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Spring awakening temperature and survival of sediment-covered eastern oysters *Crassostrea virginica*

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ABSTRACT

In the Gulf of St. Lawrence estuaries, mesh bags containing cultured oysters (*Crassostrea virginica*) are lowered onto the bottom in autumn prior to the formation of a thick ice cover. The oysters remain quiescent and unattended in near-freezing waters for four to five months, during which time they are susceptible to accidental burial by sedimenting particles. The objectives of this study were (1) to gain insight into the mechanism cueing the spring awakening of oysters, (2) to determine the approximate burial depth that oysters can withstand, and (3) to estimate the time it takes for mortality to occur under conditions of excessive siltation. Results indicate that water temperature is the primary factor controlling the timing of awakening, with the majority of oysters suddenly opening their valves when temperatures increased to 2.61 ± 0.66 °C. Supplementing the diet to mimic spring bloom conditions had no modulating influence on awakening behaviour. Oysters buried under 20 mm of sediment initially exhibited erratic valve movements and sometimes remained closed for days. Within 2 weeks, however, they did succeed in expulsing the overlying silt around their valve margins and in resuming normal valve movements, including circadian rhythmicity. By comparison, burial under 40 or 60 mm of silt invariably led to death within 11.7 ± 1.3 days. It is concluded that oysters should be re-suspended as soon as the ice cover breaks apart and moves offshore in the spring.

1. Introduction

The eastern oyster, *Crassostrea virginica* (Gmelin), has a remarkable distribution range extending approximately 4000 km in the Western Atlantic (Carriker and Gaffney, 1996). It can be found from the Gulf of Mexico northward through to the Gulf of St. Lawrence (GSL), Canada (Fig. 1). At its northernmost distribution limit in the GSL, it is inactive for four to five months during the winter when estuarine temperatures are stable over a narrow range between −1 °C and 0 °C (Comeau et al., 2012). The lack of pumping activity and valve movement during this extended period may render these animals susceptible to burial by sedimenting particles. Burial may be accelerated by heavy rainfall events in autumn which promote land runoff and soil erosion. Periods of high wind in October–November may also cause significant sediment re-suspension and localized siltation (Comeau et al., 2014; Mallet et al., 2006). In spring the melting of snow may aggravate matters by increasing land drainage and sediment loading in the estuaries. In addition, anthropogenic siltation may be a major contributor in regions with intensive agriculture, highway construction or dredging. Both natural burial and anthropogenic burial of oysters have long been recognised as widespread occurrences in Atlantic estuaries (Wilber et al., 2005). In Texas, for example, some reefs are found under more than 3 m of mud (Galtsoff, 1964).

Sedimentation rates in cultured shellfish systems are generally higher than in the natural environment (Arakawa, 1980; Willemsen, 2005). Mesh Vexar bags tend to interfere with local hydrodynamics, reducing flow rates and promoting sedimentation, which may result in accidental burial, particularly when structures remain unattended for prolonged periods of time. For example, in GSL estuaries, mesh bags containing oysters are typically lowered onto the seabed in October–November and recovered five to six months later, i.e., after the thick (~1 m) winter ice cover breaks up and moves offshore, rendering the aquaculture farm site accessible again. Upon sinking to the bottom in the fall, bags tend to settle down into the soft sediment, thereby increasing the risk of burying the oysters. Such accidental burials may cause little stress to the oysters as long as they remain closed and reliant upon anaerobic metabolism (Bumett and Stickle, 2001; Gade, 1983; Greenway and Storey, 1999; Stickle et al., 1989). On the other hand, deleterious effects may arise when oysters resume their interaction with the environment in early spring. This postulate is consistent with industry members occasionally reporting oyster mortalities when bags are recovered from the seabed. The dead oysters have dark gaping shells containing black anoxic sediments and traces of still-decomposing tissues indicative of recent mortality.

Few studies have quantitatively examined the effect of siltation on the survival of *C. virginica*. The earliest studies focussed on oyster

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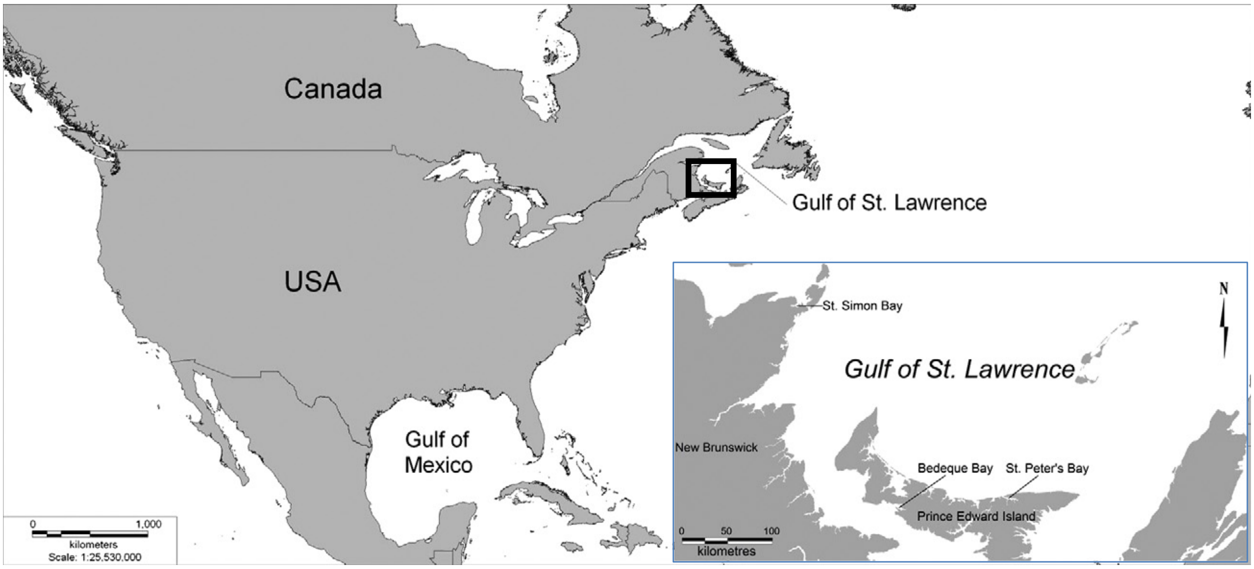

Fig. 1. Map of the study area showing the Gulf of St. Lawrence, the northernmost distribution range of *Crassostrea virginica*.

survival near dredged material disposal sites. Following the dredging of the Intracoastal Waterway of South Carolina, Lunz (1938) concluded that the deposition of mud up to 25 mm thick causes no ill effects to wild oyster beds. Experimental work later demonstrated that excessive siltation can clog the gill apparatus with lethal consequences. Hsiao (1950) reported that oysters die when silt (amount not specified) deposited upon their shells remains for more than 3 days. Dunnington (1968) purposely buried oysters under conditions that did not permit recovery (76 mm of sediment) and reported survival times ranging between 2 days in summer (>25 °C) to 3 weeks in winter (<5 °C). The delayed onset of mortality in winter was attributed to a lower metabolic rate and slower consumption of energy reserves. It was also mentioned that oysters buried in less than 13 mm during pre-experiment trials "could usually clear their bills of sediments if the water was warm enough for pumping." From these reports, it appears that oysters can deal with moderate siltation levels, but that mortality occurs quite rapidly under excessive siltation.

The first objective of this study was to gain insight into the mechanism triggering the spring awakening behaviour of *C. virginica*. Temperature was experimentally manipulated in order to verify whether this variable cues awakening. Food levels were also manipulated to gauge whether they can modulate the process, perhaps by stimulating oysters to awaken at lower temperatures than they would under low food conditions. The second objective was to determine the approximate burial depth that oysters can withstand. The third objective was to assess the time it takes for mortality to occur under excessive siltation.

2. Methods

2.1. Valve opening

In each experiment described below, oyster valve opening was measured using a valvometry system based on the Hall element principle (Nagai et al., 2006). The system allowed for the simultaneous monitoring of up to 32 individuals. A coated Hall element sensor (HW-300a, Asahi Kasei, Japan) was glued to one valve at the maximum distance from the hinge (Fig. 2). Then a small magnet (4.8 mm diameter × 0.8 mm height) was glued to the other valve, directly below the Hall sensor. The magnet and the Hall element weigh 0.1 g and 0.5 g, respectively. For comparison purposes, a 6-mm diameter live barnacle, a common epibiont on oyster shells (Doiron, 2008), weighs approximately 0.12 g. The magnetic field (flux density) between the sensor and magnet was a function of the gap between the two valves. The magnetic field in the form of output voltage (μV) was acquired by strain recording devices (DC 104R, Tokyo Sokki Kenkyujo Co., Japan). Output voltage was recorded once every minute. At the end of the experiments, voltage was converted into valve opening by applying conversion algorithms specific to each sensor assembly. More precisely, the adductor muscle was severed, and small calibration wedges were manoeuvred between the two valves at the point farthest from the

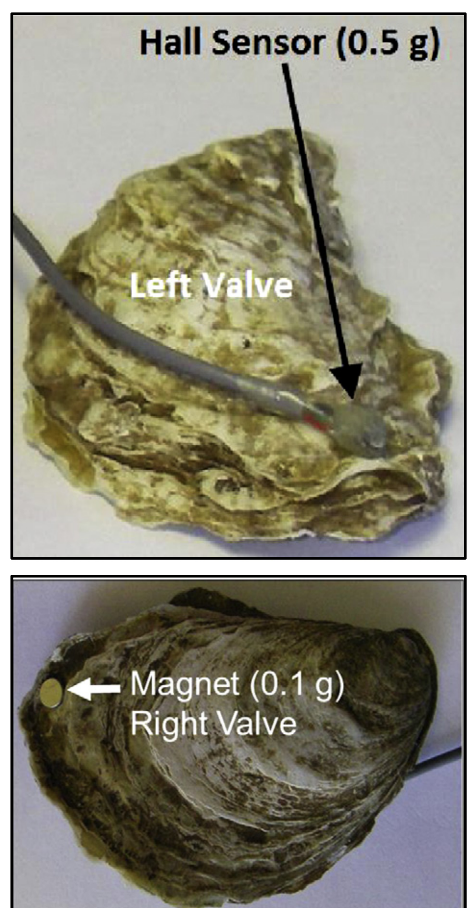

Fig. 2. Oyster wired with Hall magnetic sensor.