APPENDIX H

Review and Advice on the Impacts of Rail Corridors on Livestock Production

ILLABO TO STOCKINBINGAL RESPONSE TO SUBMISSIONS

INLAND RAIL IS A SUBSIDIARY OF
AUSTRALIAN RAIL TRACK CORPORATION

ARTC–UNE Project: Review and advice on the impacts of rail corridors on livestock production

Report produced for the Australian Rail Track Corporation Inland Rail Project by the University of New England

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March 2022

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Executive Summary

The Australian Government has committed to delivering a significant piece of national transport infrastructure by constructing a high-performance and direct interstate freight rail corridor between Melbourne and Brisbane, via central-west New South Wales (NSW) and Toowoomba in Queensland. Inland Rail is a major national project that will enhance Australia's existing national rail network and serve the interstate freight market. The Inland Rail route traverses rural areas that accommodate a wide extent of agricultural and animal husbandry activities. There is limited research on rail stimuli specifically affecting Australian livestock species; therefore, an interpolative approach has been employed in this review, assessing known impacts of specific rail stimuli (noise, vibration, visual stimulus and physical rail infrastructure) on livestock, extrapolating impacts of similar stimuli on wild sheep or other species of ungulates, and integrating knowledge of behaviour, physiology and animal production systems to make inferences of the impact new rail corridors on livestock production systems, and recommendations for Australian Rail Track Corporation (ARTC) and livestock producers located along the rail corridor.

The report considers potential stressors based on differing phases of the construction and ongoing use of the rail corridor. It discusses the behavioural and physiological impacts of rail stimuli on livestock, and then assesses the impact on subsequent livestock production systems, including grazing, reproduction, lambing and mothering, predation and growth. An important consideration is the change between an initial phase of high novelty when rail traffic is first introduced, and the long term, where rail traffic is a normalised part of the landscape. This change is a process of adaptation, where livestock are habituated to the stimuli of rail traffic, refine their assessments of the risk(s) that rail traffic poses, and modulate their behavioural, physiological and production responses to rail stimuli. During the initial phase of adaptation to a working rail corridor, some acute impacts are likely to occur, and livestock should be allowed to express behavioural responses to the novel stimuli, such as ability to move away from the railway line, to minimise physiological and productivity impacts during this phase. It is recommended that intensive production systems, such as lamb feedlots, which do not permit animals to manage a perceived threat by moving away, be situated at distance from rail traffic. Sheep that are particularly vulnerable to the effects of stress, such as lambing ewes, should not be housed within a proximity to rail traffic, as a risk management measure; however, rail traffic is highly predictable in its behaviour, which will support rapid sheep learning and refinement of their assessment of the threat that rail traffic poses. Thus, the sheep will, in time, become habituated to rail traffic, and so production, physiological and behavioural responses will be reduced. Individual variation in the extent of this habituation is expected, and genetic selection for calm temperaments (i.e. avoiding retaining highly anxious animals) in the livestock herd may be a long-term strategy that could be employed to reduce impacts of rail stimuli, and improve productivity in general, if habituation is insufficient in some animals.

1. Introduction

The Australian Rail Track Corporation (ARTC) is an Australian Government-owned statutory corporation, operating the largest freight rail networks in the nation, spanning 8,500 km across five states. Inland Rail is a 1,700 km freight rail line that will connect Melbourne and Brisbane via regional Victoria, New South Wales and Queensland.

The ARTC commissioned this report in response to stakeholder feedback about the impact of rail traffic and construction on livestock production systems and the welfare of the livestock located in the vicinity of the proposed rail corridors. The impacts of rail traversing the landscape has been well studied in the context of wildlife and environmental considerations; however, research on the impact on livestock welfare and production is less prolific. Along with the changes to the environment, this report considers whether noise, vibration and visual disturbance may have an impact on the welfare and behaviour of livestock, grazing behaviour, parturition and mothering behaviours as well as any flow-on effects on predator–prey interactions. This review aims to analyse the literature in the context of potential impacts on sheep and cattle welfare and production from a new rail network. This work will inform planners and producers in their mitigation or management strategies.

Given the scarcity of research specific to domestic livestock and how rail corridors affect their behaviour, physiology and production systems, this report applies an interpolative approach, drawing on known impacts from research on how the environmental changes expected from rail traffic affect livestock, and discussing potential impacts, which are more speculative, but can be inferred from research on wild sheep and other wild ungulate (e.g. deer, elk, antelope) populations, or from research on the effects of other stressors on domestic sheep.

The report considers potential stressors based on differing phases of the construction and ongoing use of the rail corridor. The first phase of impact on livestock production systems is the construction phase, which incorporates significant human activity, a variety of novel sounds and sights, and substantial unpredictability for nearby livestock. The novelty of this phase means any stress arising can be considered acute (i.e. short-lived, although this descriptor does not imply a particular level of severity). This phase will last weeks to months. The next phase of stress arising from a new rail corridor is a period of adjustment to rail traffic. During this phase, a stressor of new rail traffic will appear 'novel' to the livestock in the vicinity of the rail corridor, which will potentially be another acute stress. Finally, in the long-term, rail traffic will become a 'normalised' part of the landscape. In this phase, livestock may learn to predict the 'actions' of trains and, as they do so, they will adjust their assessment of the threat that rail traffic provides in a process of habituation. The outcomes of this may include: a reduction in stress associated with rail traffic as livestock down-grade their perception of the threat posed (habituation), changes in behaviour as mechanisms to cope with now-expected rail stressors, and/or chronic stress arising from situations where livestock are unable to be habituated or implement coping mechanisms. This report assesses current knowledge of livestock behavioural and physiological responses to the stressors associated with rail corridors, to provide advice on the expected outcomes in individual behaviour and physiology, and their implications for livestock production systems.

2. Rail infrastructure and rail traffic as sources of stress for livestock production systems

Rail infrastructure construction and operational rail traffic provide multiple sources of stress for sheep. Noise stress is the most significant of these, in terms of area of impact, duration of impact and interaction with prey animal perception of threat. Vibration from rail traffic is difficult to distinguish from noise, as this stressor increases as sound from trains increases. The visual stressor of trains passing at high speed, and with a large, brightly coloured appearance, will have limited impact in terms of area or distance from the rail corridor affected. Olfactory changes to the environment from passing rail traffic have potential to interfere with sheep-to-sheep communication. Finally, the physical railway line itself and the construction of stock underpasses may have diverse impacts on sheep and cattle utilisation of, and movement around, affected properties.

2.1. Auditory (Noise) and vibration disruption

Livestock in general, being a prey animal, are sensitive to sounds and tend to respond to sounds by orientating their ears towards the sound source. The majority of studies on livestock sensitivity to sound have focused on sound intensity (loudness) but have not addressed sound frequency (pitch). Pigs, sheep and dogs have similar auditory ranges (Heffner, 1998), and may have similar aversion to high-noise environments. Sheep have the ability to hear in the ultrasound range, a range which humans are unable to perceive (Adamczyk et al., 2015) and this may affect how the sheep respond to machinery that emits noise in this range.

Noise can mask, or inhibit, the perception of sounds (Barber et al., 2010) and has the potential to affect behaviour and communication between animals. This masking is not just related to hearing acuity but also the cognitive perception of auditory stimuli (Gutschalk et al., 2008). While local background ambient farm noise levels may be difficult to quantify, previous measurements by Thorne (2010) have estimated ambient levels at a study farm to be in the range of 34 dBA and 35 dBA. Other characteristics of the sound (continuous or intermittent) contribute to its stressfulness. Sheep have shown ability to adapt to continuous noise, whereas loud, unpredictable, intermittent sounds are often recorded as the most aversive to sheep (Weeks, 2008). Sheep show evidence of an ability to habituate, or acclimatise, to 100 dB intermittent noises (including electrical and diesel engines, jet and propeller planes) within 9 days (Ames and Arehart, 1972). Further to this, Haas and Scrivener (2015) describe the impact of high-speed rail on equines in terms of rapid onset rate, i.e. how quickly a loud noise is produced and is measured in dB per second, resulting in a potential startle effect on animals. The recorded effects of noise on several species of domestic animals is described in Table 1 and demonstrates the knowledge gaps associated in the area of noise and livestock, particularly around habituation. Noises at almost three times that of ambient background farm noise generally result in responses such as increased movement or vigilence behaviours, and increased heart rate, but also shows capacity for habituation, often within several days (Waynert et al., 1999; Van Der Staay et al., 2011). While the impact of high-level (120 dB) noise is known to cause hearing loss in sheep and other animals (Griffiths et al., 1994); more subtle effects of lower level noise, such as masking of communication (Rosa and Koper, 2018), are less well known.

TABLE 1 SUMMARY OF NOISE LEVELS ASSOCIATED WITH EFFECTS ON DOMESTIC ANIMALS

Noise Level *	Duration (if known)	Type of noise	Species	Response	Source
Unknown	3s every 10s during test	White noise	Sheep	Reduced performance in maze test compared to silent	Doyle et al., 2013
34–35 dB		Ambient farm noise A *			
45–55 dB, 2.7 kH	2 seconds repeated 3 times with 2 second intervals	Beep from collar**	Sheep	Increased vigilance behaviour compared to control	Kearton et al., 2019
53.6 dB(A)	Continuous during fattening period	Wind turbine 50 m away	Pigs	Meat quality impacts compared to pigs reared 500 and 1000 m away from the turbine	Karwowska et al., 2015
56.3 dB (A)	12 weeks	Wind turbine 50 m away	Geese	Meat quality reduced when compared with geese reared 460 m away from the turbine	Karwowska et al., 2014
58–68 dB, 6.1 kH	2 seconds repeated 3 times with 2 second intervals	Recording of barking dog**	Sheep	Increase in vigilance, and movement compared to control	Kearton et al., 2019
88	NA	Machine gun fire at a distance of 328m***	Sheep	No visible behavioural changes	Hauser and Wechsler, 2013
85–86 dB(c)	1-minute exposure once per day for 5 days	Recorded handling noise (human shouting and metal clanging)	Cattle	Increased heart rate and movement	Waynert et al., 1999
90 dB	NA	'White noise'	Sheep	Decreased thyroid activity	Ames, 1978
97 dB	NA	Tractor engine sound	Dairy cows	Increased glucose concentration and leukocyte counts in the blood; reduced level of haemoglobin	Broucek et al., 1983
100 dB		'White noise'	Sheep	Increased heart rate, respiration	
	NA	General noise (4 kHz)	Sheep	Increase in number of lambs per ewe	Ames, 1978
105 dB	NA	General noise	Dairy cows	Reduces feed consumption, milk yield, and rate of milk release	Kovalcik and Sottnik, 1971
109dB	NA	Machine gun fire at a distance of 80 m***	Sheep	Moderate avoidance responses with a rapid return to normal behaviour	Hauser and Wechsler, 2013
110 dB	3 minutes once per day for 4 days of testing	Helicopter flyover at 50 m	Goats	No significant change in behaviour or physiological response following habituation (goats)****	van der Staay et al., 2011
	NA	General noise	Dairy cows	Increase in glycaemia, nonesterified fatty acids, creatin; decrease in haemoglobin and thyroxin concentration	Broucek et al., 1983
102–120 dB	NA	General noise	Pigs	Influence on hormonal system	Borg, 1981
128 dB	NA	Machine gun fire at a distance of 16 m***	Sheep	Persistent avoidance responses	Hauser and Wechsler, 2013
120–135 dB	NA	Recorded aircraft noise	Pigs	Increased heart rate	Bond et al., 1963

Noise as a stressor has been shown to reduce the quality of farm animals' lives, with a threshold of approximately 100 dB emerging from the literature as a possible threshold for stress (Chai et al., 2010; De la Fuente et al., 2007; Voslarova et al., 2011). For example, exposure of domestic pigs to repeated noise stress caused changes in neuroendocrine regulations, which are characterised by temporal alterations in the responsiveness of the hypothalamic-pituitary-adrenal (HPA) system (Kanitz et al., 2005). That research concluded that repeated exposure of pigs to noise levels, of 90 dB affected HPA function, resulted in a state of chronic stress that may have negative implications on animal productivity and welfare. Pigs exposed to 90 dB prolonged or intermittent noise increased cortisol, noradrenaline to adrenaline ratio (Otten et al., 2004). Pigs are very sensitive to noise and they should not be exposed to constant or sudden noise; therefore, noise levels above 85 dB must be avoided in buildings where pigs are kept (Fottrell, 2009). Chloupek et al. (2009) determined a significant negative influence of noise exposure (80 and 100 dB) on the stress and fearfulness of broiler chickens, while Campo et al. (2005) exposed laying hens to 90 dB truck, train and aircraft noise for 60 minutes finding increased stress and fear responses.

Evidence for thresholds of noise having an impact on domestic ruminants (sheep, cattle and goats) is more limited. Below 100 dB, sheep and cattle tend to respond behaviourally—movements such as startle reflexes, or moving away from the sound, show a level of aversiveness, and behavioural responses are a first-line defence against greater impacts on animal welfare at a physical or physiological level; however, even at volumes around 80–100 dB, sheep and cattle show an ability to habituate to noise, reducing their behavioural responses, often within 5–10 days.

Distance from the source of the noise can also ameliorate many of the negative behavioural effects. For example, sheep exposed to the sound of a machine gun showed reduced behavioural signs of disturbance the further from the source, and no behavioural signs were observed at a distance of 328 m from the source of the noise (Hauser and Wechsler, 2013). Because behavioural responses to stimuli are the primary reaction of animals, livestock will first seek to move away from any rail stimuli they find aversive, and once the stimuli has decreased (as the train passes), may return. Therefore, impact of noise and vibration is likely to be greatest where livestock are detained in small areas, such as in handling yards or in intensive grazing cells, and lowest where paddock dimensions allow stock to move away from the rail line. The impact of distance from the rail line can also be utilised in management strategies, such that stock that may be most vulnerable to the effects of rail stimuli, such as young lambs and new stock who have not been previously exposed to the rail line or ewes in late gestation, are located in paddocks at a greater distance to the tracks.

Noise created by the train will occur congruently with the vibration as the train approaches, and then passes by the livestock. It is therefore difficult to separate the two potential stressors from each other. Previous studies have reported the effect of vertical vibration in poultry, rodents and livestock during road transport (Randall, 1997; Abeysinghe, 2001; Garcia, 2008; and Doggett, 2018); however, there are no known studies that assess rail vibration on livestock productivity or welfare. It is likely that the intensity and duration of vibration experienced by animals being transported is far greater than that experienced by animals in a paddock near a railway, as the extent of animal behaviour and physiological effects rely on the frequency and magnitude of the vibration (Rabey et al., 2015). The vertical vibration levels experienced by animals being transported is constant for the duration of the trip and is reported to vary from 0.5 Hz to 25 Hz, whereas railway-derived vibrations are generated primarily at the wheel–rail interface (ranging from 2 to 80 Hz depending on track structure and train velocity (Thompson, 2009) and then travel into the soil (i.e. ground–borne vibrations). One important aspect to be considered is that the ground-borne vibrations propagate up to 50 m from rail (Sheng et al., 1990), which is likely below the threshold of effect in livestock.

Ground–borne vibrations also result in ground-borne noise; in that case, rail traffic at night-time brings vibration, noise and light to the landscape, possibly causing stress by disrupting sleep in nearby sheep. The effect of freight train noise and vibration impacting sleep in humans has been investigated (Croy et al., 2013), with sleep fragmentation (Smith et al., 2016) and increased heart rate during sleep observed. While the impact of rail noise and vibration on animal sleep is not known, chronic disturbed sleep can have long-term impacts on neurodegeneration (Owen and Veasey, 2020). Sheep have shown similar sleep characteristics to humans (Schneider et al., 2020) and similar effects of sleep deprivation (Perentos et al., 2016). Interactions between sleep and noise have been studied in laboratory animals, with Rabat (2008) reporting environmental noise resulting in more sleep disturbance in rats than white noise. Stress responses are activated by noise through the autonomic nervous system, with levels even below accepted thresholds showing impacts (Turner et al., 2005) and intermittency of noise having a greater impact (Rabat et al., 2004). Ground covering or vegetation, including groundcover, may help to reduce or diffuse the direct travel of rail vibration through the paddocks or pastures in which the sheep are housed (Thompson, 2009). It may also offer livestock the option of move/rest away from the railway by avoiding the implementation of small paddocks in the proximities of the railway, giving the animals the opportunity to choose whether to experience the negative stimuli (Kearton et al., 2020).

2.2. Visual disruption

There is direct recorded evidence that moving trains, carriages or vehicles per se are an aversive visual stimuli for domestic livestock. There is no evidence that particular colours or materials may be more aversive than others to livestock nor is there any evidence that the increased speed of movement of the perceived threat, object or vehicle is associated with increased stress. At close proximity, in handling yards, moving vehicles can be a distraction to livestock and cause them to baulk. Combined with the auditory and vibration effects when stock are housed close to the rail line, there could also be a tendency for sheep to exhibit startle or escape behaviours and flee when the train is in sight.

Designing yards and races with blocked-out lines of sight of moving vehicles is a long-standing recommendation. Location of yards close to rail corridors may cause problems with ease of handling of sheep, unless they are habituated to passing rail traffic. Tree lines or vegetation may be used to break up the visual impact of the trains as they pass by, creating a 'safe' barrier between the perceived threat and the animal. Over time, habituation to rail traffic will reduce the perceived threat of moving trains, and the accompanying stress.

2.3. Physical rail infrastructure

The physical infrastructure of the rail corridor consists of the railway line (fenced off) and level crossing or underpasses for stock passage across the railway line. The subdivision of paddocks by the rail corridor will reduce paddock size in a fashion similar to a fence line; however, where a simple fence line provides only a physical and visual barrier to free livestock movement across the landscape, a railway line has additional impact in the aversive nature of the rail stimuli (outlined above), but the impacts are not specific to the landscape division, and so are not addressed in greater detail here, but throughout this report. Stock underpasses are a unique characteristic of a railway line, and potentially offer positive and negative impacts to livestock production systems.

Underpass and overpass use by wildlife has been extensively investigated, with a number of known and potential impacts. Impacts of use by domestic animals depend on factors such as drainage, maintenance, and whether the underpass will be designed for animals to travel freely across areas divided by the railway or whether it is only for controlled movement (Casburn and Cumming, 2009).

While there is potential for predators to exploit the use of an underpass by prey animals, there is little evidence for this occurring (Little et al., 2002; Martinig et al., 2020). Underpasses could provide shade and shelter with the correct design, enabling free access and safe moving of livestock from one side of the track to the other (James, 2020).

To mitigate the risk of predators congregating around underpasses it is recommended that monitoring and control measures incorporate stock underpasses as a potential predation risk area. If the animals have free access to the underpass it is important to ensure that there is adequate drainage so that the animals are not traversing persistent stagnant or muddy conditions that may lead to foot rot and other bacterial infections (Abbott and Egerton, 2003). Design of the underpass should also consider options that facilitate the flow of movement through the area, avoiding dark openings, uneven footing, and sharp corners (James, 2020). Inclusion of a light source in the underpass itself, e.g. solar-powered lighting above animal passageway, will encourage animals to move effectively from entrance to exit. Vegetation around the entrance can reduce noise and visual disturbances around the underpass, facilitating stock movement (Casburn and Cumming, 2009).

3. Behavioural and physiological changes

The stimuli of the construction and ongoing traffic of a rail corridor elicit a range of behavioural and physiological effects on livestock, which can change over time. The characteristics of the specific stimuli (outlined in Section 2) need to be assessed in terms of their predictability by the livestock. If a certain level of predictability can be established or 'learned' by the animal, then a process of habituation can occur, whereby the stress that a particular stimulus elicits in the animal is reduced, either by a change in how stressful the animal perceives the stimuli to be, or by coping mechanisms implemented by the livestock in response to the stimuli. Stress responses and coping mechanisms are manifested in behavioural responses to the rail stimuli. If the animal does not reduce its perception of the stressfulness of the stimuli or is not able to implement effective behavioural coping mechanisms, then physiological changes may occur. Temperament is an important consideration when investigating the impact of a novel stressor—reactions can vary between and within species and breeds within species.

3.1. Predictability of rail stimuli

Predictability of a negative stimulus is known to influence the subsequent stress and behavioural responses in animals (Weiss, 1972), with lambs showing a reduced startle response to a sudden event that was signalled with a light cue compared to those that had received an un-signalled event (Greiveldinger et al., 2007). Furthermore, sheep that are able to control their negative experiences have shown reduced stress responses in virtual fencing case studies (Kearton et al., 2020).

Although the timing of trains may not always be predictable or consistent, a passing train could be considered a predictable stimulus due to 1) considerable auditory and visual signalling as the train approaches, and 2) consistency of 'behaviour' from the train.

The ability of an animal to determine the speed of an object via temporal changes has been observed to have a relationship to body size and metabolism, with smaller animals with high metabolisms showing an ability to perceive changes over finer timescales than larger animals (Healy et al., 2013). This ability may also be confounded in the case of vehicles and trains, which can move much more quickly than a natural predator, meaning timing of the sound and visual approach may be unable to be effectively processed by the sheep's sensory and neurological capacities. Therefore, sheep and cattle may be less able than smaller animals to accurately predict when an approaching train will arrive, possibly explaining observations of persistent startle and avoidance behaviours even when these species are accustomed to passing trains; however, due to the lack of literature available, it is difficult to determine whether this sensory capability impacts on the ability of sheep or cattle to effectively acclimate to passing trains.

During the construction phase of the proposal, a variety of human and machine activity will result in low predictability of stimuli but sheep and cattle will quickly learn the constrained spatial impact of the activity. Once the phase of rail traffic adaptation begins, the consistency of train 'behaviour' will increase the speed at which sheep learn the limitations of train movement and potential impact. This is essential for the process of habituation to occur, to minimise the duration of this phase, and for stock to move into the final phase of normalised rail traffic.

Acclimation to the new rail traffic and environment may take some time to occur, with some work finding that sheep adjusting to a new environment had not fully acclimatised to their new surroundings within a 9-week study period (Fordham et al., 1991). The low predictability of activity during the construction phase may result in sheep avoiding the area close to the activity during this phase. High predictability during the adaptation to rail traffic phase will shorten this phase but to reduce the incidence of a startle response in sheep, and promote neutral interactions with rail traffic, grazing sheep within sight and sound of rail traffic, but not containing them close to the track is recommended in the initial weeks of Phases 1 and 2. Predictability does not only rely on a temporal pattern of rail traffic but also on low-impact signalling of a more stressful stimulus, for example, an increasing volume of noise from an approaching train before it passes close to stock. There is insufficient information in the literature to make a firm recommendation on a distance at which a startle response is less likely to occur but allowing stock freedom to respond behaviourally (see section 3.3), for example with flight, will aid in the process of habituation.

3.2. Habituation

Habituation occurs when animals are exposed to the same stimuli repeatedly and eventually stop responding to that stimulus. Suddenness, unpredictability and unfamiliarity combined serve to enhance physiological (e.g. heart rate) and behavioural (e.g. startle or flight) responses to a stimulus (e.g. a passing train), while familiarity can serve to modulate the behavioural response to a sudden event (Désiré et al., 2006). Sheep have also shown reduced responses over subsequent exposures to sonic booms, suggesting that sheep can become accustomed to loud noises, although some sheep still showed avoidance behaviours even after repeated exposure (Rylander et al., 1974). A strong habituation effect was observed in work by Rylander et al. (1974) investigating behavioural responses to sonic boom and subsonic flight. Cattle showed slight startle responses to the boom effect, returning to neutral within 10 seconds. Sheep showed reduced reactions to flyovers over time but were not exposed to sonic boom so could not be compared to cattle. Ducks showed interrupted behaviour upon exposure to the boom effect; however, avian responses varied greatly (Rylander et al., 1974).

Such physiological and behavioural responses can be energetically expensive and so, through the learning process, habituation allows animals to refine their assessment of the threat a stimulus, such as a passing train, poses and only respond as necessary. The speed of habituation can be highly variable, depending on the temperament of the animals, the frequency of exposure to the stimuli, the predictability of the stimuli, and the learned consequences of the experiences the animals have with the stimuli.

Additionally, risk-disturbance theory may play a role here. This theory suggests that some areas may be avoided due to human disturbance but can be regulated by the attractiveness of the resources (Lowrey and Longshore, 2017); therefore, while grazing animals may initially avoid grazing close to human activity, if the grazed area is comparatively attractive, they may show a higher tolerance to this activity.

Throughout this report there is acknowledgment that habituation may occur and therefore mitigation strategies that may reduce impact during the initial exposure to rail stimuli will potentially become obsolete over time.

3.3. Behavioural responses of individuals

A behavioural response to a stimuli is the animal's first line of defence against stress. A well-understood example is a flight-behaviour response to a perceived threat. Other changes in behaviour that could be expected from rail stimuli (at least initially, and potentially long term) include increased vigilance (visually checking for and assessing potential threats), startle and flight behaviours, and changed use of the landscape close to the railway line, among others. These are discussed in detail later in this report. A change in animal behaviour alone, from rail stimuli, is not an indication of increased stress per se but may be an animal seeking to avoid a potential negative impact from that stimuli; however, changes in behaviour can have negative impacts, for example, if increased vigilance reduces grazing time. Alerting distance can also vary across species and environments to novel stimuli; polar bears, for example, detected the approach of a snowmobile over 5 km away but avoidance responses varied significantly (Andersen and Aars, 2008). Behavioural responses to rail stimuli will change over time as animals become habituated to stimuli, learning about how trains 'behave' and refine their assessment of the threats they pose.

Behavioural responses to the introduction of a rail line in their environment will vary depending on the stage of development, human activity in the area, and time for habituation to occur. It is well known that many wildlife species change their behaviour in response to human-altered landscapes but it is less evident how this may impact livestock given their management already involves a certain degree of human disturbance.

Livestock that are habituated to handling show reduced stress responses (Tamioso et al., 2017; De Palo et al., 2018). Habituation results in a reduction of the magnitude of Hypothalamic-Pituitary-Adrenal (HPA) axis activation; however, the degree of this response can be impacted by other factors, such as predictability, in which the more predictable the stimulus the more rapidly an animal will habituate. An animal may become habituated to other stimuli in addition to the original stimulus, known as generalisation (Grissom and Bhatnagar, 2009)). This generalisation may have positive implications for production, such as reduced reactivity to novel stressors; conversely, there may be a reduction in predator awareness and vigilance behaviours.

The behaviour of other ruminants than domestic sheep or cattle, such as wild elk and pronghorn, in response to road traffic noise has shown reduced responsiveness (vigilance, flight, travelling and defensive behaviours) with increasing vehicle traffic (Brown et al., 2012). It was suggested by Brown et al. (2012) that these animals could not afford to maintain responsiveness to the most frequent stimuli and, while this might be beneficial in terms of energy investment, detection of predator activity and other cues may be impacted.

Behavioural reactivity to stimuli can be impacted by genetic temperament, breed, sex and age in sheep (Dodd et al., 2012), and there is considerable within-flock individual variation. As the stock habituate to the rail stimuli, their average flight distance from trains will reduce but there may be some proportion of the flock that will always maintain a large flight distance, regardless of their experience. As herd animals, cattle to some extent, and sheep to a large extent, are allomimetic, meaning that the behaviour of one animal can cause a similar response in the rest of the group. A single nervous, highly reactive animal that startles in response to train stimuli can therefore cause disturbance in the rest of the mob. These highly reactive animals are potentially at greater risk for long-term effects on production (e.g. growth or reproduction, see Section 4). Cattle can respond to stress in conspecifics and become more fearful (Boissy et al., 1998).

There is no quantified evidence to support a recommendation on a particular distance necessary to reduce behavioural impacts of rail traffic on stock. Allowing stock freedom to express behavioural responses during the adaptation phase will be important as a coping mechanism to prevent physiological impacts of stressful stimuli, during the process of habituation. While reduced behavioural responses to rail traffic over time are a good indication of habituation, it is important to consider that lack of reactivity does not mean absence of impact. An example might be a reduction in flight responses as sheep perception of the threat posed by rail traffic is downgraded but if trains disturb animal sleep cycles, this could have a cognitive, psychological or physiological impact, without eliciting a behavioural response. Monitoring of impacts on production is recommended (Section 4).

3.4. Physiological responses (acute, chronic, adaptation)

Until habituation occurs, if behavioural responses to rail traffic are insufficient to reduce the impact of the rail stimuli on sheep, then physiological responses may result, with acute, chronic and adaptive impact. These physiological responses are not necessarily negative: for example, an acute flush of adrenaline, increasing blood pressure and heart rate, can stimulate a flight behavioural response, which reduces the risk of a more serious physical impact; however, if physiological responses to stimuli occur frequently and act for long periods, then animal health, welfare and productivity can be affected.

While the conditions of freight rail specifically have not yet been evaluated in terms of their impact on sheep and cattle physiology, it is possible to use known impacts on other species to make predictions about likely impacts of rail tracks on domestic stock.

Increased heart rate during sleep (Croy et al., 2013) responses to freight train noise and vibration have been observed in humans; however, to date, no work has been done to investigate effects of rail disturbance on heart rate in sheep. Despite this lack of specific literature, much is known about the impact of various stressors on the health and physiology of sheep. An acute stressor, such as a barking dog, will elicit a plasma cortisol response; however, this response is multimodal and can vary in lactating and non-lactating sheep (Cook, 1997). Similarly, repeated stress associated with handling and isolation has been shown to have longer term impacts on immunological function in young lambs (Coppinger et al., 1991). When considering environmental stressors, the impact of disrupted rest and isolation resulting in chronic stress shows physiological impacts of HPA-axis dysregulation and judgement bias (Verbeek et al., 2019) and learning deficits (Destrez et al., 2013) in sheep.

Physiological impacts of stressors occur when animals are not able to either habituate to the stimuli (so that it is no longer stressful) or adjust their behaviour so that they can cope with a stressful stimulus. Although some acute physiological impacts are fleeting and are stimulants or associates to behavioural responses, for example increased heart rates associated with flight responses, chronic impacts of rail traffic stimuli on sheep physiology will indicate that the stock are not being offered freedom to respond to the stressful stimuli with a behavioural response. An example could be the freedom to move further away from the railway line to a location where the auditory stimuli and perceived threat of the visual stimuli are lessened. Any physiological impacts will usually become most readily evident in reduced growth or reproduction. More subtle signs of physiological responses, such as increased heart rate or impaired immune function may not be readily detected in grazed stock. Monitoring of sheep for productivity impacts, and ability of the sheep to implement behavioural adaptations so that physiological impacts do not occur, will be essential. Promoting habituation and allowing behaviour responses by initially grazing sheep where they can see and hear trains, but are not fenced close to the railway line, is recommended.

4. Impacts on sheep and cattle production

4.1. Grazing and foraging behaviour

The main potential impacts of a rail corridor on grazing relate to 1) the time spent grazing, and whether the perception of rail traffic as a threat may increase vigilance behaviours at the expense of grazing time when they are located close to the rail corridor, and 2) paddock utilisation, and whether stock will spend less time and therefore utilisation of those parts of the paddock close to the rail corridor.

Foraging and vigilance are mutually exclusive activities and, if vigilance is increased, grazing time may decrease (Lian et al., 2007). When stock perceive a risk or threat of predation, this affects their behavioural patterns and time spent grazing, as the time allocated to maintaining vigilance is increased (Hopewell et al., 2005). The individual behavioural response to a stimulus affects how quickly that individual returns to grazing: The magnitude of a startle response produced by a blast of air to the face of sheep was correlated with the time taken to return to eating following the startle (Salvin et al., 2020). Time spent in vigilance behaviours appears to be directly related to the frequency of traffic passage (Lian et al., 2011). Helicopter traffic in the Grand Canyon national park may be considered analogous to rail traffic in its frequency, volume and duration of auditory impact. Within a 3–5 minute feeding bout, helicopter disruption was found to reduce foraging time by 50 per cent for sheep within 50–200 m of a flying helicopter, and 10–30 per cent for sheep within 100–450 m of a helicopter (Stockwell et al., 1991). Sheep more than 450 m away from flying helicopters were not disturbed during their feeding bouts (Stockwell et al., 1991). Although this indicates that within an individual, short-term feeding bout, loud traffic noise can cause a disturbance in grazing behaviour, the proportion of total active time that sheep are likely to spend on vigilance behaviours, even in high-risk settings is low, 1–2 per cent of active time, compared to 60–80 per cent of active time spent grazing, on average (Hopewell et al., 2005; Dumont and Boissy, 2000). Bouts of induced vigilance (responding to an auditory or visual stimuli) are usually short lived (seconds), and so the cost to grazing time of greater levels of induced vigilance is expected to be low (Mcdougall and Ruckstuhl, 2018).

There is little research on the effect of human disturbance and traffic on paddock utilisation in domesticated ruminants; however, suggestions of the impact on the use of land close to rail corridors for grazing can be inferred from observations of wild ungulates. Proximity to a highway (between 0 and > 500 m distance) had only a minor effect on the amount of time that Tibetan antelopes spent foraging, although bouts of foraging were shorter when the antelope were closer to the highway, most likely due to interruptions to express vigilance behaviours (Lian et al., 2011). Wild Bighorn sheep avoid heavy road traffic (Papouchis et al., 2001) and prefer to graze away from roads in their habitat; however, those sheep whose habitats were located in areas with heavy use roads, showed clear signs of habituation and, in fact, used road corridors more frequently than areas of their habitat away from road corridors (Papouchis et al., 2001).

When considering the effects of road corridors on wild ungulate grazing and vigilance behaviours, it is important to consider that road corridors may also bring a change in the environment in wilderness areas: road corridors are likely to be cleared of trees, whereas areas distant from a traffic corridor, but still utilised by wild ungulates, may be wooded. Therefore, wild ungulates may have heightened vigilance as a result of the perception of increased risk in open spaces. In the commercial sheep and cattle production systems of Central NSW and Victoria, domesticated stock will be habituated to grazing open grasslands, pastures and forage crops, and wooded areas will be relatively light in tree density. The implication is that evidence of road proximity affecting grazing behaviours in wild sheep breeds and other wild ungulates may be unrelated to traffic noise, and not relevant to domestic sheep and cattle production systems.

The short-lived duration of vigilance behaviours suggests that once habituation has occurred, it is unlikely that rail traffic will cause an increase in vigilance behaviours to the extent that they reduce grazing time. During the period of habituation after introduction of the rail corridor, while stock are expressing increased vigilance while they are learning and assessing the threat that passing trains pose, it is possible that grazing time may be reduced, as animals allocate more time to vigilance. The extent of this increased vigilance, however, combined with the frequency of expected rail traffic passage to stimulate vigilance behaviour, is unlikely to impede grazing time to the extent that productivity is affected.

Within a flock or herd, variation in fearfulness/boldness is expected. These animals may perceive, or respond differently to, rail traffic and rail traffic may increase the anxiety of innately fearful individuals more than their bold flock-mates. Shy sheep have previously been shown to have a smaller range, and more restricted utilisation of dispersed grazing areas, even in a fairly homogenous grazing environment (Sibbald et al., 2009). Selection for temperament may be one way to improve the habituation of highly anxious flocks to a rail corridor in the long-term, but would also likely bring other productivity benefits in growth, pasture utilisation, weaning rates and meat quality.

4.2. Reproduction, lambing/calving and mothering

Fertility is known to respond to chronic and acute stressors, with impacts on ovulation rate, abortions and dystocia. Because the hypothalamus and pituitary gland are involved in reproduction and stress response, one may think that reproductive functions can be influenced by stress. In males and females, reproduction is mediated by the gonadotrophin-releasing hormone (GnRH) produced from the hypothalamus that stimulates the anterior pituitary to release luteinising hormone (LH); this then acts on the ovaries and testes to produce oestrogen or testosterone, respectively (Dwyer, 2008). In this sense, oestrus can be delayed or blocked due to its effect on the preovulatory surge of LH (Ehnert & Moberg, 1991). Similarly, stress may also reduce the expression of oestrus behaviour as well as libido in rams (Dobson et al., 2012).

Following a successful reproduction, the greatest cause of lamb losses is the starvation-mismothering complex (Refshauge et al., 2016), a well-characterised problem in sheep production systems. Rail traffic poses a risk for mismothering if ewes exhibit startle responses to passing trains, causing separation from their lambs, or if sound or olfactory stimuli from trains interferes with ewe-lamb bonding.

Sheep reactivity (temperament) is known to consistently affect weaning rates in sheep, with calm ewes weaning 10–17 per cent more lambs than nervous ewes (van Lier et al., 2017). Nervous ewes have a lower ovulation rate, resulting in fewer multiple pregnancies than calm ewes (van Lier et al., 2017). Although temperament is heritable, a stressful environment that results in higher than expected levels of anxiety in breeding ewes could result in a similar physiological response that could impact on reproduction rates.

Sound stress, specifically, has shown equivocal relationships with ovulation rate, with continuous sound at high volumes (100 dB) possibly showing an increase in ovulation rate (Ames, 1974). This result has not been replicated elsewhere. It is not possible to conclude whether rail noise will have a deleterious effect on sheep reproduction or lambing rates.

Olfactory recognition is an important aspect of social and maternal behaviour in sheep. The role of olfaction in bonding between ewes and lambs is well established, with ewes developing selective olfactory memory for their lambs shortly following birth (Mora-Medina et al., 2016), and interference from other ewes can inhibit this bond. Whether external olfactory stimuli can also interfere with this process is unknown and bears further investigation; however, it is known that, following bonding, if olfaction is inhibited, an ewe may reject her lamb despite the presence of visual and auditory stimuli (Numan and Insel, 2006). Due to the important role of olfactory stimuli in maternal behaviour, particularly suckling (Alexander and Stevens, 1985), potential impacts of olfactory stimuli cannot be ruled out.

Vocal recognition of the mother plays an important role in the maintenance of the ewe–lamb contact. Within days after birth most lambs can find their mother when hidden behind a canvas (Shillito, 1975; Nowak, 1991). The acoustic features of a lambs' bleat are an important part of the social bond between ewes and their lambs; when this cue is deficient, there is a negative impact on the maternal response (Morton et al., 2018). Ewes are able to discriminate between the bleats of their own lambs and those of an alien lamb 24 hours following birth (Sèbe et al., 2007), and lambs able to discern the acoustic signature of their mother at 48 hours old (Sèbe et al., 2007). Based on the lack of literature in this area, no conclusion can be made about whether noise disturbance may play a role in rates of mismothering in a population. Cattle also have highly developed vocal recognition systems and mothers and calves can recognise each other with high frequency calls from 10 days of age (Padilla de la Torre and McElligott, 2017). While little is known about the importance of other types of vocalisation in cattle it is hypothesised that it may be important for other interactions such as mating and dominance status.

The impact of rail traffic on reproduction is mediated by perception of the threat that trains pose. Habituation to rail traffic will reduce the perceived threat and the accompanying stress. Genetic selection in the flock or herd for consistent calm temperament will reduce the perception of the scale of the threat and promote habituation.

As potential rail traffic interference with maternal bonding cannot be ruled out, it is recommended that young lambs and lambing ewes be situated at a distance from the rail line which would reduce interference from rail stimuli to ambient levels. There is no existing literature that would suggest the distance at which an impact may be evident, along with the type of stimuli that may be implicated.

4.3. Predation

Predation is a significant cause of lamb losses in Australian sheep production systems, accounting for ~7 per cent of neonatal lamb deaths (Refshauge et al., 2016). The impact of a rail line on predation behaviour has not been extensively studied in livestock; however, there is a large body of research looking at predator–prey interactions in wildlife impacted by roadways and rail lines. The presence of human activity during the construction phase may reduce predation risk as domestic animals may perceive the humans the lesser risk (Muhly et al., 2010). Although no research has examined the effect of underpasses on lamb losses to predation, stock underpasses on rail lines may provide new sources of cover for lambs and ewes but, similarly, may provide cover to predators, such as foxes. In areas with predation risk by wolves in the US, cattle responded to the presence of these predators by grazing closer to areas of human activity (Muhly et al., 2010).

4.4. Growth

While the impact of rail noise has not yet been studied, an impact of varying levels of road noise has been found on behaviour and productivity in lambs (Quaranta et al., 2002). Most research on the effects of noise on sheep productivity has tested constant noise, which will be quite different in characteristic to the intermittent noise of rail freight. When lambs were exposed to the noise of a motorway (75–95 dB, frequency 100–6,300 Hz), for long periods (8 hours/day for 42 days), growth rate and feed efficiency reduced by 15 per cent, compared to animals in a control group (Quaranta *et* al., 2002). In that research, the sheep did not show signs of adapting to the noise, rather, effects were cumulative, so that reductions in live weight gain were greater in the last two weeks of the experiment than in the first two weeks of the experiment. Dry matter intake was not affected, which indicates that the reduced performance was affected by increased stress and maintenance energy requirements of the sheep exposed to the noise; however, this contrasts with no effect of similar noise (54–95 dB, with a constant, high frequency of 2,000 Hz) on growth performance (Quaranta et al., 2002), suggesting that the specific characteristics of the noise, in particular the frequency band and range, may be more important than the volume, when predicting impact on productivity.

Promoting habituation and allowing performance of behavioural responses during the adaptation phase will be important to mitigating the effects of rail stimuli on growth. In research on the effects of noise on lamb growth, subject animals have typically been penned, and unable to change their behaviour to avoid or lessen the impact, for example, by moving away. If grazing animals are allowed space to move away from rail traffic then the impact of rail noise on growth will be negated, and perhaps removed entirely, in all but the most anxious of animals. The location of intensive facilities, however, such as weaning yards or feedlots close to railway lines and rail traffic, will restrict the ability of stock held in those facilities to implement behavioural adaptations to lessen the stressfulness of the rail stimuli, and physiological and productivity impacts will be more likely. It is strongly recommended that feedlots (which already place a degree of stress on the animals) are not located close to railway lines or rail traffic. Genetic selection for consistent, calm temperament will reduce the perception of the scale of the threat posed by rail stimuli and promote habituation, leading to reduced impacts on growth.

5. Conceptual model development

While short-term stressors and challenges are normal aspects of life, the ability of an animal to cope with these is impacted by the type of stress event, the duration of the stress event, and the combined impact of stressors, known as the allostatic load (Edes et al., 2018). This is an important aspect when considering the impact of rail construction, noise, vibration and other factors. While each of these impacts may be minimal, and largely mitigated through habituation, when combined with other stressors encountered through normal farm activities, such as mustering, weaning, shearing and other husbandry practices, it may contribute to the allostatic load experienced by the animals (Figure 1).

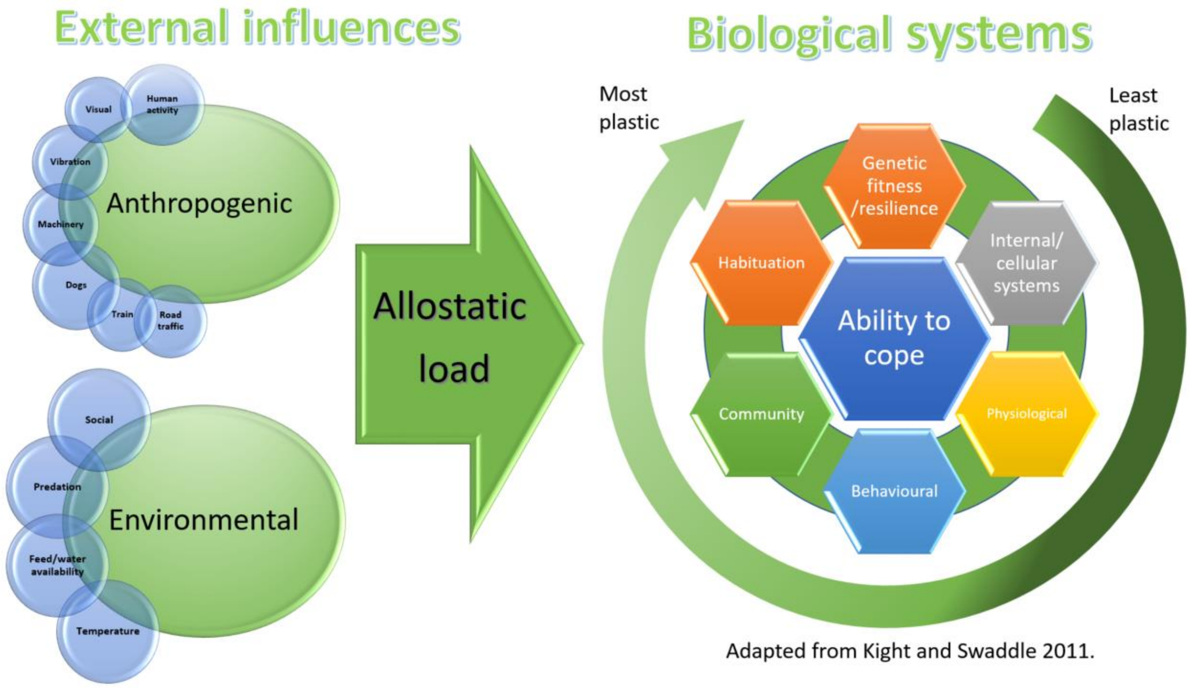

FIGURE 1 DIAGRAM ADAPTED FROM KIGHT AND SWADDLE (2011) DEMONSTRATING THE IMPACTS OF ANTHROPOGENIC AND ENVIRONMENTAL INFLUENCES ON ALLOSTATIC LOAD AND THE ANIMAL'S ABILITY TO COPE.

Once the stressors have been identified, we can then try to predict the level of response and duration of the stressors on the animal (Figure 2). For example, shearing elicits a greater stress response than intermittent rail noise and both of these stressors may only occur for a fraction of the time compared to a consistent low-level noise (Figure 2).

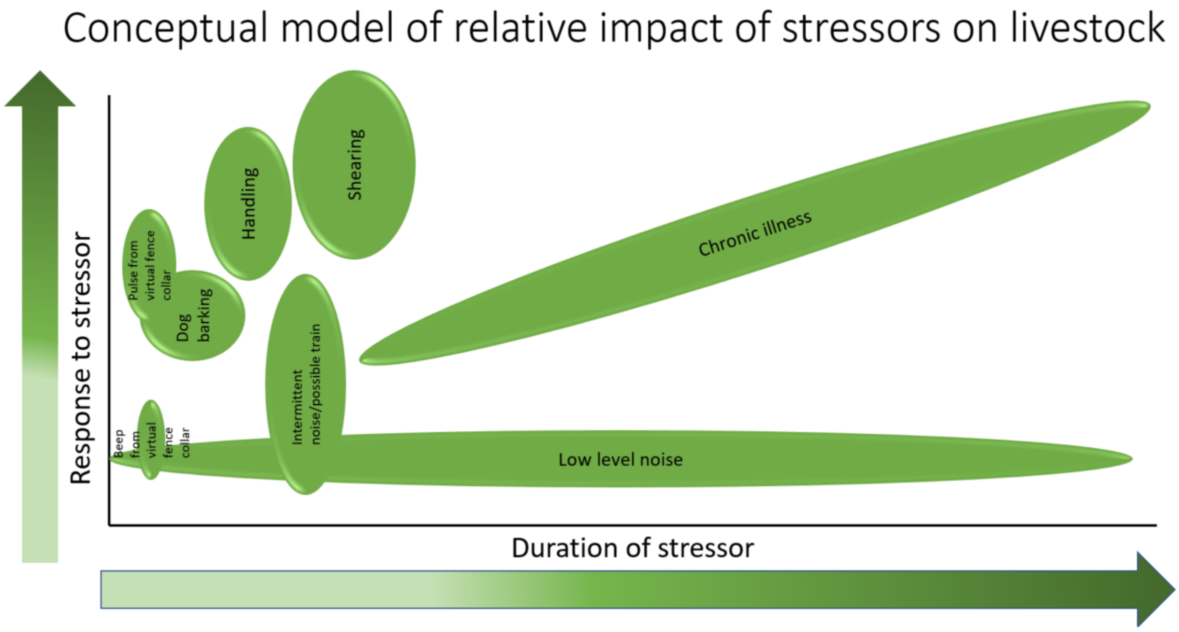

FIGURE 2 A CONCEPTUAL MODEL OF THE RELATIVE IMPACT OF CERTAIN STRESSORS ON LIVESTOCK IN RELATION TO THE LEVEL AND DURATION OF STRESSOR.

A conceptual framework for understanding how noise stimuli impacts on wildlife has been described in Francis and Barber (2013); however, at present, is not applicable to domestic livestock. This framework describes the impact of the types of anthropogenic noise, from sudden or erratic through to more frequent sounds with spectral overlap, within the context of the biological impacts described in the literature. The relative lack of comprehensive literature on the impact of anthropogenic noise on domestic animals limits an adaptation of this framework for this purpose currently. We have proposed the above conceptual models outlining factors likely to impact on the ability of an animal to cope with environmental stressors, including noise, in Figure 1 and Figure 2. These figures aim to provide context for the likely/possible impact, given the limited data available. To quantify the impacts of these stressors will require empirical data that is does not currently exist.

6. Conclusions

This review has assessed the available literature across multiple species to provide an understanding of potential impacts on livestock situated close to the proposed rail corridor during multiple phases of construction and beyond. Although the literature testing specific effects of noise, vibration and visual stimuli similar to those presented by rail traffic on domestic sheep and cattle is scant, supplementary information on wild ungulates, and application of fundamental knowledge of sheep and cattle behavioural and physiological responses to stressors, has been used to estimate an impact of a new rail freight corridor on grazed sheep and cattle production systems.

The main areas of focus that were found to be relevant in the available literature included, in no particular order of importance, noise and vibration, visual, behavioural and physiological changes, potential impacts on livestock production, anthropogenic disturbance on livestock, and predator behaviour.

Most research on noise or road traffic stimuli considers either acute/short-term or more-or-less continuous stimuli, neither of which fits the pattern of stimuli provided by freight trains passing at regular intervals throughout the day. There is evidence from a range of domestic livestock species to show that a threshold of approximately 100 dB could be considered the point at which noise stimuli moves from a moderately aversive stimulus to a stressor that animals are compelled to avoid. With most rail noise presenting vibration impacts <100 dB at 15 m, this suggests that the effect on sheep and cattle is likely to be limited.

The main response of sheep and cattle to rail freight stimuli is likely to be movement away from the passing train. The flight distance to which an animal will relocate, and initial distance from a train that will prompt relocation, is likely to be highly individualistic and dependent on temperament, but in herd animals such as sheep and cattle, may be affected by the behaviour of their conspecifics. The literature on livestock responses to noise indicates that at distances where rail noise is <90 dB, behavioural responses for many animals may be minor. For most animals, the behavioural response of moving away from a train as it passes will prevent higher order impacts on physiology and productivity from occurring. In production environments where animals are prevented from moving away to a distance at which they feel the threat is suitably diminished, such as feedlots, stockyards, or intensive cell grazing systems, welfare may be impacted so that there are physiological responses, or productivity impacts. For some animals, flight responses could have deleterious effects: lambing and recently lambed ewes are at particular risk, and it is recommended that lambing paddocks are not close to the rail tracks. While impacts of noise masking on animal communication are not investigated in the literature, it should not be excluded as a potential impact.

Habituation will play a major role in reducing stress and behavioural responses over time, particularly when human activity around construction reduces and the rail activity becomes more predictable. Increasing sound from approaching trains will enable animals to predict that a train is soon to pass, which will reduce the stress associated. Learning will refine animal assessment of the threat posed by passing rail freight, which will modulate behavioural responses over time. Part of this habituation involves learning that the threat has passed, and that it is safe to return to an area close to the rail line. It is not possible to predict how long a herd of sheep or cattle will take to habituate to rail freight traffic. There is some evidence that movement responses to noise stimuli reduce after five exposures but it is likely that some animals will always exhibit a temporary flight response when they are close (within 20–50 m) to passing rail traffic.

7. Recommendations

Based on our findings from this review we have listed below considerations that could be explored further:

- placement of yards and areas with high stocking density away from the track may help to reduce contagious startle responses
- housing ewes/cows and newborn lambs/calves in paddocks away from the track until bonding has been well established will mitigate impact of noise and auditory stimuli interfering with bonding (at least 2 days for sheep, at least 10 days for cattle)
- stockpersons and farm managers to be aware when working with livestock close to rail corridor of potential accumulation of multiple stressors and the allostatic load on the animals (as described throughout this review but also outlined in Figure 1)
- awareness of the potential impact of noise above ambient levels as a consideration by stockpersons and farm managers
- where animals are housed with sufficiently low anthropogenic noise during critical periods, such as during lambing and calving, there is likely to be a reduced impact of noise masking communication between animals
- periodic exposure is likely to increase habituation of the animals
- vegetation would likely reduce the impact of visual and auditory stimuli.

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