barrier between the land and sea, protecting the land beyond.

Coastal sand dunes develop where there is a good supply of sand in the intertidal zone and where onshore winds are common. This is aided by the presence of a sufficiently large beach plain whose surface dries out between high tides. The dry sand is then blown in towards the land and deposited above the high-water mark and trapped by specialised dune-building grasses that grow up through successive layers of deposited sand (Cornwall Wildlife Trust, 2010). Dune systems have various sequential stages that evolve with distance from the shore, embryo dunes, mobile dunes, semi-fixed and fixed dunes, dune slacks and dune scrub (figure 1). Fixed dune grassland, where this study occurs, forms closed swards where sand accretion is no longer dominant, the surface has been stabilised and some soil development has taken place.

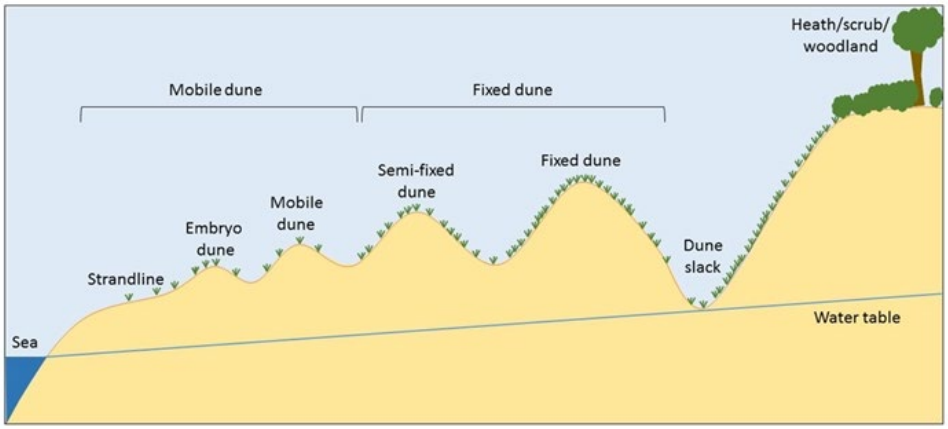

Figure 1. Dune lifecycle (Dynamic Dunescapes, 2021).

Atlantic dune (Mesobromium) grasslands, the main type found in the UK, are characterised by dry, calcareous grasslands, poor in nitrogen and are typically rich in floral species of calcareous substrates (Rodwell, 2000). Atlantic dune grassland consists of short sward vegetation with Red fescue (*Festuca rubra* L.) and Lady's bedstraw (*Galium verum* L.) and in the southwest of England wild thyme (*Thymus polytrichus* Borbas) (Houston, 2008).

They are popular recreational areas due to the attractiveness of the site for outdoor activities like dog (*Canis familiaris* L.) walking, horse riding, sun-bathing, and picnicking. These uses are not detrimental at low activity levels but when visitor numbers are high and sustained, damage can occur to the fragile, low-nutrient environment and create issues for those managing and conserving these sites. The ephemeral and low-nutrient nature of dune systems means that even without excessive recreational uses the habitat can be susceptible to elevated levels of erosion, compaction and nutrient inputs which can alter an ecosystem trajectory leading to the eventual loss of the habitat as environmental conditions change or stabilise and scrub and woodland encroach.

The pressures from recreational activities, namely dog walking, have steadily increased with time and, considering the COVID-19 pandemic, have only become more acute with the increasing popularity of the "staycation" (Day, 2020), driving up visitor numbers. With increased visitor numbers comes an increased incidence of dog waste deposition due to some dog owners not picking up their canine faecal deposits as current

legislation requires (Clean Neighbourhoods and Environment Act, 2005). However, this can also be accounted for by a lack of awareness as it has been shown that a dog-walkers contextual perception can play a role in the amount of dog waste deposited and not picked up (Lowe *et al.,* 2014) as they may consider it acceptable to not pick up and dispose of their dog waste responsibly when in a “natural” setting.

Threats to, and pressures on these sensitive habitats are numerous and can lead to changes in nutrient availability and species richness and composition and eventual succession and loss of the dune habitat. Coastal vegetation is known to be extremely sensitive to nitrogen deposition (Pakeman *et al.,* 2016) and an increase in nitrogen input can lead to the domination of tall grasses in stable dune grasslands (van den Berg *et al.,* 2005) and a reduction of plant species richness (Jones *et al.,* 2004). An increase in nitrogen can lead to an increased risk of local plant extinctions (McClean *et al.,* 2011) and for this reason can be considered as a threat to terrestrial ecosystems (Field *et al.,* 2014).

Manures are a form of nutrient enrichment (Edmeades, 2003) so it is assumed dog faeces act in the same way, but this has not been quantified. If this is the case then it may contribute to succession and the growth of invasive species, potentially leading to a reduction in these rare habitats as they can be sensitive to environmental change (Rust and Illenberger, 1996; Hansom, 2001), therefore an understanding of how dog fouling affects nutrient-poor habitats would be beneficial to the improved management of these habitats. Dog faeces contains approximately 0.7% nitrogen (N), 0.25% phosphorus (P) and 0.02% potassium (K) (Jaber, 2012), which are low levels of nutrients but in substantial amounts and in the low nutrient soil of dune systems, this can accumulate to have detrimental effects on flora. Dog faeces were also shown, through weathering, to be a source of pathogenic bacteria on a beach and in a playing field’s soil (Jaber, 2012; Wright *et al.,* 2006).

This nutrient enrichment encourages succession and can also enable invasive species, that would normally be constrained by the nutrient-poor soils, to outcompete native flora (Plassman *et al.,* 2009). A lack of management or grazing disturbance can also allow shrub species to encroach and stabilise the dunes (Pye *et al.,* 2014) leading to

succession and the establishment of invasive species. Succession on the dune system will lead to the stabilisation of this dynamic environment by the encroachment of scrub and woodland leading to a loss of this rare and ecologically important habitat (Provost *et al.,* 2011). Recreational pressure from trampling has also been shown to be detrimental (Hylgaard and Liddle, 1981), though there is some evidence suggesting a small amount of soil compaction can be beneficial to certain dune flora (Plantlife International, 2005).

There is currently no published literature on the effects of dog faeces on dune habitats, however, there are numerous studies which have focused on how dog faeces may contain bacteria and parasites due to human health implications (Mandarino-Pereira *et al.,* 2010; Paoletti *et al.,* 2015), and the contamination potential of faeces on water sources (Ervin *et al.,* 2014).

Grazing, primarily by rabbits (*Oryctolagus cuniculus* L.), maintains the short species rich grasslands characteristic of coastal dunes with topography, aspect, slope, soil condition differences and bare sand patches contributing to this diversity. Without this disturbance natural succession would lead to a continuous sward of grasses and the establishment of scrub, then woodland. Ranwell (1963) found that the loss of rabbits from the myxomatosis virus in the 1950s lead to changes in vegetation and the growth of scrub on many sites as the rabbit activity of grazing, burrowing, trampling, and dunging were key factors in the maintenance of the habitat and its heterogeneity. Grazing induces spatial heterogeneity and maintains successional stages with high numbers of species (Gibson, 1988), with species richness highest at intermediate levels of rabbit pressure (Zeevalking and Fresco, 1977) showing rabbits play a significant role in the maintenance of the dune vegetation.

Dogs will likely influence rabbit behaviour as they avoid grazing in their presence. Furthermore, the presence of dog faecal matter may also influence grazing behavior even without the presence of dogs due to the odour of a predator persisting. One study of Red foxes (*Vulpes vulpes* L.) found they were highly interested in the odour of wild dogs suggesting that odours are likely to play a significant role in mediating competitive interactions (Banks *et al.,* 2016) but would also lead to a higher incidence of fox incursions putting further pressure on grazing behaviour.

Human activity, primarily trampling of flora and compaction of soils, has negative impacts on the dune system (Isermann and Krisch, 1995) but Anderson (1995) found that intermediate trampling can support species richness and so levels of human use will have a significant impact on floral species composition and richness, however, this influence will vary widely depending on floral species and soil type.

There is also a risk of human and dog activity introducing non-native species. One invasive plant causing a problem locally on Penhale dunes is a popular ornamental plant Crocosmia (*Crocosmia montbreata* Lemoine) which has 'escaped' from areas it was introduced and cultivated and is now a problem in some UK dune habitats. It is capable of flourishing in a range of soil types and conditions and aggressively outcompetes natives for nutrients and water, as well as having dense foliage and underground corns that push out other plants (Dynamic Dunescapes, 2021).

The soil type of coastal dunes plays an influential role in the leaching of nutrients to maintain the nutrient poor soils characteristic of this habitat. Sand grain size, organic matter content and calcium content are the main factors determining this leaching and vary across Europe (Houston, 2008). Dune systems that overlie shingle formations, known as 'dry core systems' have a high rate of leaching and more acidic conditions can form close to the fore dunes (Rhind *et al.,* 2006). Soil development can also lead to a larger retention of nutrients but is countered by several processes. In young moss-dunes physical humus erosion can be considerable, but in more stable grassland the main losses of soil organic matter are due to biochemical decomposition (Houston, 2008). Dune soils which have stabilised can decalcify through continuous carbonate leaching, though the process is slowed by the movement of sand sheets, blowouts, and the light rain of sand characteristic of dunes on exposed coasts (Provoost *et al.,* 2004). Nitrogen and phosphorus are key elements of plant growth and so are partly co-limiting in the nutrient dynamics of grey dunes (semi-fixed dunes) (Kooijiman *et al.,* 1998).

Plant communities can vary on north and south facing slopes with some species being confined to specific zones, for example, grey hair-grass (*Corynephorus canescens* L.) on south slopes and crowberry (*Empetrum nigrum* Hagerup*)* and common polypody

(*Polypodium vulgare* L.) on north slopes (Houston, 2008), which will play some role in influencing soil conditions, stability and vegetation composition.

Soil type, micro-climate, precipitation, underlying rock type, floral species and even faecal constituents will all influence the retention and cycling of nutrients in the soil and will play some role in the effect nutrients released from dog waste will have on the dune habitat and for how long.

It is currently unknown what effects the deposition of substantial amounts of dog waste has on the soil, floral composition, and vegetation type in sand dune habitats and for how long the added nutrients (N and P) and pH changes persist. Quantifying these effects will contribute to better management of visitor numbers, protecting the more sensitive areas of the habitat and raising public awareness of responsible dog walking in sensitive sand dune habitats.

1.1 Hypothesis

1. The substantial amounts of dog waste deposited in the sand dune environment is increasing the availability of nitrogen and phosphorus and altering the pH of the calcareous low nutrient soil.
2. The increased nutrient availability and altering of pH is leading to a reduction in dune adapted vegetation, an increase in invasive vegetation, and a change in dune vegetation type, threatening the loss of the dune habitat to scrub and woodland.

2 Methods

2.1 The Study Sites

Study sites were zones within the larger sand dune ecosystem that stretches from Hayle estuary (50.19256°N 5.43111°W) in the west to Godrevy headland (50.19256°N 5.43111°W) in the north comprising the second largest area of sand dunes in Cornwall with a coverage of 5.5km^2. These dune systems are split into smaller areas each with their own identity.

The dunes formed around 5000 years ago and have since been used by people to live, graze animals, harvest food and more recently for industrial purposes with Upton Towans being a site of explosives production from 1888 to 1920 and St Gothian Sands being a site of sand extraction for minerals from 1944 to 2005. These industrial activities played a significant role in shaping much of the landform seen today with square dunes still present at Upton Towans and the lagoon created for wildfowl when sand extraction ceased at St Gothian Sands. Contemporarily, they are primarily used for recreational activities, although many people still live on the dune systems.

Upton Towans falls within the Gwithian to Mexico Towans SSSI and both Upton Towans and St Gothian Sands are designated Local Nature Reserves (LNR) and County Wildlife Sites (CWS). Lethlean Towans is privately owned but there is public right of way through some of the area. Upton Towans is owned and managed by Cornwall Wildlife Trust and St Gothian Sands by Cornwall Council. There are multiple landowners on the entire dune system with most of them participating in the Dynamic Dunescapes project which aims to monitor and manage the health of the dune habitats through community participation and citizen science whilst another organisation, The Towans Partnership aims to bring together landowners, local government, government agencies and other parties interested in protecting, managing, and enhancing the Towans. Management of these sites consists of seasonal grazing of ponies and the cutback of scrub for the purposes of disturbance to control the proliferation of scrub and invasive species. Strategically placed signage also informs the public of best practice dune behaviour and dog waste bins are placed at busy dune access points.

The Towans and St Gothian Sands are important for wildlife hosting one fifth of the flora found in Cornwall (Cornwall Council, 2021) as well as hosting rare and endemic species e.g., Petalwort (*Petalophyllum ralfsii* Wils.). National Vegetation Classification (NVC) gives sand dunes the code of H6.1-7 depending on the stage of the dune lifecycle.

Four areas were chosen as study subjects due to their dog walker activity levels, Lethlean Towans (low activity), Upton Towans (high activity), St Gothian Sands (high and low activity). All study areas were the same size at 0.2km^2 and located within the fixed dunes zones of the overall dune habitat for consistency and like for like comparisons (figure 2).

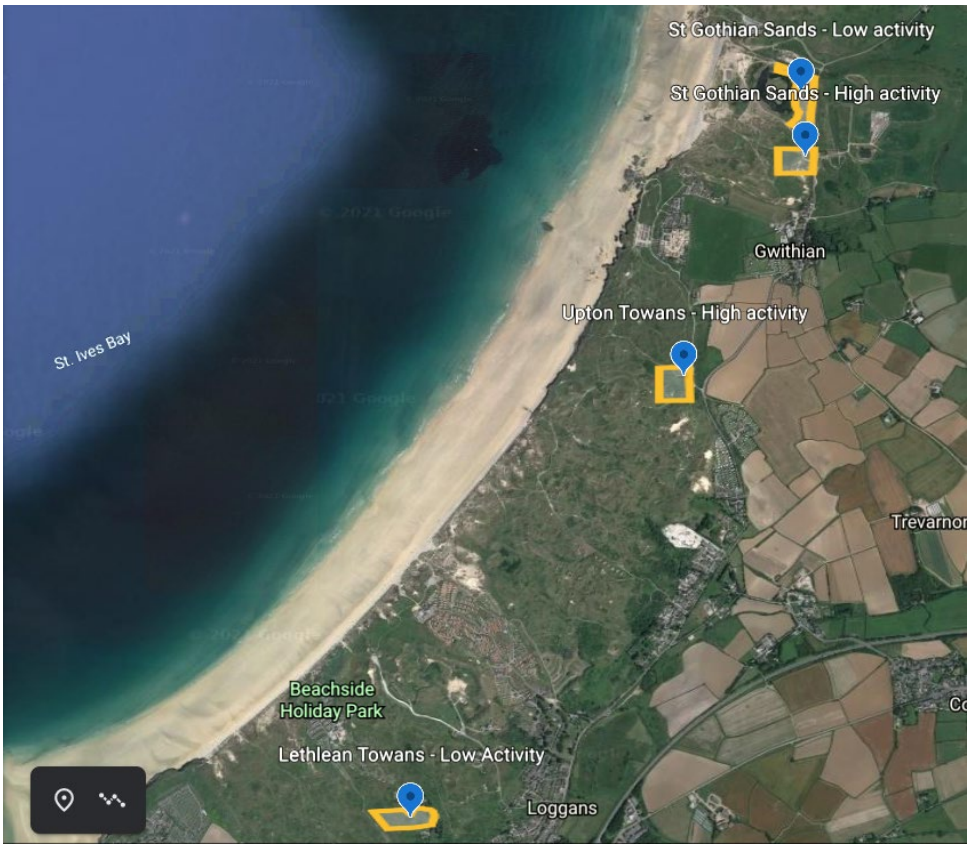

Figure 2. The four study sites of Lethlean Towans, Upton Towans and St Gothian Sands. © Google Earth, 2021.

Lethlean Towans (figure 3) is a privately owned area of the dune systems with some public right of way. It was chosen as a low activity area due to its extremely low

incidence of visitor numbers with only one member of the public (without a dog) observed in one and a half months of data collection.

Figure 3. Lethlean Towans – low activity area. Google Earth, 2021.

Upton Towans (figure 4) is a publicly accessible area of the dune system owned and managed by Cornwall Wildlife Trust. It is situated adjacent to the B3301 and has two free car parks. The ease of access to this part of the dune system makes it desirable for dog walkers so for this reason it has been designated a high activity area. This high activity was observed during data collection and was further confirmed by the high incidence of dog waste within the area.

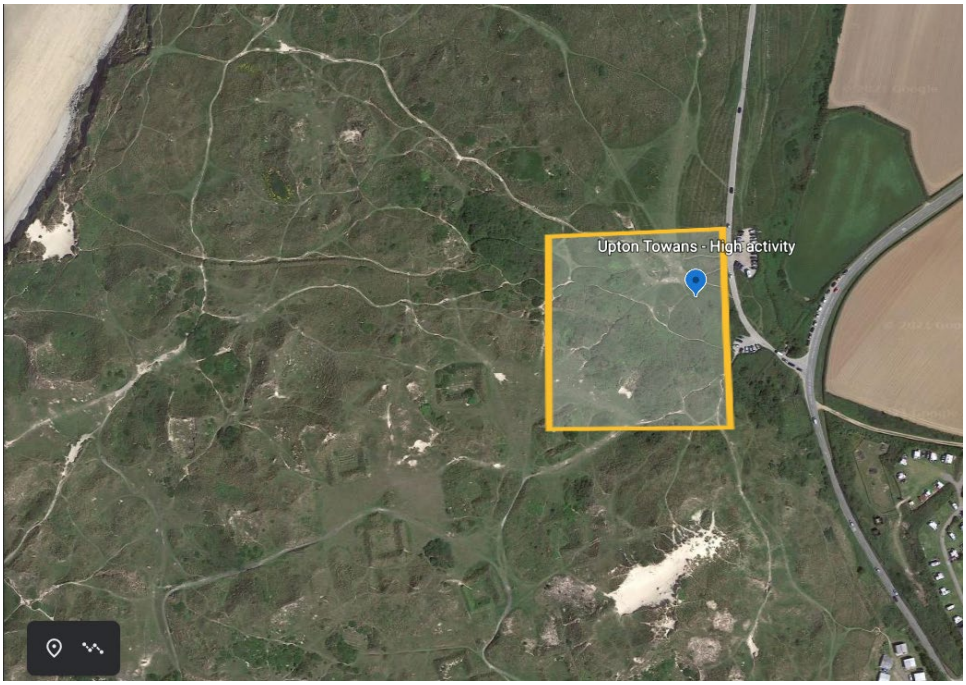

Figure 4. Upton Towans – high activity area. © Google Earth, 2021.

St Gothian Sands (figure 5) is a publicly accessible area of the dune system owned and managed by Cornwall Council. It is also situated adjacent to the B3301 and has a free car park and car parking lay-bys. The ease of access makes it desirable for dog walkers and for this reason has been designated a high activity area. This high activity was again observed during data collection and further backed up by the incidence of dog waste within the area.

Figure 5. St Gothian Sands – high activity area. © Google Earth, 2021.

St Gothian Sands also contains a lagoon area for wildfowl which has been fenced off from public access to minimise wildfowl disturbance from people and dogs (figure 6). The lagoon has an area of land adjacent to it which is also part of the fenced off area so has no human or dog activity. This was further confirmed during data collection as no people or dogs were observed in the area over the month and a half on site.

Figure 6. St Gothian Sands – low activity area. © Google Earth, 2021.

2.2 Data Collection

2.3 Soil samples from beneath dog faeces

Due to the low activity areas having restricted public access or negligible visitor activity dog waste was only observed in the high activity areas so these areas were where the dog waste searches were focused. To obtain soil N, P and pH levels and corresponding nutrient leaching rates from the dog waste, data collection occurred over a four-week period. At the beginning of week one all existing dog waste deposits were marked out with biodegradable spray paint so as not to be included in the proceeding dog waste searches as the length of time the deposit had been there could not be verified. At the end of week one another dog waste search was undertaken, with all unmarked dog waste found considered deposited in the first week. These then had their GPS (Global Positioning System) coordinates recorded using the android application GPS Test, and a white flag put next to it as a visual aid for relocating the deposit with ease. The process of dog waste searches and recording of position was repeated in the proceeding three weeks and at the end of week 4 five deposits from each of the four weeks were located and soil samples taken from beneath each. Soil samples were

retrieved using a hand trowel to dig to a depth of 15cm and the soil beneath retrieved for laboratory analysis.

2.4 Soil samples from all study areas

To act as controls and comparisons 10 soil samples that were not beneath dog waste were also taken from each area at the end of week four for laboratory testing. This was achieved by taking 10 randomly selected soil samples from each area using a hand trowel to dig to a depth of 15cm and the soil sample retrieved.

2.5 Quadrats and sward height

During the second week 10 quadrats per area were undertaken to determine if species present were desirable, undesirable, or unknown to coastal sand dune habitats. Desirable flora includes species such as *Galium verum* (Lady's bedstraw) or *Euphrasia* spp. (Eyebright), undesirable flora includes species such as *Urtica dioica* (Common nettle) or *Rubus fruticosus* agg. (Bramble), and species unknown to dune health such as *Daucus carota* (Wild carrot) or *Pilosella officinarum* (Mouse-ear hawkweed) (Dynamic Dunescapes, 2020). Average sward height per quadrat was also recorded. Quadrats were 0.5m^2 and randomly selected for each area by gridding the area and assigning each grid a number. Numbers were then randomly generated using the excel random number generator with the numbers generated matched with area grid numbers with the quadrat survey undertaken in the corresponding grid. The quadrat's GPS position was then recorded and all species within the quadrat were identified, recorded, and categorised to ascertain the number of desirable, undesirable, or unknown plant species to coastal sand dunes. Bare ground was also recorded as this is an indicator of the health of dune habitat due to stabilisation of the dune soils leading to an increase in vegetation and reduction in bare ground (Dynamic Dunescapes, 2021). Mean sward height was recorded by taking 5 vegetation height measurements within the quadrat, four at each corner and one in the middle.

2.6 Transects

During the fourth week 10 transects per area were walked to determine the dominant vegetation type based on a classification of bare ground, pathway (bare ground or

trampled vegetation), short vegetation (very short or grazed vegetation e.g., *Galium verum* (Lady's bedstraw)), long grassland (tall shrubs or long grasses e.g., *Dactylis glomerata* (Cock's-foot)) and scrub (e.g., *Ulex europaeus* (Gorse)). All transects were 100m long and 5m across (500m^2) meaning 5000m^2 of each area was surveyed. Transects were walked from random starting points and parallel to each other to avoid overlap with each transect divided into 2.5m sections and the dominant vegetation type of each section recorded. The total of each vegetation type for each area was then calculated.

2.7 Soil laboratory analysis

All soil samples obtained from the study sites were sieved to remove vegetation and organic material and laboratory tested for pH and levels of nitrogen and phosphorus.

2.8 pH

3g of each sample were placed in falcon tubes and 30ml of deionised water added. They were then placed in a shaker for 10 minutes. Once shaken a benchtop Genway 3310 pH meter probe was placed in each and the pH recorded.

2.9 Nitrogen

N levels (g/kg) of each sample were obtained using the Agrocares near infra-red spectrometer – range: 1300-2550nm MEMS technology.

2.10 Phosphorus

P levels (mg/kg) of each sample were obtained using prepared reagents and following the prescribed schedules provided by LaMotte (Chesterton, MD, USA, www.lamotte.com) for use with their LaMotte Smart 3 colorimeter. Minerals were extracted from soil samples using the standard acid extraction method followed by the Schwarzenbach EDTA method for Ca analysis, and the ascorbic acid reduction method deploying the low range colorimeter setting for P04 analysis.

2.11 Data analysis

All statistical analysis was carried out using the statistical program RStudio version 1.4.1717 (available at https://www.rstudio.com/). Shapiro-Wilk tests were carried out to test the data for normality with some data normally distributed and some not, therefore non-parametric tests were used in the analysis of the datasets.

Areas were grouped based on activity level and the presence of faeces into “High Activity – faeces", “High activity” and “Low activity” areas. Kruskal-Wallace rank sum tests were used to determine if there were any differences in soil N, P, and pH between the three groups. Evidence was found that area affects soil P and pH so post-hoc pairwise analysis was carried out using the Dunn test.

To test for levels of undesirable species between areas of high and low activity, Pearson's Chi-squared test with Yates' continuity correction was carried out.

To test for differences in sward height between high and low activity areas data was plotted using a normal Q-Q plot and found to be non-linear, therefore a Mann-Whitney test was used as data was non-parametric and a Wilcoxon rank sum test with continuity correction was performed.

To test for differences in scrub, long grassland, bare ground, and grazed vegetation types in high and low activity areas a chi-square test was carried out as the data was in the form of counts.

3 Results

3.1 Soil nitrogen

Mean soil N (table 1) did not vary significantly across the three grouped area types (high activity-faeces 3.87g/kg, high activity 3.99g/kg, low activity 3.90g/kg) with range and median soil N also not varying significantly (figure 7). Shapiro-Wilk tests for normality across the three grouped areas showed data to be mostly non-normally distributed (high activity-faeces $p<0.05$, high activity $p>0.05$, low activity $p>0.05$). A non-parametric Kruskal-Wallis rank sum test was performed (Kruskal-Wallis, chi-squared = 0.75, df = 2, p-value = 0.69), showing no evidence for a difference in mean soil N levels between any of the grouped areas.

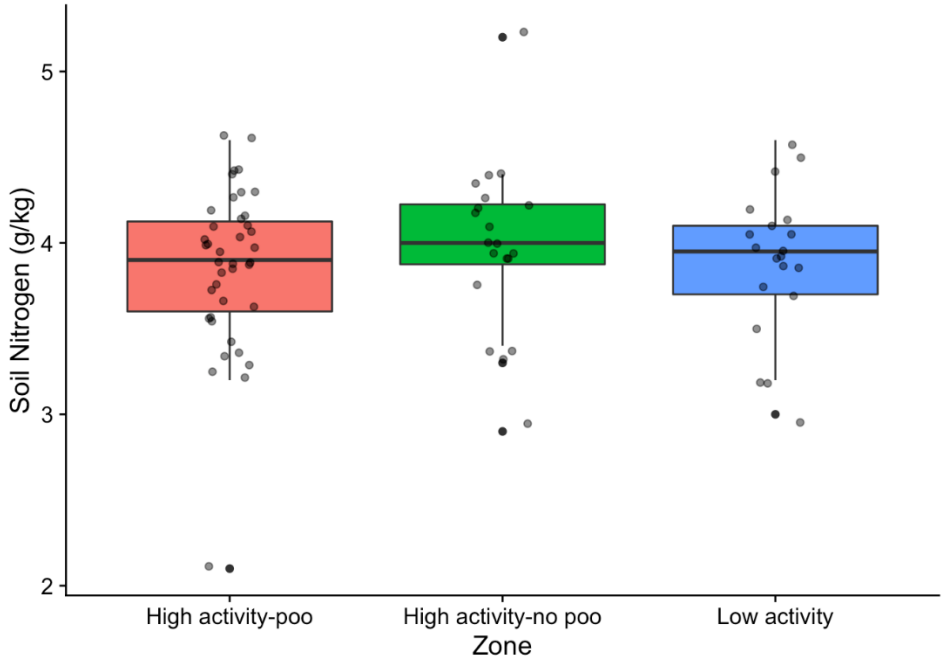

Figure 7. Boxplot of soil N (g/kg) and grouped areas of high activity-faeces, high activity, and low activity showing the median, range, and upper and lower quartiles of the data.

Activity level & faeces/no faeces	Mean soil N (g/kg)
High activity-faeces	3.87
High activity	3.99
Low activity	3.90

Table 1. Mean soil N.

3.2 Soil phosphorus

Mean soil P (table 2) varied significantly across the three grouped area types (high activity-faeces 4.99mg/kg, high activity 2.12mg/kg, low activity 0.27mg/kg) with range and median soil phosphorus also varying significantly (figure 8). Shapiro-Wilk tests for normality across the three grouped areas showed data to be normally distributed (high activity-faeces $p<0.05$, high activity $p<0.05$, low activity $p<0.05$). A non-parametric Kruskal-Wallis rank sum test was performed (Kruskal-Wallis, chi-squared = 30.69, df = 2, $p<0.001$) showing evidence that area affects soil P levels. Post-hoc pair wise comparisons using the Dunn test were then performed on the data showing that the soil P levels in high activity-faeces areas exceed that in high activity areas by 2.87 +/- 0.85 mg/kg ($p=0.023$), while the level in these in turn exceeds that in low activity areas by 1.85 +/- 0.5 mg/kg ($p<0.01$).

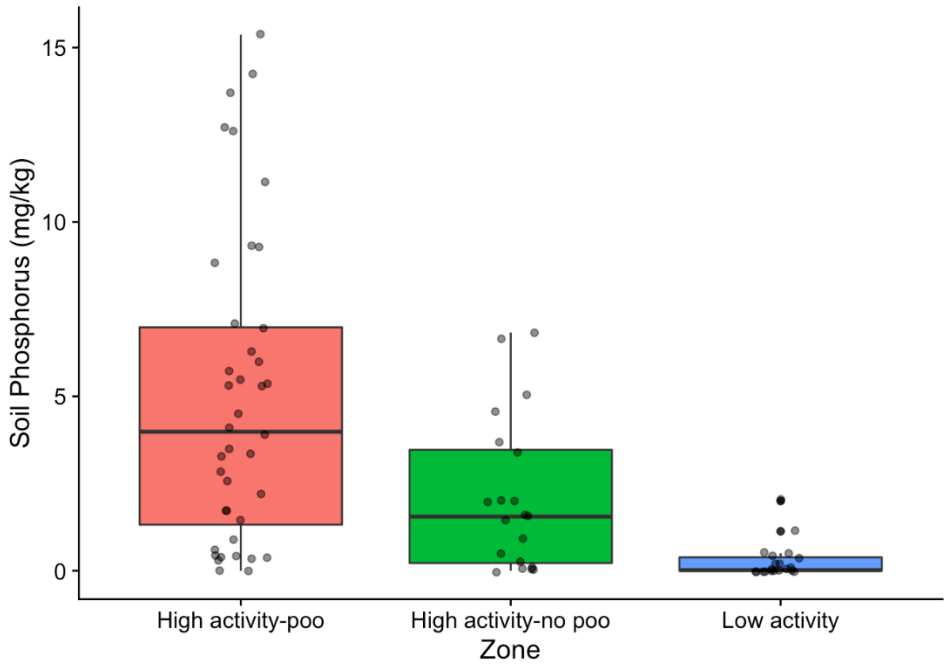

Figure 8. Boxplot of soil P (mg/kg) and grouped areas of high activity-faeces, high activity, and low activity showing the median, range, and upper and lower quartiles of the data.

Activity level & faeces/no faeces	Mean soil P (mg/kg)
High activity-faeces	4.99
High activity	2.12
Low activity	0.27

Table 2. Mean soil P.

3.3 Soil pH

Mean soil pH (table 3) varied significantly across the three grouped area types however the high activity and low activity means were similar (high activity-faeces pH 7.88, high activity pH 8.43, low activity pH 8.4) with median and range also varying significantly (figure 9). Shapiro-Wilk tests for normality across the three grouped areas showed data to be non-normally distributed (high activity-faeces $p>0.05$, high activity $p>0.05$, low activity $p>0.05$). A non-parametric Kruskal-Wallis rank sum test was performed (Kruskal-Wallis, chi-squared=48.4, df=2, $p<0.001$) showing evidence that area affects soil pH. Post-hoc pairwise comparisons using the Dunn test show that mean soil pH values are more acidic (pH 0.545 +/- lower) in high activity-faeces areas than in high activity areas ($p<0.001$) and they are also more acidic in high activity-faeces areas than in low activity areas by 0.52 +/- 0.064 ($p<0.001$). There is no evidence for a difference in soil pH values between high activity and low activity areas ($p=0.053$).

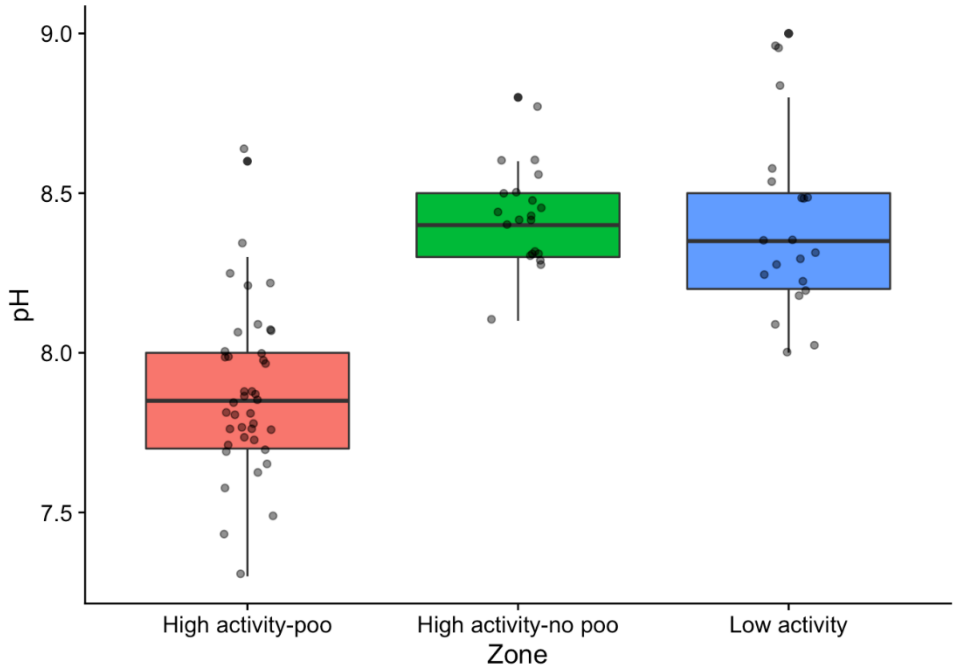

Figure 9. Boxplot of soil pH and grouped areas of high activity-faeces, high activity, and low activity showing the median, range, and upper and lower quartiles of the data.

Activity level & faeces/no faeces	Mean pH
High activity-faeces	7.88
High activity	8.43
Low activity	8.40

Table 3. Mean pH.

3.4 Desirable/undesirable sand dune vegetation

For the purposes of data analysis all flora identified when conducting quadrat surveys that could not be ranked as desirable or undesirable, due to no available information, were ranked with desirable flora. Pearson's Chi-squared test with Yates' continuity correction was performed and, on this basis, no evidence was found to suggest that high activity areas alter the proportion of undesirable to desirable species compared to low activity areas (Chi-Square, chi-sq=3.4, df=1, p=0.064). However, counts are less than 5 in one case (table 4), making the chi-square test unreliable.

Activity level	Undesirable Yes(Y) or No(N)	Count
High	N	49
High	Y	16
Low	N	41
Low	Y	4

Table 4. Desirable/undesirable vegetation count data.

3.5 Sward height

Mean sward height (table 5) varied significantly between high and low activity areas (high activity 335.20mm, low activity 159.45mm) with median and range also varying significantly (figure 10). Diagnostics of the data were run, and a normal Q-Q plot showed the data to be non-linear. A non-parametric Mann-Whitney test was performed showing evidence that high activity areas have higher sward height (mean height = 335 +/- 68 mm) than low activity areas (mean height = 159 +/- 47 mm) (Mann-Whitney, W=283, p=.0256).

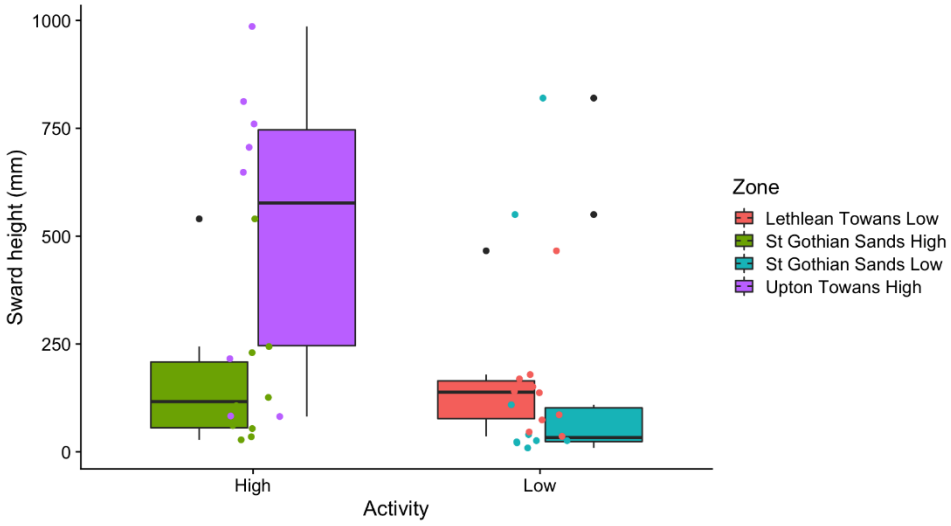

Figure 10. Boxplot of mean sward height and study areas showing the median, range, and upper and lower quartiles of the data.

Activity level	Mean sward height (mm)
High	335.20

Low	159.45

Table 5. Mean sward height.

3.6 Vegetation type

A Pearson's Chi-squared test was performed on the transect vegetation type count data (table 6) showing that the area affects the type of ground cover ($\chi 2 = 372$, df=9, $p<0.001$). Figure 11 provides a visual representation of the data showing higher levels of bare ground and short vegetation in the low activity areas, higher levels of bare ground and short vegetation in the low activity areas, higher levels of scrub and pathway in the high activity area, and similar levels of long grassland in both area types.

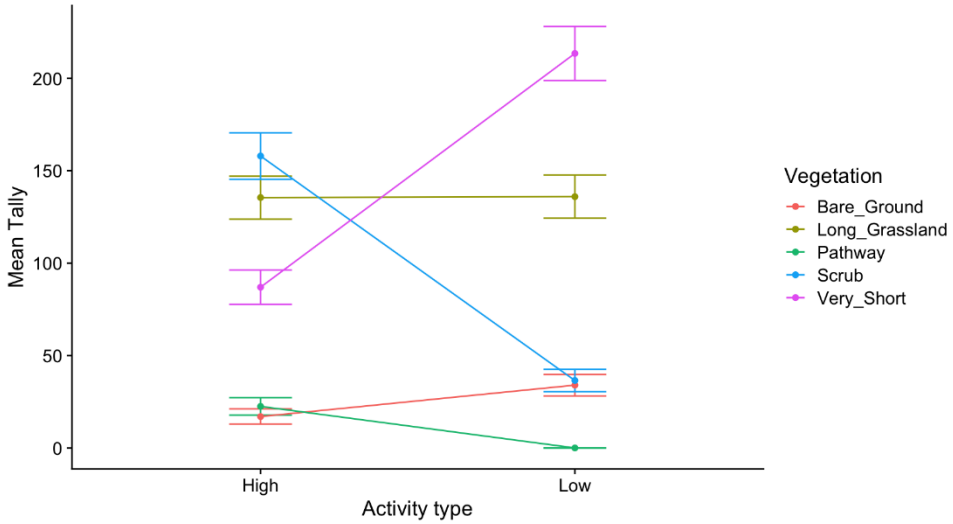

Figure 11. Pairs plot showing links of tallies of the same vegetation type in each of the activity areas.

Activity level	Bare ground	Pathway	Very short	Long grassland	Scrub
High	37	45	174	271	316
Low	68	0	427	272	73

Table 6. Transect vegetation type counts.

3.7 Nutrient leaching rates from dog waste

Leaching rates of N (Table7) into dune soils from dog waste did not vary between week 1-4 for both high activity areas. The leaching rates of P (table 8) did show a decreasing trend, however not consistently with week 2 being a lower value than week 4 in Upton Towans and weeks 2 and 3 being a lower value than week 4 in St Gothian Sands.

Area, activity level & week	Mean soil N (g/kg)
Upton Towans week 1	4.04
Upton Towans week 2	3.76
Upton Towans week 3	4.04
Upton Towans week 4	4.2
St Gothian Sands week 1	3.98
St Gothian Sands week 2	3.56
St Gothian Sands week 3	3.34
St Gothian Sands week 4	4.00

Table 7. Weekly soil N mean.

Area, activity level & week	Mean soil P (mg/kg)
Upton Towans week 1	9.88
Upton Towans week 2	4.96
Upton Towans week 3	7.71
Upton Towans week 4	5.39
St Gothian Sands week 1	6.62
St Gothian Sands week 2	1.64
St Gothian Sands week 3	1.64
St Gothian Sands week 4	2.05

Table 8. Weekly soil P mean.

3.8 NVC classification

Although a full Phase 1 habitat survey was not undertaken much of the surveyed vegetation from quadrats (appendix 1) was characteristic of coastal fixed sand dune and fell within the NVC classification for dune grassland of H6.5, however, the high activity

areas contained patches of *Ulex europaeus* (Gorse) more characteristic of the NVC classification for scrub A2.2.

4 Discussion

This study was undertaken to determine the impact of excessive levels of dog waste deposited on the low nutrient soils of coastal sand dune habitats, what effect this is having on dune soils pH and nutrient composition and if any changes in pH and soil nutrient composition can explain any differences in dune vegetation type and species. The hypothesis cannot be fully accepted as all the results did not reflect it entirely as it stated that the addition of dog waste was acting as a fertiliser, increasing nutrient availability, altering pH, and changing soil conditions leading to a reduction in dune adapted vegetation, an increase in invasive vegetation and loss of the dune habitat. Results indicate this is happening, but the process is more nuanced with some aspects of the hypothesis vindicated and some not.

The study found there was no significant difference in levels of N between all the areas contrary to published literature indicating the addition of manures acting as a form of nutrient enrichment. N levels are most prevalent nutrient within dog waste meaning there are other influencing factors acting on the prevalence and duration of N within dune soils. N is a key element of plant growth (Kooijiman *et al.,* 1998) and so it may be that N leached from dog waste is immediately taken up by plant roots. The nature of sand dune soils may be another influencing factor as sand grain size, organic matter content and calcium content are the main factors determining leaching (Houston, 2008). Dogs are also fed a variety of foods containing varying nutrient levels, so this coupled with the varying size of dogs and their corresponding faecal deposits may have meant the dog waste samples found did not contain high enough levels of nitrogen to influence soil nitrogen. This variance in dog faecal size and nutrient content is also a limitation as standardisation between samples was not achievable.

P levels were found to be significantly different between the grouped areas of high activity-faeces, high activity and low activity with levels decreasing respectively in line with published literature and indicating a negative impact on the low nutrient dune soils from dog waste. This is likely to influence dune vegetation as P is a key element of plant growth so is partly co-limiting in the nutrient dynamics of fixed dunes (Kooijiman *et al.,* 1998) meaning an excess will influence soil conditions making them more favourable for

invasive non-dune adapted vegetation and leading to an increase in undesirable vegetation which is evident from the desirable/undesirable species counts showing a fourfold increase in undesirable floral species in high activity areas. Calciferous dune vegetation is physiologically adapted to P limitations (Provoost *et al*,. 2004) meaning any increase in P availability will favour invasive vegetation. P has also been observed to increase root growth as a form of plasticity (Jackson *et al.*, 1990) which would contribute to the stabilisation of the dune soils, driving succession and an increase in undesirable scrub flora.

pH levels were found to be significantly different between samples located beneath dog waste and those not but not between high and low activity areas suggesting that the influence of dog waste on dune soils is localised to the dog waste deposit. Published literature states that the pH of a soil influences availability of nutrients, nutrient leaching, and soil structure (Gentili *et al.*, 2018, Perry, 2003) with increased plant growth in more acidic and sub-acidic pH's, which would lead to a reduction in dune adapted vegetation that requires more alkali calcareous soils (Provoost *et al*,. 2004). However, as the effect of pH reduction is localised to beneath dog waste the impact on dune soils and vegetation may not be so great, although it could provide a way in for invasive species. An interesting connection between soil P and pH is that P availability is pH dependent and shows an optimum at pH 5.2 in calcareous dunes in the Netherlands (Kooijiman and Besse, 2002) with P at higher pH's largely fixed in calcium phosphate making it a limiting factor in biomass production important for sand dune habitats (Provoost *et al*,. 2004) so lower pH's will be increasing P soil availability further exacerbating the already increased P levels from the dog waste and making conditions more favourable to undesirable invasive vegetation.

Statistical tests found no evidence activity levels and so levels of dog waste alter the proportion of desirable and undesirable vegetation, however, due to the low count number of the undesirable low activity vegetation the test was rendered unreliable. The count data does, however, show that undesirable vegetation increased fourfold in high activity areas compared to low activity areas. This can be linked to increases P availability as this can stabilise soils and favour invasive vegetation. An increase in

undesirable vegetation is also self-sustaining as N is overwhelmingly supplied by the decomposition of plant material in these habitats and would partly explain the encroachment of invasive vegetation, most likely stimulated by the deposition of atmospheric nitrogen, as once established, it is self-maintaining due to increased nitrogen mineralisation (Houston, 2008).

Mean sward height varied significantly between high and low activity areas showing a loss of dynamism as a reduction in short vegetation is an indication of a change in grazing regime (Dynamic Dunescapes, 2021) and increase in scrub vegetation, all leading to succession and a loss of dune habitat to scrub. Mean sward height in the high activity areas was more than double that of the low activity area showing clear evidence of the negative impact of high activity and the addition of dog waste making the conditions more favourable to invasive vegetation. Another factor influencing the increased sward height in the high use areas is the disturbance to grazers e.g., rabbits, by the increased presence of humans and dogs as grazers maintain the short sward vegetation characteristic of sand dune habitats. This is likely further exacerbated by the scent of dog waste affecting grazing behaviour even when humans and dogs are not present, as well as the scent of dog waste attracting wild fauna e.g., foxes also affecting grazing behaviour. A further study to examine the effects of dog waste scent on the grazing beahviour of rabbits would provide answers and contribute to improved management of the dune habitat.

Statistical analysis showed that activity level affected the dominant vegetation type in that area with greater amounts of scrub and pathway in high activity areas and higher amounts of bare ground and short vegetation in low activity areas. This is indicative of a loss of dynamism, increase in nutrient enrichment or a change in grazing regime and can be linked to increases in soil P levels, with mean sward height and levels of undesirable vegetation showing similar trends in the data. Long grassland count levels were similar at both activity levels which can be explained by a healthy dune system having a mix of long grassland e.g., Marram grass and grazed vegetation. The increase in amount of pathway in high activity areas to low activity areas is explained by the increased number of visitors creating and sustaining pathway whereas one low activity

area (St Gothian Sands – low activity) was completely closed off to public access so had no pathway.

One of the aims of the study was to ascertain nutrient leaching rates from dog waste into the dune soils over time and there was evidence from the weekly means that P levels increase with time as week 1 levels were greater than week 4 levels meaning over the course of four weeks the amount of P leaching into the dune soil increased. However, this was not the case for N as levels remained constant and the increased P levels could be accumulating and not being absorbed by plant roots or leaching out of the porous dune soils. This may also be the case for N as it may be quickly absorbed by plant roots or leached out with the N levels recorded being ambient dune soil N levels.

The study was affected by certain limitations that without would have given a fuller picture of the effect of dog waste on dune soils and vegetation. Time for data collection was limited to July and August, which falls within peak growing season so nutrient uptake from soil will be at its greatest and may explain the lack of differences in soil N between high -faeces, high and low activity areas. Plant growth when not in peak growing season is limited so lower rates of nutrient uptake would occur leading to greater nutrient loading but may be countered by the increased rainfall over winter months increasing leaching rates. Dog waste persists in the environment for longer periods than the four weeks of observation with studies on faecal applications as fertiliser showing there was a release of nutrients in the first 20 days of deposition (Chang *et al,.* 2017) with another showing immediate nutrient leaching from moose faeces upon deposition and after a year of decomposition (Guernsey *et al*,. 2015). It would be useful to quantify the leaching of nutrients from dog waste from deposition to full decomposition and the nutrients persistence within the soil after full decomposition. Another limitation to this study is the varying amounts of rainfall experienced throughout data collection as weeks with increased rainfall would have seen increased leaching of nutrients from dog waste and conversely weeks with dryer, hotter weather would have seen reduced leaching rates which may explain the inconsistency in the reduction of P levels from week 1 to 4. N is the largest nutrient constituent of dog waste, so it does not follow that mean N levels within the samples did not vary as N levels were found not to

differ between the high and low activity areas, as well as from the soil samples taken from directly beneath dog waste. A more in-depth study to determine the reasons for this similarity would contribute to understanding what form any excess N is in, where it is going, and why it is going so quickly.

St Gothian Sands low activity area was restricted to dogs and humans but there were large numbers of Canada geese present throughout the study with goose excrement observed in high proportions throughout the area. As geese are highly mobile, they have the capability of introducing substantial amounts of exterior nutrients into the soil from their excrement, however mean soil N levels within the area were similar to the other study areas and mean soil P levels were the lowest of all the areas indicating the effects from this input is negligible.

There were issues during the study with recorded dog waste deposits being removed and other instances of the flags used for visual aids being removed which, in hindsight, would have been better to have used less conspicuous visual aids so as not to draw attention to the study. Notifying the public with leaflets and informative signs would likely also reduce the incidence of sabotage.

Throughout the study certain questions were raised that further studies may answer. It was not known at what rate nutrients leached from dog waste were in turn leached from the dune soils so it would be useful to quantify these rates to determine if leached nutrients from dog waste are available long enough to favour invasive species that require higher nutrient levels than dune adapted vegetation. Another major influence on the level of leaching rates is the prevalence of moisture within the environment. At optimal moisture and temperature increased microbial activity leads to increased decomposition rates (Waksman and Gerretsen, 1931) as will an increase in precipitation increase leaching rates. It would be useful to know when leaching rates are likely to be the greatest so mitigation measures could be put in place. This mitigation could be in the form of “crack” dog waste removal teams that are mobilised before an increased leaching event or restricting the area when leaching is greatest. Whilst collecting soil samples some dog waste deposits were observed to have invertebrate activity within them raising the question of whether the dog waste could be providing a habitat, or if

the samples with invertebrate activity were being broken down quicker, increasing leaching rates, and why some dog waste attracted invertebrates and some not. A further study investigating these would be useful as coupled with the proposed future study of soil nutrient persistence, could be used to increase decomposition rates of dog waste which given the porous nature of dune soils may reduce nutrient persistence by leaching them from the soil quicker. A more in-depth study of nutrient leaching rates from dog waste would be beneficial as this study only determined that leaching of P increased from week 1 to week 4 but did not quantify this or define if it was nutrient loading or increased leaching as decomposition progressed. Quantifying the rate would determine if there were an optimum window to remove the dog waste before leaching intensified. Previous studies have shown the addition of fertiliser increases microbial activity and alters bacterial community composition (Tian *et al*,. 2015), all of which can affect leached nutrient availability and persistence so a fluorescein diacetate (FDA) hydrolysis would shed light on microbial activity (Gillian and Duncan, 2001) following dog waste deposition, with associated community changes quantified using high-throughput amplicon sequencing of environmental DNA (eDNA) (Yan *et al,*. 2018).

Another limitation of the study was the lack of a controlled environment meaning certain variables, such as precipitation, were uncontrollable. An influence on soil type and nutrient availability is the heterogeneity of conditions in dune habitats as the undulating slopes produce differences in aspect, slope, and micro-climate. Bringing the study and its proposed further studies into a laboratory would allow greater control over variables as well as improved standardisation of samples, however, a limitation of this is the removal of natural variation seen in situ meaning a true representation is not possible. The same can also be said for levels of human activity as this would most certainly be a contributing factor to the species of vegetation within the habitat due to trampling of vegetation and invasive species introductions so further studies quantifying these effects would complement data obtained from this study. Another limitation was the randomly generated positions of quadrats as a small number of them fell within areas too overgrown to be accessible, so these quadrats were moved to the edge of the overgrown areas meaning a true representation of dune vegetation was not achievable.

This study was proposed by Cornwall Wildlife Trust to better understand the impact of excessive amounts of dog waste deposited on sand dune habitats to aid in management decisions and while this study has shown there to be a detrimental impact, mitigating those impacts is challenging. Dog waste bins are currently restricted to the entrances of both high activity areas and studies have shown a better response to owners picking up after their dog waste when dog waste bins are easily accessible (Lowe *et al,.* 2014). However, placing more dog waste bins within the high activity areas comes with its own issues in that vehicular access would be required to retrieve full bins, putting further pressure on the habitat, and the addition of more bins would also be unsightly. These two issues could be overcome with the use of compostable dog waste bins placed within wooden structures to fit in with the natural setting. This increase in dog waste bins could then be coupled with a further study determining if they have had a positive impact of reducing dog waste left by owners. Another mitigating factor would be to reduce the incidence of owners being unaware of their dog fouling by enforcing a policy of on-lead walking within the dunes as a previous study has shown dog owners are less likely to pick up after their dog if it is off-lead (Reid *et al,.* 1984), however, this could be met with some resistance. Another mitigating factor would be a public campaign to increase awareness of sensitive dune habitats and improve owner responsibility and behaviour as this has been shown in earlier studies to improve rates of owners picking up their dog's waste (Rock *et al,.* 2016). During data collection it was noted that the incidence of dog waste was greatest closest to the car parks so a further study to investigate this could contribute to understanding where dogs are most likely to defecate, and these areas turned over for this purpose to reduce pressure on less impacted areas of the dunes. In results it was found that some parts of the high activity vegetation had a scrub NVC classification so to determine if this scrub is spreading regular Phase 1 habitat surveys would aid in management decisions to reduce its impacts.

5 Conclusion

There is a clear conflict between the use of coastal sand dunes for recreation and its conservation with this study showing the detrimental impact on dune soils and

vegetation excessive amounts of dog waste can have. If coastal sand dunes are to be protected and conserved as well as kept open for public recreation, the information gained from this study should be used to engage the public with educational campaigns to improve awareness and increase dog waste pick-up rates and inform the conservation goals of site management. Whilst this study provides answers to important questions raised from the substantial amounts of dog waste left in coastal sand dune habitats, it can only provide a snapshot of the wider issue due to constraints in time, size of study, and influencing factors quantified, however, due to a distinct lack of data on the issue small studies can make big contributions in knowledge.

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8 Appendix list

1. Project data excel sheets.