

Short communication

# Thermal insulation of the intertidal zone by the ice foot

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## Abstract

Few studies have looked at the ecological significance of the ice foot in intertidal habitats. During the 2007 winter, we quantified the hourly variation of temperature at the intertidal zone and at the upper, dry coast on the southern Gulf of St. Lawrence (Nova Scotia, Canada) using submersible data loggers. While air temperature dropped to  $-20\text{ }^{\circ}\text{C}$  at the peak of the winter, intertidal temperature was never below  $-7\text{ }^{\circ}\text{C}$  during the winter. In fact, for almost two months when the ice foot was stable, temperature ranged only between  $-2.4\text{ }^{\circ}\text{C}$  and  $-1.1\text{ }^{\circ}\text{C}$  at the intertidal zone. The intertidal values are higher than published values of lethal temperature for cold-water intertidal invertebrates and seaweeds. Thus, the ice foot may prevent these organisms from experiencing lethal levels of thermal stress, contributing to their long-term persistence in these environmentally stressful habitats.

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## 1. Introduction

Environmental stress is a major determinant of species distribution and community organisation (Gaston, 2003; Bruno et al., 2003). In marine waters, ice develops when the temperature falls below the freezing point of seawater. In polar and subpolar intertidal habitats, a particular form of sea ice, the ice foot, forms directly on rocky surfaces (Barnes, 1999; Johnson, 2007). The ice foot may promote physical disturbance during thawing events, as ice fragments may remove benthic organisms from the substrate through scouring and rafting (Gutt, 2001). However, the ice foot may have positive effects when it is stable during the coldest periods of the year. In terrestrial habitats, snow cover provides protection against extreme drops in temperature (Marchand, 1996; Pomeroy and Brun, 2001). The ice foot might function in an analogous manner on

marine shores, especially when habitats are exposed at low tide. This is important to investigate, as intertidal temperature on cold-water shores in winter is commonly assumed to reach extreme low values similar to air temperature (Peck et al., 2006). We quantified temperature dynamics under the ice foot on a subarctic shore using submersible temperature loggers. Our objectives were to test the hypotheses that temperature fluctuations would be small under persistent ice cover (relative to areas without ice cover) and that extreme low temperatures would not be experienced under the ice foot.

## 2. Material and methods

We did the study at Sea Spray Shore ( $45^{\circ} 46' \text{ N}$ ,  $62^{\circ} 10' \text{ W}$ ), located near Arisaig, on the southern coast of the Gulf of St. Lawrence, Nova Scotia, Canada. This coast has large areas of stable bedrock composed of volcanic rock. Sea ice develops extensively on the Gulf of St. Lawrence in early winter and melts in late winter and early

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spring (Saucier et al., 2003). On 4 January 2007, when sea ice was still absent, we deployed nine temperature loggers (StowAway TidbiT units, Onset Computer Corp., Bourne, MA, USA). Six loggers were tied (using a wire and two plastic cable ties per logger) to metallic hooks that were affixed with marine epoxy (A-788 Splash Zone Compound, Z-Spar, Los Angeles, CA, USA) to rocky surfaces across the mid-intertidal zone (the intertidal range is 1.8 m). The remaining three loggers were affixed using plastic cable ties to branches (2 m above the ground) in spruce trees that were facing the sea directly; these loggers measured temperature variations solely in aerial conditions. We set loggers to record temperature every hour. On 4 April 2007, shortly after the coastal sea ice had completely melted, we collected the loggers that could be recovered. Because of the intense ice scour that occurs on this coast every winter (Scrosati and Heaven, 2006), we lost five intertidal loggers. We recovered one intertidal logger and the three control loggers attached to the branches. Temperature dynamics were very similar among the three control loggers (for simplicity, data for only one is presented), so we assume that the only intertidal logger recovered is representative of intertidal temperature dynamics.

### 3. Results

Initially after logger deployment, mostly positive temperatures occurred in intertidal and aerial locations at Sea

Spray Shore, increasingly alternating with negative values as the winter progressed (Fig. 1). Temperature fluctuations were generally lower at the intertidal zone than at the dry coast (tree branches) because of the dampening effects of high tides and wave action at low tides. The first major cooling event occurred on 18 January, when air temperature dropped to  $-16.1\text{ }^{\circ}\text{C}$ , which was closely followed by a brief, but marked, decrease in temperature variability at the intertidal zone (Fig. 1). The following rise in air temperature to  $7.7\text{ }^{\circ}\text{C}$  on 19 January resulted in intertidal temperature regaining a higher variability (Fig. 1). Such a temporal pattern in temperature suggests that the ice foot formed by first time after the first pronounced seasonal drop in temperature and that, after the subsequent rise to positive values, the ice foot broke down, exposing the intertidal zone again.

After that time, full winter conditions settled and air temperature remained almost always negative for seven weeks (Fig. 1). By mid-February, the intertidal zone was covered by a thick, stable layer of ice (Fig. 2A); the sea surface was covered by ice as well. Under the ice foot, temperature fluctuations were small. Between 6 February and 10 March, temperature ranged only between  $-2.4\text{ }^{\circ}\text{C}$  and  $-1.1\text{ }^{\circ}\text{C}$  at the intertidal zone, but between  $-18.9\text{ }^{\circ}\text{C}$  and  $8.3\text{ }^{\circ}\text{C}$  at the dry coast (Fig. 1). After this period, air temperature frequently switched to positive values again, which was again followed by temperature regaining a higher variability at the intertidal zone (Fig. 1). This period

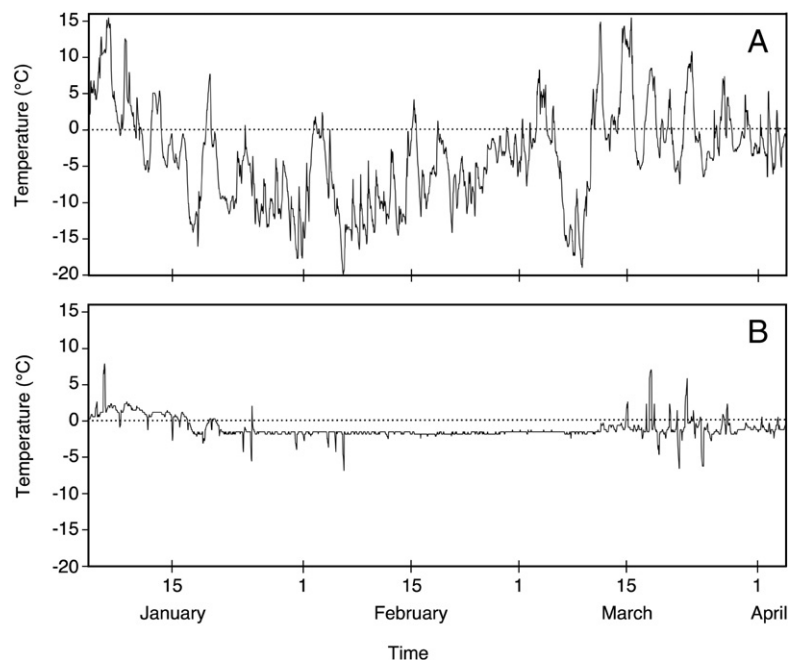


Fig. 1. Hourly variation of temperature between 4 January and 4 April 2007 at Sea Spray Shore, Nova Scotia. (A) Dry coast. (B) Intertidal zone.

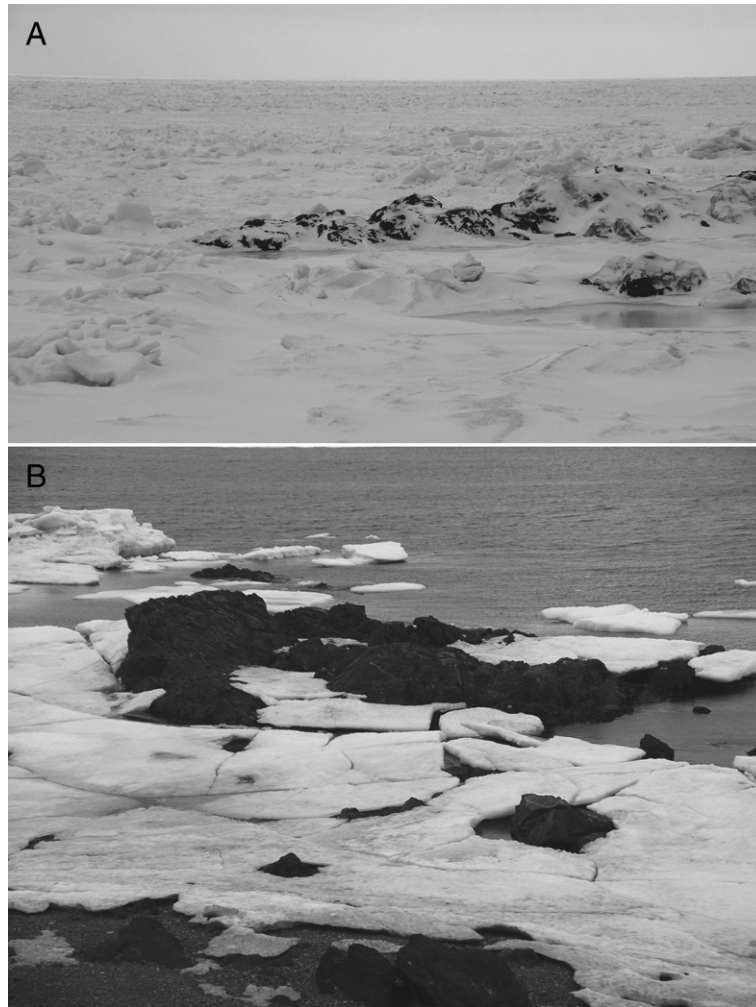


Fig. 2. (A) Intertidal zone and open sea entirely covered by ice at Sea Spray Shore on 25 February 2007. (B) Break-up of the ice foot at the intertidal zone at Sea Spray Shore on 18 March 2007. Photos by R. Scrosati.

coincided with the progressive break-up of the ice foot (Fig. 2B). Descriptive statistics for the full study period are given in Table 1.

Table 1  
Descriptive statistics for temperature ( $^{\circ}\text{C}$ ) at the intertidal zone and at the dry coast at Sea Spray Shore, Nova Scotia, between 4 January and 4 April 2007 (temperature was recorded every hour)

	Intertidal zone	Dry coast
Extreme maximum temperature	7.9	15.5
Mean daily maximum temperature	-0.2 (SE=0.20; n=91)	0.3 (SE=0.70; n=91)
Overall mean temperature	-1.0 (SE=0.03; n=2172)	-3.6 (SE=0.14; n=2172)
Mean daily minimum temperature	-1.9 (SE=0.16; n=91)	-7.2 (SE=0.65; n=91)
Extreme minimum temperature	-6.8	-19.8

#### 4. Discussion

Our findings supported our hypotheses. During the entire winter, temperature was never lower than  $-7^{\circ}\text{C}$  at the intertidal zone, while sites exposed to the air frequently experienced much lower temperatures, with a seasonal minimum almost three times lower ( $-20^{\circ}\text{C}$ ). At the intertidal zone, temperatures around  $-7^{\circ}\text{C}$  were actually rare, values being normally higher than  $-3^{\circ}\text{C}$  even during the coldest period.

These results have important ecological implications. Cold-water intertidal invertebrates and seaweeds have evolved physiological adaptations to survive negative temperatures (Storey and Storey, 1996; Collén and Davison, 2001; Waller et al., 2006), although obviously extensive mortality will occur below certain thresholds. For example, lethal temperatures occur below  $-14^{\circ}\text{C}$  in

winter for the barnacle *Semibalanus balanoides* (Crisp and Ritz, 1967; Cook and Gabbott, 1970) and  $-10\text{ }^{\circ}\text{C}$  for the mussel *Mytilus edulis* (Williams, 1970). Studies on other invertebrates (periwinkles, limpets, and other mussels; Bourget, 1983; Loomis, 1995; Ansart and Vernon, 2003) and fucoid seaweeds (Davison et al., 1989; Collén and Davison, 1999) have found comparable values, usually higher for mobile than for sessile species. These organisms are major components of rocky intertidal communities on the southern Gulf of St. Lawrence (Scrosati and Heaven, 2007). By being covered by the ice foot during the coldest period of the year, their survivorship might be higher than otherwise. The reason is not only that lethal temperatures do not occur under the ice foot, but also that the repeated exposure to sublethal temperatures (but still lower than under the ice foot) can also cause high mortality (Roland and Ring, 1977; Murphy and Johnson, 1980; Bourget, 1983; Dudgeon et al., 1990). Together with crevice availability (refuges against ice scour; Bergeron and Bourget, 1986) and the physiological acclimation to subzero temperatures, the thermal buffering by the ice foot might explain the continued presence of these organisms on subarctic shores.

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