The need for speed: Timely prevention of the dispersal of noxious weeds in relief fodder using efficient sampling procedures

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ABSTRACT

Invasive and noxious weeds are well known as a pervasive problem, imposing significant economic burdens on all areas of agriculture. Whilst there are multiple possible pathways of weed dispersal in this industry, of particular interest to this discussion is the unintended dispersal of weed seeds within fodder. During periods of drought or following natural disasters such as wild fire or flood, there arises the urgent need for 'relief' fodder to ensure survival and recovery of livestock. In emergency situations, relief fodder may be sourced from widely dispersed geographic regions, and some of these regions may be invaded by an extensive variety of weeds that are both exotic and detrimental to the intended destination for the fodder. Pasture hay is a common source of relief fodder and it typically consists of a mixture of grassy and broadleaf species that may include noxious weeds. When required urgently, pasture hay for relief fodder can be cut, baled, and transported over long distances in a short period of time, with little opportunity for prebaling inspection. It appears that, at the present time, there has been little effort towards rapid testing of bales, post-baling, for the presence of noxious weeds, as a measure to prevent dispersal of seeds. Published studies have relied on the analysis of relatively small numbers of bales, tested to destruction, in order to reveal seed species for identification and enumeration. The development of faster, more reliable, and non-destructive sampling methods is essential to increase the fodder industry's capacity to prevent the dispersal of noxious weeds to previously unaffected locales.

Keywords: emergency relief fodder, invasive weed seed dispersal, non-destructive bale testing, rapid fodder quality assessment.

1.1 Introduction

The economic damage caused by weeds is considerable. Costs to agricultural production in many countries amounts to millions, or billions, of dollars per annum (Auld and Tisdell, 1986; Auld et al., 1987; Bhowmik, 2005), with most of this cost being borne by growers (Sinden et al., 2005). A complete avoidance of economic impact due to weeds is unlikely to be achieved; however it may be possible to develop tools, techniques, and methods to minimise the cost.

In addition to the economic effects of weeds on primary production, over recent years there have been growing concerns about long-term changes in weather patterns and how these changes will influence future agricultural productivity (Moore and Ghahramani, 2013). In Australia, adverse weather events of drought, fire, and flood are expected to become more frequent in the future (CSIRO, 2009). During extended periods of low rainfall, or following large floods or fires, many livestock producers may be affected by a shortage of pasture for grazing (Moore and Ghahramani, 2013). Solutions to this problem include reducing herd numbers, but this is a severe solution for the grazier who wishes to maintain their livelihood in the long-term. A less drastic solution is to provide short-term access to feed, and a system of fodder relief programs have been developed, whereby producers in regions that are unaffected by natural disasters are able to supply those in need with feed for livestock. Indeed, provisioning fodder is a day-to-day requirement of modern agricultural practice; consequently, the scale of the fodder industry is enormous in volume and significant in economic value (Martin, 2009; DAF, 2010). Many primary producers rely on the ability to not only provision fodder for their own livestock, but also to trade it. In Australia, for example, this has resulted in the development over the past 20 years of an industry in which hundreds of tonnes of fodder is traded each year, at a value in excess of AUD $1.5 billion (Martin, 2009). However, the productivity of this sector is variable from year to year and heavily dependent on prevailing climatic conditions.

In the case of natural disasters, where normal stores of provisioning fodder are inadequate for emergency use, one readily available source for relief fodder is pasture hay. This commodity may be defined as dried and preserved whole plants that have been cut and baled from a mixed sward of grassy and broad-leaved plant species growing in a paddock that is usually grazed by livestock (Suttie, 2000). Of particular interest here is that, in emergency situtations, this pasture hay relief fodder may be sourced from widely dispersed geographic regions and it is common that some of these regions have an extensive variety of weeds that are exotic to the destination for the fodder.

It is well known that invasive and noxious weeds are a pervasive problem, which impose significant economic burdens on all areas of agriculture. Weeds are inextricably intertwined with human activity and agricultural activities are a major pathway for the dispersal of weeds (Howard et al., 1991; Hodkinson and Thomson, 1997; Thill and Mallory-Smith, 1997; Bhowmik, 2005; Groves et al., 2005; Benvenuti, 2007; Radosevich et al., 2007; Sindel et al., 2009). In this context, however, not all weed species have equally significant impacts. Invasive and noxious species are two categories that may have particularly serious effects on the livelihood of primary producers. Invasive weeds possess traits that allow them to become established within an ecosystem, after which they can successfully initiate new infestations, with or without human intervention, in places at a significant distance (>100 m) from the original site of establishment (Richardson et al., 2000). Invasive species may cause significant problems for primary producers particularly if they are difficult to distinguish from other non-weedy species that normally occur in an agricultural setting (Barrett, 1983). The term ‘noxious’ is a legal definition reserved for weed species that have especially severe impacts on agricultural or natural systems (Sheley et al., 1996; Arcioni, 2004), and as a consequence, control or eradication of noxious weed infestations is usually mandated by legislation (Sheley et al., 1996; Arcioni, 2004). In addition, commodities that are contaminated with the seeds or propagules of noxious species may not be legally sold or traded (DPI, 2009). Despite this legislation, there is evidence that noxious weeds have unwittingly been traded in common agricultural commodities, and of relevance to this review, we note that bales of fodder have been identifed as one important distribution vector (Thomas et al., 1984; Erklenz et al., 1990; Conn et al., 2010).

However, it has been shown that efforts to control weeds, notwithstanding the initial cost, time, and effort, can yield significant economic gains (Vere et al., 1997; Brennan, 2002; Vere et al., 2004;

Cacho, 2004; National Weed Spread Prevention Committee, 2006). Expressed as a benefit-to-cost ratio, prevention of weed introductions by quarantine is the most effective measure (38:1) (National Weed Spread Prevention Committee, 2006). If, for unavoidable reasons, this aim cannot be achieved, there are alternative measures, albeit with less cost benefit return, in the form of eradication of new infestations (9:1) and containment of existing weed infestations (3:1) (Cacho, 2004; National Weed Spread Prevention Committee, 2006). These concerns apply at all levels of agriculture from traversing national borders to spread between state and local borders. It is therefore evident that whilst weeds in agriculture are recognised as a significant and on-going problem and techniques for responding to the problem may be expensive and time consuming, it is nevertheless economically desirable to do so.

Multiple possible pathways of weed dispsersal in agriculture, include livestock, machinery, vehicles, personnel, clothing, and footwear (Schmidt, 1989; Fischer et al., 1996; Hodkinson and Thomson, 1997). However, the focus of this discussion is the unintended dispersal of weed seeds within pasture hay relief fodder. The need for, and use of, such fodder is increasing, and although part of the solution to this problem may be to find sources of fodder other than pasture hay bales, which are of a lower risk for weed seed contamination, the availability of pasture within reach of an emergency area will always be an attractive option for hard-pressed agriculturalists. Thus, tighter control and monitoring of emergency fodder is imperative for the cattle and agricultural industries to prevent long-term degredation of grazing land.

The objective of this review is to investigate the problem of detecting the presence of weeds in relief fodder with particular emphasis on investigating means to prevent the dispersal of invasive and noxious species in relief fodder by the development of a reliable, rapid assessment technique, or methods for screening bales of pasture hay. In reviewing the available literature, it is apparent that there is a problem due to the lack of availability of such a technique. To further elucidate the scale of this problem, it is worth briefly considering some aspects which might justify this approach.

2.1 Fodder types and risk of weed seed dispersal

The main sources of fodder for livestock, apart from live pasture plants, are legumes, grains, straw, silage, and pasture hay (Pogue et al., 1996; Martin, 2009). Legumes (e.g., alfalfa) and grains (e.g., wheat, barley, and oats) are typically obtained from high nutrient, monoculture crops to which weed control measures have been applied (Ulyatt et al., 1977; McDonald et al., 1994; Dixon and Stockdale, 1999). Straw bales are typically composed of residues from grain crops harvested for other purposes, (e.g., barley or wheat) (DAF, 2012). The process of removing the seed heads from the crop during harvest is also likely to remove the seeds of weeds that may be growing within the crop. Crops destined for silage are typically harvested prior to seeding, and while they can include disguised weeds growing with the crop species, the seeding possibilites are low post silage (Kaiser et al., 2004) . If used for relief fodder, legumes, grains and straw would not, therefore, be expected to be a significant vector for weed seed dispersal.

By contrast to these 'clean' fodder types, pasture hay is composed of a mixture of whole plants, which may also include weeds, that are cut, dried, and baled for storage (Suttie, 2000) and will, therefore, also contain a large and viable range of seeds. However, although this would seem to preclude its widespread use as fodder, there are pragmatic advantages, particularly in emergency situaions, in provisioning pasture hay for livestock fodder, over other fodder types. Pasture growth that is in excess to grazing requirements may be conveniently cut and baled, with few financial costs apart from those associated with running the appropriate machinery, making it perhaps the least expensive type of fodder available (Groover, 2009). While it is recognised that it is lower in nutritional value than the other fodder types, for example legumes, silage, or grains, pasture hay is widely accepted as a commonly provisioned fodder type and, as such, has the longest history of usage in agriculture (Pogue et al., 1996; Poschlod and Bonn, 1998; Suttie 2000; Bruun and Fritzberger, 2002). However, only relatively recently, it has been widely agreed that pasture hay bales may be a potentially significant source of weed seeds.

It is partly the increasing trends of movement of relief fodder that has brought this commodity under more scrutiny (Thomas et al., 1984; Conn et al., 2010). With the wider availability of transport and increasingly better road networks, it is now apparent that the unintended consequence of weed dispersal over large distances in relatively short time frames may occur with the movement of fodder; this includes the unintended and relatively unrecognised dispersal of noxious species (Thomas et al., 1984; Clines, 2005; DSE, 2006; Conn et al., 2010). It is this dispersal of invasive and noxious species in fodder which currently represents such a significant threat to the livelihoods of livestock producers. As indicated earlier, one method to prevent weed seed dispersal in fodder are controlled weed-free fodder programs. This approach has been developed in other countries (Saskatchewan Agriculture and Food, 2005; Clines, 2005; Schoenig, 2007), and involves weed control at the point of production of fodder, including regular inspections of source pastures and crops by suitably qualified personnel (Schoenig, 2007). However, even with the apparent logic of such an approach, complete success in preventing dispersal of noxious weeds, even from controlled areas, may be difficult to achieve. Unless all infestations are able to be detected prior to baling, stopping the act of weed dispersal is not guaranteed. In Australia, this control approach is relatively recent, and has only been introduced on a state-by-state basis. As a consequence, there is a mis-match between jurisdictions in the wording and process of declaration of weed-free status by suppliers of fodder. For example, in South Australia, only verbal declarations are required to be made, but in New South Wales, this is required in writing (DWLBC, 2010; DPI, 2011).

In addition to the inherent difficulties in assuring a weed-free controlled pasture environment, is the pressure brought by emergencies on the immediate need for any sort of fodder. In consequence, the material from regularly inspected pasture lands may be insufficient for graziers’ needs, and thus any available pasture will be accessed with less available control mechanism to detect weed infestation.

3.1 Bales as seed-banks: secondary release of weeds

A key issue in this discussion is the dispersal of seeds over time. As with the usual ecological concept of seed persistence in the environment in soil seed banks, hay bales may function in a similar fashion to allow seeds to persist in agricultural ecosystems for prolonged periods (Parker et al., 1989). Dispersal of weed seeds in hay bales will foster a secondary release of pasture weeds, whereby new infestations will occur over a wider area than would otherwise be the case if only natural dispersal mechanisms were operating (Kowarik, 2003). After the mature plants have been cut and removed from the paddock by harvesting for hay, seeds may remain intact and still be viable within the bales, as they are protected from degradation and prevented from germinating until their dormancy is broken (Baker, 1989). Seed dormancy is an important feature of many weedy species and can explain their invasive and persistent character (van der Pijl, 1982; Zimdahl, 1999). For example, it has been shown that the soil seed bank may contain many individual species that are able to survive for varying periods of time, up to decades or even centuries in some cases (Zimdahl, 1999). While these lengthy time frames are unlikely to apply to hay bales because of eventual degredation and use as fodder, this observation nonetheless highlights an important issue for weed seed dispersal from hay bales. Seeds that have a lifetime in the soil of more than a decade will be able to survive at least for one to two years during which they may be stored in bales, depending upon climatic and environmental conditions. It is unlikely that, over the period of this storage, the source of the bales will be remembered, so that even if a weed infestation is recognised post baling, recall of unused bales would be difficult. Subsequently, these seeds would be released as the bales are dismembered and fed to livestock. Germination of these weed seeds will occur after this point as the normal triggers for breaking dormancy, light, moisture, or other disturbance, become available (Baskin and Baskin, 1998; Zimdahl, 1999; Fenner and Thompson, 2005). Pasture weed species which possess the capacity for rapid growth, tolerance to a wide temperature range, early seeding and whose seeds exhibit a high percentage of viability would be significantly advantaged by dispersal in fodder (Cshures, 2008). In addition, weed seeds initially present in hay bales are also potentially mobile, a dispersal mechanism that is less available for soil seed banks. Whilst weed seeds in seed banks may be dispersed by transport and agricultural vehicles during normal farming activities where they pick up infested mud and soil (Clifford, 1959; Wace, 1977), a single hay bale may contain many more seeds than would adhere to a muddy vehicle (Thomas et al., 1984; Conn et al., 2010).

To maximise the feed values of pasture hay, it is desirable that pasture grasses be harvested prior to flowering and seed production (Pogue et al., 1996). However, this is not always possible. In southern Australia, for example, pasture hay is usually harvested during the warmest and driest months of the year when there are sufficient (usually at least three) consecutive days of warm, dry weather (Gupta et al., 1990). This allows the hay to dry sufficiently prior to baling to ensure longevity of storage, and prevent hay stack fires due to excess moisture (Suttie, 2000). The desirable fodder plant species, which are usually introduced species that have high feed value, are likely to have produced mature seeds by this time of year. Since many species of pasture weeds, including grasses, also produce seed during the warm months of year, there is a very high risk of the inclusion of viable weed seeds in pasture hay.

Once the hay has been baled it is difficult to detect weeds *post hoc*, by inspection of a pasture. Weeds may be identified prior to harvest, but it is not always practical to carry out pre-harvest surveys in every pasture. The activity would be time consuming and require expertise in identifying and quantifying weeds accurately. It is therefore inevitable that viable weed seeds will be included in pasture hay bales if they are taken from weed infested pastures. There is thus a significant and considerable threat for dispersal of weed seeds when these bales are moved from their point of harvest.

The goal of prevention of dispersal of invasive and noxious weeds both in space and over time is desirable, but is currently hampered by a lack of research in the area of the detection of weed seeds in bales in a time efficient and cost effective manner. Possessing the ability to detect which bales are likely to contain seeds *post hoc* in an efficient manner, that is to say after the bales are constituted, would be of considerable economic advantage. Furthermore, this would make a significant contribution towards improved biosecurity outcomes in Australia and elsewhere. To the present time, there has been little effort towards rapid testing of bales, post-baling, for the presence of noxious weeds, in an effort to prevent dispersal. Few studies have relied on the analysis of relatively small numbers of bales, tested to destruction, to obtain results for the identification and enumeration of included seed species. Development of faster and more reliable methods would increase capacity to prevent the dispersal of noxious weeds to previously unaffected locales. Although there have been relatively few studies that directly identify and quantify seeds in hay bales post baling, three have been identified that provide quantitative evidence of the possible scale of weed dispersal in hay bales, including noxious weeds (Thomas et al., 1984; Wells et al., 1986; Conn et al., 2010) and these will be introduced below.

4.1 Methods to detect weed seeds in bales

To detect the presence of weed seeds in hay bales, three studies from different countries have been previously undertaken to identify species presence and quantify seed load in bales. For convenience, these approaches are summarised in Table 1.

4.2 Why may these three methods not be ideal for rapid assessment?

Although these studies clearly demonstrate that transport of pasture hay bales is a significant pathway for weed dispersal, including noxious species, they provide only preliminary data for the development of a rapid assessment method. Issues that can be identified in these three studies which make rapid assessement techniques difficult, can be seen as (i) time efficiency to obtain results, (ii) the relatively small numbers of large (bulky) samples used, and (iii) the reliance on destructive testing methods. In addition, it is evident that some weed species that may have been present in the bales were not identified because their seeds did not germinate, so it is possible that some invasive or noxious species could have avoided detection. Although each study showed that the observation of weed seeds in bales that have been already constituted is possible, the methods employed were unwieldy, time consuming, somewhat unreliable, and would be expensive to apply routinely. Thus, it is apparent that less costly and faster methods for detecting weed seeds in bales are urgently needed.

As a further consideration, sampling only one bale from an entire paddock may not be a statistically reliable representation of the actual weed infestation. Weeds, like all plants, tend to grow in a patchy distribution (Rew and Cousens, 2001). Sampling of a single bale that is constituted from one discrete area of a pasture is thus unlikely to be a representative sample of the entire pasture. Therefore, an infestation of a particular weed in a property may not be detected by taking only one bale and testing it to destruction for the presence of weed, even if the testing procedures were reliable.

5.1 Proposal for an alternative method

An alternative to the testing of whole bales is the removal of small amounts of material from multiple bales obtained from a particular paddock or property, in a representative fashion, and analysing the material obtained. If sampling was conducted in this manner, for example with a core sampler, this would, in effect, increase the area of pasture sampled and enable multiple bales from a pasture to be tested in a shorter amount of time than destructively sampling single bales. It may also perhaps give a better representation of the composition of species, including weeds that were present in the pasture.

A core sampler is a device consisting of a steel tube with a cutter at one end, that may either be hand-turned (Meyer and Loftgreen, 1959; Aljoe, 2010) or driven with an electric motor (Wollner and Tanner, 1941; Kienzle and Wollner, 1944). With this device, it is possible to take multiple samples from either single or multiple bales in considerably less time than dismantling and sieving an entire, single bale. Additionally, the bales are still largely intact after being sampled, so they may still be sold for fodder once it has been determined that they do not contain any weed seeds. This method would therefore preserve the economic value, to a large degree, of the bales following sampling. Alternatively, if weed seeds are detected, steps may be taken to contain any infestations that might result after bales are broken up, because the (relative) risk of weed dispersal is known. If noxious species are detected, and the source of the bales is known, then steps can be taken to manage or eradicate such infestations as they are detected.

Sampling baled commodities for quality assurance analyses is not a new method. It has previously been applied to strategically sample bales of wool, fodder (for feed analysis), and cotton. A summary of previous work by other researchers in this area is given in Table 2.

5.2 Summary of core testing commodities for other than weed seeds

In each of the studies listed in Table 2, the researchers made observations about the process of core sampling of various commodities, indicating that this method may be investigated and developed for detecting weed seeds in fodder bales.

To determine a suitable number of cores per bale that would show minimal variance across a collection or 'lot'of bales, Wollner and Tanner (1941) core sampled wool bales sourced from four countries (Australia, South Africa, Argentina, and Uraguay). Their aim was to calculate the likely minimum number of samples that would be needed, either per lot of bales or per individual bale, to show a variance of less than 0.5% for clean wool (shrinkage). The weight of the core sample was found to be influential on results; where there was a less than 25% difference in core weights, the variation in the observed average value for shrinkage was low. These researchers formulated an approach to determine a minimum sample size based on first analysing 25 cores, either from a single bale in a lot or several of the same grade within a sub-lot to determine the minimum number required to show less than 0.5% variance, and then applying this to sample the remainder of the bales at random. Three replicates per bale, from approximately 100 bales per lot, gave a clean wool content of less than 5% variation.

Nordskog and colleagues (1945) also investigated the minimum sampling effort to give between 0.5 and 1% variance for shrinkage in wool samples. They found that there was no apparent advantage to sampling every single bale instead of a sub-set number of bales. Either three bales with 10 cores per bale or 10 bales with three cores per bale produced similar variation, within the target range of variance. Meyer and Loftgren (1959) were interested in improving upon the previously employed (inaccurate) visual methods of quality assessment of fodder. As part of this study, core sampling was compared to the method of ‘grab sampling’. These researchers found that the core sampling was not “difficult or time consuming” and that it seemed to fulfill the requirements of obtaining objective, representative samples for the modern, chemical analyses which were being perfected at the time.

Cobble and Egg (1987) investigated how to obtain representative samples from round bales of hay for dry matter analysis. They noted that core sampling a cylindrical object (the round bale) led to the problem of under-representation in the cored samples of the outer region of the bale, compared to the inner region. This may be of importance for core sampling round bales for detecting weed seed presence, since seeds may not be uniformly distributed throughout the bale, and may not be easily detectable if present in low concentrations in the outer regions.

Another topic of this research concerns the ability to obtain representative samples from a population of fodder bales that are being tested for the parameters of interest. The usual term applied is a “lot” of bales, which is defined in broadly similar terms by each of Collins et al. (2000), Aljoe (2002), AFIA (2005), and Marsalis et al. (2009), but with slight differences.

Collins et al. (2000) defined this term as ‘the same cutting, field, species, variety, maturity stage, curing conditions, storage conditions, harvested within 48 hours. Aljoe (2002) extends this to ‘a maximum number of bales (50)’. AFIA (2005) defined a “lot” as being ‘constituted from the same species, species mix or variety, the same paddock, harvested within 48 hours and also noting the effects of rain, weed content, soil type, after cutting treatment, storage conditions’ subsequent to harvest. Marsalis et al. (2009) uses the same terms as Collins et al. (2000), adding the amount to be ‘200 tonnes of dry matter (225 tonnes harvested, at 12% moisture)’.

For sample size of a ‘lot’ of bales, Collins et al. (2000), Aljoe (2002), AFIA(2005), and Marsalis et al. (2009) all recommended more than one bale per lot. The most quoted number being a minimum of

19 or 20 from a maximum lot size of 50 small square bales. However, from ‘lots’ consisting of large square or large round bales, the number of bales tested is recommended to be either 5 to 10 or 6 to 10. Lots of hay above these numbers are recommended to be treated as a second ‘lot’ and sampled accordingly.

For the minimum number of core samples per bale, when feed quality parameters (dry matter, fibre, ash, protein, moisture, and digestibility) are the object of the study, the minimum sample size of one core per bale is recommended by most, with only AFIA (2005) and Cobble and Egg (1987) specifically indicating that more cores may be required. In AFIA’s method, this applies to large round bales or large square bales, rather than small square bales (for which only one sample is recommended). Cobble and Egg (1987) attempted to obtain a representative sample from round bales, aiming to obtain the same size of sample from the outer portion of the bale as the inner.

For the analysis of contaminants in exported cotton, Department of Fisheries and Forestry (DAFF) defines a “lot” of cotton as a maximum of 114 bales and states that the acceptable minimum number of samples from a lot of cotton bales is six (DAFF, 2012).

It is noteworthy that where an entire core sample was required to test for the parameters being investigated, e.g., shrinkage in wool (Wollner and Tanner, 1941; Nordskog et al., 1945), more than one core sample was taken per bale. This contrasts with the situation where the analysis to be undertaken required a relatively smaller amount of material, whereby the accepted minimum number of cores per bale is one or two. For example, chemical analysis of feed quality (Meyer and Loftgreen, 1959; Collins et al., 2000; Marsalis et al., 2009) typically requires only a few grams of material (AFIA, 2011). This amount may be easily obtained from a single core per bale. However, the literature on this topic is somewhat lacking in the number of sources required. There is also some confusion or debate about the appropriate number of core samples from bale of fodder to investigate feed quality analysis. In the summary section of their article and in reference to sampling large numbers of bales in a lot of hay, Collins et al. (2000) made the comment (without citing the source) that: “For larger packages there have been fewer studies evaluating sampling techniques *but* *recommendations have been developed suggesting that multiple cores be taken on each bale and that several bales be sampled from each lot of hay*".

This seems to imply that the approach taken in this study of removing only single cores per bale could be criticized as being too few, but that the researchers recognize this point. Several researchers also acknowledge the difficulty of sampling the commodity in an objective and representative manner, citing its large, bulky, and non-homogenous nature. This acknowledgement is given either explicitly (Wollner and Tanner, 1941; Collins et al., 2000) or implicitly (Nordskog et al., 1945; Marsalis et al., 2009).

To detect (perhaps) only small numbers of weed seeds in large, bulky hay bales, it would likely be necessary to obtain a relatively larger sample size than for feed analysis, since single entire core samples would need to be examined for the presence of seeds, rather than being subdivided for this purpose. Therefore, multiple cores per bale would be required to give the smallest variance in results across a 'lot' of bales.

6.1 Conclusions

Whilst it has been recognised that weed dispersal is an undesirable, but inevitable, outcome of the processes of harvesting and transporting fodder for livestock, it seems that little has been done, on a systematic basis, to prevent this occurring. Indeed, the problem of detection of inadvertent inclusion of weeds in fodder is a complex, expensive, and difficult issue. However, recent responses to increasingly adverse weather and climate events have necessitated the accessment of (i) emergency fodder from a range of pastures not usually used for this purpose, and (ii) increasingly long-distance movement of this relief fodder. It is expected that climate change-driven weather events will increase this demand, making the possibility of accelerated noxious weed dispersal a significant problem over wide-spread areas. We have suggested that the application of a rapid and non-destructive core sampling technique to screen relief fodder for the presence of noxious and invasive weeds may enable a more strategic risk assessment approach to prevent the dispersal of some of the worst weeds. Detection and quantification of fodder inclusions will require experimental estimation of how many cores per bale and/or how many bales per lot would need to be tested to reliably detect seeds of noxious weeds in bales of relief fodder in order to sort bales into ‘clean’ or ‘needing treatment’ categories. Such approaches will increase community confidence in the use of emergency fodder and will be cost effective in terms of mitigating expensive weed eradication in the future.

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Table 1. Summary of methods used to identify weed species and enumerate seeds in fodder bales from three studies, conducted in Australia, the UK, and the USA.

Reference	Technique to find seeds	Number of bales tested	Identification of species	Results; number of species, numbers of seeds, fodder type with most weeds	Issues/problems of techniques applied
Thomas et al. (1984)	Single bales dismantled over a tarp and sieved with coarse mesh (1.2 cm) to separate coarse material from seeds/seed bearing material 1–2 kg seeds per bale obtained (from 26 kg bales)	38, to destruction	Germination and identification of plants at appropriate growth stage	233 seed types identified, 40 were not identified (failed to germinate) All bales, except one, contained at least one restricted/prohibited/noxious species Average species per bale 21 ± 6, ranged from 10 to 33 species per bale Single bale of lucerne hay had four noxious/restricted weeds, all with viable seeds. 490 bales in lot, from one supplier Most common weeds: wire weed (63% of bales), wild oat (32%), and sorrel (29%)	The method is useful to identify weed species, but is too slow to identify and enumerate seeds prior to transportation of fodder for relief
Wells et al. (1986)	Hand threshing and sieving, approx. 1 kg obtained, sub-sampled by quartering	Eight from single field	Visual examination of material to separate seeds in 25 g sub-sample	Mean species per bale 26, mean of 450,000 seeds per bale. Some species (0.1%) were not identified	Grass species were the most abundant (numbers of seeds) but whatever plants were seeding contributed seeds to the bales
Conn et al. (2010)	Single bales weighed, a one-fourth taken for analysis. Broken up and sieved to separate seeds	96 bales from Alaskan and out of state (Washington and Oregon) suppliers	Germination of seed bearing material	Up to 3,018 seeds/kg, highly variable numbers of seeds Grass hay (Timothy or Timothy/Brome mix) had the most seeds and weeds, wheat straw had the fewest	As for Thomas et al. (1984), also some species were not identified (failed to germinate)

Table 2: Summary of core sampling baled commodities by previous researchers

Commodity	Purpose	Method	Number of samples	Corer dimensions	Reference
Baled wool	Shrinkage analysis	Core sampling wool bales	Bales: Minimum of five per supplier Cores: 6, 7, 10 or 15 per bale	Size of core obtained from bales = 5 x 22.5cm	Wollner and Tanner (1941)
Baled wool	Shrinkage analysis	Core sampling wool bales	Bales: 95 Cores: 2 or 3 per bale (264 individual cores)	5 x 40cm	Nordskog et al. (1945)
Hay/fodder	Feed quality parameters	Core sampling rectangular bales	Bales: 19 selected at random from any population (or 'lot') of bales Cores: Not stated, presumably minimum of 1 per bale	0.95 x 45cm for manual (hand turned) corer, 1.9 x 45cm for electrically turned corer.	Meyer and Lofgren (1959)
Hay (sweet sorghum)	Dry matter loss due to weathering during storage	Core sampling round bales	Bales: 6 in total; 3 stored outside, 3 stored in barn Cores: 16 = 4 each from top, sides and bottom, 4 from centre of bale	1.5 x 45cm	Cobble and Egg (1987)
Hay/fodder	Feed quality parameters	Core sampling small square (rectangular) bales	Bales: Minimum of 20 per lot Cores: At least 20 probed cores (i.e., 1 per bale)	0.9 or 1.6cm, bale sampled to a depth of 35 – 60cm	Collins et al. (2000)
Hay/fodder	Feed quality parameters	Core sampling round and rectangular bales	Bales: Minimum of 10 or 6 per lot Cores: Not stated	2.5 x 45cm	Aljoe (2002)

Hay/fodder	Feed quality parameters	Core sampling small square, large square, and large round bales	Bales: For large round, 5 to 10 per lot Cores: 2 per bale, 1 from each side	32 mm x 450 mm	AFIA (2005)
Hay/fodder	Feed quality parameters	Core sampling rectangular bales	Bales: Minimum of 20 per lot or sample every ‘n^{th}’ bale (n/20) if more than 200 tonnes Cores: 1 per bale, up to a maximum weight of 500 g for total sample per lot of bales	As for Collins et al. 0.9 or 1.6cm, bale sampled to a depth of 35 – 60cm	Marsalis et al. (2009)
Cotton (raw, baled)	Inspection of raw cotton, prior to export, for contamination by vermin, insects, or other pests	Not stated, other than “draw samples from the goods using suitable equipment” (presumably includuing a core sampler)	Bales: 6 per lot Cores: Not stated	Not stated	DAFF (2012)