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FEATURE

State-wide prioritisation of vertebrate pest animals in Queensland, Australia

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Invasive organisms are key drivers of environmental change globally. Both native and non-native species can become pests that require management or control. Vertebrate pest animals may cause a range of economic, environmental and social impacts for which various plans are developed at a local, state and national scale to aid their management. There are multiple vertebrate pest species in Australia which vary in the type and severity of their negative effects. Prioritisation of these pests and their impacts is critical for management to be cost-effective. We accessed pest management plans (PMPs) from 66 (of 71) local government areas (LGAs) across the state of Queensland to collate a list of vertebrate pest species present in each LGA. Local government areas were then grouped into easily identifiable regions (Regional Organisation of Councils, 'ROC' regions, 10 in all) and vertebrate pest species lists were collated for each region. At regional workshops, each pest species was ranked as no, low, medium or high priority by stakeholders. Rankings were used to develop impact scores resulting in a priority list of vertebrate pest animal species at the state level. Fifty-three species were identified in individual LGA PMPs of which 25 were considered priorities at the regional level. Most species prioritised at the state level were mammals, with Wild Dogs (including Dingoes; *Canis familiaris*), Feral Pigs (*Sus scrofa*) and Feral Cats (*Felis catus*) being the three highest ranked. Similarities in priority species were evident across ROC regions, however, several regions prioritised pests specific to their location. The data supported a further amalgamation of the 10 ROC regions into five main groups based on the set of vertebrate pest species that were present. Prioritisation lists should be regularly updated as technologies develop, established pest animal impacts change and new species incursions occur.

Key words: *biological invasions, invasive species, prioritisation, risk assessment, vertebrate pests.*

Introduction

The global spread of plants, animals and other organisms, either deliberate or unintentional, is a key driver of environmental change (Early *et al*. 2016). It poses serious threats to global biodiversity, human health and the world economy (Pejchar & Mooney 2009). Various risk mitigation measures are implemented, and significant investments made to reduce the likelihood of such events occurring. Ongoing research is critical to guide development of policy frameworks and to determine best practice management where pest species have become established (Shackleton *et al*. 2019). The most recent published estimate of the number of established introduced vertebrate pests on the Australian mainland is 81 species (Bomford 2008). These comprise 25 species of mammals, 31 freshwater fish, 20 birds, four reptiles and one amphibian. Subsequent to Bomford (2008), one additional amphibian species has become established (Tingley *et al*. 2015). Management of these established pest animals is targeted

Implications for Managers

- Common mammalian invasive species remain a priority for pest animal managers in Queensland.
- Wild dogs, feral pigs, and feral cats are the highest ranked species across the state.
- Regional similarities in pest animal distribution were evident, highlighting the potential for collaborative efforts to manage invasive species.
- Prioritisation of pest animals should be regularly assessed to see how species impacts and distribution change over time.

towards protecting assets and reducing certain impacts. This is performed in a context of limited resources, making it important that management effort focuses on priorities. These priorities need to consider current and potential impacts and the feasibility of undertaking management to reduce those impacts.

Management of vertebrate pest animals (hereafter 'pest animals' or 'invasive animals') in Australia is increasingly conducted under pest animal management plans produced at the national, state and local levels. These plans identify criteria and approaches for building capacity for effective invasive animal management. The Australian Pest Animal Strategy is a national framework which aims to prevent the incursion of new pest animals into Australia and prioritise established pest animal species whose impacts to key national assets need to be mitigated (Invasive Plants and Animals Committee 2016). Each state or territory implements their own specific laws, regulations, policies and planning documents to guide management of pest animals (e.g. *Animal Care and Protection Act 2001* (Qld), *Biosecurity Act 2014* (Qld), *Nature Conservation Act 1992* (Qld)). Within the states and territories, local governments can develop Pest Management Plans (PMPs) specifically for their region (see Appendix S1). These PMPs promote collaborative and coordinated methods for effective management. Prioritising pest species to manage at the regional level is important to enhance these collaborative efforts by making best use of limited resources.

Prioritisation based on ranking the true impacts of pest species is difficult due to challenges in quantifying species' direct effects on the environment, agricultural production and public health. Variation in pest species abundance as well as the type and severity of impacts in different environments, over different periods, adds to this challenge. Quantifying impacts of pest species is further complicated by variation in the concept of 'pests' differing between regions or the ecosystems the species resides in. It can vary among people who may have subjective opinions about the impacts of an introduced species and whether it is a pest or a resource. In addition to introduced species, native animals can also be considered pests in some contexts (Cowan & Tyndale-Biscoe 1997). As a result, the perception of a 'pest' may change across space and time, with further uncertainty given the influence of fluctuating environmental conditions (Scasta *et al*. 2020). For example large terrestrial predators can cause economic strain on livestock production or threaten native wildlife species (Allen & Leung 2012). However, there is debate on the positive role that top-order predators may have on ecosystems, (Ritchie & Johnson 2009; Allen *et al*. 2011; Letnic *et al*. 2011; Moseby *et al*. 2012; Fancourt *et al*. 2019; Kreplins *et al*. 2020). Other vertebrate pests, particularly ungulates including Feral Pigs, Goats and the various Deer species, have negative impacts on agricultural production and environmental values (Parkes *et al*. 1996; Bengsen *et al*. 2014; Davis *et al*. 2016) but may also be considered valuable recreational hunting, economic or even cultural resources depending on the perception of stakeholders. As a result, setting priorities to best manage the impacts of pest species can be complex.

To understand regional differences in pest animal priorities across the state of Queensland, we aimed to establish an inventory of pest animal species present at both local and regional scales throughout Queensland. Using pest animal species abundance, perceived impact (including non-established pests) and feasibility of management derived from PMPs and from stakeholder workshops, we then ranked priority pest animal species. Finally, we collated suggested research needs from stakeholders that may improve pest animal management in Queensland.

Materials and Methods

Data collection and regional prioritisation

This study encompasses the traditional lands of indigenous groups, engaged through the Native Title Representative Bodies in Queensland, including: North Queensland Land Council, Carpentaria Land Council Aboriginal Corporation, Cape York Land Council Aboriginal Corporation, Queensland South Native Title Services Ltd and Torres Strait Regional Authority. We also acknowledge the indigenous groups within Queensland that are not formally represented through Native Title Representative Bodies.

To establish a state-wide list of invasive animal species for Queensland, we accessed PMPs from 66 out of 71 local government areas (LGAs) in the state (see Appendix S1). The five LGAs

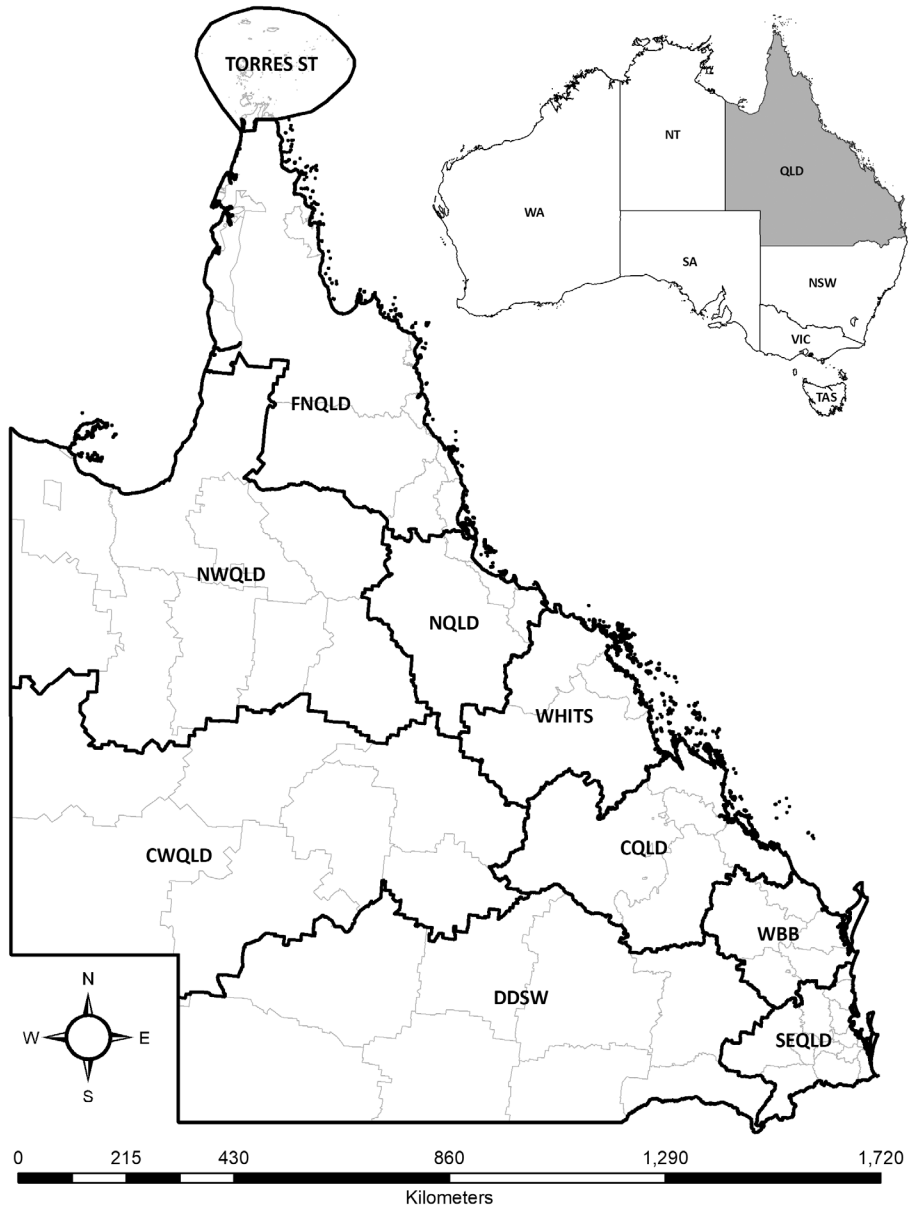

Figure 1. Regional Organisations of Council (ROC) across the state of Queensland. CQLD, Central Queensland; CWQLD, Central-West Queensland; DDSW, Darling Downs South West Queensland; FNQLD, Far-North Queensland; NQLD, North Queensland; NWQLD, North-West Queensland; SEQLD, South-East Queensland; TORRES ST, Torres Strait; WBB, Wide-Bay Burnett; WHITS, Whitsunday. Faint lines are boundaries of local government areas.

without PMPs were in localities that are very small in area (e.g. Doomadgee) and so were subsumed within larger LGAs. For each LGA PMP, the listed invasive animals were compiled into a relational database, with accompanying information for each species about the priority listing based on perceived threats or impacts (rated as high, medium or low in the PMPs) as well as management needs and legislative status. Data from the local government level were then aggregated into a regional dataset based on the Regional Organisations of Council (ROC) grouping (Fig. 1, Appendix S1). Aggregated lists were then presented to stakeholders during workshops for each of the 10 ROC regions between October 2016 and March 2017.

ROC workshops were completed concurrently with prioritising invasive plant species within Queensland. Osunkoya *et al.* (2019) published a risk-based inventory of invasive plant species for Queensland, including detailed methodology which is used for this study. To summarise, each stakeholder workshop comprised of at least two representatives from across the constituent LGAs with a minimum of 15 and maximum of 35 participants at the workshops. All participants had proven field experience in invasive plant and animal management and were representatives of either local government (employed or elected), state government or Landcare and natural resource management groups. Each ROC stakeholder workshop was presented with their aggregated information (derived from LGA PMPs) of invasive animal species for their region. First, during the workshop, a mediator discussed any relevant methodological issues and terminology with the group to eliminate language-based misunderstanding. Second, each species in the database was discussed to encourage broad participation and cross-examination within the group. Third, through deliberation and consensus building, the stakeholders, as a group, assigned a single priority ranking of either high, medium or low, based on the potential or perceived impacts (economic and ecological impacts were equally valued) and the availability of effective management tools for each species. Finally, research and management needs were discussed and recorded for each species. The option to add additional species to the regional database was provided if the group identified omissions for their region. Likewise, the option to remove species from the regional database was also available. Two regions, Far North Queensland (FNQLD) and Torres Strait (TORRES ST) completed regional stakeholder workshops, however, preferred to use their existing in-house rankings to determine their priorities

and research and management needs. Stakeholder ratings for Wide Bay Burnett (WBB) were inadvertently not recorded and were thus unavailable for analysis.

Data analysis

Impact scores initially proposed by Parker *et al*. (1999) and then expanded on by Barney *et al*. (2013) were calculated for pest animal species that were ranked at a regional level by the ROC regions, following the methods of Osunkoya *et al*. (2019). This score provides an aggregated value for the potential impact of each species across all LGAs in each region, and was calculated by the equation:

$$I = A \times R \times E$$

where I represents the invader's impact; A is the mean local occupancy, represented here as the proportion of local governments within each region listing the pest animal species (derived from local government pest management plans), summed for all 10 ROC groups; R is the total range occupied by the pest animal, represented by the proportion of ROC regions within Queensland that listed the pest animal species; E is the pest animal species' effect which is calculated by allocating numerical values to the perceived impact ratings of; 0 = Not Ranked, Low = 2, Medium = 5 and High = 8. The mean E value across all LGAs in a ROC group is then multiplied by the mean E value of all the regions to produce the state-wide E value for that species (see supplementary material appendix S2 of Osunkoya *et al*. 2019 for more details).

Mean impact scores were ranked on a scale of 1 (highest impact) through to 0 (lowest impact) where the ranked value was a result of taking the impact score (x) and applying the following equation:

$$\text{Rank} = (\text{x}-\text{min})/(\text{max}-\text{min}).$$

To explore similarities or differences between species occurrence recorded by ROC regions, we used non-metric multidimensional scaling (NMDS) using the Bray–Curtis measure. Three dimensions were plotted, as determined by the results of a scree plot. Analysis of similarities (ANOSIM) was used to test for differences between groups (in our case regions or aggregates of regions) in pest animal distribution. ANOSIM generates the statistic R, which ranges from −1 to 1. R values close to 0 represent similarity among groups. As values approach positive 1, it represents strong dissimilarity between groups (Chapman & Underwood 1999; Clark & Warwick 2001). An analysis of similarity percentages (SIMPER) was conducted between ROC regions (based on occurrence data of all pest animal species) to identify regional groupings. All ordination analyses were conducted in Primer (ver. 6) and followed the methods used in Osunkoya *et al*. (2019).

Results

A total of 53 invasive animal species were listed within PMPs of LGAs across Queensland (Appendix S2). Twenty-seven were invasive mammal species, 17 were avian invasive pests, five were freshwater fish, two were reptiles and two were amphibians. More species were listed at the individual LGA level than were considered significant pests at the regional level. Of the 53 species listed by local government in their PMPs, only 25 were classified during the stakeholders' elicitation workshops into low, medium and high rankings at the regional level, of which the majority (76%) were mammal species (Table 1).

Using the Parker *et al*. (1999) impact scores, the invasive pest animal species of Queensland were ranked in decreasing order of state-wide significance (Table 1). The top 10 priority pest species ranked by Queensland ROC regions are all mammalian. Wild Dogs (*C. familiaris*) were the only species that all 10 ROC regions and all 66 LGAs surveyed listed as a priority pest animal. This resulted in Wild Dogs being ranked as the highest priority pest animal in Queensland. Feral Pigs (*S. scrofa*) and Feral Cats (*F. catus*) were also listed highly by all ROC regions with only a few LGAs leaving them as an unranked priority. Cane Toads (*Rhinella marina*) were the highest ranked non-mammalian species. Mozambique Tilapia (*Oreochromis mossambicus*) were the highest ranked freshwater pest species and Indian Mynas (*Acridotheres tristis*) were the highest ranked of the avian species.

Regional differences

Non-metric multidimensional scaling ordination of ROC regions in Queensland indicates that there is large variation in the occurrence of pest animal species across the state. Variations in similarity appear to reflect geographical and environmental variations. NMDS trends are best explained by the inclusion of three axes (Appendix S3, Fig. A) with 66% of variation between ROC groups accounted for. However, the results of 2D ordination captures most of the variation (53%) (Appendix S3, Fig. B) and visually simplifies the identified trends of the occurrence of pest animal species. Variations of similarity (range 28–84%; see Appendix S4) roughly reflect five geographical regions across the state, consisting of a northern coastal zone (NQLD and WHITS), a broad southern region (CWQLD, CQLD, DDSW and WBB), excluding SEQLD which stands grouped alone, FNQLD which is also grouped as a single region and finally the combination of north-west Queensland and the Torres Strait islands (TORRES ST and NWQLD). SEQLD and FNQLD show strong similarity on the major axis (Axis I) in the NMDS and have also been grouped together in the dendrogram (Fig. 2). Despite this, they have been classified into separate regions,

as the dendrogram similarity point is relatively low, and 3D model of the ordination shows greater dissimilarity on both axis II and III. These results appear to stem from similarities between ROC regions in the occurrence and impacts of the most common vertebrate pest species (e.g. Wild Dog, Feral Pig, Feral Cat). However, there is considerable variation in pest animals specific to their region (e.g. 12 endemic avian species and no mammals for SEQ vs. no avian species and nine mammals for FNQLD). NWQLD and TORRES ST both had low species diversity in their lists of pest animals, which may contribute towards their unique grouping. The major pest animal species delineating the five grouped regions are indicated in Appendix S5.

Research and management needs

At the stakeholder workshops, responses highlighting research and management needs were available from nine out of the 10 ROC groups and specific priorities included only 15 of the 25 listed invasive species that were considered significant at the regional level (Appendix S6). A broad range of research and management needs for prioritised invasive animal species were identified (Fig. 3). The needs fell into three main themes: (i) more effective control methods, (ii) baseline ecological data, most commonly specific to their region or unique environment and (iii) increased and ongoing landowner and public education surrounding pest animals and their management.

Discussion

It is evident that mammalian pest species remain at the forefront of concerns for stakeholders involved in pest animal management, with Wild Dogs, Feral Pigs and Feral Cats being the most highly ranked across the entire state. Queensland is a large state (185 million ha) encompassing 13 bioregions, each varying in their vegetation, land uses, climate and pest species' abundances (Irvine & Holloway 2020; Department of Agriculture and Fisheries 2021). Although priority species were widely distributed across the state, many species were uniquely important at the regional level.

High priority species

Wild Dogs were the highest ranked pest species across the state. They are a wide-spread top-order predator in Australia and their impacts are present across all ecosystems in Queensland, from arid desert environments to highly developed urban areas. Wild dogs can regulate Kangaroo (*Macropus* spp and *Osphranter* spp.) numbers (Caughley *et al*. 1980; Pople *et al*. 2000), in some contexts providing benefit to cattle enterprises (Allen 2015; Prowse *et al*. 2015; Emmott 2021) and there is debate as to whether Wild Dogs can benefit native wildlife through suppression of Cats and Foxes (*Vulpes vulpes*) (e.g. Allen *et al*. 2011; Letnic *et al*. 2011; Moseby *et al*. 2012; Fancourt *et al*. 2019). Despite this, the negative impacts of Wild Dogs were consistently identified at the local, regional and thus state level as a high priority for management. Wild Dogs injure and kill livestock, especially small stock, leading to economic losses for producers (Gong *et al*. 2009; McLeod 2016). They prey on native wildlife including threatened species (Allen *et al*. 2016; Gentle *et al*. 2019; Augusteyn *et al*. 2020) and carry pathogens of zoonotic importance (King *et al*. 2010; Harriott *et al*. 2019). The high priority given to Wild Dogs may potentially be influenced by psychological factors including human fear of harm to persons, pets, livestock or wildlife (Kansky & Knight 2014; Ecker *et al*. 2017). However, the high priority of Wild Dogs identified in this study is consistent with previously published economic assessments of invasive species (Gong *et al*. 2009; McLeod 2016) which report the economic impacts of Wild Dogs as second only to Rabbits (*Oryctolagus cuniculus*).

Feral Pigs and Feral Cats were also ranked as state-wide priority pest species. Direct impacts to the natural environment and cropping systems caused by Feral Pigs are usually obvious due to their destructive foraging behaviour, and significant crop losses are often reported by producers (Bengsen *et al*. 2014; Gentle *et al*. 2015). Feral Pigs can also threaten locally important populations of wildlife through both habitat destruction and predation (Melzer *et al*. 2009), and harbouring both production limiting (Pearson *et al*. 2014) and zoonotic (Hampton *et al*. 2006) pathogens. Feral Cats have less obvious economic and animal welfare effects on agricultural industries, but they have substantial deleterious effects on native species diversity (Burbidge & Manly 2002). Since their introduction, they have played a major role in the extinction of unique native Australian fauna (Woinarski *et al*. 2015), indirectly affecting ecological processes, as well as competing for resources with native species. Like other pest animals, Feral Cats are vectors of pathogens that are transmissible to livestock, wildlife, domestic species and humans (Doherty *et al*. 2017; Legge *et al*. 2020).

New incursions of invasive species

The number of invasive animal species listed in LGA PMPs was considerably reduced when prioritised at the ROC regional level following stakeholder workshops. This is a result of each LGA having species of concern specific to their locality, which are not recognised as important at a larger scale. There are a small number of emerging pest animal species that are currently restricted in their distribution (e.g. Red-Eared Slider Turtle, *Trachemys scripta elegans*) or are a

Table 1. Impact scores of the 25 species identified by Regional Organisations of Councils (ROC) as priority pest animal species in Queensland. Scientific names for each species can be found in Appendix S2. ROC regions or Local Government Areas (LGAs) that list a species have recognised them as a priority in their region. This does not necessarily equate to confirmation of the presence of that species in their region

No	Common name	Recognised as Established in QLD	No of ROC regions listing invasive animal	No. of LGA listing invasive animal	Per capita-invasive animal impact (E)	Mean Invasiveness score (A × R)	Mean impact score (A × R × E)	Ranked impact score
1	Wild Dog	Yes	10	66	50.283	10.000	502.833	1.0000
2	Feral Pig	Yes	10	62	43.981	9.399	413.366	0.8220
3	Feral Cat	Yes	10	62	31.032	9.345	290.004	0.5766
4	European Rabbit	Yes	9	52	26.462	7.165	189.595	0.3768
5	European Red Fox	Yes	9	48	17.222	6.707	115.512	0.2295
6	Chital Deer	Yes	8	25	24.675	3.655	90.197	0.1791
7	Fallow Deer	Yes	8	17	27.424	1.271	34.843	0.0690
8	Rusa Deer	Yes	5	16	23.568	1.275	30.044	0.0594
9	Feral Goat	Yes	8	34	7.875	3.420	26.932	0.0532
10	Red Deer	Yes	5	17	19.271	1.271	24.484	0.0484
11	Cane Toad	Yes	7	22	7.102	2.387	16.954	0.0334
12	Mozambique Tilapia	Yes	5	10	15.950	1.033	16.471	0.0324
13	Feral Horse	Yes	6	20	8.590	1.392	11.957	0.0234
14	Indian Myna	Yes	5	17	5.916	1.895	11.213	0.0220
15	Red-Eared Slider Turtle	Yes (localised)	3	7	35.714	0.159	5.682	0.0110
16	European Carp	Yes	2	13	12.615	0.413	5.205	0.0100
17	House Mouse	Yes	5	8	2.800	0.575	1.611	0.0029
18	Ferret	No	4	4	14.500	0.077	1.113	0.0019
19	Gambusia/Mosquitofish	Yes	2	4	7.500	0.121	0.909	0.0015
20	European Hare	Yes	2	7	2.000	0.390	0.780	0.0012
21	Asian Black Spined Toad	No	1	1	64.000	0.009	0.582	0.0008
22	Hog Deer	No	2	3	10.667	0.051	0.540	0.0007
23	Sambar Deer	No	2	3	10.667	0.051	0.540	0.0007
24	Pea Fowl	Yes	1	3	3.000	0.103	0.309	0.0003
25	Feral Water Buffalo	Yes	2	4	2.500	0.068	0.170	0.0000

high-risk import stowaway (e.g. Asian Black-Spined Toad, *Duttaphrynus melanostictus*), that were not highly ranked in comparison to established invasive species, but still included in the regional prioritisation list. This inclusion may be due to their localised establishment (Burgin 2007), the potential for repeat accidental introductions, which would enhance the probability of more widespread establishment (Tingley *et al*. 2018), as well as the significant environmental impact they would cause if they were to become widespread (Mo 2019). This is reflected in their high invasive animal impact scores (which are similar to or higher than many of the top-ranked established pests), but their overall low ranking is due to their currently limited distribution. These species have the potential to transition into highly ranked invasive animal species in the future if their spread is not contained (Bomford 2008). However, only a small subset of new invaders were considered by stakeholders. A substantial number of species such as Boa Constrictor (*Boa constrictor*) and Burmese Python (*Python bivattatus),* which are among 56 known non-native reptiles or amphibians seized by government officials in Queensland between 2008 and 2016 (Csurhes *et al*. 2016), were not considered. Stakeholder knowledge of new and potential invaders is likely driven by external research and surveillance programs being conducted in these regions, and from seizures of prohibited species.

Some species that are currently listed as absent or localised but are ranked at a low priority have the potential to cause significant environmental damage. In the absence of knowledge of future impacts, it is crucial to reduce the risk of new incursions and contain localised pest animals. While Australia has stringent biosecurity laws, the increased likelihood of establishment of exotic species through invasion pathways such as illegal trade and stowing away means rigorous border biosecurity and the implementation of early detection surveys are critical for better management of the risks (Myers *et al*. 2000; Csurhes *et al*. 2016). In particular, reptiles and amphibians can be difficult to detect (Csurhes 2019; Toomes *et al*. 2020).

Regional differences

The south-east region of Queensland (SEQLD) has the highest human population density in the state (Department of Environment and Science 2020). As a result, new exotic pest incursions, aided by deliberate or accidental human-mediated import, are more likely to occur in this region. South-east Queensland has the highest number of identified invasive animal

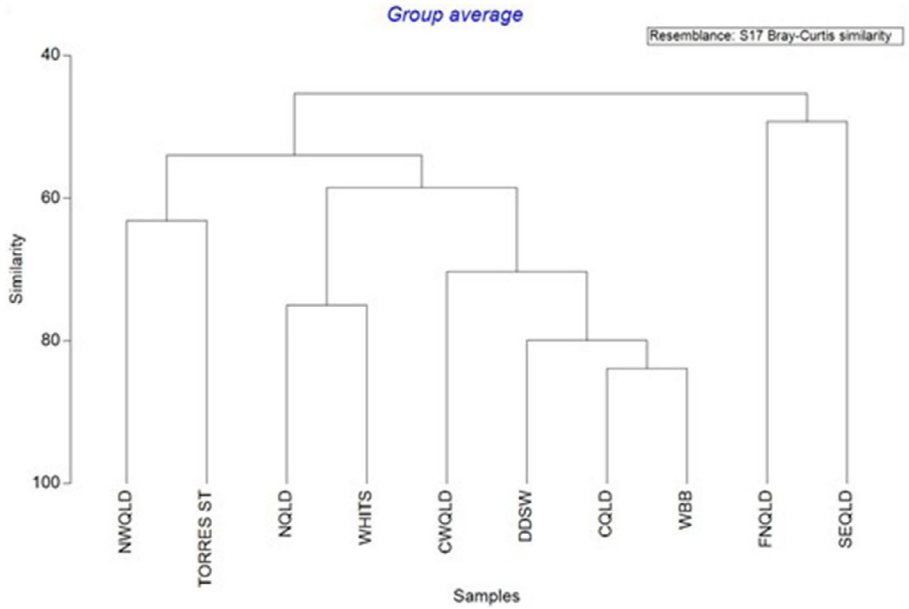

Figure 2. Dendrogram of Regional Organisations of Councils (ROC) groupings showing similarity in pest animal species occurrence as determined by stakeholders at regional workshops. Refer to Figure 1 for ROC region names.

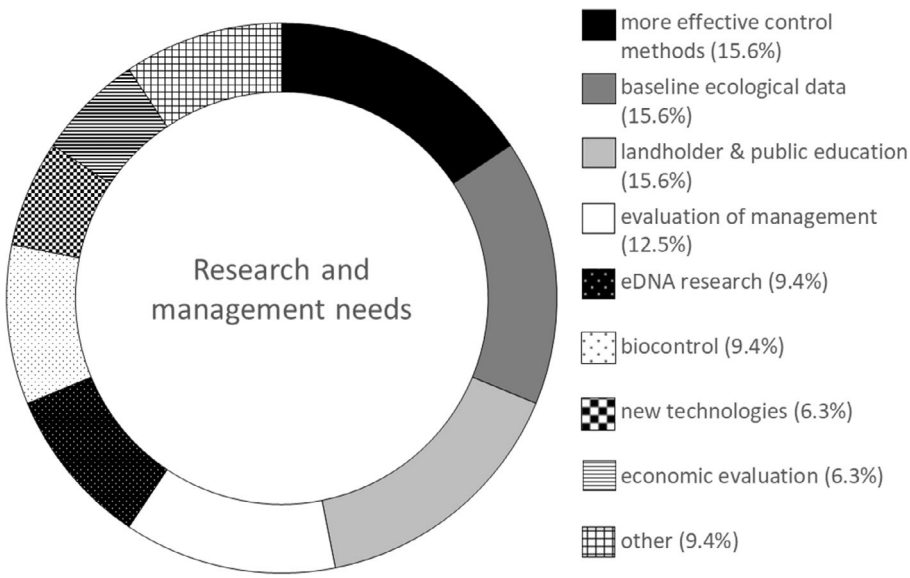

Figure 3. Research and management needs (%) as determined by stakeholders at Regional Organisations of Councils group workshops. The 'other' category includes surveillance, incentive programs (bounties) and multispecies management.

species with the greatest species diversity of all the ROC regions in Queensland (see Appendix S2)- a trend similarly reported for pest plants (weeds) (Osunkoya *et al*. 2019) South-east Queensland and Far North Queensland (FNQLD) were the most distinct regions in the state. Like SEQLD, FNQLD reported high invasive species diversity. Although these two regions were similar in their pest animal priorities including the top-ranked species (i.e. Wild Dog, Feral Pig, Feral Cat, Fox), there were pests that are specific to each of these two regions. SEQLD reported the presence of smaller invasive pest species including reptiles, fish and birds, whereas FNQLD reported the presence of larger mammalian species such as Camel and Feral Cattle. In general, it is noted that region-specific pests occurred throughout the state. Despite differences in pest animal priorities across Queensland, collaboration between regions should help minimise spread and impacts of pests that are common (e.g. Wild Dogs) as well as contain localised pests.

Research priorities

There are numerous methods available for the lethal or non-lethal management of pest species. There is also considerable information available on the ecology of the common, widespread pest species. However, the pest management practitioners at our workshops identified an ongoing need for improvements and better access to control methods, more ecological data relating to invasive species, and better, documented information to assist landholders and the broader community. The latter need may be the most important. While there are existing tools and a solid understanding of pest species' ecology, that information may not be filtering down to local land managers. The results also suggest regional variation in pest animal impacts and how they are perceived and managed. State-wide or national approaches to pest animal management may therefore miss the mark locally.

Best practice management of invasive species should improve over time as new understanding, tools and strategies develop. Importantly, pest managers must also consider community views such as animal welfare and, in some environments, engaging the community to understand their values will play a key role in uptake of programs (Please *et al*. 2018). There are opportunities for regions to work together to develop strategies for management of invasive species. Before new research can be properly

undertaken, the deficiencies of existing control options need to be identified. Some options are regarded as too expensive or too difficult to implement for practical and social reasons. These barriers need to be identified as part of new research programs.

Study limitations and considerations

This study elicited expert opinion from LGA, State Government and NRM staff experienced in the management of vertebrate pests. We recognise that selection of experts can influence outcomes (Burgman 2015; Please *et al*. 2018) and as such, results may have differed if other stakeholders (e.g. producers, academics) were consulted. We consider the selection of agency staff as appropriate for the regional and state level prioritisation given their experience across a variety of land tenures and production systems, and due to their responsibilities in pest management planning, operations, advice and investments at the local, regional or state scale. Targeting this specific cohort aimed to provide a balanced perspective on the relative actual or perceived impacts of pest animal species across such broad tenures and production systems. However, agency experts may fail to capture the relative importance of lesser known, under-recognised or under-studied impacts from species which may influence the ranking of species prioritisation (Maas *et al*. 2021). Attempting to consistently capture these impacts and their influence on prioritisation would likely require additional input from a wide-range of specialists (e.g. researchers or academics). Given the scale of the study and the lack of quality information, this approach would induce even greater uncertainties, inconsistencies, debate or further study requirements (see Williams *et al*. 2019; Maas *et al*. 2021). While we cannot accurately predict the prioritisation outcomes of choosing different 'experts', our consistent approach across LG and ROC areas was considered optimal for the (relative) prioritisation of invasive species at the regional and state level that can be built upon or modified in the future if need be.

This study focussed on identifying priority pests at the regional and state level to help inform the key species for management, policy and research investments at these scales. It is important to recognise that these results may not necessarily represent local priorities in any specific local government area within a region, which will vary widely with species distribution, and local conditions, policies and management practices. Despite this study being limited to Queensland, the methods could be similarly applied to other jurisdictions to develop similar priority lists. Although pest management structures may differ, other states and territories of Australia (and elsewhere) have both locally and broadly distributed invasive species and thus our approach may have useful application elsewhere for prioritisation.

We recognise that our approach prioritises established species which reiterates the need for regular prioritisation of pest species to assess and account for any changes. Additionally, prevention, coupled with rapid effective control of new incursions and newly establishing species, should be priorities for action prior to their impacts being realised. This is where the benefits of control are maximised and costs lowest (Invasive Plants and Animals Committee 2016). Factors such as climate change, new and modified production systems, changing community views (e.g. animal welfare standards) are likely to alter the impacts caused by pest animals into the future, which will shift management priorities and research needs (Pavey & Bastin 2014; Wang *et al*. 2019). Such changes are difficult to predict and are unlikely to be static, which supports the need for regular prioritisation.

Conclusion

The prioritisation of a small number of widespread, long-established mammal pests in Queensland (Wild Dogs, Feral Pigs and Feral Cats) for management, indicates that these species cause enduring, substantial impacts that require ongoing management. The prioritised list of invasive vertebrate pests of Queensland provides a baseline of pest species distribution and impact, which can be monitored over time to assess whether climate change, new species incursions or other changes (e.g. habitat disturbance) influence the presence, distribution and impacts of invasive species. These results can be used to guide the prioritisation of resources, management or research efforts to address the impacts of established invasive animals in Queensland as well as identify opportunities for collaboration to improve these outcomes This should assist with policy and decision making for pest animal management now and into the future.

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Supporting Information

Additional supporting information can be found in the following online files.

Appendix S1. Table of Regional Organisations of Council (ROC) regions, and their inclusive Local Government Areas (LGAs) for which Pest animal Management Plans (PMPs) were accessed and utilised for this study.

Appendix S2. Complete list of the 53 invasive vertebrate species identified in pest management plans (PMPs) of 66 local government regions (LGAs) of Queensland. Values in brackets next to ROC group names (e.g. CQLD (4)) represent the number of LGAs present within that region. Values in the table represent the number of LGAs within that ROC region to list the corresponding species as a pest in their PMP.

Appendix S3. Non-metric multidimension scaling presented in (A) three dimensions and (B) two dimensions with regions grouped (circled) based on reported species occurrence similarities by Regional Organisations of Councils at stakeholder workshops. CQLD, Central Queensland; CWQLD, Central-West Queensland; DDSW, Darling Downs South West Queensland; FNQLD, Far-North Queensland; NQLD, North Queensland; NWQLD, North-West Queensland; SEQLD, South-East Queensland; TORRES ST, Torres Strait; WBB, Wide-Bay Burnett; WHITS, Whitsunday.

Appendix S4. Index of pair wise dissimilarity (%) in diversity of vertebrate pest species among the 10 ROC regions of Queensland based on the results of NMDS ordination. Data are based on species presence/absence data extracted from pest management plans of the local governments and from the regional stakeholders' elicitations.

Appendix S5. Similarity percentages (SIMPER) of Queensland widespread vertebrate pest species. Average abundance values refer to ranking across local governments within aggregated regions (absence to rare: 0–0.5; common to very common: >0.5) and the contribution (%) to the dissimilarity between two regions. Diss = dissimilarity; SD = standard deviation. Regions were allocated in group 1 through to 5 based on NMDS analysis.

Appendix S6. Regional Organisations of Council (ROC) regions that highlighted specific research or management needs for invasive animal species. TORRES ST ROC region is not included as they did not participate in discussing research and management needs.