Inferring Organic Content of Beach Sand from Color

Andrew S. Maurer[1,2,*] and Seth P. Stapleton[2,3]

Abstract - Relative organic content in sediment is an important determinant of ecological processes, but it can be difficult to quantify in the field. Here, we present evidence that relative organic matter content of sand may be inferred from relative coloration. For 50 sand samples collected from a beach on Long Island, Antigua, West Indies, we characterized sand color intensity (brightness) using image analysis of standardized photographs and measured percent organic matter lost on ignition with dry combustion. A linear regression provided evidence for a strong negative relationship between brightness and organic content; darker-colored sand contained more organic matter. Inferring organic content from color may provide a simple way to make field-based qualitative assessments of an important parameter in beach habitats.

Introduction

Organic matter composition in sediment is a critical characteristic reflecting many biological, chemical, and physical processes. Sand can be a biogenic (i.e., weathered organismal calcium carbonate) or clastic sediment (i.e., weathered rock), and has far less organic matter than more soil-rich sediments (Pettijohn et al. 1972). The lack of organics in pure sand leaves it relatively limited in nutrients key for biological processes (e.g., nitrogen). As a result, gradients in organic matter in sandy habitats are important in regulating ecosystem processes and structure.

The ecologies of many beach organisms in the Caribbean and beyond are linked to organic matter because it provides resources needed to support life. As such, organic matter plays a central role in many coastal biological systems. For example, organic matter offers nutrients that are important for plant growth, and processes like plant mortality and decomposition may then serve to enrich proximal sediment. As a result, sand organic matter can be coupled to vegetative community structure (Karavas et al. 2005, Smith et al. 1985). Gradients in organic matter also influence the abundance and demography of meiofauna that occur in sand (Koop and Griffiths 1982, Wall et al. 2002) and can affect the ecology of beach macrofauna. For example, marine turtles depend on beaches for reproduction, and rates of reproductive success have been linked to sand organic matter (Ditmer and Stapleton 2012, Mazaris et al. 2006).

Due to the importance of organic matter to the ecology and natural history of beach flora and fauna, researchers and managers would benefit from understanding its distribution at their sites. Assessing sand organic content most often entails the

[1]Department of Biological Sciences, North Carolina State University, Raleigh, NC 27695, USA. [2]Jumby Bay Hawksbill Project, Antigua, West Indies. [3]Department of Fisheries, Wildlife and Conservation Biology, University of Minnesota, St. Paul, MN 55108, USA. [*]Corresponding author - asmaurer@ncsu.edu.

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quantification of percent organic matter lost on ignition (e.g., Ditmer and Stapleton 2012). For this method, samples must be obtained in the field and returned to a laboratory for processing in a muffle furnace. Other methods have been used to assess sediment organic content, such as spectroradiometry (e.g., Bao et al. 2017), but these techniques are typically applied for soils in agricultural and industrial contexts, leaving them comparatively underdeveloped for beaches. Both muffle furnace and sprectroradiometric techniques present logistical difficulties including securing access to equipment or transporting samples from remote field sites, sometimes across international borders. Moreover, in some management scenarios, it may be beneficial to have information on organic content in the field to inform potential research study design, management, or conservation actions.

Intuitive relationships between sand color and organics may offer a potential solution to quickly index relative organic content. Here, our objective was to assess whether variation in sand organic content is explained by color. We posed the simple hypothesis that for a given beach geology (with lightly colored sediment), darker sand should have higher organic content. Relative sand color can be indexed visually but is difficult to quantify in a meaningful way visually. However, in previous work, sediment color has been measured using image analyses (e.g., Oliveira Morais et al. 2019). Thus, to quantitatively test our hypothesis, we used image analyses of sand photographs to measure color and relate it to measured organic content, though our results may be applied visually. Our findings have broad potential conservation relevance, and we contextualize them with an example of management decision-making at beaches where sea turtles nest.

Methods

We collected 50 sand samples in 2015 from Pasture Beach on Long Island, Antigua, a barrier island located northeast of mainland Antigua, West Indies (17°09'31"N, 61°45'21"W). Pasture Beach is windward-facing and, thus, in addition to terrestrial inputs like soil, its calcareous sandy sediment receives marine subsidies such as macroalgae wrack (Maurer et al. 2015, 2019). Our sampling scheme was originally designed to make associations between sand characteristics and egg-hatching success rates of *Eretmochelys imbricata* (L.) (Hawksbill Sea Turtle; A. Maurer, unpubl. data); we do not focus on these associations herein, but this affected our sampling methods. We collected samples from the side of Hawksbill Sea Turtle egg chambers at ~25 cm depth post-hatching (after the contents of the nest had been exhumed). It is possible that organic matter values were inflated by organic material from the nest, but because we collected samples from the side of the egg chamber and scooped outward into the surrounding sand, these impacts are likely negligible and relatively consistent across samples. Further, eggshells and nest contents typically remain well below 25 cm post-hatching. We placed sand samples into plastic bags in the field, dried them at room temperature, and kept them sealed until transport to North Carolina State University (Raleigh, NC, USA). These methods may have allowed for changes in microbial biomass or the volatilization of organics during transport and storage. Though we assume any changes were negligible relative to the mass of samples, future work may benefit from minimizing storage and transport time before analysis and/or use of laboratory protocols such as freezer storage.

After samples were dried completely at room temperature, we placed subsamples of sand (mean weight = 29.82 ± 0.91 SD g) into aluminum trays. We then photographed each sample in a controlled laboratory setting with a Canon DSLR camera using standardized height, magnification, overhead angle, and lighting conditions without a flash against a black background. To compute the percent mass lost on ignition (LOI), we placed sample trays in a muffle furnace at 500 °C for 8 h and reweighed them.

We analyzed sand sample images (JPEG) using ImageJ software (Schneider et al. 2012). After cropping images to a region bounded by the circular tray, we quantified the mean gray value. For color images (RGB), this ImageJ analysis converts each pixel to grayscale before computing the gray value. Mean gray value is a unitless measure of the brightness of pixels—lower values are associated with darker coloration. Figure 1 provides examples of a variety of mean gray and LOI values.

To quantify the relationship between organic matter LOI and mean gray value for the 50 samples, we fit a linear regression between these 2 variables in R (version 3.3.1; R Core Team 2016) using RStudio (version 1.0.136; R Team 2015).

Results

Sand samples from Pasture Bay had a mean percent mass LOI of 3.08% ± 0.88 SD, with a min–max of 2.11–5.81%. The mean for the 50 gray values measured with ImageJ was 107.4 ± 8.10 SD. The linear regression provided evidence that mean gray value is a significant predictor of organic matter LOI, with a strong negative relationship (b = -0.0861 ± 0.0098 SE; $P < 0.001$; $R^2 = 0.61$; intercept = 12.3 ±

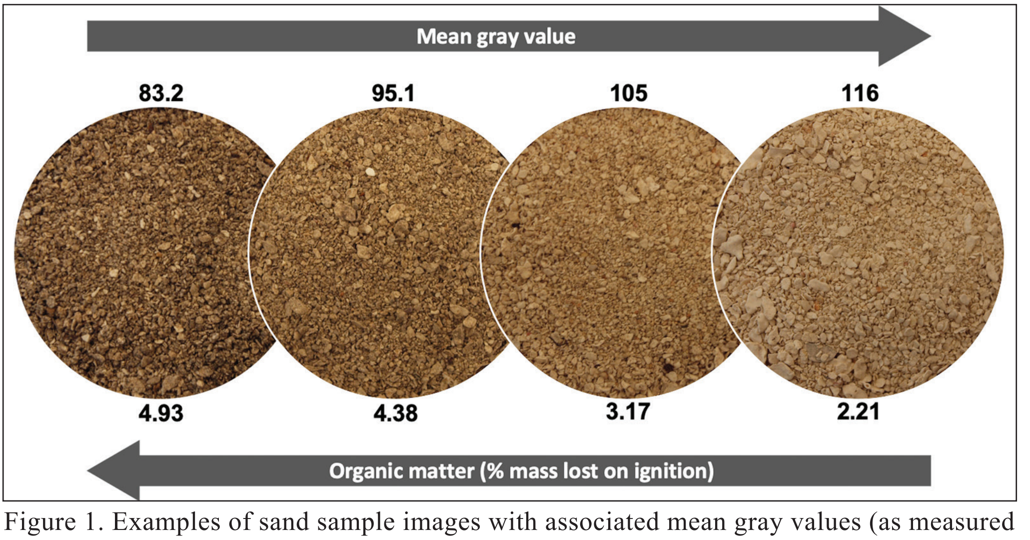

Figure 1. Examples of sand sample images with associated mean gray values (as measured in ImageJ) and percent mass lost on ignition (LOI) with dry combustion.

1.1). As sand color increased in brightness, percent organic matter declined (Fig. 2). The raw residuals and estimated standard error were not evenly distributed, with a smaller confidence interval at lighter sand colors and lower organic matter.

Discussion

The results presented here support the hypothesis that darker sand has higher organic content, and the strength of the association between these variables (i.e., $R^2 = 0.61$) suggests that color may indeed be used to infer organic content at Pasture Bay, Antigua. The most useful application of these results is likely to guide the inference of relative organic matter based on color—not for inferring absolute percent organic matter values (i.e., given a sand photograph). Our results also suggest that inferences regarding relative organic matter may be weaker for the darker end of the sand-color spectrum. The residuals of the linear regression were greater for dark sand compared to light (Fig. 2). Darker sand is likely a more heterogeneous substrate than light sand, and with increasing heterogeneity comes more variability in organic-matter composition. Further work at sites representing diverse geographic regions, sand colors, sand grain sizes, and sedimentary geologies will help to quantify the relationship between sand color and organic content more broadly; dark or black sand beaches may be particularly interesting case studies (e.g., Tilley et al. 2019).

Organic content influences various ecological processes in sandy habitats, and thus our results may be applied in a variety of contexts where inference about relative organics is useful. As a basic example, for sediment sample collection with an objective of covering the range of organic content values at a given study site, selecting from the full spectrum of sediment colors would be prudent. Conservation and research applications for our results will be case-specific, but a better understanding of patterns in organic matter in beach sand may facilitate inferences about ecological communities such as plants and meiofauna (e.g., Smith et al. 1985, Wall et al. 2002).

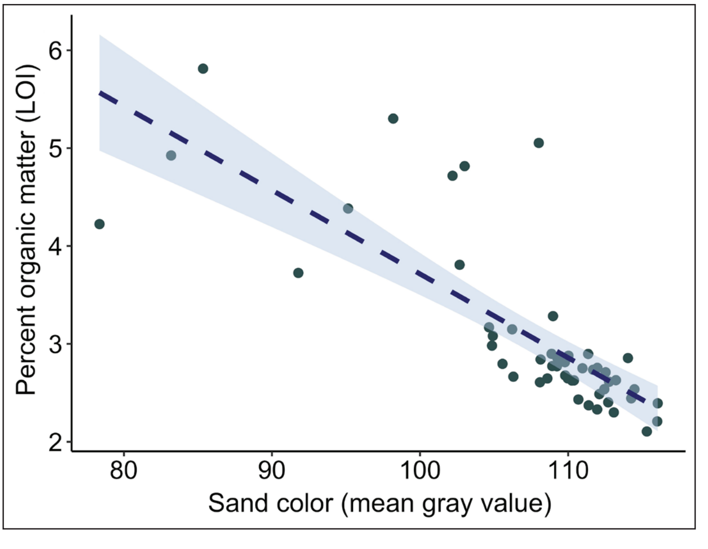

Figure 2. Lighter-colored sand (higher mean gray values) contains less organic matter (lost on ignition; LOI). The dashed line shows the model fit for a linear regression ($P < 0.001$, $R^2 = 0.61$), and the shaded area represents the 95% confidence interval from the model fit. Data were collected from 50 sand samples in 2015 from Pasture Beach, Long Island, Antigua, West Indies.

Our study beach is home to a long-term monitoring program for a regionally important nesting population of Hawksbill Sea Turtles (e.g., Levasseur et al. 2020), and we use this context to explore potential applications of our results in more depth. Organic content has been associated with nest placement (i.e., the choice of a nesting site after emerging onto a beach to nest) and nesting success of sea turtles (e.g., Mazaris et al. 2006), and is among several important environmental variables that projects monitoring nesting beaches may document, along with factors such as slope (e.g., Maurer and Johnson 2017, Wood and Bjorndal 2000) and beach vegetation (e.g., Ditmer and Stapleton 2012). Thus, sand color may be used by monitoring projects to serve as a coarse index for organic content. Greater organic content has been associated with lower egg-hatching success at Pasture Bay (Ditmer and Stapleton 2012), which may be related to moisture levels or fungal and microbial abundance (Bézy et al. 2015). Therefore, sand color may be among the criteria used for identifying new sites suitable for clutches requiring relocation (e.g., due to risk of inundation). Though some managers may seek to improve hatching success by relocating to lighter sand, it is often suggested that relocation sites match original nest sites as closely as possible. Regardless, any information to aid relocation efforts is beneficial, as nearly all observed nests are relocated under certain conditions in the management of some beaches where sea turtls nest (e.g., García et al. 2003).

Sand color may be used to infer relative organic content, representing a simple way to make field-based qualitative assessments of an important parameter in sandy coastal habitats. Such information can broadly inform on-site decision-making (e.g., sampling design, management, or conservation action) at study beaches when access to more sophisticated approaches is limited (e.g., analysis with a muffle furnace).

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