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Consumption of crops by feral pigs (*Sus scrofa*) in a fragmented agricultural landscape

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Abstract. Feral pigs (*Sus scrofa*) consume and damage crops and impact the environment through predation, competition and habitat disturbance, although supporting dietary data are lacking in agricultural landscapes. This study was undertaken to determine the relative importance of food items in the diet of feral pigs in a fragmented agricultural landscape, particularly to assist in predicting the breadth of likely impacts. Diet composition was assessed from the stomach contents of 196 feral pigs from agricultural properties in southern Queensland. Feral pigs were herbivorous, with plant matter comprising >99% of biomass consumed. Crops were consumed more frequently than non-crop species, and comprised >60% of dietary biomass, indicating a clear potential for direct economic losses. Consumption of pasture and forage species also suggests potential competition for pasture with domestic stock. There is little evidence of direct predation on native fauna, but feral pig feeding activities may impact environmental values. Seasonal differences in consumption of crop, pasture or animal food groups probably reflect the changing availability of food items. We recommend that future dietary studies examine food availability to determine any dietary preferences to assist in determining the foods most susceptible to damage. The outcomes of this study are important for developing techniques for monitoring the impacts of feral pigs, essential for developing management options to reduce feral pig damage on agricultural lands.

Additional keywords: competition, damage, diet, impacts.

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Introduction

Feral pigs (*Sus scrofa*) may cause significant economic damage to grain crops (Benson 1980; Pavlov 1980; Tisdell 1982; Caley 1993), reducing yields through direct consumption of plant and seed, trampling plants for bedding or from travelling through crop areas. They are a predator of livestock, including goats (Seward *et al*. 2004) and particularly lambs, sometimes inflicting heavy losses (Plant *et al*. 1978; Pavlov *et al*. 1981), and harassment may potentially increase lamb mortality and reduce fertility (Pavlov and Hone 1982). They are also increasingly recognised as environmental pests due to their omnivorous and destructive feeding habits (Barrios-García and Ballari 2012; Bengsen *et al*. 2014).

Feral pigs are common and widespread throughout southern Queensland, and can reach high densities (>6 pigs km^{-2}) during favourable periods (Gentle and Pople 2013). Landholders in the Queensland Murray–Darling Basin (hereafter QMDB) perceive damage to agricultural commodities from feral pigs to be significant and field assessments indicate that significant losses to some crops can occur (Gentle *et al*. 2011). Predation on, and competition with, native species, and destruction of habitat by feral pigs in the QMDB are also suspected, despite the lack of research to support these conclusions (Ford and Stark 2011).

Feral pigs are considered to be opportunistic omnivores, consuming a wide variety of plant and animal material (Choquenot *et al*. 1996; Seward *et al*. 2004). Pigs have reportedly high preference for green vegetation, readily available during flush periods (Giles 1980), but rely on other food sources during other periods. While there are limited studies of feral pig diet in Australia (e.g. Giles 1980; Pavlov 1980; Alexiou 1983; Fordham *et al*. 2006), there are none in the fragmented, mixed-farming lands of southern Queensland where agricultural crops are readily available.

Feeding and food selection are key ecological processes, and diet studies can help determine the relative importance of food items in an animal's diet. Determining feral pig food requirements can help to identify how and when communities may be impacted, and help to predict the potential impacts on human production (Wood and Roark 1980; Baubet *et al*. 2004; Cuevas *et al*. 2013). Quantitative analysis of diet directly supports studies into pest impact (Sweetapple and Nugent 1998), and understanding impacts is essential to develop and implement effective management strategies (Braysher 1993; Bengsen *et al*. 2014).

This study investigates the diet of feral pigs in a fragmented, agricultural landscape of southern Queensland, with particular reference to the importance of production crops in their diet. The implications of the results for management and relevance for future research are briefly discussed.

Materials and methods

Study area

The feral pigs sampled as part of this study were collected from properties in the QMDB (~261 000 km^2) in southern Queensland. The QMDB is a highly productive agricultural and pastoral region producing large quantities of cereal and food crops, cotton, and sheep and beef production (Australian Bureau of Statistics 2008). This study was conducted primarily in the Border Rivers and Maranoa–Balonne subcatchments of the southern QMDB, where intensive agricultural production dominates the fragmented landscape. This region is also environmentally diverse, hosting more than 3000 native plant species, and 600 species of native fauna, including more than 90 priority species for conservation management (Ford and Stark 2011). The study area of ~10 000 km^2 encompasses properties located near the township of Talwood (see Fig. 1). Annual rainfall for Talwood averaged ~620 mm for the study period (2008–11), greater than the long-term average (555 mm) (Australian Bureau of Meteorology 2014).

Collection and diet analysis

Diet composition was assessed through analysing the stomach contents of 196 feral pigs shot either as part of lethal control programs or opportunistically by hunters between August 2008 and March 2011. Stomachs were removed from shot animals, individually bagged and frozen (−16°C) until analysis. After thawing, stomach contents were sorted into individual prey components and the percentage volume of each food component was visually estimated using a grid system. The wet weight (grams) for each food component was also measured. Hair samples from faunal prey were placed into individually labelled paper bags and oven-dried at 100°C for 4 h to kill parasite eggs. Faunal prey components were identified to the lowest possible taxonomic level through comparison with reference samples and/or the software *Hair ID* (Triggs and Brunner 2002) using the technique described by Brunner and Coman (1974). Plant identification was performed by comparison of morphological features to known reference samples, in consultation with botanists from the Queensland Herbarium.

Plant food items were identified to the lowest taxon possible. Where identification to species level was not possible, food items were grouped into one of several categories (viz. Massei *et al*. 1996; Baubet *et al*. 2004): wheat/barley/oats, grass, other dicotyledons and carrion. All items were also grouped into the higher-order categories of crop, pasture/forage, and animal food items to examine the relative proportion of these items. For each plant item (other than grasses), we also estimated the proportion of herbaceous (i.e. leaf/fruit/seed) or stem/root material consumed.

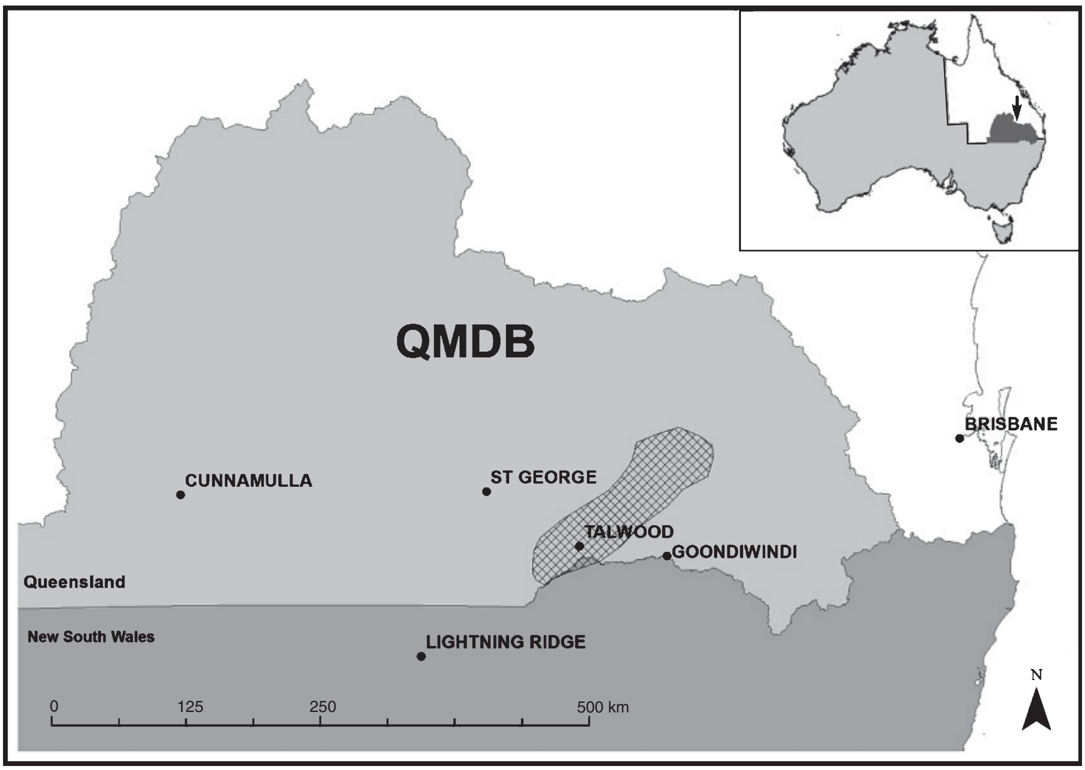

Fig. 1. The study area (hatched) in the Queensland Murray–Darling Basin (QMDB) encompassing properties located near the township of Talwood.

Dietary composition

Dietary composition was described through frequency of occurrence and the biomass percentage of each food item. The frequency of occurrence was calculated as the number of pig stomachs containing each food item divided by the total number of pig stomachs analysed expressed as a percentage. The wet-weight of each food item was converted to a percentage of total stomach contents weight to provide a percentage biomass. Frequency of occurrence can overweight the importance of frequently consumed small items, while percentage biomass can similarly be influenced by food items eaten in high quantities but at low frequency (Hart *et al*. 2002). Therefore, results from both methods were considered to overcome limitations associated with each.

Seasonal differences in the percentage biomass of crop, non-crop and animal foods consumed were examined separately through one-way ANOVA. Percentages were arcsine-transformed before analysis (Sokal and Rohlf 1995; Crawley 2007). Tukey Contrasts were used to examine differences within factors. Seasonal differences in the occurrence of crop, non-crop and animal foods consumed were examined separately through analysis of deviance with a binomial error structure (Crawley 2007). Statistical testing was performed in the software *R* ver. 3.1.1 (R Core Team 2014).

To ensure that sample size was adequate to represent feral pig diet (Milanesi *et al*. 2012; Cuevas *et al*. 2013), the cumulative number of prey items in stomachs, and the Brillouin Index (H_B) were performed on randomly selected batches of five samples to examine their relationships with sample size. Dietary diversity was calculated using the Brillouin Index (H_B):

$$H_B = \frac{\ln N! - \sum \ln n_i!}{N}$$

where n_i is the number of individuals in the ith species, and N is the total number of individuals in the sample. The Brillouin Index is recommended where sampling may be non-random (Pielou 1975).

Results

Comparison between sample size and the cumulative number of prey items detected in stomachs indicates that sample size was sufficient to represent feral pig diet. Brillouin's Index reached an asymptote at ~95 stomachs, further confirming that the sample size (196 stomachs) sufficiently described feral pig dietary diversity.

Dietary composition

The dietary composition, presented as frequency of occurrence and percentage biomass of food items, is shown in Table 1. Plant matter was dominant in the diet of feral pigs, consisting of 99.4% of consumed biomass and occurring in all (100%) stomachs sampled. In total, 19 food groups were consumed by feral pigs, comprising eight crop varieties, five groups of non-crop plants, and animal matter from six groups. Crops were consumed more frequently than non-crop plants (~65 and ~56%), and in greater amounts (~64 and ~36% respectively). Crops consumed were wheat (*Triticum* spp.), barley (*Hordeum vulgare*), oats (*Avena* spp.), grain sorghum (*Sorghum* spp.), as well as the pulses chickpea (*Cicer arietinum*) and mungbean (*Vigna radiate*). Wheat/barley/oats and grain sorghum comprised more than 50% of the biomass of crops consumed, while pulses comprised 28% of their diet. Maize (*Zea mays*) was the least consumed crop, constituting less than 1% of total biomass consumed.

Table 1. Frequency of occurrence (%) and biomass (%) of food items in the stomachs of feral pigs (n = 196) in mixed agricultural lands of southern Queensland

Food item	Occurrence (%)	Biomass (%)
Crop		
Wheat/barley/oat[A]	25.00	23.94
Chickpea (*Cicer arietinum*)	14.29	11.48
Cotton (*Gossypium* sp.)	12.24	11.32
Grain sorghum (*Sorghum* spp.)	10.71	10.28
Mungbean (*Vigna radiate*)	7.65	6.05
Maize (*Zea mays*)	1.02	0.72
Total crop	65.31	63.80
Non-crop		
Grass	29.59	15.87
Wild melon (*Citrullus lanatus*)	15.82	7.61
Forage sorghum (*Sorghum* spp.)	10.71	8.11
Other dicotyledon	6.63	3.70
Pigweed (*Portulaca oleracea*)	1.53	0.31
Total non-crop	56.12	35.59
Total crop and non-crop (pooled)	100	99.40
Animal		
Mammals	9.18	0.41
Carrion	5.61	0.03
Frogs	4.08	0.15
Invertebrates	3.57	<0.01
Lizards	0.51	<0.01
Birds	0.51	<0.01
Total animal	21.43	0.60

[A]Pooled: wheat (*Triticum* spp.), barley (*Hordeum vulgare*) and oats (*Avena* spp.).

A comparison between the consumption and availability of foods is required to determine the extent to which feral pigs are selectively consuming particular food items. Although estimates of food availability for the sample collection area are unavailable, regional crop production statistics can provide a broad measure of crop availability at a landscape scale. Data were available for the 2006–07 cropping season (Australian Bureau of Statistics 2008). The total area under non-cereal, cereal, and pasture crop production (~378 000 ha) comprises only ~10% of the region, but comprises ~64% of consumed biomass, suggesting that feral pigs may be actively selecting for crop, rather than non-crop, foods. However, the relative ranking of crops in the diet of feral pigs appear broadly similar to crop availability in the Border Rivers region. Wheat/barley/oat crops dominate production, being grown over larger area (232 800 ha) than sorghum (38 170 ha), legume (including chickpea, mungbean and field beans/peas, 30 613 ha) cotton (11 516 ha) and maize (210 ha) (Australian Bureau of Statistics 2008).

Non-crop species included wild melon (*Citrullus lanatus*), pigweed (*Portulaca oleracea*) and forage sorghum (*Sorghum* spp.), and various pasture grasses and dicotyledons. Various grasses (pooled) were the most common non-crop plants consumed by feral pigs (~16%), with forage sorghum, wild melons, other dicotyledons, and the succulent pigweed being consumed less frequently and in smaller amounts (see Table 1).

The proportion of plant components in stomachs indicates that feral pigs consumed a consistently high proportion of herbaceous material (leaf/fruit/seed) from crop and non-crop plants (see Fig. 2). While seed and leaf proportions were not assessed separately, seed (grain or fruit) usually dominated leaf material for wheat/barley/oat, grain sorghum, and chickpea, but not for mungbean and cotton (G. Story, pers. obs.). Stem/root were recorded typically when entire crop plants were consumed, particularly for mungbean and cotton seedlings. In total, stem/root comprised only ~11% of plant material ingested by feral pigs.

Animal matter was consumed by approximately one-fifth of feral pigs, although it comprised less than 1% of the total biomass ingested. Mammals, comprising unknown macropods, pigs (*Sus scrofa*), cattle (*Bos* spp.) and foxes (*Vulpes vulpes*), and unidentified carrion (degraded, unidentified animal flesh) were the most common. Other vertebrates (lizards, frogs, birds) and invertebrates (insects, snails) were rarely consumed, and were present only in trace amounts. No priority species for fauna conservation in the QMDB region (Ford and Stark 2011) were consumed.

Individual food items were pooled into crop, non-crop or animal categories to investigate seasonal differences in occurrence and biomass of these foods in pig stomachs (Fig. 3*a* and 3*b*, respectively). Few stomachs were collected during summer ($n = 3$), due to hunter inactivity and the lack of control programs in the study area, and were subsequently excluded from seasonal analyses. The occurrence of crop ($P = 0.02$) and animal foods ($P = 0.01$) in pig stomachs were significantly influenced by season. Season did not affect the occurrence of non-crop plants ($P = 0.16$) in pig stomachs. Significant temporal differences occurred in the relative percentage of biomass of all three food categories: crop ($F_{2,165} = 3.90$, $P = 0.02$), non-crop ($F_{2,165} = 3.28$, $P = 0.04$), and animal ($F_{2,165} = 6.15$, $P < 0.01$). Crops comprised a greater proportion of stomach biomass in spring than winter ($t = 2.76$, $P = 0.02$), with the autumn proportion in between ($t = 2.09$, $P = 0.09$). This corresponded to non-crop plants comprising a significantly higher proportion of stomach biomass during winter than spring ($t = 2.54$, $P = 0.03$). Significantly more animal biomass was ingested in autumn than winter ($t = 3.25$, $P < 0.01$) and spring ($t = 2.96$, $P < 0.01$).

Discussion

Feral pigs in the mixed agricultural lands of the southern QMDB are primarily herbivorous, with plant material occurring in all stomach samples and comprising >99% of the biomass consumed. Crops (comprising grain, pulse and fibre plants) are a major contributor to overall pig diet, occurring more frequently, and being consumed in relatively greater amounts, that non-crop species. The relative contribution of crop foods to dietary biomass changes seasonally, peaking to contribute to more than 70% of ingested biomass in spring. The typically diverse diet of feral pigs and variations in seasonal consumption of crop, non-crop and animal foods suggests that diet composition is largely driven by food availability and energy requirements (Massei *et al*. 1996; Schley and Roper 2003; Baubet *et al*. 2004; Cuevas *et al*. 2013; Ballari *et al*. 2015), although seasonal and geographic variation may also affect food selection (Ballari and Barrios-García 2014).

Our comparison of regional areas under crop production with the diet composition of feral pigs broadly suggests that pigs are selectively consuming crop over non-crop foods. The dominance of wheat/barley/oats in both pig diet and area under

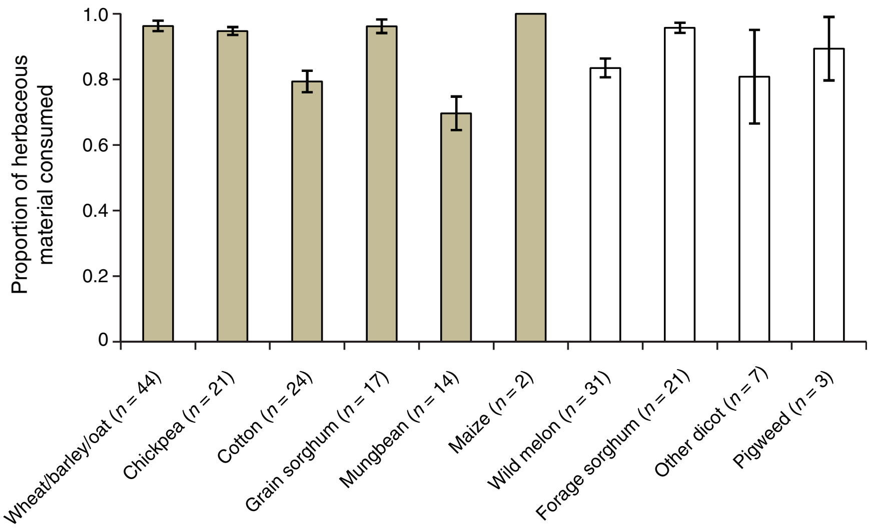

Fig. 2. The mean proportion of leaf/seed consumed by feral pigs for each plant item (excluding grasses). Plants categorised as crop are shown as filled bars, non-crop are hollow bars. Error bars represent standard error. The number of samples assessed for each food item is recorded in parentheses. Note: excludes grasses.

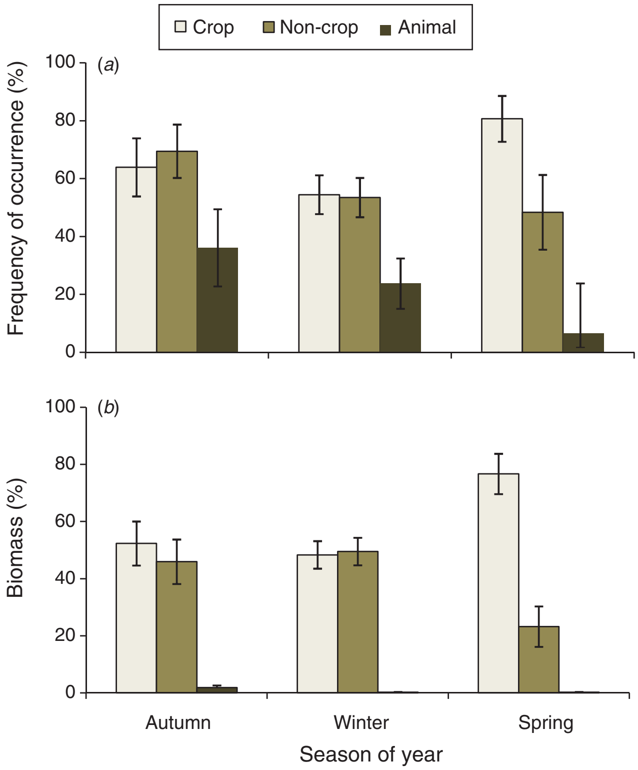

Fig. 3. (*a*) Frequency of occurrence (%) and (*b*) biomass (%) of food categorised as crop, non-crop, and animal in the diet of feral pigs for autumn, winter and spring seasons. Error bars represent standard error (biomass) and normal approximation of standard error (frequency of occurrence).

production and broad similarities for other crops between areas and their proportion in pig diet suggests that pigs are probably consuming crops according to their availability. However, our data on food availability are poor. Regional estimates of crop areas provide a coarse, ranking measure of the relative availability of food resources and estimates were available only for the previous year. Location data for collected samples were often incomplete or missing, foiling attempts to calculate localised estimates on crop food availability and, thus, diet selection. Resource availability is determined at the individual or population level, and reliable estimates are needed at this level to determine the extent to which pigs are selecting specific food types. Feral pigs in Australia are known to consume a variety of agricultural crops, including cereals, sugarcane and bananas (Pavlov 1980; Tisdell 1982; Caley 1993; Mitchell and Dorney 2002), whereas in Europe wild boar frequently consume crops including wheat, barley, oats, maize and sorghum (Schley and Roper 2003) but prefer to consume maize over cereal grains (Herrero *et al*. 2006; Schley *et al*. 2008). Little maize was consumed in our study, most probably due to its low abundance relative to other crops. When available, the dominance of cereals, seed and other crops in pig diet probably reflects the energy content and digestibility of foods; pigs are monogastric and have difficulty digesting cellulose (Choquenot *et al*. 1996). Pigs have high energy and protein requirements (Giles 1980; Choquenot *et al*. 1996; Ballari and Barrios-García 2014), suggesting that high-calorific foods will be consistently attractive (Massei *et al*. 1996).

It is important to acknowledge the potential influence of food items provided for control campaigns, or through supplementary feeding for livestock, on natural diet. Free-feeding for trapping or baiting feral pigs often uses production crop seed (e.g. cereals, pulses), chosen deliberately for their attractiveness and palatability to pigs (Mitchell 2008). Most feeding pigs succumb to the control campaign, and were thus unavailable for sampling. Also, the irregular frequency (typically less than two events per year) and extent of control undertaken on the study site (D. Marshall, unpubl. data) would have been insufficient to influence the dominance of crops in the diet. Additionally, the importance and dominance of crop foods are supported by many studies on wild boar in agricultural regions (see Schley and Roper 2003; Ballari and Barrios-García 2014).

The consistently high frequency and large proportion of crops in feral pig diet indicates a clear potential for direct economic losses by producers from feral pigs at high densities, at least locally. Landholders in the QMDB commonly reported damage to cereal crops, but legume, corn (maize), cotton, vegetable and peanut crops were also damaged by feral pigs (Gentle *et al*. 2011). Damage assessments of QMDB wheat and sorghum crops also recorded significant losses to feral pigs (Gentle *et al*. 2011), but other cereals like barley may also be targeted, with preferences shown for non-bearded varieties (Pavlov 1980). Consumption often contributes a small proportion to overall crop damage compared with trampling damage (Kristiansson 1985; Gentle *et al*. 2011). Quantifying yield reductions requires comparisons between crops in the presence and absence of pigs to account for factors that cannot be measured by diet composition alone (e.g. trampling or rooting losses, partial or total crop compensation, consumption of supplementary food). Nevertheless, the variety and dominance of crop foods in the diet of feral pigs in the southern QMDB, in addition to their habit of trampling crops, suggests that feral pigs cause significant damage to a range of agricultural crops.

The potential for economic damage to pastures is less clear. Various pasture and forage species were also commonly consumed by feral pigs, suggesting potential production losses through competition for pasture with domestic stock. Feral pigs are well known for damaging native and improved pastures (e.g. Hone 1980, 2012) and significant damage to pastures and forage crops (mean 14.5% lost production) has been reported by QMDB landholders (Gentle *et al*. 2011). However, competition may be important only during periods of feed shortage, with little or none occurring when resources are abundant (i.e. during ‘flush’ periods). Impacts may not be restricted to reductions in pasture biomass (Hone 1980); the associated rooting damage can disturb plant communities, altering species composition and richness, invertebrate fauna and physical properties of soils. Although there is clear potential for losses or damage to pasture, this is likely to be less economically significant than impacts to production crops.

Animal-based foods formed a very minor proportion of food consumed (0.6%) by feral pigs in cropping lands. Although pigs are largely herbivorous, the occasional presence of animal foods in pig diet supports their categorisation as opportunistic omnivores (Giles 1980; Choquenot *et al*. 1996). Feral pigs are known predators of various small animals, including invertebrates, reptiles and amphibians (Choquenot *et al*. 1996; Seward *et al*. 2004), but our data show that these are relatively unimportant dietary items on agricultural lands. They also suggest a limited capacity for environmental impacts through direct predation of native species in our study area (Ford and Stark 2011), at least during the observed conditions. Most of the various mammal species consumed were probably consumed as carrion (fresh or degraded), given that direct predation of larger species (e.g. cattle, fox) is unlikely and other carcasses are often readily available from hunting, damage mitigation practices and roadside kills (D. Marshall, pers. obs.). The quantity of animal matter consumed was typically small, but its percentage occurrence in the diet was not negligible (in contrast to biomass) suggesting that animal matter is attractive and important, even in small quantities. Animal matter is a protein-rich food, and is an important supplement for growth and survival of wild pigs, particularly when resources are scarce (Schley and Roper 2003; Ballari and Barrios-García 2014).

The dominance of herbaceous plant components (fruit/seed or leaf) over root/stem material consumed suggests that feeding habits were primarily focussed above ground. While feral pigs commonly consume large amounts of nutritious plant roots, especially in dry periods (Pavlov 1980), the ratio of above-ground to subterranean food in their diet is determined by season and resource availability (Ballari and Barrios-García 2014). The ready availability of crop and pastures during our study period suggests that only limited subterranean foraging may have been needed to satisfy food requirements. However, we did not estimate the structural components of grasses, nor distinguish between (soil) invertebrates, which may have shown increased levels of subterranean foraging. Pigs may also chew, but not ingest, root material from some woody plants, leading to underestimates in studies of diet composition (Wood and Roark 1980). Rooting activity can also vary spatially and temporally (see Hone 2012), suggesting that our data may merely reflect above-average seasonal conditions during the course of this study (Australian Bureau of Meteorology 2014). Limited control activities meant few stomachs were collected in summer, the wettest season, when rooting may have been most pronounced.

The relative importance of crop foods in the diet of feral pigs has important implications for measuring and managing the impacts of feral pigs on agricultural lands. This breadth of crops consumed and the dominance over non-crop foods in all seasons tested suggests that pigs can damage a variety of crops year-round. Furthermore, damage-mitigation practices may require sustained, rather than seasonal, implementation to minimise damage to available crops. Techniques to mitigate feral pig damage on agricultural lands rely on reducing pig abundance through implementing lethal control measures such as trapping, aerial shooting, hunting/harvesting and poisoning (Bengsen *et al*. 2014), although non-lethal measures (particularly fencing) are sometimes used (Geisser and Reyer 2004; Chauhan *et al*. 2009; Massei *et al*. 2011). While lethal control techniques can be effective at reducing pig abundance, more study is needed to better quantify impacts, particularly to develop density : damage relationships, to help guide the type and level of control required (see Choquenot *et al*. 1996).

This initial examination of pig diet highlights the significant potential for consumption and trampling damage to production crops in southern Queensland. Although seasonal influences on relative consumption of foods is apparent, we recommend that future studies on pig diet in agricultural landscapes collect concurrent data on the availability of agricultural crops and pastures to assist in quantifying food selection and determining the crops most susceptible to damage. Our data provide important background for monitoring the range of potential impacts from feral pigs on agricultural lands, which is essential for developing management strategies to reduce damage.

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