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Saltmarsh pool and tidal creek morphodynamics: Dynamic equilibrium of northern latitude saltmarshes?

Carol A. Wilson [a,*], Zoe J. Hughes [b], Duncan M. FitzGerald [b], Charles S. Hopkinson [c], Vinton Valentine [d], Alexander S. Kolker [e]

[a] *Vanderbilt University, United States*
[b] *Boston University, United States*
[c] *University of Georgia, United States*
[d] *University of Southern Maine, United States*
[e] *Louisiana Universities Marine Consortium, United States*

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ABSTRACT

Many saltmarsh platforms in New England and other northern climates (e.g. Canada, northern Europe) exhibit poor drainage, creating waterlogged regions where short-form *Spartina alterniflora* dominates and stagnant pools that experience tidal exchange only during spring tides and storm-induced flooding events. The processes related to pool formation and tidal creek incision (via headward erosion) that may eventually drain these features are poorly understood, however it has been suggested that an increase in pool occurrence in recent decades is due to waterlogging stress from sea-level rise. We present evidence here that saltmarshes in Plum Island Estuary of Massachusetts are keeping pace with sea-level rise, and that the recent increase in saltmarsh pool area coincides with changes in drainage density from a legacy of anthropogenic ditching (reversion to natural drainage conditions). Gradients, in addition to elevation and hydroperiod, are critical for saltmarsh pool formation. Additionally, elevation and vegetative changes associated with pool formation, creek incision, subsequent drainage of pools, and recolonization by *S. alterniflora* are quantified. Pool and creek dynamics were found to be cyclic in nature, and represent platform elevation in dynamic equilibrium with sea level whereby saltmarsh elevation may be lowered (due to degradation of organic matter and formation of a pool), however may be regained on short timescales (10^{1-2} yr) with creek incision into pools and restoration of tidal exchange. Rapid vertical accretion is associated with sedimentation and *S. alterniflora* plant recolonization.

1. Introduction

Many saltmarshes exhibit notable pool formation (sometimes referred to as ponds) where shallow depressions are filled with saltwater throughout the tidal cycle (Fig. 1a; Harshberger, 1916; Chapman, 1960; Redfield, 1972; Wilson et al., 2009, 2010). Pool environments are unvegetated and provide critical habitat for fish and wildlife, including breeding and nourishing grounds, and are also important biogeochemical hotspots on saltmarsh platforms (Fig. 1b; van Huissteden and van de Plassche, 1998). Pools in high latitude saltmarshes, such as those in New England, Canada, and northern Europe, typically exist above mean high water (Millette et al., 2010). Processes responsible for pool formation have been described as both physical (ice rafting, wrack, creek blockage from slump block; Harshberger, 1916; Chapman, 1960; Redfield, 1972; Argow, 2007) and biogeochemical (waterlogging and stress on vegetation that causes senescence and subsequent degradation of organic matter; Chapman, 1960; van Huissteden and van de Plassche, 1998). An increase in pool area has been noted in recent decades in many saltmarshes (Pethick, 1974; Kearney et al., 1988; Hartig et al., 2002; Cavatorta et al., 2003), and many authors allude to waterlogging from sea-level rise to be the culprit for pool formation (Orson et al., 1985; Warren and Niering, 1993; Kelley et al., 1995; Hartig et al., 2002). On the other hand Wilson et al. (2009) suggest that pool and creek dynamics may be independent of changes in local sea level.

An important dynamic interaction exists between saltmarsh pools and tidal creeks: creeks incise into pool areas, causing drainage of the pools and subsequent formation of an unvegetated mudflat (Fig. 1c; van Huissteden and van de Plassche, 1998; Wilson et al., 2009). Over time, these mudflats are recolonized, most notably by *Spartina (S.) alterniflora* vegetation (Wilson et al., 2009). The process of pool formation and recovery has been described as far back as Harshberger (1916), however only a few recent studies have focused on quantifying pool formation, drainage and recovery (van Huissteden and van de Plassche, 1998; Wilson et al., 2009, 2010). Work by Wilson et al. (2009, 2010) in Maine's saltmarshes is perhaps the most comprehensive to date, whereby they document pool dynamics including pool formation, enlargement (through expansion or merging of two or more pools), and finally senescence (from intersection with a tidal creek via

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* Corresponding author. Tel.: +1 615 323 2358.
E-mail address: c.wilson2@vanderbilt.edu (C.A. Wilson).

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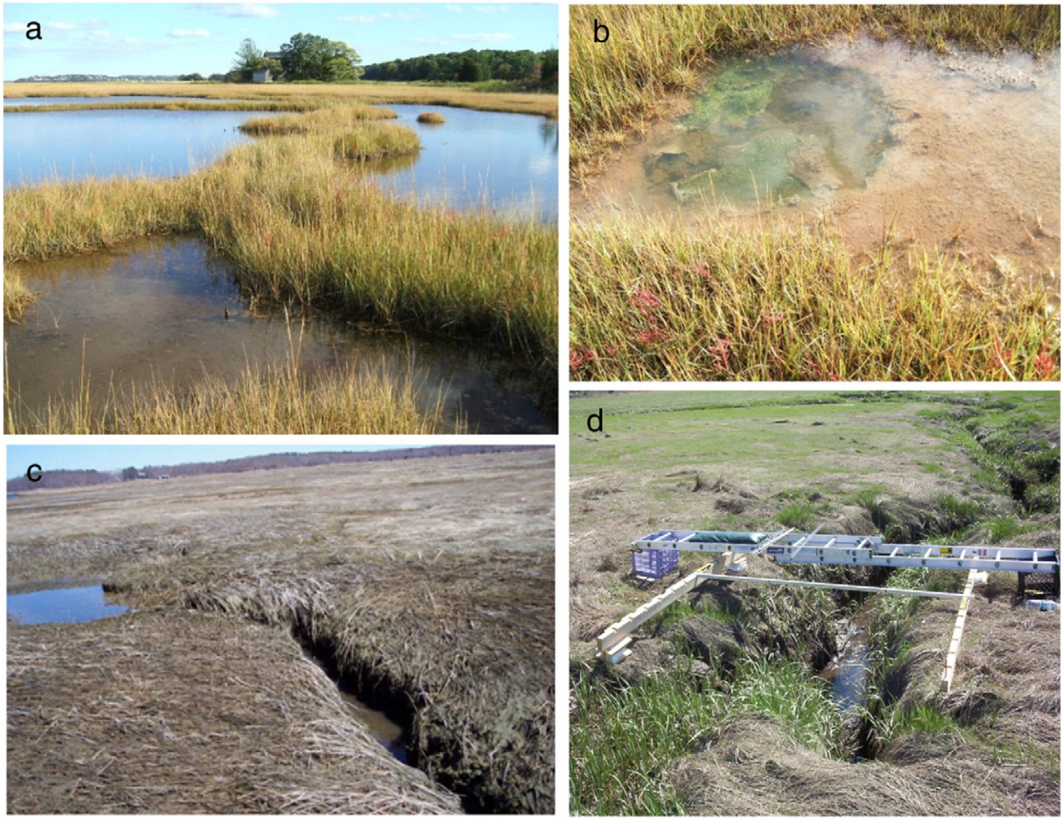

Fig. 1. a) Pool features commonly found in northern saltmarshes; b) waterlogging, death of *Spartina* vegetation, and degradation of organic matter by sulfate-reducing microbes is a common mechanism for pool formation; c) a saltmarsh tidal creek incising the saltmarsh platform could connect to adjacent pools (e.g., pool in upper left of photo), causing their drainage; d) constructed gSET apparatus described in text to measure tidal creek incision rates and saltmarsh topographic changes.

creek incision or pool enlargement) and plant recolonization. Sediment accretion rates in revegetating pools can be 2 to 4 times greater than on the saltmarsh platform (Wilson et al., 2010). To date, little research has centered on the elevation changes associated with creek and pool dynamics despite the fact that any process resulting in elevation loss is critical for saltmarsh sustainability in the face of sea-level rise (Reed, 1995; Cahoon and Reed, 1995; Allen, 1997; Morris et al., 2002; Kirwan and Guntenspergen, 2010).

In addition, existing studies have yet to relate an increase in pool occurrence to changes in tidal creek drainage, although it has been hypothesized that pool occurrence and evolution are heavily influenced by drainage patterns. For example, Redfield (1972) observed high pool density on high saltmarsh platforms in Barnstable, Massachusetts, but noted fewer pools in regions heavily ditched. Ditching for agricultural or mosquito control purposes has been a common practice in many saltmarshes world-wide. Efforts to control mosquito populations resulted in ditching or re-ditching ~90% of U.S. coastal saltmarshes from Maine to Virginia by 1938 (Adamowicz and Roman, 2005, and references therein). Redfield (1972) maintained that anthropogenic ditches provide “over-drainage of the saltmarsh”, and natural creek length decreases as a result. Adamowicz and Roman (2005) found ditched saltmarshes in New England have significantly lower natural creek length and significantly lower total pool surface area than unditched saltmarshes. Additionally, pool formation is most noticeable on high saltmarsh platforms in inter-creek areas where waterlogging is prevalent. In a study of Plum Island Estuary saltmarshes (Massachusetts), Millette et al. (2010) found water-filled pools are more concentrated on the high saltmarsh above MHW. In contrast, pools are not as common in areas of lower elevation where the saltmarsh platform is flushed more frequently with the tide (Fig. 2a, b). In Plum Island Estuary, drained pools cover a relatively high percentage of the total surface area in low saltmarshes (Millette et al., 2010). Millette et al. (2010) hypothesize that stronger tidal processes at lower elevation facilitate the expansion of tidal channels which intercept and drain pools.

We test the hypothesis that pool dynamics are related to changes in drainage, rather than changes in local sea level. Our investigation combines GIS analysis of historical photographs combined with a number of field studies including core transects and stratigraphic analysis, elevation and vegetation surveys, measurement of natural and anthropogenic creek dynamics (drainage density, infilling and incision), and determination of vertical accretion rates (both long- and short-term) on saltmarsh platforms and in revegetating pools. We found that pool formation on high and low saltmarsh platforms is closely linked to changes in drainage, and elevation changes suggest that platforms are in dynamic equilibrium with sea level. We further discuss how pool and creek dynamics can affect saltmarsh sustainability in New England.

2. Methods

2.1. Regional setting

Plum Island Estuary is situated in northeastern Massachusetts behind the sandy barrier of Plum Island, which developed prior to 3.6 ka during a slowing of the rate of sea-level rise in the Holocene (Hein et al., 2012; Fig. 2a). It is ~60 km^2 in size with tidal saltmarshes occupying ~40 km^2 of the area. The mean tidal range in this estuary is approximately 2.5 m, and tide gauge records from Boston (~40 km away, including the period 1920–2010) record an average sea-level rise rate of ~2.6 mm/yr (Fig. 2a). The Parker and Ipswich Rivers are the major contributors of freshwater (Vallino and Hopkinson, 1998), but little suspended sediment is transported downstream of the Parker River Dam (Cavatorta et al., 2003). The Rowley River is located approximately in the middle of the estuary and is largely tide-dominated except during extreme flood events. Adjacent saltmarshes are the focus of many