Continental Shelf Research 69 (2013) 110–122

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Historical variability in past phytoplankton abundance and composition in Doubtful Sound, New Zealand

Susanne E. Schüller [a], Mead A. Allison [b,c], Thomas S. Bianchi [d,e], Feng Tian [a,f], Candida Savage [a,g,*]

[a] Department of Marine Science, University of Otago, Dunedin, 9054, New Zealand
[b] The Water Institute of the Gulf, Baton Rouge, LA 70825, USA
[c] Department of Earth & Environmental Sciences, Tulane University, New Orleans, LA 70115, USA
[d] Department of Geological Sciences, University of Florida, Gainesville, FL 32611-2120, USA
[e] Department of Oceanography, Texas A&M University, College Station, TX 77843-3146, USA
[f] Singapore Health Sciences Authority, Singapore
[g] Department of Biological Sciences and Marine Research Institute, University of Cape Town, Rondebosch, South Africa

ARTICLE INFO

Article history:
Received 3 March 2012
Received in revised form
2 September 2013
Accepted 15 September 2013
Available online 27 September 2013

Keywords:
Fjords
Palaeoecology
Pigments
Diatom frustules
Past productivity
Sediment records

ABSTRACT

Doubtful Sound, New Zealand, provides an exceptional opportunity to study a 'baseline' coastal ecosystem with an intact watershed. We present the first data on historical changes in phytoplankton abundance and community composition for three sites in Doubtful Sound using sediment records. Profiles of sedimentary concentrations of β-carotene (a proxy of total algal abundance, 0.021–1.345 mmol g organic carbon^{-1}) and carotenoids were generally depleted, indicating low autochthonous production. Phytoplankton pigments and diatom frustules in Doubtful Sound indicate that diatoms have been prevalent for at least the last ca. 350 years; however, the relative importance of marine and freshwater diatoms has varied through time. Further, the timing of change in phytoplankton biomass and community composition differed among the sites within Doubtful Sound. This finding highlights the need to use multiple sites and complementary biomarkers when studying historical changes in phytoplankton communities in complex ecosystems with strong physicochemical gradients such as fjords.

1. Introduction

Coastal and fjord ecosystems with no or minimal human impact are rare in the twenty-first century, especially with a growing human influence on coastal biogeochemistry (Doney, 2010). As anthropogenic activities have altered coastal watersheds through logging, urbanisation and farming, and increased land-derived nutrient inputs, cultural eutrophication and anoxia/hypoxia events have been recorded in several fjords worldwide (Paetzel and Schrader, 1992; Tunnicliffe, 2000; McQuoid and Nordberg, 2003; Buschmann et al., 2006). By contrast, Fiordland, New Zealand, is a World Heritage Area with 2.6 million ha of intact temperate rainforest that drains into 14 major fjords (McLeod et al., 2010). This region provides an exceptional opportunity to study a 'baseline' coastal ecosystem with an intact watershed and minimal anthropogenic influence. In this paper, we examine the temporal and spatial variability of past phytoplankton communities in Doubtful Sound, New Zealand, using palaeoecological techniques (diatom frustules and algal pigments in sediments). Accordingly, we present the first investigation of historical changes in phytoplankton abundance and community composition in Doubtful Sound. This study also adds to the limited data on organic matter sources to sediments in fjords, which have recently been recognised as hotspots of organic carbon burial (Smith et al., in review).

In situations where instrument and ecological records are unavailable, palaeoecological methods can provide valuable information on historical changes in organic matter sources and the ecology of aquatic ecosystems. Both direct comparison of long-term records and palaeo-proxies including diatoms, pigments and stable isotopes (Bianchi et al., 2000a; Bianchi et al., 2002) and numerical models (Cuddington and Leavitt, 1999) have verified the validity of palaeoecological techniques to reconstruct long-term changes in organic matter sources and phytoplankton abundance and composition. Specifically, photosynthetic pigments (e.g., Bianchi et al., 2000a; Bianchi et al., 2002) and diatoms in sediments (Cooper, 1995; Hay et al., 2003) have been used effectively as biomarkers to characterise past algal communities and describe relative changes in algal groups within an ecosystem. It is rare that these two approaches (pigment biomarkers; diatom frustules) are combined

* Corresponding author at: Department of Marine Science, University of Otago, Dunedin 9054, New Zealand. Tel.: +64 3 4798324; fax: +64 3 4798336.
E-mail address: candida.savage@otago.ac.nz (C. Savage).

0278-4343/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.csr.2013.09.021

in a study, particularly in marine systems, and also uncommon that several sites within an ecosystem are examined for palaeoecological studies.

In this study, we combine sedimentary pigments and diatom frustule counts to reconstruct shifts in phytoplankton abundance and composition, and the timing and magnitude of these changes, at three sites in Doubtful Sound, Fiordland, New Zealand. The Doubtful Sound fjord complex is characterised by strong spatial gradients in physicochemical parameters (e.g., light, chromophoric dissolved organic matter (CDOM), effective freshwater depth, water column stratification and salinity; Wing et al., 2004). These gradients and the proximity to different sources affect the relative contribution of marine (autochthonous) (Schüller and Savage, 2011) and terrestrial (allochthonous) (Smith et al., 2010) organic matter sources to surface sediments across Doubtful Sound. The steep fjord walls (ca. 70° in Doubtful Sound; Goebel, 2001) and high rainfall (ca. 6000 mm yr^{-1}; Bowman et al., 1999) create frequent landslides that transport terrigenous material into fjord sediments (Smith et al., 2010) and affect the light environment. The marine production in Doubtful Sound is particularly influenced by the light environment and water column mixing regimes, which varies from inner to outer fjord regions (Schüller and Savage, 2011). Once organic matter reaches the sediments, the deep basins typically experience low oxygen conditions favourable for preservation of biomarkers such as pigments.

While the terrestrial environment of Fiordland is pristine, the marine habitats experience some human impacts from fishing, tourism and a hydroelectric power (HEP) scheme, although these impacts are minimal and only relatively recent. The HEP was established in 1969 and currently discharges freshwater at an average flow rate of 450 m^3s^{-1} (Gibbs et al., 2000) from Lake Manapouri into Deep Cove at the head of Doubtful Sound. This augmented freshwater discharge has significantly increased the volume of freshwater into the fjord since 1969 (Bowman et al., 1999) and increased the freshwater depth at the fjord head from <1 m (Batham, 1965) to an average effective freshwater depth of 2–4 m (Goebel et al., 2005). Apart from basic oceanographic observations and descriptions of macroalgal and faunal communities (Batham, 1965), historical information on environmental conditions in Doubtful Sound prior to the HEP is lacking.

Flagellates dominate modern phytoplankton communities in twelve of New Zealand's fourteen fjords. By contrast, Preservation Inlet and Doubtful Sound are presently dominated by diatoms, especially during phytoplankton blooms (Pickrill et al., 1992; Goebel, 2001). Preservation Inlet is distinct from the other fjords in terms of its shallow sill (29 m) that limits circulation (Pickrill, 1987, 1993) and promotes diatoms. It is unknown whether the current dominance of diatoms in Doubtful Sound is a consequence of the HEP or whether diatoms have always been an important component of this fjord's phytoplankton community. Therefore an investigation into the palaeo-history of Doubtful Sound is needed to examine past phytoplankton composition and to assess the future of anthropogenic influences on phytoplankton community dynamics. Water column phytoplankton composition has been described in Doubtful Sound in relation to physical gradients, nutrients and species succession (Goebel et al., 2005), and the distribution of phytoplankton remains in surface sediments investigated in relation to environmental drivers (Schüller and Savage, 2011). To date, geological records have been published for six out of 14 New Zealand fjords (Pantin, 1964; Glasby, 1978; Pickrill et al., 1992; Pickrill, 1993), but not for Doubtful Sound. This is the first palaeoecological study in this fjord and provides valuable baseline information of past phytoplankton abundance and composition.

The objectives of this study were: (1) to investigate past phytoplankton community composition at three locations within a near-pristine fjord using palaeoecological techniques; (2) to assess whether the timing and direction of change is consistent across the three sites within the fjord; and (3) to determine whether diatoms have historically been an important component of the phytoplankton community and whether there were shifts in the relative contribution of freshwater and marine diatoms to the sedimentary record.

2. Methods

2.1. Site description

The Doubtful Sound fjord complex (45°18′S, 166°59′E; Fig. 1) is the second longest (ca. 40 km) of the New Zealand fjords and characterised by pronounced gradients in salinity. The deepest basin exceeds 400 m and the mouth is characterised by a moderately shallow sill at 101 m (Stanton and Pickard, 1981). Salinity-stratification in Doubtful Sound is persistent due to high rainfall (ca. 6000 mm yr^{-1}; Bowman et al., 1999), leading to input of freshwater from the Lake Manapouri HEP (450 m^3s^{-1}; Gibbs et al., 2000), natural rivers (ca. 135 m^3s^{-1}; Bowman et al., 1999), and land run-off. The resulting low salinity layer (LSL) decreases in thickness towards the ocean, creating classic estuarine circulation (Bowman et al., 1999). Estuarine mixing at the halocline promotes primary production, as the surface LSL is silicic acid-rich but nutrient-poor while the underlying marine water (saline layer, SL) is nutrient-rich and silicic acid-poor (Goebel, 2001; Peake

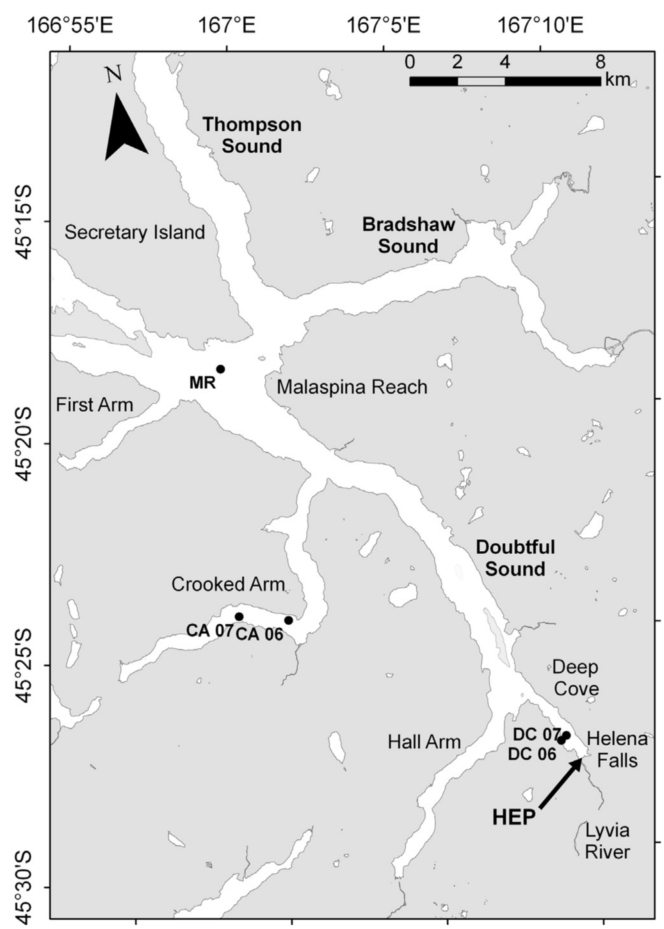

Fig. 1. Map of the Doubtful Sound fjord complex in Fiordland, South Island, New Zealand, with the sample stations indicated as filled circles. Deep Cove (DC) and Crooked Arm (CA) were sampled in 2006 (DC 06, CA 06) and 2007 (DC 07, CA 07), Malaspina Reach (MR) was sampled in 2007.