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Research Paper

Development of an effective sampling strategy for ammonia, temperature and relative humidity measurement during sheep transport by ship

Yu Zhang [a,*], Allan T. Lisle [b], Clive J.C. Phillips [a]

[a] Centre for Animal Welfare and Ethics, School of Veterinary Science, The University of Queensland, Gatton, 4343 QLD, Australia
[b] School of Agriculture and Food Science, The University of Queensland, Gatton, 4343 QLD, Australia

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Ammonia, high temperature and high humidity have adverse effects on animals during long distance livestock export from Australia to the Middle East, but none of these is effectively measured currently. On the basis of data maps obtained on two voyages of live sheep export, this study determined sampling strategies for ammonia, temperature and humidity measurement on the vessel. The difference between predicted high and low ammonia sites on the shipment could be detected with approximately 5 measurement sites of each. Margins of error were determined, which suggested that dry bulb temperature could be measured with 6–8 measurement sites, but even 20 measurement sites were not sufficient to measure relative humidity. For the vessel recorded, considerably more ammonia measurement sites are required on closed decks than on open decks, with less variation for temperature measurement. The number of pens measured contributed more to the variance of ammonia and temperature measurement than the number of sampling locations within each pen on open decks. This study highlights the importance of a suitable sampling strategy to measure ammonia, temperature and relative humidity on board ship during live export.

1. Introduction

As the world's largest exporter of live sheep, Australia exported 2.18 million live sheep in 2014–15, with 97% transported to the Middle East (MLA, 2015), nearly all by sea in voyages lasting about 10 days (Phillips, 2008).

During such long duration transportation at high stocking density, ammonia (NH_3) is released from animal excreta, which accumulates on the pen floor during the voyage and is not cleaned out until after discharge of the animals at the destination port. NH_3 exposure has detrimental effects not only on human health in various workplaces, but also on animal health, growth and production performance (Cole, Todd, & Wing, 2000; Costa, Accloly, & Cake, 2003; De Boer & Morrison, 1988; Kristensen & Wathes, 2000; Michiels et al., 2015; Phillips et al., 2010; Phillips, Pines, Latter, et al., 2012; Phillips, Pines, Muller, 2012). Under simulated live export

* Corresponding author.
E-mail address: yu.zhang2014@gmail.com (Y. Zhang).
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Nomenclature

T_{DB}	dry bulb temperature
T_{WB}	wet bulb temperature
DP	dew point
RH	relative humidity
SD	standard deviation
GLM	general linear model
ANOVA	analysis of variance
MoE	margin of error
df	degree of freedom
SED	standard error of the difference between two means
P	probability value
SEM	standard error of the mean
THI	temperature–humidity index

conditions, NH_3 adversely affected the welfare of steers and sheep by inducing inflammation of the respiratory system and reducing feed intake and body weight gain (Phillips et al., 2010; Phillips, Pines, Latter, et al., 2012; Phillips, Pines, Muller, 2012). Therefore, not only have stakeholders in the industry identified NH_3 as one of the top five welfare issues (Pines, Petherick, Gaughan, & Phillips, 2007), but also researchers have hypothesised it to be related to one of the main causes of sheep mortality, inappetence (Richards, Norris, Dunlop, & McQuade, 1989).

So far there is no universally applied maximum NH_3 concentration for live export. The current threshold value for NH_3 exposure (25 ppm) recommended for the Australian live export industry (Costa et al., 2003; MAMIC, 2001; NOHSC, 1995; Stacey, 2003) is based more on human safety limits suggested as a time weighted average exposure level to ammonia (the average exposure during an 8 h day) than on animal welfare. Despite this, a critical concentration of 30 ppm NH_3 has been suggested for steers on the basis of physiological responses to high NH_3 environments for 12 days under simulated live export conditions (Phillips et al., 2010). Similar research with sheep suggested that the critical concentration should be the same as proposed for steers (30 ppm), but with limited evidence (Phillips, Pines, Latter, et al., 2012; Phillips, Pines, Muller, 2012). Due to a lack of enforced regulation of NH_3 concentrations, studies on livestock voyages from Australia to the Middle East have found some NH_3 concentrations to be above the recommended maximum, 25–30 ppm (MAMIC, 2001; Pines & Phillips, 2011; Tudor et al., 2003). The most comprehensive investigation conducted by Pines and Phillips (2011) showed the concentrations at most of their measurement locations were below 18 ppm, however, several sites were above 25 ppm, in particular those parts of the ship with insufficient ventilation and/or high temperatures and humidity. Some sites registered up to 59 ppm, which is above the levels recommended for humans (NOHSC, 1995).

Dry and wet bulb temperature (T_{DB}, T_{WB}) and dew point (DP) are strongly positively correlated with NH_3 accumulation (Pines & Phillips, 2011), and these could provide auxiliary information for NH_3 monitoring. High temperatures during export from Australia to the Middle East could cause the reduction of feed intake in sheep (Stockman et al., 2011), in the same way as high NH_3. The two are inter-related. Combined with insufficient ventilation, high temperatures and relative humidity (RH) contribute to NH_3 volatilisation, and exposure to a high NH_3 environment could reduce animals' evaporative heat loss via increased respiratory rate, because of detrimental effects on normal respiratory function (Costa et al., 2003). Panting becomes common in sheep when maximum daytime T_{DB} reaches 26 °C, which is normally exceeded by the end of the voyage during live export from an Australian winter to a Middle East summer (Phillips, 2016; Thwaites, 1985). However, only a single daily measurement for T_{DB}, T_{WB} and humidity per deck is required by Australian standards for the export of livestock (ASEL, 2011), which is usually recorded in the morning in order to report this to the captain later in the day. This is probably not indicative of the maximum daytime temperature. The location for temperature measurement is not prescribed and could be in the best ventilated part of each deck. Moreover, temperatures might be under-reported by ship veterinarians, who are employed by the livestock exporting companies (Caulfield, Cambridge, Foster, & McGreevy, 2014).

The Australian live export industry has developed a heat stress risk assessment model (Ferguson, Fisher, White, Casey, & Mayer, 2008; Caulfield et al., 2014). Although published details are scant, the model uses predicted T_{WB} en route and at the destination port, as well as ship factors, such as ventilation rate. However, it has been criticised for, amongst other things, not being validated against performance data and ignoring important ship characteristics, such as the difference between open and closed decks (McCarthy, 2005). For effective validation against performance, it is important to know the temperature on board accurately, but there is currently no validated sampling strategy to achieve this.

NH_3 concentration varies spatially on live export vessels due to ventilation rates, temperatures and the extent of faecal accumulation on the deck (Pines & Phillips, 2011). High NH_3 in one shipboard study occurred particularly on closed decks, as well as at the front of the vessel and near the engine block on open decks (Pines & Phillips, 2011). The number of sampling locations determines the spatial resolution of the NH_3 concentration profile, but this is often constrained by equipment, time, and manpower. The growing use of electronic measurement systems may make it possible to sample automatically on ships, as has been done in livestock buildings by drawing air from multiple locations to a central electronic gas measurement unit (Banhazi, 2009; Groot Koerkamp et al., 1998; Phillips et al., 1998). Because the labour input associated with routine measurements is one of the major costs of monitoring, the use of electronic monitoring systems could help reduce the cost required for operating the system and processing the data (Banhazi, 2009). However, it must be noted that the environment on livestock shipment is hostile for electronic measurement, damp and without electricity. The sampling devices must be out of reach of the animals, but NH_3 concentration decreased with height above the deck in one study, on average from about 19 ppm at sheep height to about 17 ppm at a height safe from damage by sheep (Pines & Phillips, 2011). However, no matter what monitoring method is used, selection of the most representative sampling locations on the shipment is of