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Do marine rooted plants grow in sediment or soil? A critical appraisal on definitions, methodology and communication

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ABSTRACT

Mangroves, saltmarsh plants and seagrasses grow in coastal areas near the land–ocean interface. Marine scientists normally identify the substratum in which these plants grow as sediments. For half a century, sediments supporting emergent vegetation have been described by pedologists and some ecologists as soils. However, more recently, some pedologists began to suggest that subtidal marine substrata should be "subaqueous soils." This followed a change in the definition of soil in the 2nd (1999) edition of *Soil Taxonomy* by the US Department of Agriculture. These developments have caused concerns among many coastal marine scientists, and have led to the emergence of serious and important questions which we address in this paper. We conclude that the terms "*sediment*" and "*soil*" to describe the substrata in coastal environments vegetated by mangrove forests, saltmarshes and seagrass beds are not mutually exclusive. Coastal marine substrata will still be denoted sediments by most marine scientists. Pedologists should recognize and affirm the appropriateness of this historical convention, while they at the same time for specific purposes can use the term "soil" when justifiable according to the definition. Furthermore, research methodology must be appropriate to the environments under study and recognize the uniqueness of these water saturated and largely anoxic environments. This is critical to avoid flawed and incomparable results and to facilitate better communication among scientists working in the coastal zone. A mutual awareness and appreciation among involved communities will help to avoid confusion and improve the understanding among the marine and soil researchers studying these systems. We hope that these ideas can be adopted by the marine and terrestrial scientific communities and look forward to further cooperation through a continued positive dialogue.

Contents

1. Introduction

We have for years reviewed many scientific manuscripts for various journals on marine rooted vegetation, i.e. mangrove forests, saltmarshes

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and seagrass beds, and have noted an increasing use of multiple terms, in relation to intertidal, and particularly subtidal, wetland habitats. A perplexing situation that we feel deserves attention is the use of both the terms "*sediment*" and "*soil*" to denote the marine substratum in which mangroves, saltmarsh plants and seagrasses grow. Marine scientists have always studied sediments in intertidal habitats, while pedologists have described these as soils only since the early 1970s. However, except for the rare voices of European scientists like Kubiena (1953), Muckenhausen (1965) or Ponnamperuma (1972) which had no serious following, pedologists first moved into subtidal territories around the turn of the millennium (e.g. Demas and Rabenhorst, 1999; 2001), mostly without involvement of marine scientists. This entrance followed a change by the US Department of Agriculture—Natural Resources Conservation Service in the definition of "soil" at the time of the publication of the second edition of *Soil Taxonomy* (Soil Survey Staff, 1999). The revised definition now permits inclusion of shallow subtidal environments for what pedologists have named "subaqueous soils" to describe what marine scientists normally identify as subtidal sediments or sedimentary deposits (Fig. 1). The term "subaqueous soils" is difficult to conceptualize for the latter community, and without a proper dialogue it can lead to confusion and ultimately form barriers between those pedologists and marine (and also freshwater) scientists who share a common interest in shallow water environments.

In this paper we express our concern about the confusing use of terms and attempt to clarify when and where it is appropriate using "sediment" and/or "soil" to denote intertidal and shallow subtidal marine substrata vegetated by rooted plants. Despite our different backgrounds in marine biogeochemistry (EK) and pedology (MCR), we have through a positive and constructive dialogue reached a consensus regarding this issue. We propose that the terms "sediment" and "soil" are not necessarily mutually exclusive. Materials that have been transported to and deposited on the floor of an aquatic environment should be denoted sediment. Soil may be an appropriate notation when pedogenically formed "horizons" can be observed. We also stress the importance of using similar research approaches that are appropriate for the environments under study to avoid flawed and incomparable results and conclusions in the literature. This can only be facilitated through improved communication among scientists working in the coastal zone.

2. Trends in science on coastal marine plant ecosystems

Scientific studies (e.g. biology and ecology) on vegetated intertidal and subtidal coastal marine areas (mangrove forests, saltmarshes and seagrass beds) were scarce 40 years ago. However, according to *Thomson Reuters Web of Science* the number of publications has increased in a similar pattern for all three ecosystems during the last decades; most pronounced after 1990 and particularly dramatic after 2005 for mangrove forests (Fig. 2). It must be noted here that *Web of Science* has continuously increased its coverage of journals, which may lead to an overestimate of the true expansion. The few early studies published in the 1960s and 1970s were mostly descriptive, attempting to identify and describe the resident plants and animals, and how they have adapted to these often hostile environments (e.g. Chapman, 1941; Scholander et al., 1962; Macnae, 1968; Gray and Bunce, 1971; Odum and Heald, 1972; Frith et al., 1976). Subsequently, studies on biogeochemical and ecological functioning of vegetated coastal ecosystems were sparked in the 1980s (e.g. Nedwell and Abram, 1978; Carlson et al., 1983; Kristensen et al., 1988; Snedaker, 1989). At the same time deterioration of mangrove forests and saltmarshes accelerated due to urban, agriculture and aquaculture development (e.g. Valiela et al., 2001; Hughes and Paramor, 2004), while light limitation rapidly diminished the expansion of seagrass beds in severely eutrophic areas due to uncritical discharge of nutrients from cities and agriculture (e.g. Short and Wyllie-Echeverria, 1996; Duarte, 2002). Increasing awareness in the late 1980s inspired scientists to examine the ecological functioning of these systems to elucidate their importance for adjacent marine ecosystems and to evaluate their ecosystem services for human populations (e.g. Ewel et al., 1998; Duarte, 2000). A general concern about climate change caused by increasing levels of CO_2 in the atmosphere from anthropogenic combustion of fossil fuels has within the last decade led to search for mitigating actions. It actually turned out that rapid accretion of mangrove, saltmarsh and seagrass sediments combined with anoxic and sulfidic conditions hampering microbial degradation made these ecosystems perfect locations for sequestration and permanent burial of carbon (e.g. McLeod et al., 2011; Alongi, 2012; Pendleton et al., 2012). The rapid increase in mangrove publications after 2005 has, besides the potential for CO_2 sequestration, also been driven by research on mangrove restoration and coastal protection against storms and tsunamis. Thus, the disastrous 2004 tsunami in Southeast Asia clearly showed that intact mangrove fringes along coastlines have the potential to save thousands of lives (e.g. Alongi, 2008; Osti et al., 2009; Zhang et al., 2012).

The expanding and more diverse interest in vegetated coastal ecosystems has over the years involved a wide spectrum of scientific disciplines ranging from sediment biogeochemistry to coastal zone management (e.g. Ellison, 2008; Saint-Paul and Schneider, 2011). Many of the involved disciplines use their own, and in many cases different terms and approaches for examining the same phenomena, which can be confusing and in certain cases lead to serious misunderstandings. Biogeochemists, ecologists and other scientific groups from the marine community have for years used similar terminology, and denoted the substratum in which marine rooted plants grow for "sediment", based on its formation, structure and functioning (e.g. Burdige,

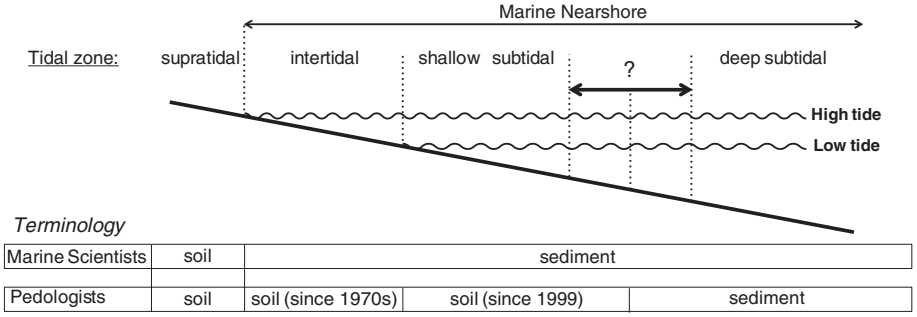

Fig. 1. Schematic drawing of the Marine Nearshore subsystem with indications of tidal zones. The terminology used by marine scientists and pedologists for the substrata is indicated in the bars below. Most marine scientists use the term "soil" only for the supratidal zone and apply the term "sediment" within the entire Marine Nearshore. Most pedologists also use the term "soil" to describe substrata in the supratidal and have for the last 4 decades also used this term in the intertidal zone. More recently, they have also described substrata in the shallow subtidal zone as "soil", according to a change in the USDA-NRCS definition of soil that accommodates permanent inundation with water provided that the surface is not "covered by water too deep (typically more than 2.5 m) for the growth of rooted plants." This has led some (especially in the marine science community) to question the appropriateness of using the term "soil" in the nearshore subsystem. This paper is an attempt to discuss these issues and questions.