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Research paper

Salt-marsh sea-level indicators and transfer function development for the Magdalen Islands in the Gulf of St. Lawrence, Canada

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ABSTRACT

Late Holocene salt-marsh sediments allow the reconstruction of pre-industrial relative sea-level changes. Typically, reconstructions are derived by quantifying a relationship between contemporary proxies and elevation which is then applied to down-core fossil assemblages via a transfer function. Common sea-level indicating proxies are salt-marsh foraminifera and diatoms, however, testate amoebae represent an alternative complementary proxy. With current sea-level research increasingly invoking (multi-)decadal timescale processes such as ocean current strength or wind stress to explain relative sea-level changes, there is a need for increased vertical precision in reconstructions. This paper presents new surface assemblages of salt-marsh foraminifera and testate amoebae with respect to elevation from two coastal locations in the Magdalen Islands in the Gulf of St. Lawrence, eastern Canada. We analyse the suitability of each proxy for reconstructing sea level using multivariate statistics, ordination and regression modelling. Testate amoebae are found in greater abundance and diversity than foraminifera and their assemblage variations can be better accounted for by changes in elevation. The contemporary training sets from the Magdalen Islands were able to predict marsh-surface elevations (viz. sea level) to precisions of ± 0.08 m and ± 0.12 m for testate amoebae and foraminifera respectively. There were no benefits from combining the two proxies into a unified training set. It was possible to improve the performance of the foraminifera-based transfer function by incorporating a second dataset from Newfoundland which served to increase the range of the sampled environment and improve the correlation coefficient between sample elevations and model predictions. In accordance with existing literature, we find transfer function performance to be better at locations with smaller tidal ranges.

1. Introduction

Calculations of global mean sea-level rise from tide gauge (Jevrejeva et al., 2014) and satellite altimetry data (Rahmstorf et al., 2012) average 3.1 and 3.2 mm yr^{-1} respectively. The IPCC AR5 report (Church et al., 2013) states that "the regional distribution of sea-level rise" remains a "significant uncertainty" when forecasting future trends, which is particularly pertinent in regions experiencing higher than average rates of relative sea-level (RSL) rise. Land subsidence can significantly contribute to rapid positive RSL trends, i.e., rates exceeding 3.0 mm yr^{-1} (Cronin, 2012). Subsidence may be caused by ground water extraction (e.g., Indonesia: Abidin et al., 2013; Chaussard et al., 2013), compaction of deltaic sediments (e.g., Mississippi: Törnqvist et al., 2006; Yu et al., 2012), or migration and collapse of a glacial forebulge (Koohzare et al., 2008). In the Gulf of St. Lawrence (eastern Canada), negative vertical land motion, associated with the rebounding lithosphere and collapse of the ice-sheet-peripheral forebulge since deglaciation (Peltier, 2002), results in many regions experiencing higher than global average rates of RSL rise (Peltier et al., 2015). These trends are of concern for coastal communities throughout the Gulf of St. Lawrence (Bernatchez and Dubois, 2004; Friesinger and Bernatchez, 2010), particularly for residents of the Magdalen Islands (Fig. 1) where coastal erosion rates can exceed 6 m yr^{-1} in some locations (Bernatchez et al., 2012). Understanding past regional sea-level trends and being able to explain the governing mechanisms are pre-requisites to forecast attempts. Many coastal areas lack nearby tide gauges or gauge records present short time series which is a major problem for predicting sea-level rise on a regional scale (Boon, 2012). When satellite or tide gauge data are too short to investigate decadal or centennial sea-level variability, it becomes necessary to turn to the geological record (Douglas, 2008; Woodworth et al., 2009; Siddall and Milne, 2011; Woodroffe and Murray-Wallace, 2012) where indicators (proxies) can be used to validate and calibrate sea-level prediction models (Bittermann et al., 2013). However, the magnitude of uncertainty associated with projections remains substantial

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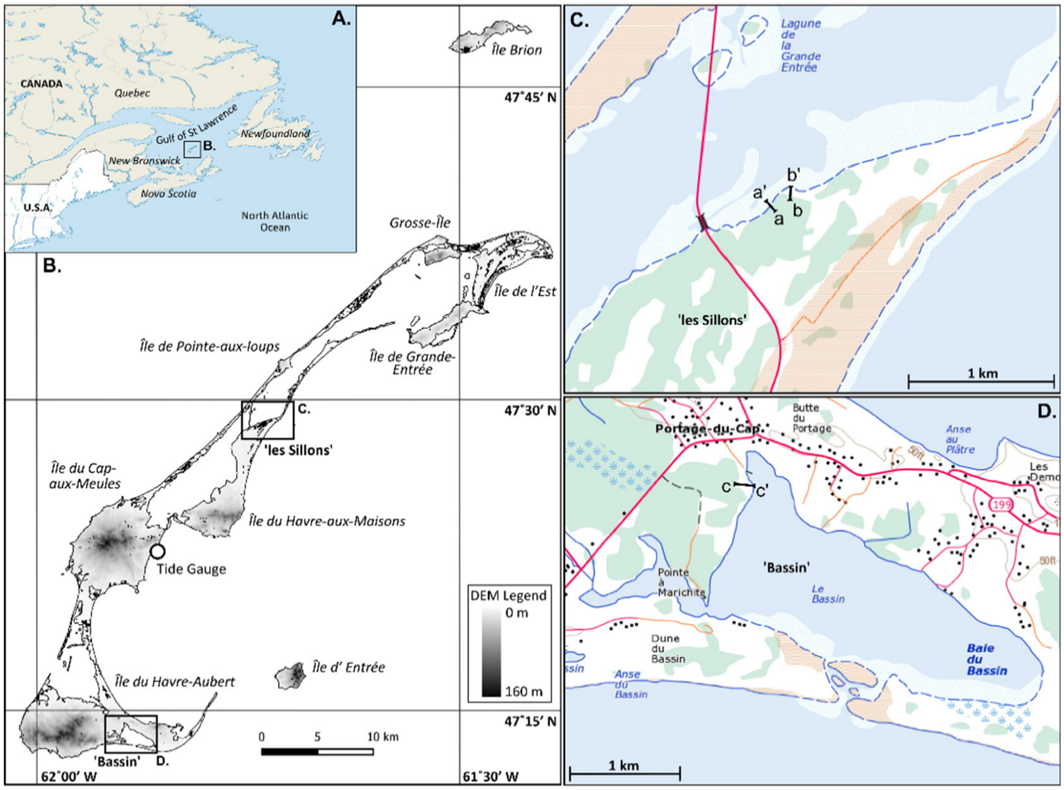

Fig. 1. Location map (A) for the Magdalen Islands (B) and sites mentioned in the text including the two field locations of les Sillons (C) and Bassin (D) with surface transects highlighted (a, b, c).

(Horton et al., 2014) despite advances in our understanding of the relevant mechanisms involved (Slangen et al., 2014).

Late Holocene salt-marsh deposits provide the means to investigate recent changes in RSL through studying microorganisms such as foraminifera that inhabit the sediments (Scott and Medioli, 1978, 1980). The effects of tidal inundation on contemporary foraminiferal assemblages can be quantified along a gradient of elevation and used to define an elevation–proxy relationship related to the tidal frame (Scott and Medioli, 1980). This relationship can be applied to fossil assemblages from salt-marsh sediment stratigraphy to derive quantitative estimations of former sea level (Scott and Medioli, 1982). Recently, long (up to 2500 years, Kemp et al., 2013b) and precise ($\pm$0.05 m, cf. Gehrels and Woodworth, 2013) reconstructed RSL changes have been achieved using salt-marsh sediments. Vertical uncertainties associated with these reconstructions are smaller in comparison to other salt-marsh proxies such as pollen stratigraphy (e.g., Chmura et al., 2001; Roe and van de Plassche, 2005) or basal peat dating (e.g., Törnqvist et al., 2004) as they rely on previously defined, accurately quantified elevation–proxy relationships derived from local or regional contexts (e.g., Gehrels, 2000; Gehrels et al., 2001, 2006a; Edwards et al., 2004; Horton and Edwards, 2005a, 2005b; Horton et al., 2006; Massey et al., 2006; Woodroffe and Long, 2009; Kemp et al., 2009a, 2012).

Commonly used sea-level indicators from salt-marsh environments include plant macrophytes (e.g., van de Plassche et al., 1998; Patterson et al., 2005), foraminifera (e.g., Edwards and Horton, 2000; Gehrels et al., 2005, 2006a,b; Kemp et al., 2013a) and diatoms (e.g., Long et al., 2009; Barlow et al., 2012, 2014; Saher et al., 2015). Salt-marsh testate amoebae represent an alternative proxy which remain infrequently used in sea-level reconstructions (Barnett et al., 2015). Testate amoebae are freshwater unicellular protists (Tolonen, 1986) found abundantly in peatlands but they also inhabit brackish and freshwater marshes. Foraminifera and testate amoebae are two complementary proxies in salt-marsh environments as their diversities increase in opposite directions in relation to tidal inundation (Gehrels et al., 2001; Charman et al., 2002). Both proxies demonstrate zonation across salt-marsh surfaces, however, that of testate amoebae is more clearly defined in the high marsh zone when compared against foraminiferal zonation (Charman et al., 1998). In an analysis of testate amoebae assemblages across three salt marshes in the UK, elevation and tidal inundation were consistently identified as the primary controlling variables of zonation within the tidal zone (Charman et al., 2002). These variables had greater influence than other parameters such as salinity, pH, grain size and carbon content, implying that testate amoebae are a suitable proxy for estimating palaeo-marsh surface elevations (PMSEs) from fossil salt-marsh assemblages. Testate amoebae assemblage compositions change noticeably in the supratidal zone, a feature that can be used to identify the limit of tidal inundation (Ooms et al., 2012). Transfer functions based on contemporary distributions of this proxy are able to predict PMSEs to within uncertainties of $\pm$0.04 to $\pm$0.19 m (Gehrels et al., 2006c; Ooms et al., 2011, 2012; Barnett et al., 2013). The two applied salt-marsh testate amoebae-based transfer functions that exist have both produced precise (less than $\pm$0.10 m vertical uncertainty) and accurate (compared with nearby tide gauge data) sea-level reconstructions for the past ~100 years (Charman et al., 2010; Barnett et al., 2015).

1.1. Context and objectives

The Magdalen Islands occupy the centre of the Gulf of St. Lawrence. The local tide gauge on Cap-aux-Meules (Fig. 1) records a contemporary linear RSL trend of 4.3 mm yr^{-1} (1964 to 2013). This tide gauge provides the only precise RSL data for the archipelago, yet records only extend back to the early 1960s and contain data hiatuses. Reconstructing sea-level trends using salt-marsh foraminifera has been successfully applied along the North American eastern seaboard (Gehrels et al., 2005; Kemp et al., 2013a,b, 2014). Reconstructions reliant on testate amoebae alone show promise when applied to the past ~100 years (Charman et al., 2010; Barnett et al., 2015), yet when applied to older sediments, such as mid-Holocene coastal deposits, the proxy may suffer from selective