animals

MDPI

Review

Review of Livestock Welfare Indicators Relevant for the Australian Live Export Industry

Patricia A. Fleming *, Sarah L. Wickham, Emma J. Dunston-Clarke, Renee S. Willis, Anne L. Barnes, David W. Miller and Teresa Collins

College of Science, Health, Engineering and Education, Murdoch University, Perth, WA 6150, Australia; sarahlwickham@outlook.com (S.L.W.); Emma.Dunston@murdoch.edu.au (E.J.D.-C.); reneeswillis@gmail.com (R.S.W.); A.Barnes@murdoch.edu.au (A.L.B.); d.miller@murdoch.edu.au (D.W.M.); T.Collins@murdoch.edu.au (T.C.)

* Correspondence: t.fleming@murdoch.edu.au; Tel.: +61-8-9360-6577

Received: 1 June 2020; Accepted: 8 July 2020; Published: 21 July 2020

Simple Summary: The live animal export industry is under increasing public scrutiny to ensure optimal animal welfare conditions are met. To date, the main animal-based welfare indicator used to review and regulate this industry has been mortality. For a proactive industry wanting to transition to reporting on animal welfare not mortality, a broader suite of measures is needed. We reviewed a total of 71 potential animal welfare measures, identifying those measures that would be appropriate for use throughout the live export chain for feeder and slaughter livestock animals, and categorised these as animal-, environment- and resource-based. After considering the industry-specific constraints for animal welfare assessments, measures were categorised according to their application to the three identified sectors of the live export industry. We identified measures already undertaken or that are relevant for specific situations as part of the industry. Further research is currently underway to validate the applicability and value of these measures.

Abstract: Animal welfare is an important issue for the live export industry (LEI), in terms of economic returns, community attitudes and international socio-political relations. Mortality has traditionally been the main welfare measure recorded within the LEI; however, high mortality incidents are usually acted upon after adverse events occur, reducing the scope for proactive welfare enhancement. We reviewed 71 potential animal welfare measures, identifying those measures that would be appropriate for use throughout the LEI for feeder and slaughter livestock species, and categorised these as animal-, environment- and resource-based. We divided the live export supply chain into three sectors: (1) Australian facilities, (2) vessel and (3) destination country facilities. After reviewing the relevant regulations for each sector of the industry, we identified 38 (sector 1), 35 (sector 2) and 26 (sector 3) measures already being collected under current practice. These could be used to form a 'welfare information dashboard': a LEI-specific online interface for collecting data that could contribute towards standardised industry reporting. We identified another 20, 25 and 28 measures that are relevant to each LEI sector (sectors 1, 2, 3, respectively), and that could be developed and integrated into a benchmarking system in the future.

Keywords: physiology; behaviour; quality assurance; welfare indicators; benchmarking

1. Introduction

Over recent years, there has been an increase in concern from the general community regarding animal welfare in livestock production [1,2]. 'Social licence'—whether a sector has ongoing approval and broad acceptance within the local community and other stakeholders—is vital for the continued

support of all livestock production industries. Such concerns particularly impact the live export industry (LEI), where there is a divide between community expectation, government regulation and LEI performance [3]. Heightened public awareness around the industry (e.g., [4]) means that improving welfare outcomes and avoiding high mortality situations are priorities.

Developing comprehensive measures of animal welfare is a necessity for quantifying and communicating outcomes. Quantifying and monitoring animal welfare (Box 1) across the entire live export supply chain is therefore an important step towards reporting and transparent quality assurance, which can be used to educate and reassure the general community. Most importantly, quantifying animal welfare as part of the LEI will enable future benchmarking—establishing criteria that can become aspirational and encourage continuous industry improvement.

In this review, we examine why animal welfare assessment is needed for the LEI, examining the current industry and legislative context under which animal welfare is currently managed and regulated. Next, we consider who should carry out animal welfare assessments, as well as potential constraints of assessment under industry conditions. The aim of this review was to identify internationally accepted and currently used indicators of animal welfare relevant to the LEI. Specifically, we sought to identify relevant indicators for each point in the live export supply chain for feeder and slaughter cattle and sheep that could contribute to developing a benchmarking system for animal welfare using a 'Welfare Dashboard' [5]. We have therefore reviewed a range of potential animal welfare measures, identifying (I) those that are already undertaken by the LEI, (II) those animal welfare measures that are relevant to the industry but are not required to be recorded under current Australian Standards for the Export of Livestock (ASEL) v2.3 (2011) regulations and (III) those that have limited application for day-to-day management but are more likely to be used for specific situations (e.g., research, sentinel animals). These findings are summarised in a table listing 71 potential animal welfare measures that address the 12 welfare criteria and 4 welfare principles identified by the European Union's Welfare Quality audit. We detail these measures in the Supplementary Materials accompanying this publication. Our conclusions include identification of potential future direction.

Box 1. What is animal welfare?

In order to begin to measure animal welfare, we need to first understand what it is. There is a growing body of literature that examines the definition of what good animal welfare means (e.g., [2,6–9]). Animal welfare is a multidimensional concept that embraces the physical and mental aspects of the animal, including positive, neutral and negative mental states [10,11], the animal's physiology and functioning, as well as its interaction with the surrounding environment and how the animal copes with the challenges faced. Many measures of welfare are needed because stressors can act on one or several parameters at different times and to differing degrees [12]. For example, an animal experiencing thermal challenge on a hot day will feel uncomfortable and show physiological signs of hyperthermia, will consequently alter its behaviour to seek shade, while the need to perform this behaviour may, in turn, result in a lowered function. Different animals may exhibit varied responses to the same challenge, due to genetics, sex, body weight, level of acclimatisation, etc., which can be addressed when multiple welfare measures are collected, allowing for some interpretation as to when normal responses to stressors become aberrant or pathological.

Mellor and colleagues [6,13] have proposed Five Domains of animal welfare: four physical/functional domains which all impact on the fifth domain, that of mental state. The European Union Welfare Quality® program similarly recognises four key welfare principles and 12 welfare criteria for animal welfare assessment [14]. We have used these Domains and Principles (Table 1) as a framework for understanding animal welfare for the current review.

Table 1. The Five Domains of animal welfare [7] (left hand column) and their association with the Principles (middle column) and Criteria (right hand column) forming the basis of the Welfare Quality® assessment [14] protocols. Colours are cross-referenced to Table 3.

Five Domains	Welfare Principles		Welfare Criteria
1. Nutrition	Good feeding	1	Absence of prolonged hunger
		2	Absence of prolonged thirst
2. Environment	Good housing	3	Comfort around resting
		4	Thermal comfort
		5	Ease of movement
3. Health	Good health	6	Absence of injuries
		7	Absence of disease
		8	Absence of pain induced by management procedures
4. Behaviour	Appropriate behaviour	9	Expression of social behaviours
		10	Expression of other behaviours
		11	Good human-animal relationship
5. Mental state		12	Positive emotional state

1.1. Why Do We Need to Measure Animal Welfare in the LEI?

Australia is a major exporter of livestock and the industry is worth $1.79 billion to the Australian economy [15]. In 2018/9, almost 10,000 people were employed across the live cattle supply chain, which exported a total of 1.26 million cattle (89% of which were feeder/slaughter animals) worth AUD 1.64 billion Free On Board value) [15]. Furthermore, in the same year, 0.989 million sheep worth AUD 142 million, and 18,650 goats worth AUD 7.2 million were exported live from Australia [15] (Figure 1). The sheer number of animals that are processed through the LEI warrants the development of animal welfare assessment tools that are tailored to the conditions experienced throughout the supply chain.

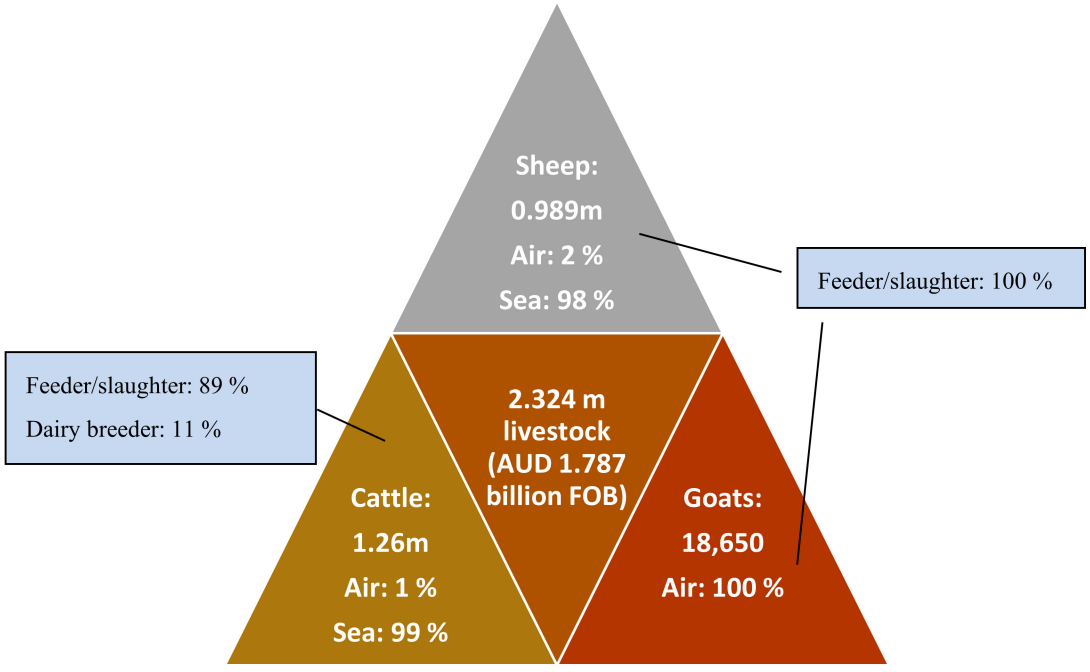

Figure 1. Animal numbers for live export from Australia for 2018/9 [15] by species (sheep, cattle, goats) and transport (air or sea), and total Free on Board (FOB)—value at the time of selling/buying the animals in Australia (i.e., the values quoted here do not include the cost of shipping/transport).

Most cattle and sheep are transported by sea, principally to south-east Asia and the Middle East (cattle and sheep respectively), while goats are largely transported by air to south-east Asia. Because most animals are transported by sea, most animal welfare measures have addressed this form of transport; much less has been done about animal welfare as part of air freight [16].

Currently, the Australian LEI and stakeholders use on-board mortality and compliance with the Australian Standards for the Export of Livestock (ASEL; [17]) and Exporter Supply Chain Assurance System (ESCAS; [18]) as indicators of welfare for feeder and slaughter animals. LEI industry reviews have previously provided suggestions that would lead to improved animal welfare monitoring. For example, the 2011 Farmer Review [19] recommended that the adoption of a Quality Assurance system that included all sectors of the supply chain would provide the needed 'whole of industry' surveillance approach, while also complementing current government regulatory compliance programs [20]. More recently, the 2018 McCarthy Review and 2018 ASEL review recommended that the LEI cease relying on mortality as the primary indicator of animal welfare. This approach is supported by stakeholders and the industry's desire to show best practice is applied to avoid adverse publicity [21].

The issue with simply monitoring mortality and non-compliance with regulation is that problems can only be indicated retrospectively. Under current animal welfare reporting, the main welfare issues identified for the LEI are environmental conditions, resource access, and species-specific causes of morbidity and mortality. Being able to effect change proactively, on the basis of animal outcomes that do not result in mortality, could enable pre-emptive modifications and adaptive management solutions before animal welfare is compromised. Furthermore, a single incidence of high mortality substantially contributes towards negative community attitudes to live export, while continued efforts made by the industry towards managing animal welfare along the supply chain can go unrecognised.

Previous reviews have been informative for the development of animal welfare measures as part of the LEI. In 2004, an Australian study identified seven key indicators of welfare on-board a ship: mortality, clinical disease, respiration rate, wet bulb temperature, space allowance, change in body weight, and ammonia levels [22]. For many measures, baseline information from which deviance from optimum and/or critical levels could be detected, has not yet been established. Application of welfare measures across the whole supply chain (including on trucks, in feedlots, and in abattoirs both in Australia and at the importing country) would require other indicators that can be applied more broadly. Behavioural indicators were not identified as part of the 2004 study, although understanding and application of behavioural measurements to assess welfare have markedly advanced over the intervening decade [23–25]. A 2015 review described 19 animal-based indicators considered valid for assessing sheep welfare and of these nine were considered feasible for use in UK abattoirs [26]. These indicators were: body cleanliness, carcass bruising, diarrhoea, skin lesions, skin irritation, castration, ear notching, tail docking, and 'obviously sick' animals. Grandin [27] provided five animal welfare measures for auditing purposes at stunning in the USA; the efficiency of stunning, use of electric prodders, and cattle behaviour during handling and the procedure (vocalisations and falls). An aim of this study was to expand on these published reviews and address the specific context of the LEI.

1.2. Industry and Legislative Context

To understand the complex legislative context of the Australian LEI, we reviewed all current standards and regulations pertaining to livestock transport and slaughter at International (2 sources) Commonwealth (8 sources), State and Territory (10 sources) levels. We also located five LEI reviews that have occurred since 2003 in addition to two national animal welfare and health schemes and five Australian livestock industry-led animal management schemes and programs (Table 2). These sources were obtained from searching Australian Government and livestock industry websites, which provide details on the standards, regulations and programs. Sources that were not relevant to livestock management on farms, in feedlots and/or during transport (both land and air) were not included in the review.

In Australia, there is a broad trend in animal welfare regulatory reform to reduce prescriptive regulation and to move to a model of shared-responsibility with non-government stakeholders (industry, community) playing more direct roles. This is described in general government information related to

good regulatory practice and in current Commonwealth and state regulatory reforms, as illustrated through various Biosecurity Bills/Acts/Standards and Guidelines at Commonwealth and State levels (Table 2).

Animal welfare in live export is a complex regulatory issue within Australia. Exports are within the domain of the Commonwealth, but animal welfare and disease control are regulated at State/Territory levels (Table 2). In some States, there is further delegation of responsibility to other bodies (RSPCA inspectors, State Government Departments etc.). This hierarchy of laws and regulations contributes to conflicts and lack of clarity over roles, responsibilities and relevant legislative instruments [20].

The development of the Livestock Global Assurance Program (LGAP) is an important component of a shared-responsibility model [28]. LGAP follows a number of international standards, such as the World Organisation for Animal Health (OIE), Exporter Supply Chain Assurance System (ESCAS) and World Trade Organisation (WTO). AniMark is an independent, not-for-profit Australian company that has been appointed to implement LGAP [15]. Under current ESCAS policy, exporters are responsible for appointing auditors who report to government via the exporters. Under LGAP, facilities and operators will perform internal audits to be prepared for external auditing, with AniMark to train and appoint auditors who will review and report on all levels of the chain directly back to LGAP. It is likely that new proposed LEI welfare indicators would be valuable and could to be implemented through the proposed LGAP system.

Table 2. Laws or regulations that are relevant to the live export industry. Included are examples of government and industry-led management guidelines.

Jurisdiction		Purpose
International	International Air Transport Association (IATA) Live Animal Regulations (LAR) [29]	Global standards and guidelines to transporting animals by air in a safe, humane and in a cost-effective manner
	World Organisation for Animal Health (OIE) standards [30]	International trade standards for the transport and slaughter of animals produced for consumption
Commonwealth	Navigation Act 2012	Regulate international shipping
	Australian Maritime Safety Authority Marine Order 43 (AMSA MO43)	Cargo and cargo handling—livestock
	Australian Meat and Livestock industry Act 1997	Regulate industries
	Australian Meat and Livestock industry (Export Licensing) Regulations 1998	Regulate industries
	The Australian Standards for the Export of Livestock (ASEL) [31]	Standardise export procedures
	Exporter Supply Chain Assurance System (ESCAS) [18]	Regulate supply chain—requires evidence that animals will be handled and processed in accordance with the internationally-accepted OIE animal welfare guidelines
	Export Control Act 1982 and Export Control (Animals) Order 2004	Regulate animal export industries
	Inspector-General of Live Animal Exports Bill 2019 [32]	Overseeing monitoring and reporting, permits and licencing
State/territory	National Land Transport Standards [33]	Guidelines for land transport of livestock
State	Animal Welfare Acts	Overarching animal welfare legislation
	Codes of Practice/ Animal Welfare Standards and Guidelines [34]	State-level codes
Industry-led examples	Livestock Global Assurance Program (LGAP)	Overarching review and regulation of the LEI
	Livestock Production Assurance program [35]	
	Grazing Best Management Practices (Grazing BMP) [36]	Identifying best management practices
	National Dairy Industry Animal Welfare Strategy [37]	Leadership to improve animal welfare
	National Feedlot Accreditation Scheme [38]	Quality System for beef feedlots

Table 2. *Cont.*

Jurisdiction		Purpose
Other	2003 Keniry Review	8 recommendations; Australian livestock export code established (which became ASEL)
	2011 Farmer Review [20]	14 recommendations; conditions around supply chains
	2018 McCarthy Review [19]	23 recommendations; including assessment of animal welfare rather than mortality, stocking rates, reportable mortality levels
	2018 Moss Review [39]	31 recommendations; including around internal regulatory practice, performance and culture, developing welfare indicators and using these as part of the regulatory framework
	2018 Technical Advisory Review of ASEL by sea [40]	49 recommendations, including stocking density, voyage reporting and on-board personnel and assessment of animal welfare
	Australian Animal Welfare Strategy (AAWS)	Information and development of future directions for improvements in animal welfare—no longer funded
	Animal Health Australia (AHA) Standards and Guidelines	Coordinating the development of national livestock welfare standards and guidelines

2. Constraints on Animal Welfare Assessments

Conducting welfare assessments across all stages of the export chain (1. Australian facilities, 2. Vessel and 3. Destination country facilities) may be constrained by the vast environmental and management differences animals are exposed to. Subsequently, welfare assessment measures need to be specific to, or sensitive to, changes across LEI sectors. Here we discuss who should carry out welfare assessments and possible physical and logistical constraints on recording as part of consideration of applicability for the LEI.

2.1. Who Should Carry Out Welfare Assessments?

As part of developing animal welfare assessment methods for the LEI, consideration should be given to who will be undertaking the observations and how long such assessments would take. The frequency and duration of the assessments will also influence the credibility of the reporting. Welfare checks are something that AAVs (Australian Accredited Veterinarian) and proficient stock handlers perform when working with livestock on a day-to-day basis [41] to ensure the management of the livestock. A Welfare Dashboard [5] could be used to capture standardised reporting of the information observed during these daily assessments. Alternatively, comprehensive welfare measures could be included in existing pre-export inspections, shipboard reporting requirements and ESCAS audits.

A survey conducted in 2015 indicated that the general public and animal welfare advocates strongly favour assessments of animal welfare as part of the LEI being carried out by independent animal welfare assessors [21]; ensuring quality assurance and confidence in the value of the assessments may rely on such independence. Hence, careful consideration of the review period and the selection of assessors with suitable auditing and inspection skills to report on livestock welfare is therefore required for each stage of the supply chain [42].

Current LEI reporting structures during sea voyages require the AAV or an accredited stockperson to provide Daily Voyage Reports for voyages ≥10 days, in addition to an End of Voyage Report. These reports and the End of Air Transport Journey Report are provided to the Australian Department of Agriculture, Water and the Environment (the Department) and exporter [17]. From October 2018, Independent Observers (IOs) were required to travel on all sea voyages, unless decided otherwise by the Department [43] (2019: IOs no longer required for all short-haul shipments considered 'low-risk' [44]), to observe and collect information on exported livestock from pre-export facility until the end of discharge in the importing country. IOs provide a report to the Department independent of those provided by the AAV or accredited stockperson [45]. Exactly who would be responsible for the

collection of additional animal welfare measures and the standardisation of collected data during sea voyages should be determined by the industry and the Department.

2.2. Constraints to Animal Welfare Assessment Protocols

2.2.1. Individual vs. Group Assessments

On board and in pre- and post-vessel facilities, livestock are usually housed in close proximity; stock handlers moving around animals/pens can cause disturbance that may confound some measurements being recorded. Thus, it is difficult to conduct a physical examination on any individual animal (e.g., temperature, auscultation, palpation, inspection of mucous membranes, collection of samples) because capture and restraint agitates all animals in the pen, causing unnecessary stress and the possibility of injury. Individual animals with ill-health may be moved to designated hospital pens where they can be restrained for individual animal examination and treatment; however, collecting physiological information from these isolated sick individuals will not necessarily provide representative physiological information for the animals in the home pen. Consequently, it is suggested that most of the currently proposed welfare measures would be taken by observation and collected at a group (pen) level without removing individuals [5].

2.2.2. Visibility

Animal welfare assessments require good visibility of animals. The use of yards, races and crushes to move and restrain animals, allowing handling, examination and treatment, varies between countries and livestock species. Cattle in Asian countries tend to be handled individually with varying or little use of yards etc, while sheep in Middle Eastern countries may be managed in yards/feedlots that are similar to those in Australia. Where handling facilities are used for holding and lairage, lighting, the availability of equipment, and the age, condition and hygiene of these facilities can vary markedly. There can also be a welfare cost to additional handling required for some animal welfare assessments.

During vessel transport itself, low light conditions may mean that a single vantage point has restricted visibility of some parts of the pen. Furthermore, ship pen design follows the structure of the decks, and therefore some parts of the pens may be obstructed from view. Stocking density will also preclude visibility of all parts of each animal and bedding can reduce visibility of animals' feet. As part of air freight, animals are held in crates and access to the cargo hold may limit visibility *en route*.

2.2.3. Restricted Animal Movements During Transport

The restriction of movement by the animals due to pen size and stocking density will mean that behavioural differences (e.g., changes in gait) may not be obvious in some contexts. Under dense stocking conditions, such as on trucks or in crates, animals may have limited opportunities to move away.

2.2.4. Appropriate Times to Carry Out Assessment

Experience, skills and stock handler skills are likely to vary greatly between sectors of the LEI supply chain, while there are also different attitudes towards livestock handling across the globe [46–48]. The staff and the time available to carry out animal welfare assessments will therefore vary across the chain and needs to be considered when designing protocols. For example, loading and unloading of vessels are carried out as efficiently as possible to reduce the time trucks wait at the port and ship docking times, resulting in all personnel being occupied. Animals are also likely to show heightened responses during loading and unloading and any handling procedures, which may mask more subtle behavioural or physical responses. However, recording animal gait, stock handler skills and the use of goads to move livestock on/off trucks and the ship are possible. An appropriate time for the initial assessment may be after penning (feedlot) or loading (vessel) is completed and the animals have had a chance to settle into their novel environment, with regular daily assessment required thereafter.

Time of day, ambient temperature, feed routine and circadian rhythms need to be considered when selecting the optimal time of assessment. Ensuring that measures are appropriate to the context and environment will therefore need to be considered [5].

2.3. Review of Potential Animal Welfare Measures and Their Applicability to the LEI

To establish a list of LEI-applicable animal welfare measures, we reviewed all current legislation/regulations/guidelines relevant from on-farm through to market (e.g., [18,31,40]; full list in Table 2) to identify recommended and implemented animal welfare measures. Using search terms for animal welfare, transport, live export, handling, we also carried out a literature search of Australian (e.g., [22]) and international studies (e.g., [26,27]) that proposed measures applicable to livestock. In considering applicability and relevance to the LEI, we captured the requirements of each method (i.e., whether it required trained personnel or specialised equipment, and whether there were already threshold values for animal welfare expectations for each measure) and considerations relevant to the LEI (i.e., requires animal handling, involves invasive measures, the relative cost of the measure above operating costs, and approximate amount of time that would be required).

Welfare indicators are currently being developed for shipboard reporting [5] that could be collected by AAVs, accredited stockpersons or IOs. These may also be incorporated as part of ASEL and ESCAS, or within LGAP audits in the future. Our review provided a list of 71 potential indicators of animal welfare (Table 3) and their application to all stages of the LEI. As the LEI involves many different environments, we divided the industry into three sectors:

(1) Australian facilities, including farm-yards, pre-export facilities and land transport;
(2) Vessel (ship and aeroplane); and
(3) Destination facilities, including feedlots and abattoirs.

When considering the application of each of the 71 measures to these three sectors, the relevant legislation and regulations were reviewed to determine which measures are currently regulated or not. Specifically, Animal Welfare Acts (Western Australia, Norther Territory, Queensland and Victoria), Codes of Practice, Animal Welfare Standards and Guidelines [49–52] and the National Feedlots Accreditation Scheme ([53]; applicable to feedlots who wish to produce grain fed beef to domestic and international markets; note, not all pre-export facilities are NFAS accredited) for Australian facilities, ASEL for sea transport, and ESCAS auditing for destination facilities. We described the indicators in terms of animal-, environment-, resource-, and management-based measures (Table 3). Some of these measures are carried out at an individual animal level (e.g., body temperature), and therefore, a subsample of sentinel animals could be monitored as part of the LEI process. Most measures can be carried out at a group level (e.g., behavioural scores (posture, activity and demeanour) or respiratory panting scores in a pen of animals) [54–57]. Here we summarise the feasibility and application of each measure to the LEI. Supporting information for each measure is detailed in the Supplementary.

Table 3. Mapping of animal welfare measures onto the European Union's Welfare Quality® framework, per sector of the livestock export supply chain (1 = Australian farm, pre-export feedlots and land transport, 2 = Australian Standards for the Export of Livestock (ASEL) (on-board the ship/plane reports), 3 = Exporter Supply Chain Assurance System (ESCAS) (destination feedlot and abattoir). Measures are identified as (C) currently used as part of the life export industry (LEI) in some form, (R) relevant to the LEI, (I) largely irrelevant to the LEI sector due to impracticality or lack of opportunity. Colours are cross-referenced to Table 1.

Welfare Principles		Welfare Criteria	LEI Sector 1	2	3	Animal-Based	LEI Sector 1	2	3	Environmental-Based	LEI Sector 1	2	3	Resource-Based
Good feeding	1	Absence of prolonged hunger	R	R	R	Digestion					C	C	C	Feed access
			C	R	R	Weight and body condition score (BSC)					C	C	R	Feed consumption
											C	C	C	Feed hygiene
											C	R	R	Time off feed
											R	R	R	Time to resume feeding
	2	Absence of prolonged thirst	I	I	I	Acid-based disturbances					C	C	C	Water access
			I	I	I	Hormones					R	C	R	Water consumption
											C	C	C	Water hygiene
											C	R	R	Time off water
											R	R	R	Time to resume drinking
Good housing	3	Comfort around resting	R	R	R	Ethograms					R	C	C	Cleanliness, dry lying area at all times
			R	R	R	QBA [a]								
	4	Thermal comfort	I	I	I	Respiration rate	C	C	R	Shade and shelter	C	C	R	Manure pad moisture
			R	C	R	Panting					R	R	R	Enough shade/shelter for all animals to access
			I	I	I	Body temperature								
	5	Ease of movement	R	R	R	Ethograms	C	C	C	Space allowance	C	C	C	Adequate space
		Other	R	R	R	QBA					I	R	R	Flooring/terrain
							I	C	I	Ventilation				
							I	R	R	Ammonia				
							R	C	R	Temperature & humidity				
							R	R	R	Noise				
							I	C	I	Lighting				
							R	R	I	Driving conditions, balance, slipping/falling				
							C	C	I	Journey plan				
							C	C	I	Carrier design				
							C	C	C	Facilities (ramp/race, holding pen)				
							C	R	C	Hygiene of facilities				
Good health	6	Absence of injuries	C	C	I	Mortality								
			C	C	R	Morbidity and health								
	7	Absence of disease	C	C	R	Morbidity and health								
	8	Absence of pain induced by management procedures	R	I	I	Hormones								
			R	I	I	Haematology								
		Other	I	I	I	Reproductive efficacy								
			C	C	R	Pregnant status								
			I	I	R	Meat quality and yield								

Table 3. *Cont.*

Welfare Principles		Welfare Criteria	LEI Sector 1	2	3	Animal-Based	LEI Sector 1	2	3	Environmental-Based	LEI Sector 1	2	3	Resource-Based
Appropriate behaviour	9	Expression of social behaviour	R	R	R	Ethograms								
			R	R	R	Stereotypic behaviour								
			R	R *	R	Emotional state								
	10	Expression of other behaviour	I	I	I	Heart rate								
			I	I	I	Heart rate variability								
	11	Good human-animal relationship	R	R	R	Flight zones								
			R	R	R	QBA								
	12	Positive emotional state	R	R	R	QBA								
Other						**Management-based**				**Industry-management**				**Management-based**
			C	C	I	Appropriate sourcing (incl. breed, genotype, size, age)	C	C	C	License and Accreditation	C	C	C	Stocking rate
											C	I	R	Time at feedlot
			C	C	C	Mixing	C	C	C	Assurance schemes	C	C	C	Euthanasia
			C	C	C	Isolation/separation	C	C	C	Auditing and compliance	I	I	C	Slaughter method
			C	C	C	Hospital pen	C	C	C					
			R	R	R	Habituation to transport or handling				Documentation and Reporting				
							R	C	C	Stock handler skills				
			C	C	C	Traceability	C	C	C					
			C	R	I	Rejections				Standard operating procedures				
			C	R	C	Use of electric prods/dogs/stick etc.								

[a] Qualitative Behavioural Assessment (QBA). * Indicates a measure that has been suggested to be included in ASEL regulations by the Technical Advisory Committee 2018 [58] but is not currently under ASEL v2.3 (2011) regulations. Current practice (C) were those included in the reviewed legislation and regulations for the LEI, including the proposed revisions by the Technical Advisory Committee 2018 for ASEL sea [59] and 2019 ASEL air transport reporting requirements [60].

2.4. Measures that Are Already Undertaken by the LEI

2.4.1. Management

It has been well established that stock handler attitudes and skills influence the way they handle livestock, which directly impacts an animal's welfare. Many measures relating to industry management (e.g., livestock sourcing, rejections, animal traceability, electric prodder use; Table 3) are already being documented [61–63]. Recording certification of stock handler training in low stress handling, and experience etc. for truck drivers, feedlot workers, ship crew, and abattoir workers, for each consignment, has the potential to be included in the Welfare Dashboard.

Animal management substantially influences the welfare of the animals under consideration. Many of these measures are currently monitored through ASEL and ESCAS, for example sourcing, breed, mixing, rejections, traceability, isolation/separation (Table 3). Being able to capitalise on improvements in this area requires traceability of livestock through the LEI chain, which could be facilitated through better tracking facilitated by radio-frequency identification (RFID) tags and central collation of these data.

Some measures are currently undertaken within the LEI as part of day-to-day proceedings, e.g., as part of the Daily Voyage Report and End of Voyage Report requirements under ASEL [17,59], and through the regulation and auditing of industry sectors (NFAS, Animal Welfare Standards and Guidelines and ESCAS). Existing compliance requirements are therefore being used as the starting basis for the development of welfare indicators (e.g., LIVEX-Collect [64]), and some/many of these measures can be extended forward in the supply chain to be used during land transport and in feedlots and abattoirs in the destination country. The various resource, environment and management measures currently recorded as part of animal welfare assessments, predominately during the sea transport stage of the supply chain that have applicability to the whole LEI supply chain (Table 3) could be included in a Welfare Dashboard [5].

2.4.2. Mortality

Mortality recorded in each sector of the LEI indicates the effect of overwhelming disease, injury or lack of care, and therefore the end result of poor quality of life for the animal [65]. Mortality is already recorded at all sectors of the LEI. During sea and air transport, mortality is reported by the AAV, accredited stockperson or exporter directly to the Department and is not accessible or used for any other purpose (except at the conclusion of investigation for incidences that exceed the reportable mortality rate for that species [66]; Figure 2). Daily mortality records should be included under the proposed Welfare Dashboard with more specific data detailing voyage day, location of events (e.g., decks) or class of animals, to inform and help manage future risks. Tracking animals through the live export chain (e.g., using National Livestock Identification System (NLIS) tags) will allow greater insight into morbidity (and mortality) events and is recommended as a first step towards developing this understanding of potential underlying causative factors. A tracking method could also allow the point of origin to be identified, which may start to identify patterns in on-farm conditions, such as animal exposure to feed types, vaccination histories etc. [67]. Such information could form part of risk assessments in the future.

Cattle by ship:
(1) Bovine respiratory disease
(2) Injuries from rough sea conditions
(3) Lameness

Sheep by ship:
(1) Heat stress
(2) Suffocation or temperature extremes
(3) Rumen acidosis

Goats, Sheep, Cattle by air:
(1) Inadequate ventilation

Contributing factors (examples)

- Novel and challenging environments (transport, handling, high noise levels, mixing/ separation) contribute to stress
- High environmental temperature and humidity en route or at destination
- Delays in journey time increase risk of disease outbreak, encountering temperature or sea condition extremes, change of diet required.
- Rough sea conditions
- Inadequate or failure of ventilation (poor air quality contributes to respiratory disease, suffocation, heat stress)
- Bedding, hygiene or shelter conditions in feedlots or on ship contribute to heat stress, cold stress, disease transmission
- Access to feed and water, or insufficient feed requiring a change in diet contribute to inappetence, lost body condition, dehydration, rumen acidosis or enteritis.

Figure 2. Main causes of mortality for livestock during sea and air transport for 23 notifiable incidences (2012–2016) where the level of mortality on a consignment exceeded the reportable mortality rate (reviewed under Investigations into Mortalities carried out by the Department of Agriculture, Water and Environment [66]). Left are proximate causes of mortality identified by these investigations; those underlined were recorded for three or more of these investigations. Right are examples of contributing factors.

2.4.3. Morbidity and Records of Animal Treatments

Disease and health status of animals is an important component of the overall status of the animals, and can reflect poor welfare [68]. There is also an economic cost to treating ill or injured animals and removing the animal from the export chain if required. A number of consignment delays and contentious situations can be traced back to incidence of disease [67,69], therefore, preventing the spread of disease and health issues has benefits for both animals and the industry.

Morbidity, records of animal treatments, and animals moved to hospital pens are important for the LEI as a method of monitoring health status and screening for potential disease outbreaks. Intensive housing with animals in close proximity, mixing of animals from a variety of origins, and increased shedding of organisms by animals under stress can result in the rapid spread of pathogens to previously naïve cohorts, so acute outbreaks of disease may be unavoidable. Therefore, evidence of active management responses towards disease or injury may be more relevant for a Welfare Dashboard than simply the incidence of disease. Daily observations of pens to identify individuals showing clinical signs of disease or injury are part of the routine of AAVs and stock handlers at all stages of the LEI. These could be expanded to include other measures of poor demeanour (e.g., dull, unresponsive) or abnormal behaviour, and animals classed as 'obviously sick', thus relevant to health status. Clinical signs that indicate poor welfare may include lameness, dyspnoea, coughing, nasal discharge, diarrhoea, ocular health, or excessive scratching or rubbing. These can all be assessed by observation at the pen level, such as the percentage of animals in the pen with each condition, without physically restraining the animals for individual examination.

2.4.4. Environmental Conditions and Animal Responses

Environmental conditions can affect animal health and welfare. Periods of extreme heat are of particular relevance for the welfare of live animals exported from Australia across the Equator,

especially when animals move from the southern hemisphere winter into the northern hemisphere summer [70].

Some environmental factors are already measured at some sectors of the industry. For example, during sea transport on voyages ≥ 10 days, daily records of (1) average dry bulb and wet bulb temperature for each deck, (2) humidity for each deck, and (3) bridge temperature (ambient) are reported under the Daily Voyage Report. A summary of environmental conditions ("comment on weather, temperature, humidity, ventilation and decks/bedding") is required in the End of Voyage Report for all voyages. Australian feedlots are required to have a stationary weather station that constantly records temperature, humidity and solar radiation, facilitating the gathering of daily weather data. Continuous digital monitoring of temperature and humidity is now required on sheep voyages to the Middle East from June to September [17,70].

Heat stress reporting requirements do not currently extend beyond sea voyages ≥10 days unless a notifiable mortality limit is reached in a pre-export facility or during a short haul voyage. Collating environmental information as part of a Welfare Dashboard [5] would provide a robust method of monitoring and could assist in assessing the effects of duration and intensity of heat (or cold) on any group of animals for immediate and ongoing management, as well as determining site, vessel and seasonal trends, for future risk management.

Animal responses to their environmental conditions are also currently monitored to some extent; in particular the response of livestock to hot conditions. Sheep and cattle use the respiratory system as their principal means of heat dissipation, and progress through identifiable stages of panting with an increasing physiological response to the heat [71–73]. Panting scores are a quick, non-invasive indicator of respiratory character and hence welfare state that can be used in all areas of the LEI, which, in combination with assessments of behaviour and demeanour at a pen level, may reveal the extent of heat stress, as well as the presence of respiratory disease [74]. When combined with environmental or behavioural measures, the cause of panting can be determined, such as heat stress or fear response. Panting scores have been historically been assessed daily on a deck basis during voyages by sea as part of the Daily Voyage Report for voyages ≥10 days. Respiratory character (1 = normal, 2 = panting, 3 = gasping) and *"Whether and to what extent the livestock show heat stress"* are recorded. More detailed panting score measures have been included in Daily and End of Voyage reporting requirements for sheep during sea transport in response the to the McCarthy Review 2018 and the revision of ASEL 2018 [19,40]. Species-specific panting scores are provided in the veterinary handbook for cattle, sheep and goats [75], which is available to AAVs and stockpersons, facilitating the possibility of standardised reporting upon inclusion in the Welfare Dashboard.

2.4.5. Feeding

More research is required to identify the effects of feed and water withdrawal, with novel welfare indicators needed to assess short term hunger and thirst [26]. Feed and water consumption and availability are part of the daily monitoring of livestock at pre-export facilities, the Daily Voyage Report (*"average per head"*), End of Voyage Reports (ASEL) and ESCAS auditing reports, although, there is no guideline for standardised collection of this information. For example, the ship reports require: *"Feed and water—comment on stock access and if there were any issues with maintenance"*, leaving reporting of this information to individual discretion. Maximum time off feed and water is regulated under Australian Standards and Guidelines for transport, under ASEL for sea transport, and at abattoirs under ESCAS. These measures have the potential to be expanded as part of the Welfare Dashboard, as developing guidelines for their recording would improve standardisation and repeatability of monitoring.

2.5. Relevant Measures, Not Currently Required in the LEI, That Could Be Applicable to Welfare Assessments

2.5.1. Management

Collating land transport details, such as time off water and food, and time between mustering, loading and transport (regulated under ASEL in Australia) along with any issues, including delays in transport and animal injury as the animals progress through the chain, could provide long term monitoring and indicate areas for improvement. Delays experienced at the wharf during loading or unloading of the livestock could be included here. The transmission of data about each cohort of animals along the chain could enable prospective management decisions that optimise the subsequent care and therefore welfare of those animals.

Appropriate design and construction of facilities can increase productivity and reduce welfare risks. The ESCAS audit process contains measures of facilities, such as presence of protrusions or gaps where animals may be injured or trapped, adequate fencing to provide restraint, width of races, non-slip flooring, and animal responses to facilities, including rate of animal slips and falls and the number of times animal flow stops. The use of the ESCAS welfare audit and ASEL regulations may be a starting point for developing standardised welfare assessments that are applied earlier in the supply chain, such as during loading and unloading at farm, pre-export facilities, ship/aircraft, destination feedlot/farm and abattoir. Hygiene indicators used at abattoirs need to be modified to enable hygiene assessments for transport vehicles and feedlots.

2.5.2. Food and Water Access and Consumption

Measures that relate to both immediate and longer term availability of food and water and consequences of consumption can be made. These are fundamental to health and welfare of the animals, ensuring their needs are met, and are very important in the LEI due to the link of inappetence of sheep with disease such as salmonellosis [76,77] and the need for adequate hydration especially during hot environmental conditions so that physiological cooling mechanisms can continue [78,79].

Rumination and gut fill can be determined on observation of the animals as an indication of recent feed and/or water consumption [80,81], and are measures that can be used in day-to-day management. Rumination is best observed in undisturbed animals at rest, and as a group measure [82–84]. Gut fill could be assessed subjectively, by observing the animal for abdominal distension or hollow sides in the flanks behind the ribs; standardising this assessment can be aided by using image charts and a grading system from empty (hollow sides) to full [85,86].

The behaviour of animals at feeding could be used as a measure of how hungry the animals are, especially useful in situations where animals receive intermittent feeding, when they may demonstrate behaviour indicating urgency to eat. Animals that stay away from feed can also be detected, and may be animals suffering disease, or may indicate concerns related to adequacy of trough space and food for the group size and hierarchy. The responses of animals to provision of water, for example after troughs are cleaned or refilled, could indicate thirst, as well as a desire to access cooler water under hot environmental conditions [87].

Body mass and body condition score (BCS) can indicate the longer term results of feeding. ASEL state the minimum and maximum weight and BCS for animals entering the LEI, and monitoring and recording will allow compliance to be demonstrated. Change in BCS over time can reveal how animals are being managed and coping with their environment [88]. While it is usual practice during live export of sheep to feed only at maintenance, cattle may be fed for weight gain; loss of BCS over the process indicates lack of feeding. The BCS at any point in time may also provide information that can be used in risk assessment; for example animals in heavy body condition may be more susceptible to heat stress and to injury [66]. Sheep in high BCS may be more susceptible to metabolic effects of inappetence in the second half of the year [89], while heavy cattle may be less capable of dealing with rough seas, and may be more susceptible to foot and leg injuries.

Alternatively, or in addition, carcass classification can provide information regarding long term feeding, with the possibility of video image analysis technologies being tested [90].

2.5.3. Behaviour

Assessing behavioural events (behaviours that occur both frequently and infrequently) can be performed by visual observation, it is non-invasive and does not require specific equipment. For example, shivering could be recorded as an indicator of possible thermal discomfort, while specific abnormal behaviours, such as bouts of aggression or inappetence, could identify animals that may need to be removed from a pen for treatment. Stereotypical behaviour is common in confined animals [91] and generally indicates long-term challenges for animals, i.e., over months or longer [92] or can be a coping mechanism [93]. The reporting of stereotypical or unusual behaviour in confined animals [91] can be used to indicate the mental state. The expression of stereotypies as part of the LEI could reflect boredom (e.g., in feedlots and during sea transport) and environmental enrichment may reduce the expression of stereotypies.

Activity budgets—capturing the proportion of time that an animal spends doing particular actions—provide an easy to measure, non-invasive method that can target behavioural states that are welfare-relevant (e.g., eating, resting). Although ethograms can be time consuming with large numbers of animals, developing monitoring protocols for representative groups is achievable. These measures have the potential to be expanded and used as part of the Welfare Dashboard [5].

The incidence of particular activities can also be informative. For example, evidence of panting can reveal how animals experience the temperature and humidity of their environment. Currently, panting score is monitored at pre-export facilities and reported daily under ASEL. If a standardised reporting format was presented, these data could be collated and compared with weather conditions and animal handling procedures, with the potential to reveal sectors of the LEI that pose the most risk for heat or cold stress conditions and respiratory disease.

Observing behavioural preferences can also reveal how animals are responding to their environment. For example, shade is important for livestock in feedlots, especially in climates with high solar radiation and high temperatures, and sheep (e.g., [94]) and cattle (e.g., [95]) use shade if it is available. The effectiveness of shade types can be measured by observing animal outcomes (such as animal preferences and thermoregulation) under varying conditions and shade access [96].

Qualitative Behavioural Assessment (QBA) can indicate 'how' the animal is behaving rather than what it is doing, by looking at how the animal interacts with its environment [41,97]. QBA is a quantitative measure of the animal's demeanour, capturing subtle differences in behavioural expression that reflect an animal's environment as well as their physiological state [98–102]. Consequently, QBA scores are a useful measure of the animal's experience with its environment and can reflect the valence of its emotional state. QBA was included as one of 13 measures as part of the 2004-2009 European Commission's Welfare Quality® audit [103–105] and is aligned with the scoring of demeanour as 'bright, alert, responsive', which is a routine tool for veterinary practice (e.g., [106]). QBA should be applicable for all species and in all areas of the LEI supply chain, although a degree of training is required for data collection, analysis and interpretation of results. Developing protocols can provide immediate feedback to the assessors, but the data can also contribute to long-term analyses. For example, current practice around sorting animals at loading and scanning pens as part of daily monitoring involves stock handlers observing animals and using their judgement to identify animals that behave differently; this informal approach is effectively using aspects of the animal's demeanour to identify and sort individuals. A more formal approach could be developed using appropriate scoring sheets developed for particular species and stages, and results from this provide feedback to training packages for stock handlers. These measures have the potential to be included as part of the Welfare Dashboard and contribute to long-term datasets.

2.5.4. Environment

Environmental measures, such as temperature and humidity, at pre-export feedlots and on vessels (both ships and aeroplanes) are already monitored in the LEI (Table 3). Ventilation serves to maintain environments appropriate to the physiological needs of livestock [107,108]. Ventilation is important to remove air pollutants (such as ammonia and carbon dioxide, and dust) and maintain air quality. Ventilation in feedlots and on trucks is usually by natural means, whereas on board ship, ventilation is by mechanical means. High ammonia concentrations can irritate the eyes causing conjunctivitis, and upper respiratory tract leading to coughing (particularly on hot days) and rapid breathing. The small airways of the lower respiratory tract become inflamed after exposure to ammonia [109]. Environmental conditions in Australia, on board ship, and in the Middle East and Asia are favourable for ammonia gas production. Already part of LEI management procedures and regulation, ensuring frequent changing of bedding and adequate ventilation can bring fresh air and remove ammonia gas [109]; however, low air turnover and ventilation dead spots can be issues on board ships [107].

2.5.5. Other

Ideally, pregnant livestock do not enter the feeder/slaughter export supply chain; those that do are recorded under the pre-export facility monitoring or Daily Voyage Report ("Births and abortions including estimated stage of pregnancy") and health and welfare of the livestock ("the number of livestock born, the number of abortions and estimated stage of pregnancy") as part of the End of Voyage Report. The conditions during export are not conducive to good welfare of heavily pregnant animals or those giving birth and the offspring. Currently, actions such as pregnancy testing and careful animal selection are taken to reduce the likelihood of pregnant livestock entering the feeder/slaughter LEI supply chain, with incidences of births and abortions during voyages collected under current reporting requirements. Collating this information as part of a Welfare Dashboard would be advised for feedback to suppliers and subsequent improved management.

2.6. Measures Relevant for Specific Situations (e.g., Research, Sentinel Animals), but Unlikely to Be Used for Day-to-Day Management

We recognise that there are numerous animal welfare measures proposed for on-farm protocols that are unlikely to be feasible under normal LEI practice due to impracticality of the measurement (e.g., heart rate, body temperature, stress hormones), where the measure recorded is not relevant to the short time frame within the supply chain (e.g., reproductive rate), or measures are delayed and therefore would not provide immediate feedback required to act immediately (e.g., meat quality).

Heart rate and heart rate variability are indicators of the emotional responses of an individual to a short-term problem, and can increase in anticipation to, and during, an event [110–112], changing within 1 or 2 heart beats [113]. This means that both measures can also be affected by the act of measuring them. Remote methods for monitoring may be useful in controlled situations; however, application under LEI is impractical.

Body temperature is an indicator of the onset or degree of thermal stress in an animal [114], and can also be used to indicate the presence of disease (pyrexia) and stress [115]. Body temperature of an animal can be measured rectally at a specific time point with a standard thermometer; however multiple readings of the same animal, in order to account for circadian patterns [116], require repeated handling. Remote continuous temperature monitors are available but are expensive (limiting the number of animals monitored) and can be intrusive. Body temperature is not a practical animal-based measure for the LEI with its use limited to necropsy, sick animals, those that are individually examined, and those used in research (e.g., [117]).

'Stress hormones', such as cortisol (e.g., [118–121]) as well as haematology and blood biochemistry (including acid-base disturbance; e.g., [118,121–124]), are measures that require blood sampling for assessment. Animals must be restrained to collect a sample, which is then sent away for analysis. This can be costly and may not provide immediate results. Additionally, other measures need to be

used in conjunction to provide enough information for correct interpretation. Relevance in the LEI is, therefore, limited.

The assessment of carcasses for bruising and meat quality at slaughter may provide information on the recent experience of livestock. Glycogen is required for good meat quality, but glycogen is also the first energy store to be depleted, especially for stressed animals [125–128]. Stress therefore leads to a decline in acidification of the meat, which increases risk of spoilage and an abnormal colour that makes it difficult to market [129]. Consequently, meat quality can decline with both physical and emotional stress the animals are exposed to (e.g., during transport or from mixing unfamiliar animals together, or handling prior to slaughter [128,130,131]). Meat quality measures are usually obtained post-mortem, so provide only retrospective information for the animals tested. To collect these measures, access to the destination market abattoir would be required, while abattoir surveillance for disease and carcase condemnation could provide data on the health of the animals at slaughter.

3. Conclusions

Animal welfare assessment is required to identify compliance with legislation, policy and regulatory standards, market assurance, for the management of risks and in response to public attitudes and concerns [2,132]. The welfare status of animals also influences the quality of the product, either directly or indirectly, via consumer perceptions [133]. Proactive animal welfare monitoring and engagement with all stakeholders are therefore needed to ensure continued social licence to trade for the LEI.

Current LEI welfare assessments are focussed around mortality, morbidity, environmental measures and the resources provided to animals. This emphasis is likely to change as the government seeks to move towards more focus on reporting on animal-based measures of welfare that are more likely to be met through a combination of measures addressing 'good feeding', 'good housing', 'good health' and 'appropriate behaviour' (Table 1). We considered 71 potential animal welfare measures that address 12 welfare criteria and 4 welfare principles of animal welfare (Table 3). We identified the measures that would be appropriate for use as part of the live export supply chain, and categorised these as animal-, environment- and resource-based. After reviewing the relevant regulations for each sector of the industry, we identified measures already collected under current practice that can be expanded on to form a Welfare Dashboard: a LEI-specific online interface for collecting of data that could contribute towards benchmarking the industry [5]. Importantly, this suite of measurements will allow us to start identifying patterns or associations allowing algorithms to be developed that could rely on measuring a few key indicators to benchmark animal welfare. Although we note that many measures may be perceived by the general public as relevant to the LEI [21], we identified and dismissed measures that were not appropriate for the LEI due to impracticality.

Care is needed for compliance approaches based on environment-, resource- and animal-based measures, and tick-the-box assessments (i.e., using threshold values), since these are not necessarily associated with good welfare outcomes [42]. For example, mortality reporting uses fixed thresholds that trigger a formal mortality investigation [66]; however, not reaching mortality thresholds does not necessarily mean the majority of livestock experienced acceptable welfare outcomes. Increasing the scope of animal welfare assessment tools could therefore extend the capacity to drive improvement.

The need for effective feedback and continuous improvement on performance requires established and detailed protocols for consistency over time and locations and between practices. Monitoring can be useful for exporters to measure the performance of a facility, supply chain or management team, such as by differentiating between average and high performers, or detecting declines in performance before actual non-compliance occurs [134]. We note that awareness of the differing objectives of assurance systems compared with benchmarking is important. While assurance systems work towards compliance, they do not naturally engender self-driven improvements. In the case of the LEI, benchmarking is likely to increase ownership and investment into the system, with the LEI participants determining how they best modify their own systems to improve welfare outcomes.

Engaging a range of novel sensors in ongoing monitoring could be productive in animal welfare assessments. Current technology is available to monitor animal physiology, including heart rate, core temperature (iButtons or loggers [135,136]) and surface temperature (thermal imaging cameras [137]), health (biosensors [138]), activity and posture (accelerometers and pedometers [139,140]) as well as bioacoustics [141,142]. Devices that can be externally mounted are desirable for minimised impact on the animal, although there are issues with damage in high density environments (e.g., animals chewing and damaging devices) such as part of the LEI. As these technologies develop and become more feasible and practical, adoption within the LEI may occur, although this will only progress if validity, representativeness and value of such monitoring is demonstrated.

Environmental sensors that monitor temperature, humidity ammonia and carbon dioxide are also becoming more available and affordable [143]. For the adoption of these technologies to occur on vessels (ships and aeroplanes), many environmental constraints such as vessel design and infrastructure impeding signals of remote technologies need to be considered. Future LEI benchmarking systems could facilitate adoption of sensor systems as they are shown to be relevant and of value.

Further work is required to develop a system that can be tailored to the logistics and requirements of the Australian LEI. Ideally, the aim would be to provide non-invasive, cost effective, and implementable measures that incorporate animal-based factors, such as behaviour and physiology, and (independently) environmental-based factors relevant to sheep, cattle, buffalo and goats. As well as capturing measures in such a way that LEI participants can use these data to improve their practice. Development of appropriate data entry forms (possibly through handheld devices) that feed into a web-based database can facilitate easy pen-side data collection of standardised information and make reporting requirements more efficient and effective. Collating and recording these data over a period of time can value add to current practice, providing the baseline data against which industry improvements can be measured.

Some areas are noted where more research is required. For example, the development of measures suitable to determine whether animals in the LEI have a positive emotional state, addressing potential time delays between entering data and accessing comparison with benchmarking data, as well as developing versatile and informative tools to communicate findings to a broad range of stakeholders. Identifying how various stakeholders want to see the industry transparently assessed [21] is also a consideration in building such tools. The next generation of industry regulation, and adaptation by the industry of new benchmarking and audit methods, will work towards addressing community expectations.

Supplementary Materials: The following are available online at http://www.mdpi.com/2076-2615/10/7/1236/s1, Table S1: Measures that are direct indictors of animal welfare.

Author Contributions: Conceptualisation, P.A.F., S.L.W., A.L.B., D.W.M. and T.C.; formal analysis, P.A.F. and S.L.W.; writing—original draft preparation, S.L.W.; writing—review and editing, P.A.F., S.L.W., A.L.B., D.W.M., E.J.D.-C., R.S.W. and T.C.; funding acquisition, P.A.F., S.L.W., A.L.B., D.W.M., and T.C. All authors have read and agreed to the published version of the manuscript.

Funding: This project was funded by Meat & Livestock Australia W.LIV.3032, LiveCorp and matched funding from the Department of Agriculture, Water and the Environment.

Conflicts of Interest: The authors declare no conflict of interest; however, all authors have received research grant funding by MLA. In addition, TC and AB have received consultancy funding provided by the Department of Agriculture and the Environment, Commonwealth of Australia.

Abbreviations

AAV	Australian Accredited Veterinarian
ASEL	Australian Standards for the Export of Livestock [17]
ESCAS	Exporter Supply Chain Assurance System [18]
IO	Independent Observers
LEI	live export industry
LGAP	Livestock Global Assurance Program
QBA	Qualitative Behavioural Assessment
WQ	European Commission's Welfare Quality® audit [103–105]

References

1. Rousing, T.; Bonde, M.; Sorensen, J.T. Aggregating welfare indicators into an operational welfare assessment system: A bottom-up approach. *Acta Agric. Scand. Sect. A Anim. Sci.* **2001**, *30*, 53–57.
2. Colditz, I.G.; Ferguson, D.M.; Collins, T.; Matthews, L.; Hemsworth, P.H. A prototype tool to enable farmers to measure and improve the welfare performance of the farm animal enterprise: The unified field index. *Animals* **2014**, *4*, 446–462. [CrossRef] [PubMed]
3. Coleman, G. Public animal welfare discussions and outlooks in Australia. *Anim. Front.* **2018**, *8*, 14–19. [CrossRef] [PubMed]
4. Phillips, C.J.C. Ethical perspectives of the Australian live export trade. *Aust. Vet. J.* **2005**, *83*, 558–562. [CrossRef] [PubMed]
5. Dunston-Clarke, E.J.; Willis, R.S.; Fleming, P.A.; Barnes, A.L.; Miller, D.W.; Collins, T. Developing an animal welfare assessment protocol for livestock transported by sea. *Animals* **2020**, *10*, 705. [CrossRef] [PubMed]
6. Mellor, D.; Webster, J. Development of animal welfare understanding drives change in minimum welfare standards. *Sci. Tech. Rev. OIE* **2014**, *33*, 121–130. [CrossRef]
7. Mellor, D.; Beausoleil, N. Extending the five domains model for animal welfare assessment to incorporated positive welfare states. *Anim. Welf.* **2015**, *24*, 241–253. [CrossRef]
8. Botreau, R.; Bonde, M.; Butterworth, A.; Perny, P.; Bracke, M.; Capdeville, J.; Veissier, I. Aggregation of measures to produce an overall assessment of animal welfare. Part 1: A review of existing methods. *Animal* **2007**, *1*, 1179–1187. [CrossRef]
9. Botreau, R.; Bracke, M.; Perny, P.; Butterworth, A.; Capdeville, J.; Van Reenen, C.; Veissier, I. Aggregation of measures to produce an overall assessment of animal welfare. Part 2: Analysis of constraints. *Animal* **2007**, *1*, 1188–1197. [CrossRef]
10. Keeling, L. Positive Affective States and Positive Animal Welfare. In Proceedings of the XXXI International Ethological Conference, Rennes, France, 19–24 August 2009; pp. 65–66.
11. Sandøe, P.; Simonsen, H.B. Assessing animal welfare: Where does science end and philosophy begin? *Anim. Welf.* **1992**, *1*, 257–267.
12. Sevi, A. Animal-based measures for welfare assessment. *Ital. J. Anim. Sci.* **2009**, *8*, 904–911. [CrossRef]
13. Green, T.C.; Mellor, D.J. Extending ideas about animal welfare assessment to include 'quality of life'and related concepts. *N. Z. Vet. J.* **2011**, *59*, 263–271. [CrossRef] [PubMed]
14. Blokhuis, H.J. International cooperation in animal welfare: The Welfare Quality® project. *Acta Vet. Scand.* **2008**, *50*, 1. [CrossRef]
15. LiveCorp. *Annual Report 2018/19*; LiveCorp: Sydney, Australia, 2019.
16. Collins, T.; Stockman, C.; Hampton, J.O.; Barnes, A. Identifying animal welfare impacts of livestock air transport. *Aust. Vet. J.* **2020**, in press. [CrossRef]
17. Department of Agriculture Fisheries and Forestry. *Australian Standards for the Export of Livestock and Australian Position Statement on Export of Livestock, Version 2.3*; Department of Agriculture, Fisheries and Forestry, Austalian Government: Canberra, Australia, 2011.
18. ESCAS. *Exporter Supply Chain Assurance System (ESCAS)*; Department of Agriculture, Fisheries and Forestry, Austalian Government: Canberra, Australia, 2011.
19. McCarthy, M. *Independent Review of Conditions for the Export of Sheep to the Middle East. During the Northern Hemisphere Summer*; Department of Agriculture and Water Resources, Australian Government: Canberra, Australia, 2018.

20. Farmer, B. *Independent Review of Australia's Livestock Export Trade*; Department of Agriculture, Fisheries and Forestry: Canberra, Australia, 2011.
21. Fleming, P.A.; Wickham, S.L.; Collins, T.; Barnes, A.L.; Miller, D.W. Stakeholder opinions about animal welfare in the Australian live export industry: A survey. in review.
22. Pines, M.; Petherick, C.; Gaughan, J.B.; Phillips, C.J.C. *Developing Alternative Methods of Measuring Animal Welfare on Ships. Stage One: Survey of Industry Opinion*; Meat and Livestock Australia: Sydney, Australia, 2004.
23. Duncan, I.J.H. Science-based assessment of animal welfare: Farm animals. *Rev. Sci. Tech. Off. Int. Epizoot.* **2005**, *24*, 483. [CrossRef]
24. Broom, D.M. The scientific assessment of animal welfare. *Appl. Anim. Behav. Sci.* **1988**, *20*, 5–19. [CrossRef]
25. Barnett, J.L.; Hemsworth, P.H. The validity of physiological and behavioural measures of animal welfare. *Appl. Anim. Behav. Sci.* **1990**, *25*, 177–187. [CrossRef]
26. Llonch, P.; King, E.M.; Clarke, K.A.; Downes, J.M.; Green, L.E. A systematic review of animal based indicators of sheep welfare on farm, at market and during transport, and qualitative appraisal of their validity and feasibility for use in UK abattoirs. *Vet. J.* **2015**, *206*, 289–297. [CrossRef]
27. Grandin, T. Auditing animal welfare at slaughter plants. *Meat Sci.* **2010**, *86*, 56–65. [CrossRef]
28. MLA. Livestock Global Assurance Program. Available online: http://www.livecorp.com.au/research-development/reports/livestock-global-assurance-program (accessed on 12 July 2020).
29. IATA. Live Animals Regulations. Available online: https://www.iata.org/en/publications/store/live-animals-regulations/ (accessed on 22 April 2020).
30. OIE. The OIE Global Animal Welfare Strategy. Available online: http://www.oie.int/animal-welfare/oie-standards-and-international-trade/ (accessed on 22 April 2020).
31. Australian Government. *Australian Standards for the Export of Livestock 3.0*; Department of Agriculture, Water and the Environment, Australian Government: Canberra, Australia, 2020.
32. Australian Government. Inspector-General of Live Animal Exports. Available online: https://www.iglae.gov.au/ (accessed on 4 April 2020).
33. Australian Government. *Australian Animal Welfare Standards and Guidelines; Land Transport. Standards and Guidelines*; Department of Agriculture, Fisheries and Forestry, Australian Government: Canberra, Australia, 2012.
34. Australian Government. Australian Animal Welfare Standards and Guidelines. Available online: https://www.agriculture.gov.au/animal/welfare/standards-guidelines (accessed on 17 April 2020).
35. MLA. Livestock Production Assurance (LPA). Available online: https://www.integritysystems.com.au/on-farm-assurance/livestock-product-assurance/ (accessed on 22 April 2020).
36. Future Beef. Grazing BMP. Available online: https://futurebeef.com.au/projects/grazing-bmp/ (accessed on 22 April 2020).
37. Dairy Australia. Animal Management. Available online: https://www.dairyaustralia.com.au/dairyaustralia/farm/animal-management?keyword=animal%20management (accessed on 22 April 2020).
38. NFAS. National Feedlot Accreditation Scheme. Available online: https://www.ausmeat.com.au/services/list/livestock/nfas/ (accessed on 22 April 2020).
39. Moss, P. *Review of the Regulatory Capability and Culture of the Department of Agriculture and Water Resources in the Regulation of Live Animal Exports*; Department of Agriculture and Water Resources, Government of Australia: Canberra, Australia, 2018.
40. Australian Government. Review of the Australian Standards for the Export of Livestock. Available online: https://www.agriculture.gov.au/animal/welfare/export-trade/review-asel (accessed on 22 April 2020).
41. Fleming, P.A.; Clarke, T.; Wickham, S.L.; Stockman, C.A.; Barnes, A.L.; Collins, T.; Miller, D.W. The contribution of Qualitative Behavioural Assessment to livestock welfare assessment. *Anim. Prod. Sci.* **2016**, *56*, 1569–1578. [CrossRef]
42. Main, D.C.J.; Webster, A.J.F.; Green, L.E. Animal welfare assessment in farm assurance schemes. *Acta Agric. Scand. Sect. A Anim. Sci.* **2001**, *51*, 108–113. [CrossRef]
43. Australian Government. Independent Observations of Livestock Export Voyages by Sea. Available online: https://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/independent-observations-livestock-export-sea#2018 (accessed on 4 April 2020).

44. Brann, M.; Brown, C. Live Export Independent Observers Only Required Where ,'Most Needed after Policy Change. Available online: https://www.abc.net.au/news/rural/2019-10-22/independent-observer-change-for-short-haul-live-export-voyages/11623816 (accessed on 12 July 2020).
45. Australian Government. Independent Observation of Livestock Export Voyages by Sea. Available online: https://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/independent-observations-livestock-export-sea (accessed on 17 April 2020).
46. Sinclair, M.; Derkley, T.; Fryer, C.; Phillips, C.J.C. Australian public opinions regarding the live export trade before and after an animal welfare media expose. *Animals* **2018**, *8*, 106. [CrossRef]
47. Pulido, M.A.; Mariezcurrena-Berasain, M.A.; Sepúlveda, W.; Rayas-Amor, A.A.; Salem, A.Z.M.; Miranda-de la Lama, G.C. Hauliers' perceptions and attitudes towards farm animal welfare could influence the operational and logistics practices in sheep transport. *J. Vet. Behav.* **2018**, *23*, 25–32. [CrossRef]
48. Munoz, C.A.; Coleman, G.J.; Hemsworth, P.H.; Campbell, A.J.D.; Doyle, R.E. Positive attitudes, positive outcomes: The relationship between farmer attitudes, management behaviour and sheep welfare. *PLoS ONE* **2019**, *14*, e0220455. [CrossRef]
49. Animal Health Australia. *Australian Animal Welfare Standards and Guidelines: Land Transport of Livestock*, 1st ed.; Version 1.1; Animal Health Australia: Canberra, Australia, 2012.
50. Animal Health Australia. *Australian Animal Welfare Standards and Guidelines for Cattle*, 1st ed.; Version One, Endorsed January 2016; Animal Health Australia: Canberra, Australia, 2014.
51. Animal Health Australia. *Australian Animal Welfare Standards and Guidelines for Sheep*, 1st ed.; Version One, Endorsed January 2018; Animal Health Australia: Canberra, Australia, 2014.
52. Animal Health Australia. *Australian Industry Welfare Standards and Guidelines for Goats, May 2019 ed.*; Animal Health Australia: Canberra, Australia, 2019.
53. AUS-MEAT Limited. *National Feedlot Accreditation Scheme Handbook. Rules and Standards of Accreditation*, September 2018 ed.; AUS-MEAT Limited: Tingalpa, Queensland, Australia, 2019.
54. Goddard, P. Welfare assessment in sheep. *Practice* **2011**, *33*, 508–516. [CrossRef]
55. Phythian, C.; Cripps, P.; Grove-White, D.; Jones, P.; Michalopoulou, E.; Duncan, J. Observing lame sheep: Evaluating test agreement between group-level and individual animal methods of assessment. *Anim. Welf.* **2013**, *22*, 417–422. [CrossRef]
56. Phythian, C.; Cripps, P.; Michalopoulou, E.; Jones, P.; Grove-White, D.; Clarkson, M.; Winter, A.; Stubbings, L.; Duncan, J. Reliability of indicators of sheep welfare assessed by a group observation methods. *Vet. J.* **2012**, *193*, 247–263. [CrossRef]
57. Widowski, T.M.; Rushen, J.; Tuyttens, F.A.M.; Veissier, I. Implementing animal welfare assessments at farm and group level: Introduction and overview. *Anim. Welf.* **2012**, *21*, 305–306.
58. Department of Agriculture Water and the Environment. *Review of the Australian Standards for the Export of Livestock*; Department of Agriculture, Water and the Environment, Australian Government: Canberra, Australia, 2018.
59. ASEL Review Technical Advisory Committee. *Review of the Australian Standards for the Export of Livestock: Sea Transport—Final report*; Technical Advisory Committee, Department of Agriculture, Fisheries and Forestry, Austalian Government: Canberra, Australia, 2018.
60. Department of Agriculture. *Review of the Australian Standards for the Export of Livestock: Air Transport Final Report. September 2019*; Technical Advisory Committee: Canberra, Australia, 2019.
61. Grandin, T. Transferring results of behavioral research to industry to improve animal welfare on the farm, ranch and the slaughter plant. *Appl. Anim. Behav. Sci.* **2003**, *81*, 215–228. [CrossRef]
62. Coleman, G.J.; Hemsworth, P.H. Training to improve stockperson beliefs and behaviour towards livestock enhances welfare and productivity. *Rev. Sci. Tech.* **2014**, *33*, 131–137. [CrossRef]
63. Grandin, T.; Shivley, C. How farm animals react and perceive stressful situations such as handling, restraint, and transport. *Animals* **2015**, *5*, 1233–1251. [CrossRef]
64. LiveCorp. LiveCorp. LiveCorp Supplementary Submission—Voyage Reporting. In *Review of Australian Standards for the Export of Livestock (ASEL)—Stage 2*; Australian Livestock Export Corporation Ltd. (LiveCorp): Sydney, Australia, 2019.
65. Von Keyserlingk, M.A.G.; Rushen, J.; de Passillé, A.M.; Weary, D.M. Invited review: The welfare of dairy cattle—Key concepts and the role of science. *J. Dairy Sci.* **2009**, *92*, 4101–4111. [CrossRef]

66. Australian Government. Investigations into Mortalities. Available online: https://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/regulatory-framework/compliance-investigations/investigations-mortalities#previous-years (accessed on 4 April 2020).
67. Stinson, P.R. Two incidents that changed quality management in the Australian livestock export industry. *Vet. Ital.* **2008**, *44*, 177–186.
68. Segner, H.; Sundh, H.; Buchmann, K.; Douxfils, J.; Sundell, K.; Mathieu, C.; Ruane, N.; Jutfelt, F.; Toften, H.; Vaughan, L. Health of farmed fish: Its relation to fish welfare and its utility as welfare indicator. *Fish Physiol. Biochem.* **2012**, *38*, 85–105. [CrossRef]
69. Edwards, M. Pakistan Culls Entire Shipment of Australian Sheep. Available online: https://www.abc.net.au/news/2012-10-21/an-pakistan-culls-entire-shipment-of-australian-sheep/4325572 (accessed on 12 July 2020).
70. Australian Government. Sheep Exports to the Middle East. Available online: https://www.agriculture.gov.au/export/controlled-goods/live-animals/livestock/information-exporters-industry/sheep-to-middle-east (accessed on 17 April 2020).
71. Gaughan, J.B.; Holt, S.; Hahn, G.L.; Mader, T.L.; Eigenberg, R. Respiration rate: Is it a good measure of heat stress in cattle? *Asian Australas. J. Anim. Sci.* **2000**, *13*, 329–332.
72. Stockman, C.A. The Physiological and Behavioural Responses of Sheep Exposed to Heat Load within Intensive Sheep Industries. Ph.D. Thesis, Murdoch University, Perth, Western Australia, 2006.
73. Stockman, C.A.; Barnes, A.L.; Maloney, S.K.; Taylor, E.; McCarthy, M.; Pethick, D. Effect of prolonged exposure to continuous heat and humidity similar to long haul live export voyages in Merino wethers. *Anim. Prod. Sci.* **2011**, *51*, 135–143. [CrossRef]
74. Nienaber, J.A.; Hahn, G.L. Livestock production system management responses to thermal challenges. *Int. J. Biometeorol.* **2007**, *52*, 149–157. [CrossRef]
75. Jubb, T.; Perkins, N. *The Veterinary Handbook for the Livestock Export Industry*; Australian Livestock Export Corporation Limited: North Sydney, Australia, 2015.
76. Norris, R.T.; McDonald, C.L.; Richards, R.B.; Hyder, M.W.; Gittins, S.P.; Norman, G.J. Management of inappetant sheep during export by sea. *Aust. Vet. J.* **1990**, *67*, 244–247. [CrossRef]
77. Higgs, A.R.E.; Norris, R.T.; Richards, R.B. Epidemiology of salmonellosis in the live sheep export industry. *Aust. Vet. J.* **1993**, *70*, 330–335. [CrossRef]
78. Baker, M.A. Effects of dehydration and rehydration on thermoregulatory sweating in goats. *J. Physiol.* **1989**, *417*, 421–435. [CrossRef]
79. McKinley, M.J.; Weissenborn, F.; Mathai, M.L. Drinking-induced thermoregulatory panting in rehydrated sheep: Influences of oropharyngeal/esophageal signals, core temperature, and thirst satiety. *Am. J. Physiol. Regul. Integr. Comp. Physiol.* **2009**, *296*, R1881–R1888. [CrossRef]
80. Thiago, L.R.L.; Gill, M.; Sissons, J.W. Studies of method of conserving grass herbage and frequency of feeding in cattle: 2. Eating behaviour, rumen motility and rumen fill. *Br. J. Nutr.* **1992**, *67*, 319–336. [CrossRef]
81. Mattiello, S.; Battini, M.; De Rosa, G.; Napolitano, F.; Dwyer, C. How can we assess positive welfare in ruminants? *Animals* **2019**, *9*, 758. [CrossRef]
82. Caldeira, R.M.; Belo, A.T.; Santos, C.C.; Vazques, M.I.; Portugal, A.V. The effect of long-term feed restriction and over-nutrition on body condition score, blood metabolites and hormonal profiles in ewes. *Small Rumin. Res.* **2007**, *68*, 242–255. [CrossRef]
83. Phythian, C.J.; Hughes, D.; Michalopoulou, E.; Cripps, P.J.; Duncan, J.S. Reliability of body condition scoring of sheep for cross-farm assessments. *Small Rumin. Res.* **2012**, *104*, 156–162. [CrossRef]
84. Ndlovu, T.; Chimonyo, M.; Okoh, A.I.; Muchenje, V.; Dzama, K.; Raats, J.G. Assessing the nutritional status of beef cattle: Current practices and future prospects. *Afr. J. Biotechnol.* **2007**, *6*, 2727–2734.
85. Russel, A.J.F.; Doney, J.M.; Gunn, R.G. Subjective assessment of body fat in live sheep. *J. Agric. Sci.* **1969**, *72*, 451–454. [CrossRef]
86. DPIRD. Condition Scoring of Sheep. Available online: https://www.agric.wa.gov.au/apps/sheep-condition-scoring-1 (accessed on 17 April 2020).
87. Polsky, L.; von Keyserlingk, M.A.G. Invited review: Effects of heat stress on dairy cattle welfare. *J. Dairy Sci.* **2017**, *100*, 8645–8657. [CrossRef]
88. Tilbrook, A.J.; Rivalland, E.A.T.; Turner, A.I.; Lambert, G.W.; Clarke, I.J. Responses of the hypothalamopituitary adrenal axis and the sympathoadrenal system to isolation/restraint stress in sheep of different adiposity. *Neuroendocrinology* **2008**, *87*, 193–205. [CrossRef]

89. Richards, R.B.; Norris, R.T.; Dunlop, R.H.; McQuade, N.C. Causes of death in sheep exported live by sea. *Aust. Vet. J.* **1989**, *66*, 33–38. [CrossRef]
90. Rius-Vilarrasa, E.; Bünger, L.; Maltin, C.; Matthews, K.R.; Roehe, R. Evaluation of Video Image Analysis (VIA) technology to predict meat yield of sheep carcasses on-line under UK abattoir conditions. *Meat Sci.* **2009**, *82*, 94–100. [CrossRef]
91. Broom, D.M. Animal welfare: Concepts and measurement. *J. Anim. Sci.* **1991**, *69*, 4167–4175. [CrossRef]
92. Mason, G.; Rushen, J. Sterotypic behaviour in captive animals. In *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare*, 2nd ed.; Mason, G., Rushen, J., Eds.; CABI Publishing: Wallingford, Oxfordshire UK; Boston, MA, USA, 2008; pp. 325–356.
93. Würbel, H.; Bergeron, R.; Cabib, S. The coping hypothesis of stereotypic behaviour. In *Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare*; CABI: Wallingford, Oxfordshire, UK, 2006; pp. 14–15.
94. Schreffler, C.; Hohenboken, W.D. Circadian behaviour, including thermoregulatory activities, in feedlot lambs. *Appl. Anim. Ethol.* **1980**, *6*, 241–246. [CrossRef]
95. Blackshaw, J.K.; Blackshaw, A.W. Heat stress in cattle and the effect of shade on production and behaviour: A review. *Aust. J. Exp. Agric.* **1994**, *34*, 285–295. [CrossRef]
96. Tucker, C.B.; Rogers, A.R.; Schultz, K.E. Effect of solar radiation on dairy cattle behaviour, use of shade and body temperature in a pasture-based system. *Appl. Anim. Behav. Sci.* **2007**, *109*, 141–154. [CrossRef]
97. Wemelsfelder, F.; Lawrence, A.B. Qualitative assessment of animal behaviour as an on-farm welfare-monitoring tool. *Acta Agric. Scand. Sect. A Anim. Sci.* **2001**, *51*, 21–25.
98. Wickham, S.L.; Collins, T.; Barnes, A.L.; Miller, D.W.; Beatty, D.T.; Stockman, C.A.; Blache, D.; Wemelsfelder, F.; Fleming, P.A. Validating the use of Qualitative Behavioural Assessment as a measure of the welfare of sheep during transport. *J. Appl. Anim. Welf. Sci.* **2015**, *18*, 269–286. [CrossRef]
99. Wickham, S.L.; Collins, T.; Barnes, A.L.; Miller, D.W.; Beatty, D.T.; Stockman, C.A.; Blache, D.; Wemelsfelder, F.; Fleming, P.A. Qualitative behavioral assessment of transport-naïve and transport-habituated sheep. *J. Anim. Sci.* **2012**, *90*, 4523–4535. [CrossRef]
100. Stockman, C.A.; McGilchrist, P.; Collins, T.; Barnes, A.L.; Miller, D.W.; Wickham, S.L.; Greenwood, P.L.; Cafe, L.M.; Blache, D.; Wemelsfelder, F.; et al. Qualitative behavioural assessment of cattle pre-slaughter and relationship with cattle temperament and physiological responses to the slaughter process. *Appl. Anim. Behav. Sci.* **2012**, *142*, 125–133. [CrossRef]
101. Stockman, C.A.; Collins, T.; Barnes, A.L.; Miller, D.W.; Wickham, S.L.; Beatty, D.T.; Blache, D.; Wemelsfelder, F.; Fleming, P.A. Flooring and driving conditions during road transport influence the behavioural expression of cattle. *Appl. Anim. Behav. Sci.* **2013**, *143*, 18–30. [CrossRef]
102. Stockman, C.A.; Collins, T.; Barnes, A.L.; Miller, D.W.; Wickham, S.L.; Beatty, D.T.; Blache, D.; Wemelsfelder, F.; Fleming, P.A. Qualitative behavioural assessment of cattle naïve and habituated to road transport. *Anim. Prod. Sci.* **2011**, *51*, 240–249. [CrossRef]
103. European Union. Welfare Quality®: Science and Society Improving Animal Welfare in the Food Quality Chain. Available online: http://www.welfarequality.net/en-us/home/ (accessed on 12 July 2020).
104. Brscic, M.; Wemelsfelder, F.; Tessitore, E.; Gottardo, F.; Cozzi, G.; Van Reenen, C.G. Welfare Assessment: Correlations and Integration between a Qualitative Behavioural Assessment and a Clinical/ Health Protocol Applied in Veal Calves Farms. *Ital. J. Anim. Sci.* **2009**, *8*, 601–603. [CrossRef]
105. Andreasen, S.N.; Wemelsfelder, F.; Sandøe, P.; Forkman, B. The correlation of Qualitative Behavior Assessments with Welfare Quality® protocol outcomes in on-farm welfare assessment of dairy cattle. *Appl. Anim. Behav. Sci.* **2013**, *143*, 9–17. [CrossRef]
106. Rural Area Vet. Available online: https://www.ruralareavet.org/PDF/Physical_Examination.pdf (accessed on 12 July 2020).
107. MAMIC. *Investigation of the Ventilation Efficacy on Livestock Vessels*; Meat and Livestock Australia: North Sydney, NSW, Australia, 2001.
108. MAMIC Pty Ltd. *LIVE.211 Practical Ventilation Measures for Livestock Vessels*; Meat and Livestock Australia Ltd.: North Sydney, NSW, Australia, 2002.
109. Costa, N.; Accioly, J.; Cake, M. *Determining Critical Atmospheric Ammonia Levels for Cattle, Sheep and Goats—A Literature Review*; Meat & Livestock Australia Ltd: North Sydney, Australia, 2003.
110. Broom, D.M.; Johnson, K.G. *Stress and Animal Welfare*, 1st ed.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1993; p. 211.

111. Baldock, N.M.; Sibly, R.M. Effects of handling and transportation on the heart rate and behaviour of sheep. *Appl. Anim. Behav. Sci.* **1990**, *28*, 15–39. [CrossRef]
112. Schmidt, A.; Biau, S.; Möstl, E.; Becker-Birck, M.; Morillon, B.; Aurich, J.; Faure, J.M.; Aurich, C. Changes in cortisol release and heart rate variability in sport horses during long-distance road transport. *Domest. Anim. Endocrinol.* **2010**, *38*, 179–189. [CrossRef]
113. Von Borell, E.; Langbein, J.; Després, G.; Hansen, S.; Leterrier, C.; Marchant-Forde, J.; Marchant-Forde, R.; Minero, M.; Mohr, E.; Prunier, A.; et al. Heart rate variability as a measure of autonomic regulation of cardiac activity for assessing stress and welfare in farm animals—A review. *Physiol. Behav.* **2007**, *92*, 293–316. [CrossRef]
114. Silanikove, N. Effects of heat stress on the welfare of extensively managed domestic ruminants. *Livest. Prod. Sci.* **2000**, *67*, 1–18. [CrossRef]
115. Sjaastad, O.V.; Hove, K.; Sand, O. *Physiology of Domestic Animals*; Scandinavian Veterinary Press: Oslo, Norway, 2003.
116. Piccione, G.; Caola, G. Influence of shearing on the circadian rhythm of body temperature in the sheep. *J. Vet. Med. Ser. A Physiol. Pathol. Clin. Med.* **2003**, *50*, 235–240. [CrossRef]
117. Martinez, A.; Schoenig, S.; Andresen, D.; Warren, S. Ingestible Pill for Heart Rate and Core Temperature Measurement in Cattle. In Proceedings of the 2006 EMBS '06, 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, New York, NY, USA, 30 August–3 September 2006; pp. 3190–3193.
118. Nwe, T.M.; Hori, E.; Manda, M.; Watanabe, S. Significance of catecholamines and cortisol levels in blood during transportation stress in goats. *Small Rumin. Res.* **1996**, *20*, 129–135. [CrossRef]
119. Orihuela, A.; Sanchez-Mejorada, H.; Toledo, M. Effect of short transport during di-oestrus and pro-oestrus on cortisol levels and oestrous behaviour of sheep. *J. Agric. Sci.* **2002**, *138*, 93–96. [CrossRef]
120. Kenny, F.J.; Tarrant, P.V. The physiological and behavioural responses of crossbred Friesian steers to short-haul transport by road. *Livest. Prod. Sci.* **1987**, *17*, 63–75. [CrossRef]
121. Ramin, A.G.; Asri-Rezaie, S.; Mohammadi, D. Influence of the short-term road transport stress on blood parameters in cows. *Med. Wet* **2007**, *63*, 1311–1315.
122. Kent, J.E.; Ewbank, R. The effect of road transportation on the blood constituents and behaviour of calves. I. Six months old. *Br. Vet. J.* **1983**, *139*, 228–235. [CrossRef]
123. Murata, H.; Takahashi, H.; Matsumoto, H. The effects of road transportation on peripheral blood lymphocyte subpopulations, lymphocyte blastogenesis and neutrophil function in calves. *Br. Vet. J.* **1987**, *143*, 166–174. [CrossRef]
124. Cole, D.J.; Roussel, A.J.; Whitney, M.S. Interpreting a bovine CBC: Evaluating the leukon and acute phase proteins. *Vet. Med.* **1997**, *92*, 470–478.
125. Tarrant, P.V. Animal behaviour and environment in the dark-cutting condition. In *Darkcutting in Cattle and Sheep*; Fabiansson, S.U., Shorthose, W.R., Warner, R.D., Eds.; Australian Meat and Livestock Research and Development Corporation: Sydney, Australia, 1989; pp. 8–18.
126. Ferguson, D.M.; Warner, R.D. Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants. *Meat Sci.* **2008**, *80*, 12–19. [CrossRef] [PubMed]
127. McVeigh, J.; Tarrant, P. The breakdown of muscle glycogen during behavioral stress in normal and beta-adrenoceptor blocked young bulls. In *The Problem of Dark-cutting in Beef. Current Topics of Veterinary Medicine and Animal Science*; Hood, D.E., Tarrant, P.V., Eds.; Martinus Niijhoff: The Hague, The Netherlands, 1981; pp. 430–439.
128. Kenny, F.; Tarrant, P. The behavior of young Freisian bulls during social regrouping at an abattoir. Influence of an overhead electrified wire grid. *Appl. Anim. Behav. Sci.* **1987**, *18*, 233. [CrossRef]
129. Warriss, P.D. The handling of cattle pre-slaughter and its effects on carcass and meat quality. *Appl. Anim. Behav. Sci.* **1990**, *28*, 171–186. [CrossRef]
130. Grandin, T. The effect of stress on livestock and meat quality prior to and during slaughter. *Int. J. Study Anim. Probl.* **1980**, *1*, 313.
131. Tennessen, T.; Price, M. Pre-slaughter management and dark cutting in young bulls. *J. Anim. Sci.* **1980**, *51*, 110.
132. Main, D.C.J.; Kent, J.P.; Wemelsfelder, F.; Ofner, E.; Tuyttens, F.A.M. Applications for the methods of on-farm welfare assessment. *Anim. Welf.* **2003**, *12*, 523–528.

133. Jago, J.; Fisher, A.; Le Neindre, P. Animal Welfare and Product Quality. In *Biological Resource Management Connecting Science and Policy*; Balázs, E., Galante, E., Lynch, J., Schepers, J., Toutant, J.-P., Werner, D., Werry, P.A.T.J., Eds.; Springer: Berlin/Heidelberg, Gemany, 2000; pp. 163–171. [CrossRef]
134. Department of Agriculture Water and the Environment. *Exporter Supply Chain Assurance System*; Department of Agriculture, Water and the Environment, Australian Government: Canberra, Australia, 2015.
135. Beatty, D.T.; Barnes, A.L.; Fleming, P.A.; Taylor, E.; Maloney, S.K. Effect of fleece on core and rumen temperature in sheep. *J. Therm. Biol.* **2008**, *33*, 437–443. [CrossRef]
136. Lees, A.M.; Sejian, V.; Lees, J.C.; Sullivan, M.L.; Lisle, A.T.; Gaughan, J.B. Evaluating rumen temperature as an estimate of core body temperature in Angus feedlot cattle during summer. *Int. J. Biometeorol.* **2019**, *63*, 939–947. [CrossRef] [PubMed]
137. Church, J.S.; Cook, N.J.; Schaefer, A.L. Recent applications of infrared thermography for animal welfare and veterinary research: Everything from chicks to elephants. *Proc. Inframation* **2009**, *10*, 215–224.
138. Neethirajan, S. Recent advances in wearable sensors for animal health management. *Sens. Bio. Sens. Res.* **2017**, *12*, 15–29. [CrossRef]
139. Ringgenberg, N.; Bergeron, R.; Devillers, N. Validation of accelerometers to automatically record sow postures and stepping behaviour. *Appl. Anim. Behav. Sci.* **2010**, *128*, 37–44. [CrossRef]
140. Rushen, J.; Chapinal, N.; De Passille, A.M. Automated monitoring of behavioural-based animal welfare indicators. *Anim. Welf.* **2012**, *21*, 339. [CrossRef]
141. Rushen, J.; Boissy, A.; Terlouw, E.M.C.; De Passillé, A.M.B. Opioid peptides and behavioral and physiological responses of dairy cows to social isolation in unfamiliar surroundings. *J. Anim. Sci.* **1999**, *77*, 2918–2924. [CrossRef] [PubMed]
142. Boissy, A.; Manteuffel, G.; Jensen, M.B.; Moe, R.O.; Spruijt, B.; Keeling, L.J.; Winckler, C.; Forkman, B.; Dimitrov, I.; Langbein, J. Assessment of positive emotions in animals to improve their welfare. *Physiol. Behav.* **2007**, *92*, 375–397. [CrossRef]
143. Clements, M.S.; Watt, A.C.; Debono, A.P.; Aziz, S.M.; Banhazi, T.M. Low cost portable environmental monitoring system for livestock buildings. In Proceedings of the 2011 Society for Engineering in Agriculture Conference, Diverse Challenges, Innovative Solutions, Surfers Paradise, QLD, Australia, September 2011; p. 141.