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Do we need to mine social media data to detect exotic vertebrate-pest introductions?

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ABSTRACT

Invasive alien species are responsible for considerable biodiversity loss and environmental damage. Timely detection of new incursions is critical in preventing novel populations establishing. Citizen reports currently account for the majority of alien species detections, arising from the massive observation effort that the physical and digital 'eyes and ears' of citizens provide, in combination with crowd-sourced species identification. Because the reporting of alien species sightings is generally not mandatory, there is interest in whether mining social media data via image recognition and/or natural language processing can improve on existing passive citizen surveillance in a cost-effective manner. Here, we illustrate, using examples from Australia, how citizen surveillance for most vertebrate groups appears to currently be effective using existing voluntary reporting mechanisms. Where citizen surveillance is currently ineffective, for reasons of inadequate sampling, data mining of social media feeds will be similarly affected. We argue that mining citizens' social media data for evidence of invasive alien species needs to demonstrate not only that it will be an improvement on the business as usual case, but also that any gains achieved cannot be achieved by alternative approaches. We highlight the potential role of education in increasing the surveillance effectiveness of citizens for detecting and reporting sightings of alien species. Should data mining of social media platforms be pursued, we note that the scale of the task in terms of the potential number of exotic vertebrate species to be classified is very large. The expected number of false positive classifications would present a considerable workload to process, possibly undermining the efficiency rationale for the use of data mining. Hence, prioritisation is needed, and we illustrate how the number of species to be classified can be reduced considerably. If we are to deploy data mining and analysis of social media data to help with detecting introductions of invasive alien species, we need to conduct it in a manner where it adds value and is trusted.

Keywords: alien, artificial intelligence, citizen science, crowd sourcing, data mining, invasive, pest, surveillance.

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Introduction

Reducing additional Invasive alien species (IAS), by the timely detection of new introductions (and ideally cost-effective prevention of their establishment), is desirable to avoid incurring additional environmental, amenity and agricultural impacts. Challenging our ability to undertake effective surveillance for IAS is the highly diffuse nature of the incursion risk. For example, the location and modes of possible introduction are many, including points of entry associated with international trade, self-introduction over wide areas, and pet-keeping (Lockwood *et al.* 2019), which is ubiquitous with human population centres (Vall-llosera and Cassey 2017). In addition, the number of species theoretically involved is large (10s of 1000s). Indeed, the scale and nature of the risk means there will never be surveillance targeting specific IAS, other than for taxa whose risk profile is considered high enough to warrant it (e.g. Toomes *et al.* 2020*a*). Instead, authorities largely rely on reports from the general public (hereafter citizens) as a primary means of surveillance.

The observation effort from citizens is enormous. For example, by the end of 2021, FrogId (an initiative from the Australian Museum) has collected in excess of half a million observations across much of Australia. Platforms for recording bird sightings (e.g. Ebird) and all species great and small (e.g. iNaturalist) receive millions of records per year in Australia alone. The feralSCAN platform and App provides a reporting platform tailored towards mapping sightings of recognised vertebrate pests. Many of these online streams of citizen-generated data ultimately find their way into the Atlas of Living Australia (ALA), an increasingly comprehensive, accessible repository for Australia's biological data, providing a data stream to detect the observation of IAS.

But not all potentially useful observations find their way directly, or in a timely fashion, into biodiversity records. In particular, social media platforms (Facebook, Instagram etc.) host numerous groups focusing on different interactions with wildlife (e.g. identification, photography, nature appreciation, husbandry and pet-keeping). These groups harness the collective observation and identification skills of 100s of thousands of individuals; they connect people, while providing training in animal identification. One approach to tap into this resource is to have a biosecurity practitioner join the relevant groups and feeds, and spend time trawling through the material for sightings of interest. Alternatively, would it be possible to automate the process through data mining (image recognition and/or natural language processing), and would users be happy about this approach? Furthermore, do we actually need to extract surveillance information out of these data streams, or is the current self-reporting by the citizens sufficient?

In this paper, we explore the utility of mining social media data to detect post-border incursions of exotic vertebrate pests. Using Australia as an example, we illustrate the scale of the problem, in terms of the number of alien vertebrate species potentially involved, the scope for effective data mining, and the effectiveness of surveillance provided by citizen-generated data.

Methods

We adopted an expert opinion-based narrative approach to assess the need, the feasibility, and the value proposition of using data mining of social media for the timely detection of exotic vertebrate pests. We consider mammals, birds, reptiles and amphibians, and freshwater fish in turn.

Results and discussion

Do we need to mine social media data?

Mammals

For mammalian IAS, most successful invasions have been the result of deliberate introductions (Rolls 1984) that have now effectively ceased. Furthermore, as an island continent with tight restrictions around deliberate importation and strict border biosecurity around trade and visitation, the future approach rate of alien mammals from external sources will be negligible. Future incursions will result from escapes from captivity, particularly pets, although also potentially from zoos (see Cassey and Hogg 2015). However, note that zoo escapes will typically be quickly identified, and authorities notified (e.g. the recent red panda escape from the Adelaide Zoo), or be a non-viable breeding population such as the solitary pygmy hippopotamus (*Choeropsis liberiensis*) that escaped a private exotic animal collection in the Northern Territory before living alone in the wild for ~6 years (Mo 2022). Although new introductions of alien mammals are rare, there is considerable demand for exotic mammalian species as pets, of which many are considered highly invasive (Toomes *et al.* 2020*a*). However, even if there were pathways of entry for such exotic species (e.g. pygmy marmosets, *Cebuella* spp., and raccoon dogs, *Nyctereutes procyonoides*, are highly popular internationally), we argue against the need for data mining citizens' social media feeds, as a sighting of such an exotic species will trigger a report to authorities through existing reporting channels. For example, the land manager who accidentally shot the aforesaid pygmy hippopotamus promptly reported it to authorities.

Birds

Bird-watching enthusiasts, through platforms such as Ebird, have embraced the ability to share their sightings. The online birding community takes the process of correct species identification seriously, and platforms such as Ebird apply moderation to all sightings. Alerting processes for unusual sightings are in place. For example, Ebird provides an email alert system for rarities and vagrants at the spatial resolution from county/province/state to country level. The current citizen reporting system appears adequate for detecting introductions in a timely manner. For example, a recent incursion of Canada geese (*Branta canadensis*), a species considered exotic and potentially invasive, was detected by birdwatchers on the South Coast of New South Wales. The sightings quickly found their way to an online birding portal (Birdline New South Wales), and the flock continued to be sighted and reported online as they moved between wetlands, before being removed by authorities (Boles *et al.* 2016). There is now much higher uptake of online reporting by the birding community than 15 years ago and surveillance would be even more sensitive and prompt. Sightings of escaped pets are easily accessed (Vall-llosera and Cassey 2017).

Reptiles and amphibians

Deliberate introductions of reptiles and amphibians, such as the cane toad (*Rhinella marina*) in 1935 (Easteal 1981), have also ceased. However, escaped pets are identified as a significant risk (Toomes *et al.* 2020*a*). Recent examples of

pet species establishing free-living populations include the red-eared slider turtle (*Trachemys scripta elegans*; Burgin 2007), the European newt (*Lissotriton vulgaris*; Tingley *et al.* 2015), and quite possibly European corn snakes (*Elaphe guttata*; McFadden *et al.* 2017; Mo and Mo 2021). The source of these establishments were animals being released from captivity either deliberately or accidentally. Incursions arising from pet keeping (including species kept illegally) will continue (Toomes *et al.* 2020*b*; Stringham *et al.* 2021*a*). We also expect ongoing introductions, despite stringent biosecurity measures, of hitch-hiking species such as the black-spined toads (*Duttaphrynus melanosticus*; Tingley *et al.* 2018).

Fish

The aquarium trade has seen numerous exotic fish species being imported (García-Díaz *et al.* 2018), and there appear to be ongoing incursions arising from escapees, and possibly deliberate releases. Recent incursions include several species of tilapia (e.g. Mozambique tilapia, *Oreochromis mossambicus*, and the spotted tilapia, *Tilapia mariae*) in eastern Australia, and Siamese fighting fish (*Betta splendens*) in the Northern Territory (Hammer *et al.* 2019). Nearly all the detections of such incursions arise from citizens. The aquatic environment hinders the ability of citizens to make observations, including photographs needed for the crowd-sourcing of species identification. Within iNaturalist, along with other strong biases in reporting, fishes are strongly under-sampled relative to their diversity (Mesaglio and Callaghan 2021). The aquatic environment hinders the ability of citizens to make observations, including photographs needed for the crowd-sourcing of species identification.

Can we actually do it?

Is the signal there?

Citizens' social media posts will almost certainly contain images and/or text relating to IAS, although only a proportion of posts are public and, hence, accessible. Many citizens are motivated to share images and accounts of species that are novel to them, whether they consider them to be exotic or not. Shared sightings tend to be biased towards organisms that are bigger, brighter, more colourful, patterned ornately, morphologically unusual and/or exquisite (Caley *et al.* 2020), and underlying social media algorithms will likely magnify this bias. However, many potential IAS will fulfill at least one of these criteria for engagement, especially those kept as pets (that are desirable for these very attributes). For example, the adult female *Iguana iguana* was identified by a kayaker on Ross River, Townsville, Queensland, in April 2011 (Henderson *et al.* 2011). So, yes, it appears very likely that conditional on being sighted, and in particular if photographed, that information (image, description) of an alien species will find its way onto social media and/or a dedicated reporting platform. The key issue then becomes whether the signal can be correctly identified in an efficient manner.

Issues of scale

If the full set of possibilities is to be addressed, in Australia's case there are approximately 60 000 species of mammals, birds, reptiles, amphibians and fishes that are considered to be alien. This is orders of magnitude greater than one of the larger image-recognition studies of free-living wild vertebrate animals (Norouzzadeh *et al.* 2018), along with the ~5000 endemic species to be included. That is not to say that with sufficient high-quality photos and supervision the identification is not possible (see Van Horn *et al.* 2018).

Natural language processing

Mining social media to detect sightings of alien species is challenging (Welvaert *et al.* 2017), particularly where the observation and reporting are largely unintentional from a scientific viewpoint (Welvaert and Caley 2016), because this influences the quality of photographs, and the type of language used. Even in cases of an IAS sighting where the reporting is intentional, from a language perspective, the observer typically will not know either the scientific (binomial) or common name for the species. This is exacerbated by the frequent use of large numbers of trade names for many exotic pet species. For example, there are more than 20 different names used for monk parakeet (*Myiopsitta monachus*) in the aviculture trade (Stringham *et al.* 2021*b*). Hence, identification from social media feeds in the absence of images will be on the basis of natural language processing ('the application of computational techniques to the analysis and synthesis of natural language and speech'), in the presence of a large amount of noise coming from a surprising number of causes. For example, when Welvaert *et al.* (2017) set about searching for a signal in Twitter to indicate the arrival of the migratory eastern koel (*Eudynamys orientalis*), noise included 'koel' being a Dutch word for 'cool', and the name of a popular Bollywood actress.

Image recognition

Successes come from analysing camera-trap images, with the purpose of identifying a restricted number of species of interest. For example, when classifying images from the Snapshot Serengeti dataset (Swanson *et al.* 2015), Norouzzadeh *et al.* (2018) had only 48 classes of animals to classify, of which many exhibit unique conformation arising from natural selection for local ecological niches. Such morphological differentiation often disappears in the case of physically separated populations where convergent evolution has occurred. Even in this limited-choice image-classification study, and with extensive training available, the missclassification rate was a non-trivial 8% (Norouzzadeh *et al.* 2018). Impressive as this is in context (equal with human

volunteers), in the context of trawling through social media data for alien species, such a misclassification rate would generate a high workload on account of the number of images involved. Given the number of images involved, the expected number of false alarms (natives classified as alien) will be considerable (Lamba *et al.* 2019), resulting in the online equivalent of 'wild goose chases' of citizens' social media data if followed up.

Handling zoo visits, pets and holiday snaps

Handling social media posts that are missing geolocation data will be logistically problematic when determining native or alien status. The feed of quality images of alien species in particular could well be 'spammed' by zoo visits. People sharing images of their pets, along with advertising exotic pet animals for sale, could generate a large quantity of true positives from the species identification perspective, but wrong context (i.e. not a free-living specimen in the wild). Posts pertaining to IAS that are associated with trade (either 'wanted' or 'for sale') can almost certainly be effectively filtered (e.g. Stringham *et al.* 2021*b*), but those relating to pets will be harder to identify. Not only is the keeping of pets a major source of actual unwanted introductions, but it would be a major source of noise that will hinder the application of digital methods to help identify and respond to these introductions.

Will it be better than BAU?

A requirement of any new surveillance system should be that it leads to an improvement on the existing surveillance under business as usual (BAU), the comparative value proposition. Without descending into detailed benefit–cost considerations, this means that our data mining needs, at minimum, to generate additional reports of alien species from social media feeds, over and above what is already detected. Otherwise, we will be simply discovering, through potentially intensive analytics, what is already adequately reported by word-of-mouth. And human vision, processing, and word-of-mouth are demonstrably powerful, as a recent case of an alien *Boa imperator* (native to South and Central America) in Sydney demonstrated. A citizen posted a picture (not particularly detailed, with the head obscured) to a Facebook group dedicated to the fast identification of snakes (Fig. 1); a licensed reptile handler was notified, and the snake was safely captured and handed over to authorities within a matter of hours. The lack of resolution and features in the picture would make image recognition challenging, whereas the human brains involved provided the correct classification, i.e. a potentially alien species in need of further investigation. Such a crowd-sourced classification and notification system is demonstrably powerful (Caley and Barry 2023). It can also, through messaging, resolve contextual issues that an automated image classifier may struggle with, such as country (e.g. occasionally people outside of Australia

Fig. 1. Post to Facebook group Snake Identification Australia with photo of what transpired to be a *Boa imperator*. The illegally kept pet was captured by a licensed snake handler, and impounded by the appropriate authorities within hours. A simple Google image search of this image will return pictures of houses only.

mistakenly post an image to the 'Snake Identification Australia' Facebook group seeking identification) or location (e.g. captivity or wild).

The previously mentioned example of citizen birdwatchers effectively detecting an incursion of Canada geese, in combination with the knowledge of just how interested the birding community is in the identification of exotic and/or vagrant species, leads to the conclusion that data mining social media feeds is unnecessary to achieve adequate surveillance for alien birds in most situations.

Citizen surveillance for purely aquatic species, although still the primary form of reported observations for IAS, does not appear to be timely enough for preventing the establishment of IAS in this environment. However, the factors limiting the effectiveness of the surveillance are not the propensity to report an IAS given detected, but the process of detection itself, and hence the signal generation. In contrast, amphibians such as frogs are more likely to be physically sighted as they are not confined to aquatic habitats, but more importantly are easily detectable by their typically prolonged calling behaviour that makes them detectable by the citizen-driven FrogId.

What is warranted in pursuing?

For Australia, a prioritisation approach seems most warranted, with the need to even consider data mining on the basis of the risk of introduction (approach rate) and effectiveness of existing citizen surveillance. This narrows the problem space considerably by excluding mammals (too few incursions expected), birds (BAU surveillance provided by birdwatching enthusiasts adequate), or fish (lack of sightings worth mining). This leaves reptiles and amphibians as the group that are the source of most new vertebrate incursions, and where improved incursion response appears to be most usefully needed.

The global list of possible reptile and amphibians (tens of thousands) is logistically too large for image recognition with high accuracy; hence, further filtering of the species of interest is needed. Disappointingly, science has not been overly successful in identifying intrinsic biological traits that are consistent predictors of invasive potential (see Hayes and Barry 2008). However, the role of propagule pressure influencing establishment success is clear (Cassey *et al.* 2018), and there are data available on interceptions that can be used to identify which species are most likely to be introduced. Indeed, Toomes *et al.* (2020*b*) showed that a handful of species account for about half of all border interceptions. It makes sense to start to target these species, which include red-eared slider turtles, corn snakes, boa constrictors, which are all highly desirable (although illegal) pets in Australia, and the Asian black-spined toad (*Duttaphrynus melanostictus*), which have frequently been detected as stowaways (Tingley *et al.* 2018).

Both red-eared slider turtles and corn snakes are probably permanently established in Australia, although boa constrictors are not. A good initial case study would be the set of exotic snakes (mainly pythons and boas) that are highly desirable globally to keep and breed. The propensity of owners to breed such species means the escape of a single individual can initiate an invasion (e.g. Dorcas *et al.* 2012). Australia is home to several species of large python with considerable variation in colouration, so discriminating between native pythons (e.g. the carpet python, *Morelia spilota*, with all its colour morphs) and unwanted exotic python (e.g. reticulated python, *Malayopython reticulatus*) is a challenge for some citizens (as evidenced by the boa constrictor mistakenly released by Gold Coast police on responding to a report from the public), but may not be a major challenge for an image classifier if the deep-learning algorithm can discover features that are highly discriminatory.

Asian black-spined toads are easily mistaken as cane toads, so there may be utility in developing at classifier to distinguish the two. Again, we are reasonably certain that someone who is interested enough to take a photo of a toad will probably be posting it to a site (e.g. iNaturalist) where the identification will be crowd-sourced. This raises the obvious question of how much image identification should be automated, versus relying on the collective taxonomic skills of the crowd? Platforms such as iNaturalist already facilitate alerts for sightings of selected taxa within user-specified geographical regions, with an inbuilt image classifier (Van Horn *et al.* 2018). Furthermore, if we are happy that (1) sightings are being classified with sufficient accuracy, and (2) that the naming system is also workable, then we no longer need to deploy high-powered semantic-style natural language processing; simple queries based on the taxa of concern become straightforward.

What are the costs?

A large part of the argument for employing data mining of social media to detect IAS incursions is that it will be comprehensive and cheap (or at least cost-effective). The potential number of species involved, and the likely number of misclassifications involved, make this unlikely. A longer-term issue relates to the ongoing curation of algorithms, datasets, and keeping up to date with the social media platforms. Previous data-rich information systems such as the Australian Biosecurity Intelligence Network (ABIN) and International Biosecurity Intelligence System (IBIS) have either been discontinued, or were unsuccessful, because they were inaccessible and could not secure recurrent funding.

The loss of societal trust through unsolicited data mining of social media content is an expected cost. Many people would be unhappy to know that their social media posts are being scrutinised by authorities. Any benefit in improved surveillance sensitivity would need to more than compensate for this. It is likely that a proportion of people who have posted material relating to an IAS incursion may by unwilling (somewhat understandably) to cooperate as to exactly where the observation was and the context, making the extraction of useful information difficult. Finally, nefarious posts are a possibility, whereby individuals may deliberately construct sightings of IAS. Such postings can potentially consume considerable resources.

Resourcing alternative approaches?

An alternative to investing in the data mining of social media is to put greater resources into improving the existing citizen surveillance provided by intentionally shared sighting information. That is, rather than scrutinising social media posts containing low signal-to-noise ratios, we take measures to assist citizens in improving the signal within the posts that they are already willingly sharing on purpose-designed platforms. For citizen data streams that are curated online (e.g. Ebird, iNaturalist) or aggregators of biodiversity data such as the Atlas of Living Australia, it should be possible to work directly with the curator to provide the generate alerts for potential IAS sightings of concern from within.

Understanding the processes by which citizens are reporting IAS is a precursor to identifying how the reporting process

can be improved. The components of an IAS incursion being reported include the following:

- observation: citizens having an interest in and awareness of the living world around them, and
- identification: citizens having (a) a good working knowledge of endemic/native species, and/or (b) the skills to identify an species unknown to them, and/or (c) the interest in seeking identification of a species unknown to them (e.g. crowd-sourcing), and
- reporting: citizens knowing who and how to contact the appropriate authority in the event of sighting an IAS, or independent platforms for reporting them

Fostering an interest in the natural world can be achieved through the education system, at all levels. This will invariably lead to improvements in all components of the reporting process listed above.

Harnessing the passion of people for collecting things (whether animate or not) towards the biological is an opportunity to improve biodiversity reporting and hence IAS surveillance. For example, it may be possible to encourage the users of augmented reality games such as Pokemon' Go to go out and engage with real-world nature (see Dorward *et al.* 2017). A challenge in getting citizens to undertake surveillance for IAS is that by definition the IAS will be absent or uncommon most of the time. Hence, to maintain interest (and hence build a collection) necessitates that people are observing and cataloguing what is predominantly non-alien biodiversity, with IAS 'detection' an incidental event. Biodiversity 'collection' and alien species 'detection' could possibly be much better gamefied? That said, there is no market failure in the availability of suitable Apps and associated platforms for collating, comparing and sharing lists of taxa.

Improving the coverage and quality of citizens' identifications could be achieved by improving the access and awareness of platforms to facilitate identification (e.g. crowd-sourcing platforms, online keys, image classifiers). An alternative to the unsolicited use of image classification on peoples social media posts is to put the image-recognition tools in people's hands to do their own investigations, with sufficient natural history information (e.g. 'native to this region') for people to make an informed choice as to whether they should notify authorities. We note that the motivation to notify authorities of species sightings can be influenced by a range of factors (e.g. Hine *et al.* 2020).

Finally, we can improve the direct detection and reporting on IAS by citizens. For example, agencies charged with managing biosecurity could invest in targeted advertising on social media, encouraging people to report exotic species, or search in particular areas? The city of Adelaide is currently asking members of the public to report on sightings of rose-ringed and Alexandrine parakeets (*Psittacula eupatria*). This program is seen as being highly successful. Advantages of this approach include the possibility of actually influencing the citizen sampling and reporting process. Escaped pets are a major pathway of IAS introductions, and websites and social media groups devoted to reporting on lost pets and sightings of suspected escaped pets are now common and heavily used. These are an important source for potentially detecting escapes of the more common species (the escape of a highly valuable and/or illegal species may not be advertised), and act as a form of self-regulatory surveillance system.

Conclusions

We have argued that there is a limited set of situation/species combinations where it appears that the data mining of social media could be an improvement on existing citizen surveillance. Furthermore, without exploring in full detail, there are numerous challenges ranging from the technical feasibility through to the social licence to operate. If we are to deploy data mining of social media data to help with detecting introductions of IAS, we need to do it in a manner where it adds value and can be trusted. The development and provision of open-source tools for people to use themselves for species identification seems like a good place to start. Indeed, we argue it is quite possibly better to invest resources in improving the voluntary contributions of citizens to increase our ability to detect incursions of IAS.

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