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Wrack patches and their influence on upper-shore macrofaunal abundance in an Atlantic Canada sandy beach system

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ABSTRACT

Patches of stranded macrophytes (wrack) are a distinctive feature of sandy beaches worldwide and a potential food subsidy for their resident communities. Despite their relevance, the spatial variation of wrack and its potential influence on upper shore beach organisms remain poorly understood. Wrack and macrofauna were surveyed on seven sandy beaches associated with dunes, till bluffs and sandstone cliffs along the north shore of Prince Edward Island, Atlantic Canada. Wrack patch density, cover, and water content were measured, and their associated macrofauna was compared to the communities inhabiting nearby bare sediments. The survey found among-site spatial differences in wrack characteristics and identified rockweeds (*Fucus serratus*) and eelgrass (*Zostera marina*) as the main macrophyte species in the area. Macrofaunal abundances were higher in wrack than in bare sediments but this varied among locations. A field manipulation was then conducted at two sandy beaches to measure macrofauna colonization on patches of fresh and aged rockweed and eelgrass. Regardless of macrophyte's age, macrofaunal organisms preferentially colonized sediments associated with rockweeds. In addition, calculations across treatments detected positive relationships between macrofaunal abundance and wet mass, dry mass and water content of the wrack patches, regardless of macrophyte species or state. Macrophyte preferences were further explored by comparing the nutritional value of the plant tissues and assessing macrofauna feeding rates under laboratory conditions. Rockweed tissues had consistently higher protein, lipid and carbohydrate contents than eelgrass and were affected by higher invertebrate consumption rates. Overall, these results suggest that spatial variation and wrack features and species composition play key roles on the structure of the supralittoral macrofauna.

1. Introduction

Sandy beaches around the world are characterized by intertidal zones of unconsolidated shifting sands devoid of large primary producers (Ince et al., 2007; Jaramillo et al., 2006). For these habitats, most food availability is allochthonous and limited to the phytoplankton cells transported onshore (McLachlan and Brown, 2006) and the input of nearshore macroalgae and seagrasses (macrophytes; Dugan et al., 2003). The accumulation of patches of stranded macrophytes or "wrack" represents a key food subsidy for resident invertebrate communities, particularly those living at the upper levels of the intertidal (Griffiths et al., 1983; Inglis, 1989; Lastra et al., 2008; McLachlan and Brown, 2006). Wrack is expected to influence these communities, and indeed, several authors have reported increased abundances of macrofauna with wrack cover, volume or standing stock (Behbehani and Croker, 1982; Dugan et al., 2003; Ince et al., 2007; Jaramillo et al., 2006; Rodil et al., 2008; Stenton-Dozey and Griffiths, 1983). Wrack also affects the zonation of macrofauna and some macrofaunal species closely follow the movements of wrack as its position on the beach changes during the semi-lunar cycle (Colombini et al., 2000).

The invertebrates living in the supralittoral zone live buried in the sand beyond the intertidal zone, and therefore are minimally affected by intertidal swash conditions (Jaramillo et al., 2006; Koop and Field, 1980). In temperate regions, the supralittoral fauna in sandy beaches with moderate macrophyte input are often dominated by talitrid amphipods (Colombini et al., 2000; Griffiths and Stenton-Dozey, 1981; Inglis, 1989; Jędrzejczak, 2002). These organisms prefer humid environments and are considered primary colonizers of newly stranded wrack (Behbehani and Croker, 1982; Colombini et al., 2000; Griffiths and Stenton-Dozey, 1981; Inglis, 1989; Marsden, 1991; Stenton-Dozey and Griffiths, 1983), which subsequently attract and sustain secondary (predatory) species (Colombini et al., 2000; Dugan et al., 2003; Griffiths and Stenton-Dozey, 1981; Ince et al., 2007; Jędrzejczak, 2002). As wrack deposits age, they undergo severe dehydration and become covered by windblown sand (Ince et al., 2007; Rodil et al., 2008). Both processes contribute to their decomposition (Ince et al., 2007) and remineralization of seaweeds by bacteria (Kirkman and Kendrick, 1997). Given the importance of wrack as a food source and a refuge from desiccation, it is expected that indirect indicators such as water

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content and wet mass will show strong relationships with macrofaunal abundances.

Wrack species composition and biomass change spatially and temporally (Dugan et al., 2003; Lastra et al., 2008; Marsden, 1991; Orr et al., 2005; Stenton-Dozey and Griffiths, 1983) in response to local hydrological processes (Ince et al., 2007) or larger-scale processes, such as sea-level change and the dynamics of shoreline erosion (Lastra et al., 2008). Since macrophyte species have different physical and nutritive properties, species of stranded seaweeds are not uniformly used by colonizing invertebrates (Rodil et al., 2008). For example, Lastra et al. (2008) found that amphipods of the genera *Megalorchestia* and *Talitrus* rapidly consumed brown algae of the genera *Macrocystis* and *Saccorhiza*, respectively, while negligible amounts of the seagrass *Phyllospadix* were consumed. The causes for these differences are diverse. Seaweeds may vary in physical structure (levels of branching, toughness), nutritional quality and/or quantity, palatability, and decomposition rates while stranded on the beach face (Duarte et al., 2010; Dugan et al., 2003; Rodil et al., 2008; Rossi and Underwood, 2002; Stenton-Dozey and Griffiths, 1983). Despite its importance for upper shore macrofauna, only a few studies so far have attempted to describe the spatial variation of stranded seaweeds, while measuring their individual influence on sandy beach invertebrates.

Several species of seagrasses and rockweeds dominate the wrack in eastern North American shorelines. Despite their abundance, seagrasses are not always the preferred food source due to their structural polysaccharides and low proportion of available nitrogen (Inglis, 1989). Meanwhile, rockweeds are high in nitrogen content and other soluble substances (Inglis, 1989) but contain secondary metabolites that may deter herbivory and decrease herbivore assimilation efficiency and growth (Boettcher and Targett, 1993; Denton and Chapman, 1991; Pennings et al., 2000). Both types of macrophytes are common in the supralittoral wrack on the sandy beaches on the north shore of Prince Edward Island (PEI). Sandy beaches in this region are associated with shorelines backed by sand dunes, till bluffs and sandstone cliffs, among which, sandstone shorelines are known to erode at a much slower rate than dunes and till bluffs (cf. Forbes and Manson, 2002; Hawkins, 2008). These differences suggest that sandy beaches in the area will likely exhibit spatial differences in macrophyte stranding due to those differences in exposure and shoreline sediment mobility. Given that rather little is known about the influence of wrack on the upper shore macrofauna of beaches here and elsewhere, this shoreline system offers a unique opportunity to address this knowledge gap. The goal of this study was to assess the role of macrophyte wrack on the abundance of the supralittoral macrofauna using a combination of exploratory and experimental approaches. Specifically, this study reports (1) a snapshot survey of the standing crop of wrack in seven representative sandy beaches and compares macrofaunal numbers in wrack and bare sediments. (2) a field experiment assessing the rates of colonization on the two most common species of stranded seaweeds, and (3) a comparison of the nutritional quality of those two seaweed species and their corresponding rates of consumption by invertebrates in a laboratory setting.

2. Materials and methods

2.1. Study area

Seven sandy beaches located on the north shore of Prince Edward Island were sampled over a period of one week in July 2010 (Fig. 1): Cavendish, Brackley, Ross Lane (all associated to sand dunes), Doyles Cove, Cape Turner (backed by sandstone cliffs), Dalvay west I and II (backed by till bluffs). In addition, a sandy beach at the east end of Dalvay (Dalvay east or #8 in Fig. 1) was used as one of two experimental areas (see Section 2.3 below). The location, mean grain size, slope and morphodynamic classification (based on the Beach Deposit Index, BDI) of each of these sites during summer conditions are summarized in Table 1 (based on MacMillan and Quijón, submitted for publication). For the morphodynamic classification, $BDI = (1/\tan B) \times (a/Mz)$, where tan *B* is the average slope, *a* is the median grain size of the sand particle size classification scale, and *Mz* is the average sand particle size in mm (see McLachlan and Brown, 2006; Soares, 2003). BDI ranks low beaches with steep slopes and coarser sands and high those with flat slopes and finer sands in a gradient that resembles a reflective to dissipative gradient. This index was primarily chosen because it applies only to microtidal beaches like those studied here.

Briefly, there are no strong differences among beaches associated to distinctive shoreline types (dunes, till, sandstone) with respect to grain size (primarily moderately well sorted medium/fine sands), slope, and BDI. As explained by MacMillan and Quijón (submitted for publication), however, these comparisons are not necessarily a statistically contrasted result. Slope and BDI, for example, were calculated as single values per beach so, strictly speaking, there is little ground to state that spatial differences do not actually exist. Unlike the similarity in these physical variables, considerably lower levels of erosion have been estimated for beaches associated to sandstone cliffs (Cape Turner and Doyles Cove) (MacMillan and Quijón, submitted for publication). All these beaches are open to the public for recreational use, but access is limited by boardwalks and staircases, resulting in increased densities of users at these points. The surveys described below took place at least 200 m away from these entrance points to minimize potential human disturbance, which can be considered negligible and uniform across sites. In addition, use of motorized vehicles on beaches is prohibited on PEI, and as such, these sites are not groomed.

2.2. Stranded macrophyte survey

At each beach, the percent cover of macrophytes was visually estimated using 1×4 m quadrat placed randomly along ~100 m of the drift line associated to the last high tide level. The quadrat was then subdivided in four 1 m^2 subunits and the number of distinct macrophyte patches (ranging from individual fronds to large clumps consisting of multiple plants) within each subunit were counted and considered an estimator of seaweed patch density (the mean of the four values were used as an individual replicate; $n = 6$ replicates per beach).

A 20 cm diameter PVC core was then used to collect invertebrates from a randomly chosen seaweed patch within each quadrant. The core was inserted up to approximately 20 cm in order to collect both the seaweed at the surface and the sediment underneath. The macrophyte sample was carefully examined within the core to collect invertebrates in between the fronds, and placed in sealable plastic bags for further analyses in the laboratory. The sediments were then sieved through a 1 mm mesh screen in the swash zone. The macrofauna retained on the screen was stored in ethanol until subsequent sorting and identification. An additional core sample was taken approximately 1 m away from each quadrant ($n = 6$ per beach) in order to characterize invertebrates associated to bare sediments. In the laboratory, macrophyte samples were carefully re-inspected for the presence of macrofauna that may have been missed in the field, and then weighed, dried in an oven at 60 °C to a constant mass (48 h) and re-weighed to determine water content. The macrofauna was identified, counted and the majority of the invertebrates collected belonged to *Americorchestia megalophthalma* and *Americorchestia longicornis* (>95%). Due to the difficulty in differentiating between the juveniles of these two species, these amphipods were quantified as *Talorchestia* sp.

2.3. Field experiment: stranded seaweed colonization

Zostera marina (hereafter eelgrass) and *Fucus serratus* (hereafter rockweed) were the most common species of stranded macrophytes (see results) and were therefore chosen to conduct a short-term wrack colonization experiment. In this study, colonization rates denote densities of invertebrates found associated to the wrack or