# Tidal range and recovery from the impacts mechanical beach grooming

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## ABSTRACT

Mechanical grooming to remove litter and wrack from sandy beaches reduces strandline biodiversity. The impact of tidal range on recovery rates of strandline ecosystems after grooming has not been examined to date, even though tidal range is known to affect the spatial and temporal patterns of seaweed. We compared taxon richness of macroinvertebrates that occur all year round at 104 sites on two coastlines at similar latitudes in Northern Europe that have pronounced differences in tidal range. Macroinvertebrate taxon richness was positively correlated with algae depth on both groomed and ungroomed beaches but was lower on groomed beaches. This was the case even in the off season despite wrack depths returning to similar levels found on ungroomed beaches. These impacts of grooming which extend into the winter offseason where found to be higher on beaches with a lower tidal range. We suggest this is likely to be because in areas with little tidal variation, irregular and unpredictable storm events are likely to be the predominant source of new wrack deposits. Our results suggest it is particularly important that management strategies to mitigate the impacts of grooming are adopted in areas with low tidal range.

## 1. Introduction

Cumulative pressures on the world's coastlines are putting beaches at risk from a variety of anthropogenic and natural impacts. Anthropogenic pressures include residential, recreational, agricultural and commercial use of coastal land and near shore waters (Nordstrom, 2003; Davenport and Davenport, 2006). These pressures are predicted to heighten as the proportion of the human population living near the coast increases (Brown and McLachlan, 2002; Schlacher et al., 2007, 2008; Defeo et al., 2009). Physical processes such as beach erosion and accretion, freshwater transport, sediment transport and flooding, coupled with these increasing anthropogenic pressures, can substantially reduce the ecosystem services provided by beaches (Schlacher et al., 2007). It is becoming apparent that the need to act on these anthropogenic pressures is an urgent undertaking (Brown and McLachlan, 2002; Defeo et al., 2009). An increase in sea level rise has been reported globally over the last century (Meehl et al., 2007). This rise is inevitably going to increase beach erosion and landward retreat of shorelines, which will in turn lead to extensive habitat loss, particularly on beaches where human development halts natural inland migration of the shoreline (Feagin et al., 2005). The protection of beaches and sand dunes is becoming ever more critical as a defence against rising sea levels.

Conflicts between the needs of recreational users and the requirements of organisms that inhabit beaches presents a particularly difficult problem in developing a sustainable solution that accommodates both (Nordstrom, 2003; McLachlan et al., 2013; Kelly, 2016). Many beach managers adopt mechanical grooming to remove seaweed and litter from beaches and prevent unpleasant odours from decaying wrack reducing the attractiveness of a beach to tourists. However beached wrack plays a key role in a number of key shoreline processes (Dugan et al., 2003; Nordstrom et al., 2012; Kelly, 2014, 2016), such as remineralisation of nutrients, the formation and maintenance of dune systems and providing a viable habitat for coastal flora and fauna.

A number of studies have investigated the impacts of grooming (Davenport and Davenport, 2006; Defeo et al., 2009; Kelly, 2014). In California grooming resulted in a nine-fold reduction in wrack cover (Dugan and Hubbard, 2010). The loss of wrack results in the loss of habitat and resources for a large number of species including crabs (Tewfik et al., 2016) and shorebirds (Schlacher et al., 2017). For example in Wales grooming was found to reduce the overall abundance and diversity of strandline-related species (Llewellyn and Shackley,

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1996). Grooming has been found to impact talitrid amphipod populations in Italy (Fanini et al., 2005). Studies have shown grooming is associated with low strandline macroinvertebrate diversity in California (Dugan et al., 2003) and Scotland (Gilburn, 2012), with depth of wrack being identified as the most important determinant of biodiversity in the latter study. Wrack provides food and shelter for macroinvertebrates such as amphipods, dipteran larvae and scavenger beetles which in turn provide food for shorebirds (Brown and McLachlan, 2002; Ince et al., 2007; Olabarria et al., 2007; Lastra et al., 2008; Defeo et al., 2009; Gonçalves and Marques, 2011).

The impacts of beach grooming also extend beyond the strandline. The abundance and richness of coastal plants were fifteen and three times lower adjacent to groomed beaches in California (Dugan and Hubbard, 2010). These reductions are likely to be occurring as the strandline facilitates nutrient remineralisation (Maun, 1994) and enhances the growth of dune plants (Williams and Feagin, 2010). This also explains why another study where groomed material was redeposited elsewhere on a beach did not detect any substantive impact (Morton et al., 2015) as remineralisation will not have been majorly affected.

Studies investigating the impacts of beach grooming have already identified substantial ecological impacts. However, these studies have not investigated how environmental factors might have synergistic or antagonistic effects together with grooming. Considering the importance of strandlines to conservation and ecosystem services and the conflict with recreational users it is essential for the development of successful management strategies to determine whether environmental factors do interact with grooming. Tidal range is one factor that potentially could be of considerable significance. Beaches with higher tidal ranges could receive larger deposits of beached wrack and as a consequence might recover from the impacts of grooming more quickly. Ince et al. (2007) recorded higher macroinvertebrate abundance levels from beaches with high wrack inputs than from those with smaller inputs. By contrast, areas with little or no tidal range might be largely dependent on unpredictable storm events for replenishing stocks of beached wrack removed by grooming. The aim of this study was to determine how the impacts of grooming on strandline macroinvertebrate biodiversity vary between two stretches of coastline with similar latitude but with very different tidal ranges in Scotland and Sweden by comparing the taxon richness of the community at beaches both within and outside of the grooming season.

## 2. Materials and methods

### 2.1. Study regions

The study was carried along the coastlines of Eastern Scotland and Western Sweden. Both coastlines have many beaches were mechanical grooming is carried out at least once a week during the summer months. The location of the Scottish beaches sites ranged from Inverboyndie (57.669834N and −2.546297E) to Barns Ness (55.987167N and −2.451667E). The Swedish beaches were located between Apelviken (57.083448N and 12.256786E) and Kåseberga (55.399386N and 12.978539E). The tidal regime in Sweden varies from 10 to 40 cm in the Skagerrak, 5–20 cm in the Kattegat to 0 cm in the Baltic (Leppäranta and Myrberg, 2009). By contrast the Scottish coastline has a tidal range between about 4 and 5 m (UK Hydrographic Office). Salinity also varies between the two coastlines and is so highly correlated with tidal range that only tidal range was included in the study.

### 2.2. Sampling design

The study sites were 104 sections of beach, 44 in Scotland and 60 in Sweden. Where only a section of the beach was groomed a site was chosen within both the groomed and ungroomed sections. However, where the entirety of a beach was groomed then the next nearest

ungroomed beach was selected to generate an equal number of groomed and ungroomed sections of beach. All beaches were visited during both the summer grooming season and also during the winter offseason. This allowed for seasonal differences to be observed at the same beach.

The depth of the wrack was measured at various points to establish the maximum depth of wrack present at each site. Each section of beach was then sampled for a period of 10 min where organisms were observed and identified to taxon level *in situ*. The method for sampling involved searching for strandline macroinvertebrates in, on or under the wrack starting at the point of maximum depth. Patches of wrack at all zones on the beach from the high water springs down to the swash zone were searched which resulted in wrack beds of different ages and stages of desiccation being covered. Each beach was sampled once during the grooming season (June–August) and once during the off season (October–February).

### 2.3. Study organisms

Taxon richness was used as a biodiversity indicator of the fauna inhabiting the stranded seaweed as this has been shown to be an efficient surrogate for species richness generally (Williams and Gaston, 1994; Balmford et al., 1996) and in the context of strandlines (Gilburn, 2012). Using this simple measure means that large numbers of sites can be included in the study. The eight taxa chosen in the surveys were used as they the most commonly found on beaches throughout the UK and Sweden, are a diverse selection of organisms with different niches within the strandline environment and have successfully be used as an indicator of the impact of grooming on macroinvertebrate strandline communities (Gilburn, 2012). Furthermore all these taxa can be found both within and outside the grooming season. Six of the taxa were assessed at the family level, one, mesostigmata mites, was assessed at the level of order and one taxon, oligochaetes, to the level of sub-class. The eight taxonomic groups used were: 1) Diptera - Coelopidae (*Coelopa frigida* and *Coelopa pilipes*); 2) Diptera - Sepsidae (*Orygma luctuosum*); 3) Diptera - Anthomyiidae (*Fucellia maritim*a); 4) Diptera - Sphaeroceridae (*Thoracochaeta zosterae*); 5) Coleoptera - Staphylinidae – (*Cafius xantholoma* and *Aleochara algarum*); 6) Amphipoda - Talitridae (of three genera *Talitrus*, *Talorchestia* and *Orchestia*); 7) Mesostigmata (*Parasitus kempersi* and *Thinoseuis fucicola*); and 8) Oligochaete.

### 2.4. Data analysis

Statistical analyses were undertaken using R version 3.2.2 (R Core Team, 2015). The lm4 (Bates et al., 2015) and MuMIn (Barton, 2015) packages were used for statistical analysis, whilst ggplot2 (Wickham, 2009) and the effects package (Fox, 2003) were used for graphics. We performed a series of Generalised Linear Mixed-Effects Models (GLMMs) with binomial distribution and logit link (Zuur et al., 2009). We ran models using presence/absence of each of the eight taxa as the response variable with 'site' included in all models as a random (grouping) factor to quantify both within and between site variance. The following predictor variables were included in the starting model: log tidal range, aspect, exposure, Longitude, Latitude, grooming season (a factor with two levels: winter or summer), grooming status (a factor with two levels: ungroomed or groomed) and log algae depth. Models were compared and the best model selected using an information theoretic approach (Akaike Information Criteria, AIC, Burnham and Anderson, 2014). Akaike weights give the probability that a model is the best model, given the data and the set of candidate models (Burnham and Anderson, 2014). Salinity was excluded from the model due to its high level of collinearity with tidal range which resulted in excessively high variance inflation factors. A better model was generated using tidal range than salinity. All two-way interactions between significant variables were explored and a three-way interaction between tidal range, grooming status and season to determine whether