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Resistance among wild invertebrate populations to recurrent estuarine acidification

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A B S T R A C T

Acid sulphate soils (ASS), which occur on floodplains worldwide, pose a significant threat to estuarine ecosystems. In laboratory and field experiments, naïve calcifying organisms that are exposed for even short periods (1–2 mo) to runoff from ASS suffer 80% mortality and slowed growth. Based on these observations we expected that sampling of wild oyster, gastropod and crab populations at sites close to and away from drains discharging ASS runoff would reveal more depauperate populations, of sparser and smaller-sized individuals at the more acidified sites. Sampling within three estuaries of New South Wales, Australia, confirmed that the oyster *Saccostrea glomerata* and gastropods (primarily *Bembicium auratum*) were less abundant at ASS-affected than reference sites. Nevertheless, crab abundances did not differ between the acidified and reference sites and impacts to bivalves and gastropods were far smaller than predicted. Although at ASS-affected sites gastropod populations were dominated by smaller individuals than at reference sites, oyster populations were skewed towards larger individuals. Even at ASS-affected sites, oyster and gastropod abundances were within the range encountered in estuaries that are not influenced by ASS runoff. Behaviour, long-term physiological acclimation or genetic selection may be responsible for differences in the responses of wild and naïve macroinvertebrates to acidification. Alternatively, wild populations may exhibit some recovery between the rainfall events that transport ASS runoff into estuaries, despite the persistently lower pH near outflow drains. Irrespective, this study suggests that at the population level, calcifying organisms display a certain degree of natural resistance to recurrent disturbance from ASS runoff.

1. Introduction

Most aquatic organisms have an optimal pH for growth and survival (Knutzen, 1981; Guinotte and Fabry, 2008; Hendriks et al., 2010). Minor changes in pH disrupt physiological processes by altering the bioavailability and toxicity of metals, the solubility of calcium carbonate, an important structural element for many organisms and many physiological processes (Knutzen, 1981; Guinotte and Fabry, 2008; Hendriks et al., 2010). Consequently, there has been much recent interest in how CO_2-induced ocean acidification will influence biological systems (Broecker et al., 1979; Caldeira and Wickett, 2003; Orr et al., 2005). Runoff from acid sulphate soils (ASS), which represents a much more immediate threat to biologically productive estuaries, has by contrast received relatively little attention. ASS have been identified on floodplains worlwide (Dent and Pons, 1995) and runoff of acidified waters into adjacent estuaries has the potential to cause similar negative impacts on calcifying organisms as predicted for CO_2 acidification (see Caldeira and Wickett, 2003; Orr et al., 2005; Harley et al., 2006; Hendriks et al., 2010), that may propagate to dependent and trophically linked species.

ASS occur when sediments rich in iron sulfides (especially iron pyrite) are waterlogged (Dent, 1986). Although harmless while undisturbed, drainage, excavation, droughts and other disturbances expose ASS to air, oxidizing pyrites into large quantities of sulfuric acid, which in turn mobilizes metals such as iron and aluminium (Dent, 1986; Russell and Helmke, 2002; Dove and Sammut, 2007b). Floodgates, constructed to prevent flood and tidal waters from inundating low-lying agricultural land, and artificial drains, built to accelerate the removal of surface waters, concentrate ASS-affected waters and facilitate their transport into estuarine waterways during rainfall. ASS runoff can reduce the pH of estuarine waters in the vicinity of drains to 2–6 (Sammut et al., 1996; Johnston et al., 2005; NSW DPI, 2007; Nordmyr et al., 2008).

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Estuarine ecosystems may be particularly susceptible to pH changes resulting from ASS and other causes of acidification because their shallow, lower salinity waters are generally less well-buffered than those of the open ocean (Knutzen, 1981; Miller et al., 2009). Nevertheless, ASS impacts on estuarine ecosystems have received little attention despite their potential to undermine the US$19 trillion of services provided annually by estuaries and associated seagrass beds and mangrove forests (e.g. nutrient cycling, production of food and raw materials; Costanza et al., 1997; Richardson and Poloczanska, 2008). Large-scale fish kills have been observed in several estuaries following ASS runoff events (Brown et al., 1983; Callinan et al., 1993; Sammut et al., 1995). Otherwise, our knowledge of the impacts of estuarine acidification is largely limited to short-term perturbation experiments, where naïve organisms, never before exposed to ASS runoff, are transplanted into acidified conditions (e.g. Dove and Sammut, 2007a, but see Russell and Helmke, 2002). In the laboratory, only 6 h of exposure to ASS-affected water were required to produce degradation of *Saccostrea glomerata* oyster shells, soft tissue lesions and reduced filtration rates (Dove and Sammut, 2007a). It is unclear how the conclusions derived from such studies translate to the natural environment, where wild populations can be exposed to fluctuating pH for many generations, and where species interactions also play an important role (Mount et al., 1990; Russell and Helmke, 2002).

In areas subject to recurrent acidification events, organisms that are sessile or have limited dispersive ability may be expected to experience strong selective pressures for tolerance of low pH. Hence, sizeable populations of calcifying species might be able to persist in ASS-affected estuaries even in the vicinity of ASS outflow drains. We assessed the long-term effects of estuarine acidification on (1) sessile and mobile molluscs and (2) crabs within ASS-affected estuaries of New South Wales, Australia. We compared the abundance of the invertebrates between areas close to and away from ASS outflow drains, hypothesizing that oyster, gastropod and crab populations would be less abundant and comprised of individuals of smaller size close to than away from the ASS outflow drains, but that populations would nevertheless be able to persist. Molluscs and crabs are among the most conspicuous and important organisms in estuarine systems, connecting primary producers to secondary consumers in food webs, contributing to nutrient cycling and helping to maintain water quality (e.g. Newell, 2004; Kathiresan and Qaim, 2005). Studies that document long-term ecological impacts of ASS-affected waters on wild populations are crucial for developing strategies to sustainably conserve, manage and exploit estuarine macroinvertebrate communities and associated resources.

2. Materials and methods

2.1. Sampling sites

We tested hypotheses about differences in the abundance and size–structure of populations of crabs and molluscs between sites close to and away from ASS discharge drains in three estuaries of New South Wales, Australia: the Hunter (32.915S, 151.801E), Port Stephens (32.708S, 152.196E) and the Hastings (31.426S, 152.916E). All three estuaries contained areas of high ASS risk (NSW DECCW, 2010), and were situated in the same transitional subtropical/temperate climatic region, characterized by a hot summer and no dry season (Stern et al., 2000). At the time of the study, the estuaries supported valuable oyster, fishing and/or prawn harvesting industries (Tulau, 1999).

Within each estuary, we sampled at four sites with intertidal mangrove forest, dominated by the grey mangrove, *Avicennia marina*. Two sites per estuary were situated within 900 m of major ASS outflow drains (hereafter, acidified sites), at which government records indicate that pH can drop to 2–5 (Table 1). The other two sites per estuary (hereafter, reference sites) were at least 2400 m away from drains and in areas considered to be at low risk of ASS-acidification (Naylor et al., 1998; Tulau, 1999; NSW DPI, 2006, 2008, 2009). Measurements of water temperature, salinity (PSS 78) and pH at each of our study sites, using a hand-held water quality probe (Eutech CyberScan PCD650) on eight occasions (four in April–May 2009 and another four in January–February 2010), revealed that over the study period, the acidified sites had a mean pH of 6.52–6.98, and the reference sites had a mean pH of 7.72–7.93 (Table 1). All sites were of similar water temperature but the sites adjacent to drains had a slightly lower (on average ~1) salinity (Table 1). A distinguishable orange-red coloration on the mangroves, corresponding to iron deposition, confirmed the exposure of sites close to outflow drains to ASS-affected waters.

2.2. Sampling

To test the hypotheses that: (1) molluscs and crabs would be less abundant close to than away from ASS drains and (2) their populations at acidified sites would be dominated by smaller individuals than at reference sites, we sampled the mid intertidal shore at low tide in autumn (April) 2009 (oysters, crabs) and in summer

Table 1
Details of sampling sites including temperature, salinity, pH, historical pH minima and ASS-risk data. H, Hunter estuary; P, Port Stephens; S, Hastings estuary; A, ASS-acidified site; R, reference site. SD between brackets ($n = 8$).

Site	Location	Temperature (°C)	Salinity	Mean pH	pH Minima	ASS Risk
HA1	Fullerton Cove	22 (5)	26 (5)	6.94 (0.26)	~4[a]	High
HA2	Tomago Wetland	22 (3)	26 (4)	6.98 (0.34)	~4[a]	High
HR1	Southern Ash Is.	22 (4)	26 (5)	7.92 (0.14)	~7[a]	Low
HR2	Northern Ash Is.	23 (4)	27 (3)	7.92 (0.11)	~7[a]	Low
PA1	Fenninghams Is. Ck. (entrance)	22 (4)	30 (7)	6.52 (0.76)	<5[b,c]	High
PA2	Fenninghams Is. Ck. (middle)	22 (4)	30 (7)	6.60 (0.64)	<5[b,c]	High
PR1	Stuart's Island	23 (4)	32 (6)	7.93 (0.30)	~6.8[c]	Low
PR2	4 km North of Stuart's Island	22 (4)	31 (7)	7.88 (0.23)	~6.8[c]	Low
SA1	Fernbank Ck.	21 (5)	28 (9)	6.75 (0.64)	<4[d]	High
SA2	Maria River	22 (4)	28 (6)	6.85 (0.68)	~2[d]	High
SR1	Settlement Point	22 (4)	29 (7)	7.72 (0.31)	~6.5[d]	Low
SR2	Limebernurs Ck.	21 (6)	30 (5)	7.82 (0.30)	~6.5[d]	Low

[a] NSW DPI (2008).
[b] NSW DPI (2006).
[c] NSW DPI (2009).
[d] Tulau (1999).