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Routes of water loss in South African abalone (*Haliotis midae*) during aerial exposure

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Abstract

South African abalone, *Haliotis midae*, were exposed to air at 12 °C for 36 h to simulate the extent and rate mass loss experienced by animals during long distance live exports. Animals lost 15.1 ± 0.94% of their mass during the 36 h air exposure, an approximation of the highest mass losses sustained by industry.

The total mass loss was attributed to water loss, as the contribution of dry mass to the total mass remained constant under all conditions. Water content decreased from 64.8% of the body mass (M_b) under control conditions to 58.8% M_b after 36 h in air. In real terms, however, animals had lost 22% of the body water pool.

Abalone exhibited a typically high water turnover rate when in water (125 μL g^{-1} h^{-1}), which decreased markedly during air exposure (2.2 μL g^{-1} h^{-1}). Haemolymph volume decreased from 43% M_b in water to 14% M_b in air. The concomitant decrease in haemolymph pressure probably limited the first step in urine formation (ultra-filtration through the pericardium). Thus we observed that while urine flow represented about 26% of the total water loss when the animals were in water, urine flow ceased during air exposure.

The decrease in haemolymph volume in air represents a redistribution of water to the tissues and not a bulk loss of haemolymph. This is supported by the concentration of haemolymph ions by a factor of 1.2 during aerial exposure, which was predicted based on the 22% decrease in water content. Under the same conditions, evaporation from water containers with similar surface to volume dimensions as abalone, accounted for only an 8.25% mass loss. As all other water loss routes were accounted for, we measured pedal mucus production rates of abalone in water and air. During 36 h aerial exposure, the pedal mucus production represented a loss of 6.8% M_b. We conclude that water loss during 36 h air exposure is attributable to evaporation (8.25% M_b) and pedal mucus production (6.8% M_b). This paves the way for directed research into mitigating water loss during the live export process.

Keywords: Abalone; *Haliotis midae*; Water balance; Mucus; Urine; Haemolymph volume

1. Introduction

The development of a viable abalone (*Haliotis midae*) mariculture industry is currently the foremost success story in South African mariculture. Investment in abalone mariculture has been driven by decreasing commercial fishery quotas (Cook, 1998), the existence of a seemingly insatiable foreign market and the favourable exchange rates enjoyed by exporters. However, South Africa is not the only producer of cultured abalone and the industry is pressured into becoming more competitive in terms of lowering production costs and increasing product quality and yield.

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The investment in 12 South African farms is estimated at US$12 million, and production is estimated at 500 to 800 tons p.a. (Sales and Britz, 2001). Farm-grown animals are destined for freezing, canning or live export to Far Eastern markets. In excess of 60% of farmed animals are destined for the lucrative live export market segment, fetching prices around US$32 to 35 per kg living mass in the shell (Gordon and Cook, 2001). Along with Mexico's *H. fulgens*, South African *H. midae* are at the top of the price structure in China, fetching higher prices than New Zealand or Australian product (Oakes and Ponte, 1996).

Live export animals are transported on ice in plastic bags containing 100% O_2 humidified with seawater (Sales and Britz, 2001). The polystyrene containers are taped shut and only opened by the receiving party, between 30 and 42 h after sealing. The temperature inside the boxes may increase from 4 °C to ambient (between 16 and 23 °C depending on the destination and duration of the export process) during this time. During this process animals lose between 4% and 15% of their mass, which is referred to as mass loss, water loss or drip loss. As exporters are paid on landed mass, this presents a decrease of foreign revenue.

This aerial exposure is an unnatural and extreme stressor for abalone, whose natural ecological niche is the permanently inundated subtidal zone, where they occur on rocks or in kelp forests (Branch and Branch, 1982). During aerial exposure, several routes of water loss, discussed below, may operate.

The water balance of abalone during aerial exposure is of interest as the large foot presents no barrier to water movement, cannot be retracted into the shell and does not possess an operculum to close off during aerial exposure like certain intertidal gastropods.

The abalone excretory system has been studied morphologically, and only two references were found that concentrate on the functional physiology of the kidney (Cuenot, 1899; Harrison, 1962). The primary step in urine formation is ultra-filtration through the atrial walls into the pericardium, after which the primary filtrate is modified by active secretion (right kidney) and reabsorption (left kidney). The kidney seems to play no role in the maintenance of water balance (Harrison, 1962), and thus would be of limited benefit in maintaining water balance during aerial exposure.

Mucus of the tropical limpet *Cellana grata* contains 90% water (Davies and Williams, 1995) and in *Patella vulgata*, mucus is produced at an increased rate during aerial exposure (Davies et al., 1990), this has a large impact on water balance. In *Haliotis tuberculata*, mass dependent mucus production represents between 23% and 29% of the total energy budget (Peck et al., 1987) and is thus an energy drain.

By measuring changes in haemolymph volume and concentration it would be possible to attribute mass loss to actual haemolymph loss or to a redistribution of the fluid component. The latter would result in more concentrated haemolymph. Although the circulatory system is open, haemolymph flow is directed in a tissue-specific manner in *Haliotis cracherodii*. For example, the foot makes up 66% of the wet body mass (not including the shell) but receives 27% of cardiac output. On the other hand, the digestive gland represents only 6% of the body mass, and yet it receives 13% of the cardiac output (Jorgensen et al., 1984).

The aim of this study was to identify the different routes of water loss in abalone during the extreme dehydration stress of the live export process. Furthermore, we quantified the relative contributions of the different water loss routes in order to give direction to future research on the mitigation of water loss.

2. Materials and methods

South African Abalone, *Haliotis midae*, were obtained from Irvin & Johnson's Abalone Division at Danger Point, Gansbaai, South Africa over a period of 2 months. Animals were held in a recirculating system with artificial seawater (Instant Ocean, USA) at 16±0.1 °C. The tanks were cleaned daily and freshly made up artificial seawater was added to the system to maintain a volume of 400 L. Salinity (32–34 ppt) and dissolved oxygen (8.5–9 mg L^{-1}) of the system water were monitored regularly (WTW Multiline P4).

For control experiments, animals were maintained at 16 °C in 30 L plastic containers containing aerated water from the recirculating system. To simulate the dehydration encountered by animals during the live export process, animals were placed on polystyrene grids (used in the transport containers) over artificial seawater to simulate the high relative humidity of the transport containers. Experiments were carried out at 12 °C in a thermostatically controlled room (Linde), as temperature may increase from 4 to 18 °C during the transport process.

Data are expressed as the values for control animals and dehydrated animals after 36 h of aerial exposure. Rate processes were recalculated to represent the rate as a percentage of the body mass in the 36 h period of interest.

2.1. Mass loss

In order to determine mass loss encountered during dehydration, 24 animals were weighed individually to within 0.1 g (Sartorius) at the initiation of aerial exposure, and then after 6, 12, 24 and 36 h in air. Animals were patted with towelling paper before weighing. The mass loss of individual animals were calculated and expressed as average±S.E.M. for each time period. A linear regression line was fitted to the entire data set.