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Potential and limitation of combining terrestrial and marine growth records from Iceland



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ABSTRACT

Seasonally formed, perennial growth increments of various organisms may possibly contain information about past environmental changes, well before instrumental measurements occurred. Such annually resolved proxy records have been mainly obtained from terrestrial archives, with a paucity of similar data originating from marine habitats. Iceland represents ideal conditions to develop both, tree ring (dendro) and bivalve shell (sclero) chronologies from adjacent sites. Here we introduce the first network of Icelandic birch (*Betula pubescens* Ehrh.) and rowan (*Sorbus aucuparia*) dendrochronologies, as well as ocean quahog (*Arctica islandica* L.) sclerochronologies. In order to identify the dominant external drivers of tree and shell growth, we assess the common growth trends and growth extremes within and between the terrestrial and marine records, as well as relationships of both archives with instrumental-based meteorological indices. Capturing a strong signal of June–August mean air temperature, the dendrochronologies are significantly positively correlated to each other. The sclerochronologies, however, reveal much lower growth coherency, which likely results from different sampling strategies and growth habitats. Disagreement between the dendro- and sclerochronologies possibly originates from unequal sample size, offset in the seasonal timing and rate of the growth, as well as varying sensitivities to different environmental factors. Our results emphasize the importance of considering a wide range of species and taxa to reconstruct a more complete picture of terrestrial and marine ecosystem functioning and productivity across various spatiotemporal scales.

1. Introduction

Chronologies of annual growth increments extracted from a range of organisms can be used to reconstruct past environmental and climatic conditions (Jones et al., 2009). Tree rings constitute the backbone of high-resolution, terrestrial paleoclimatology (IPCC, 2013). Marine conditions at annual or even higher temporal resolutions (Thompson et al., 1980) have been reconstructed from tropical, shallow-water corals (e.g., Gagan et al., 2000; Tierney et al., 2015), coralline red algae (e.g., Halfar et al., 2000), and shells of bivalves (e.g., Wanamaker et al., 2008a; Schöne, 2013; Mette et al., 2016; Reynolds et al., 2016), for

instance. Sclerochronology is frequently applied to the study of accretionary hard tissues in some animal and algae species (Buddemeier et al., 1974; Hudson et al., 1976; Witbaard, 1996; Oschmann, 2009; Helmle and Dodge, 2011; Butler and Schöne, 2017). Among sclerochronological archives, bivalves hold a special position for their informative power; some species, such as *Arctica islandica*, can reach ages of > 500 years (Schöne et al., 2005a; Butler et al., 2013; Wanamaker et al., 2008b). This results in continuous and distinct temporal growth patterns at different resolutions, such as daily, tidal, fortnightly, monthly and annual. Environmental changes affect shell growth rates, as well as their geochemical and microstructural properties (e.g.,

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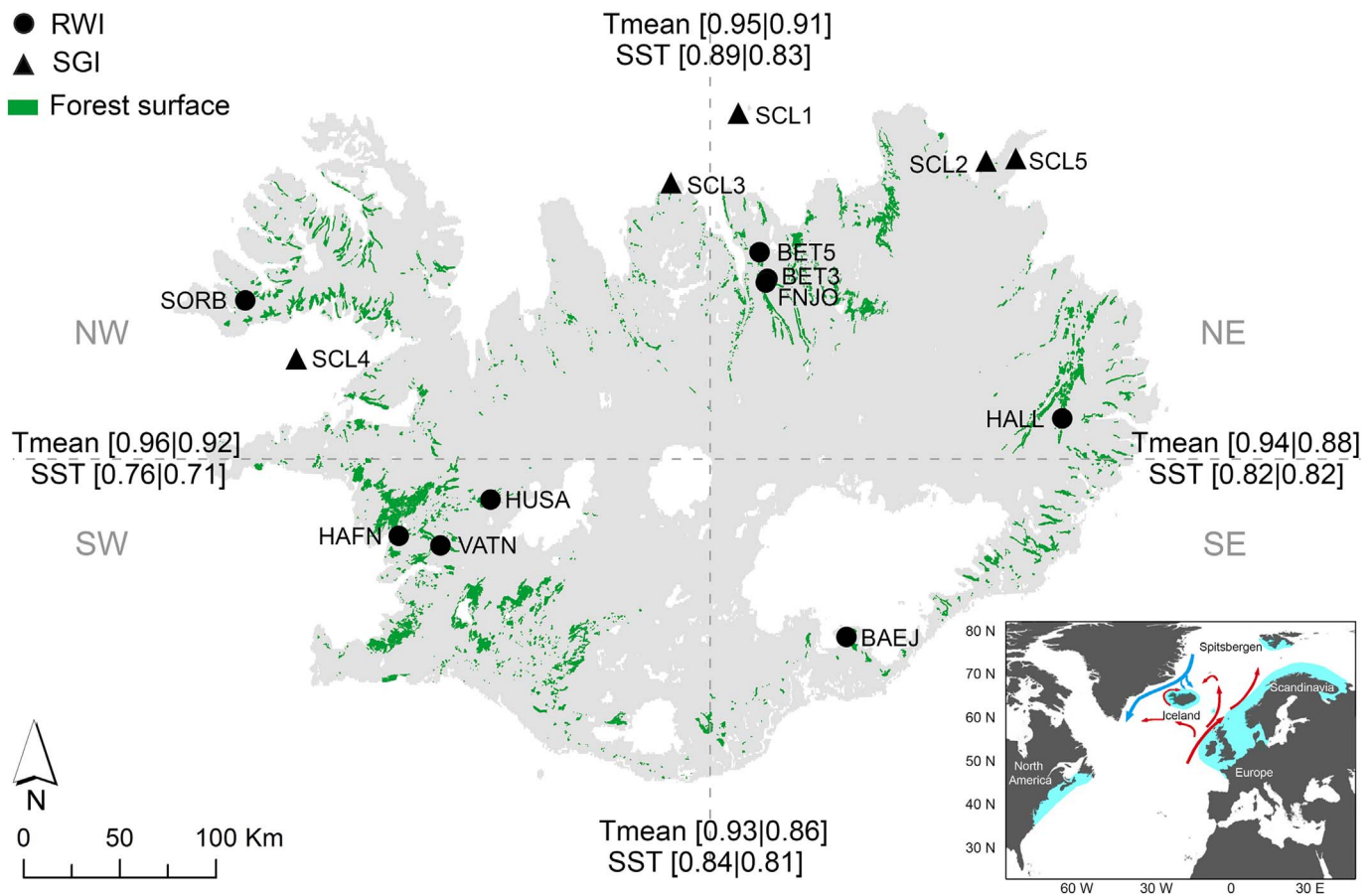


Fig. 1. Sampling sites of the dendro and sclero data (circles and triangles). White and green areas on Iceland represent ice and woodland cover (Traustason and Snorrason, 2008). Values in square brackets at the four cardinal points are correlation coefficients (r) between Tmean and SST, at the pairings of Iceland's four geographical sectors, NW-SW, SW-SE, SE-NE, NE-NW. The first, left value refers to the seasonal length of shell growth (February–September), whereas the second, right value indicates the seasonal length of tree growth (June–August). Light blue shadings in the inset depict the natural distribution of *Arctica islandica* (modified after Dahlgren et al., 2000), with red and blue arrows representing warm and cold ocean currents, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Wanamaker et al., 2008a; Helama et al., 2009; Milano et al., 2016).

Recent examples show that a combined analysis of spatiotemporally coexisting terrestrial and marine organisms can facilitate a better understanding of ecosystem-level responses to climatic forcing (Black et al., 2016). Nonetheless, only at a few localities worldwide, has information inherent in tree and shell growth rates were so far been successfully combined (Black, 2009; Black et al., 2009). Iceland appears particularly favorable in this regard, because trees and shells are often growing nearby each other. Moreover, Iceland's climate is strongly controlled by different atmospheric circulation patterns and dynamics in oceanic current and sea ice extent (Eggertsson, 1993; Wanamaker et al., 2008b; Cunningham et al., 2013).

Tree-ring chronologies from Iceland are generally scarce and composed of a few native tree species, such as downy birch (*Betula pubescens* Ehrhart), dwarf birch (*Betula nana* L.), rowan (*Sorbus aucuparia* L.), willows (*Salix* spp.), and common juniper (*Juniperus communis* L.) (Halladóttir, 1995; Ólafsdóttir et al., 2001). With a cambial age of > 100 years, downy birch and rowan can provide useful information prior to the period of instrumental measurements (Levanič and Eggertsson, 2008; Kaczka et al., 2015; Eggertsson, unpublished). Recent studies found that tree growth in Iceland is strongly influenced by summer temperature changes (Levanič and Eggertsson, 2008; Kaczka et al., 2015; Büntgen et al., 2017). Only a few studies, however, have targeted shells of *Arctica islandica* as a paleo-environmental archive (Butler et al., 2013; Marali and Schöne, 2015). *Arctica islandica* occurs off Icelandic seashores at water depths of 8 to 80 m (Mette et al., 2016), and an optimum depth of 30 to 60 m (Nicol, 1951; Dahlgren et al., 2000; Schöne, 2013). The timing and rate of shell growth in *Arctica*

islandica is still under discussion. Based on ultra-high-resolution isotopic ratios and daily increment counts, Schöne et al. (2005b) and Schöne (2008, 2013) demonstrated that the annual growth increments (equal to the main growing season) are formed between October of the current year and September of the following year. Growth line formation (period of very slow or halted shell growth) occurred ca. one month after the summer temperature maximum and lasted for ca. two months (September–October). Their data further indicated that growth rates increase when temperatures and food levels rise. Recently, Ballesta-Artero et al. (2017) showed that the physiological activity of this species is strongly linked to food supply. Valve gaping activity increases strongly in March–April when phytoplankton rates increase. Curiously, the primary production rates increase prior to the seasonal temperature minimum, and hence the shells record the lowest winter temperatures. However, the physiological activity of *A. islandica* decreases in September when food availability is low. The bivalves remain more or less inactive between September and the following March–April. It should be added that the experimental setup of Ballesta-Artero et al. (2017) cannot provide direct evidence of how much shell was formed each day and season. Reynolds et al. (2016) presented an alternative model of the seasonal time and rate of this species. They suggested that *A. islandica* grows its shell mainly between June and late September with slower rates of growth occurring during spring (April–June) and autumn (September–October) (Reynolds et al., 2016). Shell growth is primarily controlled by phytoplankton density, temperature, and light condition, but also by the amount of dissolved oxygen, salt, and turbidity (Schöne et al., 2002; Ballesta-Artero et al., 2017). As such, shell growth is also controlled by major climate

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