Rapidly mapping fire effects on biodiversity at a large-scale using citizen science

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ABSTRACT

The unprecedented scale of the 2019-2020 eastern Australian bushfires exemplifies the challenges that scientists and conservation biologists face monitoring the effects of biodiversity in the aftermath of large-scale environmental disturbances. After a large-scale disturbance there are conservation policy and management actions that need to be both timely and informed by data. By working with the public, often widely spread out over such disturbed areas, citizen science offers a unique opportunity to collect data on biodiversity responses at the appropriate scale. We detail a citizen science project, hosted through iNaturalist, launched shortly after the 2019-2020 bushfire season in eastern Australia. It rapidly (1) provided accurate data on fire severity, relevant to future recovery; and (2) delivered data on a wide range (mosses to mammals) of biodiversity responses at a scale that matched the geographic extent of these fires.

Keywords: citizen science; fire ecology; iNaturalist; fire temperature; eucalypt forests, rainforests

INTRODUCTION

The 2019-2020 eastern Australian bushfires garnered international attention, given their unprecedented scope, scale, and severity (Nolan et al. 2020), spanning ecosystems from southern Queensland to Kangaroo Island, South Australia, more than 1,700 km away. The fires represent one large-scale example of the impacts of climate change in a rapidly changing Anthropocene, with environmental disturbance predicted to increase in intensity, severity, and rate of occurrence in a warming climate (Enright et al. 2015). Other large-scale environmental disturbances predicted to increasingly impact biodiversity under climate change include more severe droughts (Fensham et al. 2015), more intense cyclones (Cheal et al. 2017), increased flooding (Milly et al. 2002) and increased warming of oceans (Hughes et al. 2018). Quantifying the impacts of these extensive disturbances on biodiversity can help develop effective policies and management for recovery and resilience of biodiversity (Hampe and Petit 2005).

The Australian bushfires in the 2019-2020 season burnt more than 7 million hectares in the two most populous states of Australia alone (New South Wales (NSW) and Victoria) (www.rfs.nsw.gov.au; www.ffm.vic.gov.au), and an unprecedented 21% of the Australian 'temperate broadleaf and mixed' forest biome (Boer et al. 2020). In NSW, 37% of all rainforest and entire distributions of many species, including those listed as threatened, were burnt (NSW DPIE 2020), while across Australia greater than one billion individual animals are estimated to have been affected (https://www.sydney.edu.au/news-opinion/news/2020/01/08/australian-bushfires-more-than-one-billion-animals-impacted.html). Inevitably, these bushfires will have large impacts on biodiversity given their size and severity. Understanding responses across the biodiversity spectrum requires a large range of data sources, given the wide-ranging effects of bushfires. Recovery will vary from rapid to possibly not at all, depending on both the species and the severity and magnitude of the fires, highlighting the importance of a rapid assessment in relation to local effects of fires (Bradstock 2010). Such essential but complex information presents a major logistical challenge, traditionally reliant on professional scientists' availability and budgets (Bakker et al. 2010), which are limited relative to the immense scale of the fires. This highlights a challenge for most government agencies around the world: an ill-preparedness for robust and timely quantification and monitoring of biodiversity impacts and responses to large-scale environmental disturbances.

How can scientists surmount this challenge? Citizen science data, collected by collaborating volunteers and professional scientists (Jordan et al. 2011), are now widely used in biodiversity research, providing conservation information at broad spatial and temporal scales relevant for policy and management (Chandler et al. 2017). These citizen science data are also an increasingly valuable option for understanding rapid changes to biodiversity from landscape-scale environmental disturbances. Moreover, modern platforms can be rapidly utilized to respond to catastrophic events, although the data collected will rarely rival professional data for detail or rigor. There are many biases associated with citizen science projects, generally related to the level of structure of a project (Kelling et al. 2019), and such citizen data needs to be combined with other data sources to provide reliable information for biodiversity management (Kosmala et al. 2016; Burgess et al. 2017), but nonetheless it represents a new, scalable tool for responding to large-scale disturbance.

Our rapid-response citizen science project, launched in response to the 2019-2020 Australian bushfires, provided data on the biodiversity response at a scale relevant to the unprecedented size of the fires. We leveraged an existing data platform – iNaturalist – and social and mainstream media to successfully design and spread awareness of the citizen science project. The goal of our project was to rapidly understand the severity of the fires, the diversity of taxa affected, and their early postfire responses in eastern Australia. It highlighted the potential for rapid assessment and broad-scale ground truthing of biodiversity impacts using citizen science. Specifically, we: (1) summarized uptake of the citizen science project and (2) compared citizen scientist observations on bushfire severity to satellite-derived measures of bushfire intensity. We also identified how future citizen science research outputs can be made accessible (open-access) for rapid influence of conservation policy and management.

METHODS

iNaturalist project

iNaturalist (www.inaturalist.org) is a global citizen science project, launched by the California Academy of Sciences, with >33 million observations of >250 thousand identified taxa globally. We created a 'traditional project', constrained to the Australian continent in the 'projects' feature of iNaturalist, quickly launching our citizen science initiative, with reasonably wide media coverage, in response to the 2019-2020 Australian bushfires, across south-east Australia. Citizen scientists can manually join projects and add their data, in the form of geolocated photographs of biota, with 'projects' able to create their own observation fields. We developed five observation fields, three related to life history and biodiversity: plants (native reseeder, weed reseeder, native resprouter, weed resprouter, unsure); animals (native alive, feral alive, native dead, feral dead, track, scat, digging, feather, unsure) and; fungi and lichen substrate (soil, wood and leaf litter, rock, unsure). The final two observation fields related to landscape burn severity: tree burn height (not burnt, burnt at base, burnt between base and middle, burnt between middle and top, burnt to top) and tree leaves (no leaves scorched, <50% scorched, 50%-99% scorched, 100% scorched, 100% consumed). We set ‘na’ (not available) as the default for each observation field, as this required manual selection of appropriate categories and avoided applying incorrect fields to an observation. We interacted with participants through the project journal and species’ identification comment features.

Hotspot data

To examine how rapid citizen science compared with other rapid assessment methods, we used the Digital Earth Australia Hotspots data (https://hotspots.dea.ga.gov.au/). These data are part of a national bushfire monitoring system, using satellite sensors to provide spectral signatures of fire (i.e., hotspots). We downloaded spatiotemporal coordinates for sites aligned with citizen science biodiversity data, and associated hot spot measure of temperature above background. We used temperature as a proxy for the intensity of a fire, given its wide-spread availability, matching our citizen science observations, and its fundamental role in remotely-sensed fire radiative power (Wooster et al. 2005). Our post-fire citizen science measure was categorical (i.e., burn severity), but nevertheless, we expected a correspondence between these two rapid measures.

Statistical analysis

We compared the categorical measure of burn severity reported by citizen scientists (i.e., no leaves scorched, <50% scorched, 50%-99% scorched, 100% scorched, 100% consumed) to the remotely-sensed temperature data. Both data sources included spatiotemporal coordinates; these were aggregated within buffers to produce a combination of thresholds at the spatial and fire severity level. We aggregated all points within specified buffer sizes, allowing for direct comparisons between the two datasets. We used a buffer size of 250 meters, the optimal spatial scale for R^2 of model fit. In this analysis, we only included iNaturalist observations which provided a measure of burn severity (n=1,107 observations). We fitted a linear model with temperature as the response variable and our categorical burn severity level as the predictor variable. Effect sizes of pairwise differences among categories were extracted using the emmeans package. Because of the likely spatial autocorrelation in the citizen science observations, we also fitted two different spatial models (GLS and glmmfields) to ensure the robustness. Both these approaches confirmed our linear model results; we present only the linear model results here. Lastly, we mapped the area of national vegetation formations (Keith 2017) across south-eastern Australia, defined here as temperate to subtropical biomes within the south eastern states (Hobbs and McIntyre 2005; Hutchinson et al. 2005), that were burnt using the National Indicative Aggregated Fire Extent dataset, and compared it with our citizen science data. All data were processed in R software (R Core Team 2020).

Data availability

All data are available through the citizen science project: https://www.inaturalist.org/projects/environment-recovery-project-australian-bushfires-2019-2020. Code and data pertaining to our analyses are available on GitHub: https://github.com/cornwell-lab-unsw/aus_fires_data. The National Indicative Aggregated Fire Extent Dataset is available here: http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B9ACDCB09-0364-4FE8-9459-2A56C792C743%7D

RESULTS

A total of 3265 observations, from 240 unique users, were submitted to the iNaturalist citizen science project (30 January 2020-16 March 2020), covering nearly 51 million ha (Figure 1, minimum convex polygon). Of these observations, 51.1 % of users added extra fields to the citizen science observations. The observations included plants (73.7%), animals (21.5%), and fungi (4.6%), totalling 688 identified species, 255 families, and 98 orders (Figure 2). Of the 610 animal observations, 376 were vertebrates and 234 were invertebrates. Of the animals, the most commonly reported taxa were insects (208), mammals (143), and birds (136). For plants, Myrtales (674, i.e., *Eucalyptus* and *Melaleuca*), Asparagales (214, i.e., orchids and grass trees), and Proteales (216, i.e., *Banksia* and *Hakea*) were the top three most commonly reported taxa. Among the rest of 132 observations, there were 36 Ascomycota, 94 Basidiomycota, and 2 slime molds.

Our categorical citizen science measure of burn severity correlated well with the continuous measure of remotely sensed temperature of the fires (Figure 3). Pairwise effect sizes showed that ‘trees 100% scorched’ had larger effect sizes than all other categories, followed by ‘trees 100% consumed’, whereas trees ‘no leaves scorched’ had the smallest pairwise effect size in all instances (Table S1).

We found that Wet Sclerophyll forests had the highest percentage of burnt habitat in south-east Australia (31.48%), followed by Dry Sclerophyll forests (19.85%) (Figure 4). Importantly, fire sensitive vegetation types also had a high percentage of burnt area, including Rainforest (15.63%), followed by Freshwater wetlands, including swamps, (7.4%). The distribution of iNaturalist observations across vegetation formations did not adequately reflect the vegetation communities burned and was dominated by those in Dry Sclerophyll Forest (n = 1502), followed by Temperate subhumid woodlands (n = 400) and Wet Sclerophyll Forest (n = 349). Among the fire sensitive vegetation formations, observations were relatively few and similarly unrelated to percentage of burnt area with Freshwater wetlands (n = 136) having more than 4 times the number of observations as Rainforests (n = 29).

DISCUSSION

The enormous scale of the 2019-2020 fire season in eastern Australia presents a challenge for scientists, including conservation biologists, policy-makers, and managers. Informed decisions about prioritising management or conservation needs to be based on the best available evidence, and usually quickly, for a rapid and effective recovery response (Kooyman et al. 2020). However, the scale of the 2019-2020 bushfires, and many other large-scale disturbances likely to increase in frequency in the future, was simply too big for a rapid response using conventional biodiversity monitoring methods, with on-the-ground observations by trained professionals, given resourcing constraints (human and financial). These more detailed approaches are needed for more targeted learning and management planning.

Citizen science will play a key role in biodiversity monitoring for these and future fires of this magnitude. Because citizen scientists were already spread out across the impacted areas, they could be mobilized without logistical constraints and sample disparate parts of the firegrounds, producing large-scale datasets quickly (Figure 1). These provided both fire severity information but also basic occurrence data on the recovery of a wide range of biota.

However, as with all citizen science projects, effort was generally haphazard in spatial and temporal sampling: the sampling is not complete, and spatially and temporally biased. These are limitations that can be offset by targeted investments in more systematic monitoring projects (Legge et al. 2018). But most importantly, citizen science occurred at the scale commensurate with the fires. It is possible for scientists to collaborate and cross-validate and gap-fill these data to ensure a robust and comprehensive sample of the event and associated phenomena. And by combining citizen science data with other data, including remotely sensed products, understanding can improve for some of the processes involved and likely opportunities for recovery of organisms and their ecosystems.

Fire scientists typically quantify fire regimes, including the intensity (i.e., the energy output from the fire itself) and extent of fires in space and time, as well as the severity of the burn (i.e., the organic matter lost by component organisms as a direct result of the fire). Estimates of severity and intensity are both useful, either for understanding fire behaviour and its different impacts on functional processes or potential for recovery (Keeley 2009). These two indices are positively correlated but they can be related weakly to each other, because of different vegetation physiognomies and fuel characteristics (Hammill & Bradstock 2006). We showed a similar positive relationship between our citizen science-generated assessment of fire severity and intensity (Figure 3). Our results suggest that accuracy of satellite mapping of fire severity is least accurate where fires burn beneath a tree layer without consuming the tree foliage, consistent with findings of Gibson et al. (2020) who used a different mapping platform, and reinforced the need for ground observations. The strength of the relationship we found was likely to be reduced in particular vegetation types, and is also limited by outliers resulting from spatiotemporal gaps in the satellite data, which sometimes miss the peak intensity of a given fire. Importantly, the on-ground validation data from citizen scientists was useful in ground-truthing broad-scale fire severity (Gibson et al. 2020). Finer-resolution remote sensing products are however the result of machine learning algorithms that require training data (e.g., Gibson et al. 2020), a process that is fire-specific and takes time to produce. A reliable understanding of fire severity patterns is important to guide immediate post-fire response efforts, such as wildlife rescue, as well as longer term strategic policies centred on protection of fire refuges and reducing risks of future fires. Citizen science observations support this effort by enabling policy decisions to be informed by a stronger and more timely understanding of the uncertainties in mapping than is possible by other means.

Two other features of this project are worth highlighting. First, by using a public platform the dataset is open and can be downloaded and analyzed by anyone including both professional and citizen scientists. This is crucial given the wide range of taxa surveyed (Figure 2) and potential utility for specialists in these fields. Second, the data can be linked to pre-fire data – collected at the same sites and sometimes by the same observers – allowing analyses of population, species, and community responses to bushfires.

Citizen science data can significantly contribute to the data we require to make decisions, particularly over large temporal and spatial scales (Chandler et al. 2017; Callaghan et al. 2019). Our project delivered rapid data on biodiversity and fire severity over a large scale. Uniquely, we demonstrated the utility of citizen scientists to respond to landscape-scale environmental disturbances such as the 2019-2020 fires in southeastern Australia. The challenge will be to continue to engage citizen scientists to collect data tracking long-term temporal change and such a large spatial scale. This can be partly met by showing how such data can significantly improve understanding of fire processes and also contribute to improving the management of the environment for the many organisms affected by such large scale fires. Citizen science is now entering an era where the platforms can rapidly mobilize data collection after large-scale catastrophic events, increasing in likelihood with anthropogenic change to the atmosphere and climate (Cheal et al. 2017).

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REFERENCES

Bakker, Victoria J., et al. "The Changing Landscape of Conservation Science Funding in the United States." Conservation Letters, vol. 3, no. 6, 2010, pp. 435–444., doi:10.1111/j.1755-263x.2010.00125.x.

Boer, Matthias M., et al. "Unprecedented Burn Area of Australian Mega Forest Fires." Nature Climate Change, vol. 10, 2020, pp170-172., doi: 10.1038/s41558-020-0716-1

Bradstock, Ross A. Flammable Australia the Fire Regimes and Biodiversity of a Continent. Cambridge Univ. Press, 2010.

Burgess, H.k., et al. "The Science of Citizen Science: Exploring Barriers to Use as a Primary Research Tool." Biological Conservation, vol. 208, 2017, pp. 113–120., doi:10.1016/j.biocon.2016.05.014.

Callaghan, Corey T., et al. "Improving Big Citizen Science Data: Moving beyond Haphazard Sampling." PLOS Biology, vol. 17, no. 6, 2019, doi:10.1371/journal.pbio.3000357.

Chandler, Mark, et al. "Contribution of Citizen Science towards International Biodiversity Monitoring." Biological Conservation, vol. 213, 2017, pp. 280–294., doi:10.1016/j.biocon.2016.09.004.

Cheal, Alistair J., et al. "The Threat to Coral Reefs from More Intense Cyclones under Climate Change." Global Change Biology, vol. 23, no. 4, 2017, pp. 1511–1524., doi:10.1111/gcb.13593.

Fensham, Roderick J., et al. "Dominant Tree Species Are at Risk from Exaggerated Drought under Climate Change." Global Change Biology, vol. 21, no. 10, 2015, pp. 3777–3785., doi:10.1111/gcb.12981.

Gibson, Rebecca, et al. “A Remote Sensing Approach to Mapping Fire Severity in South-Eastern Australia Using Sentinel 2 and Random Forest.” Remote Sensing of Environment, vol. 240, 2020, p. 111702., doi:10.1016/j.rse.2020.111702.

Hammill, Kate A., and Ross A. Bradstock. “Remote Sensing of Fire Severity in the Blue Mountains: Influence of Vegetation Type and Inferring Fire Intensity.” International Journal of Wildland Fire, vol. 15, no. 2, 2006, p. 213., doi:10.1071/wf05051.

Hampe, Arndt, and Rémy J. Petit. “Conserving Biodiversity under Climate Change: the Rear Edge Matters.” Ecology Letters, vol. 8, no. 5, 2005, pp. 461–467., doi:10.1111/j.1461-0248.2005.00739.x.

Hobbs, R.J. and McIntyre, S. “Categorizing Australian landscapes as an aid to assessing the generality of landscape management guidelines.” Global Ecology and Biogeography, vol. 14, no. 1, pp.1-15.

Hughes, Terry P., et al. “Spatial and temporal patterns of mass bleaching of corals in the Anthropocene.” Science 359: 80-83. 2018, doi:10.1126/science.aan8048

Hutchinson, M.F., McIntyre, S. et al. “Integrating a global agro-climatic classification with bioregional boundaries in Australia.” Global Ecology and Biogeography, vol. 14 no. 3, 2020, pp.197-212.

Jordan, Rebecca C., et al. “Knowledge Gain and Behavioral Change in Citizen-Science Programs.” Conservation Biology, vol. 25, no. 6, 2011, pp. 1148–1154., doi:10.1111/j.1523-1739.2011.01745.x.

Keeley, Jon E. “Fire Intensity, Fire Severity and Burn Severity: a Brief Review and Suggested Usage.” International Journal of Wildland Fire, vol. 18, no. 1, 2009, p. 116., doi:10.1071/wf07049.

Keith, David A. Australian Vegetation. Cambridge University Press, Cambridge, 2017.

Kelling, Steve, et al. “Using Semistructured Surveys to Improve Citizen Science Data for Monitoring Biodiversity.” BioScience, vol. 69, no. 3, 2019, pp. 170–179., doi:10.1093/biosci/biz010.

Kooyman, Robert M., et al. “Protect Australia's Gondwana Rainforests.” Science, vol. 367, no. 6482, 2020, doi:10.1126/science.abb2046.

Kosmala, Margaret, et al. “Assessing Data Quality in Citizen Science.” Frontiers in Ecology and the Environment, vol. 14, no. 10, 2016, pp. 551–560., doi:10.1002/fee.1436.

Legge, Sarah M. et al. Monitoring threatened species and ecological communities. CSIRO Publishing, Melbourne, 2018

Mckinley, Duncan C., et al. “Citizen Science Can Improve Conservation Science, Natural Resource Management, and Environmental Protection.” Biological Conservation, vol. 208, 2017, pp. 15–28., doi:10.1016/j.biocon.2016.05.015.

Milly, P. C. D., et al. “Increasing Risk of Great Floods in a Changing Climate.” Nature, vol. 415, no. 6871, 2002, pp. 514–517., doi:10.1038/415514a.

Nolan, Rachael H., et al. “Causes and Consequences of Eastern Australia's 2019–20 Season of Mega-Fires.” Global Change Biology, 2020, doi:10.1111/gcb.14987.

NSW DPIE (Department of Planning, Industry and Environment) “Understanding the effects of the 2019-20 fires.” https://www.environment.nsw.gov.au/topics/parks-reserves-and-protected-areas/fire/park-recovery-and-rehabilitation/recovering-from-2019-20-fires/understanding-the-impact-of-the-2019-20-fires

Wooster, M. J., et al. “Retrieval of biomass combustion rates and totals from fire radiative power observations: FRP derivation and calibration relationships between biomass consumption and fire radiative energy release.” Journal of Geophysical Research Atmospheres, 2005, 110, doi:10.1029/2005JD006318

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327 FIGURES

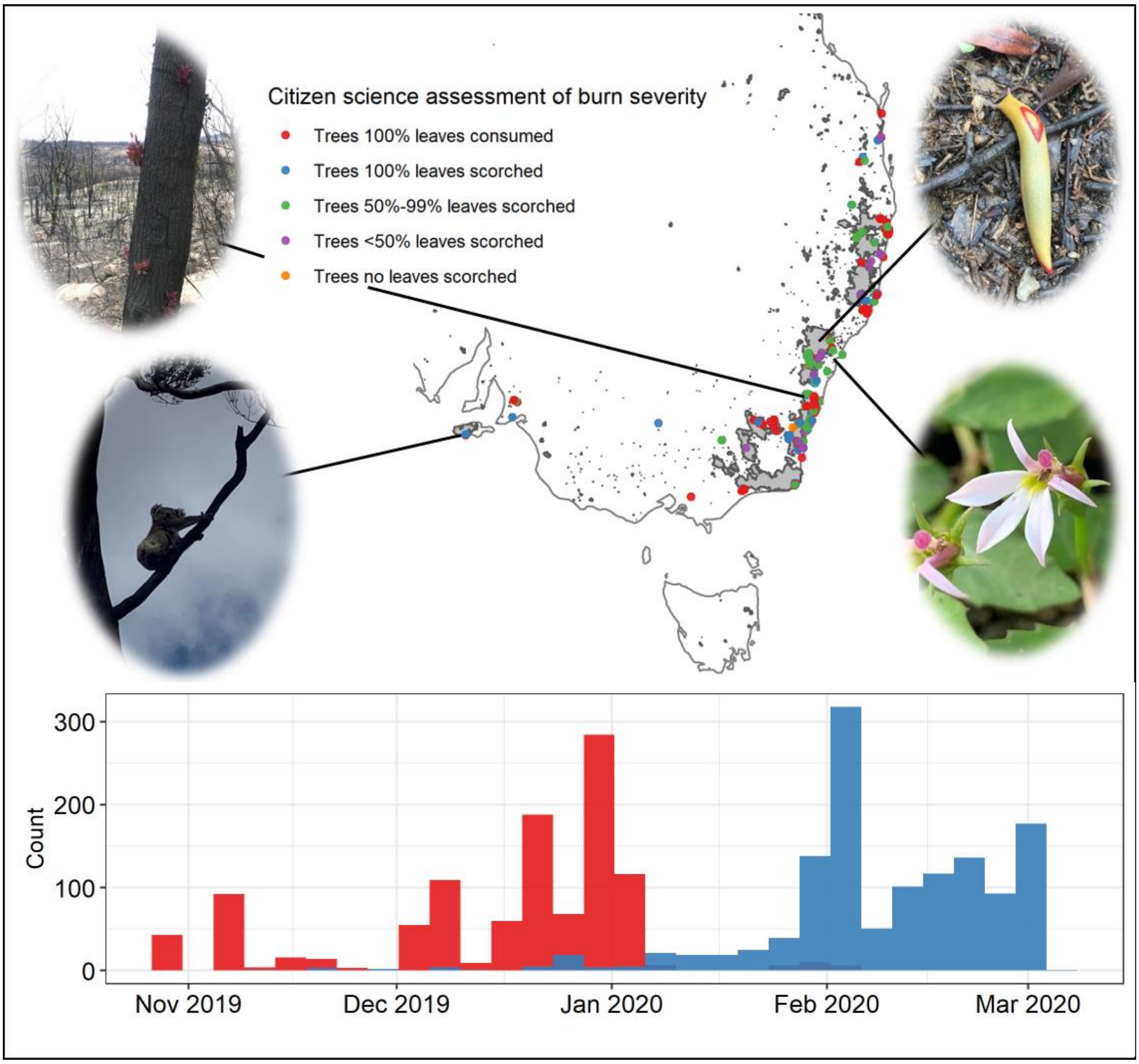

Figure 1. Map of fire extent (grey regions) in eastern Australia, with our citizen science derived measures of on ground burn severity (including five photographic observations and their contributors, top left burnt Eucalyptus: *motherj*; bottom left Koala: *tonia1971*; top right Red Triangle Slug: *mollynuge*; bottom right White Root: *gtaseski*) and a comparison between the timing of the fire front extent, measured in terms of numbers of hotspot data (red) and number of citizen science observations (blue).

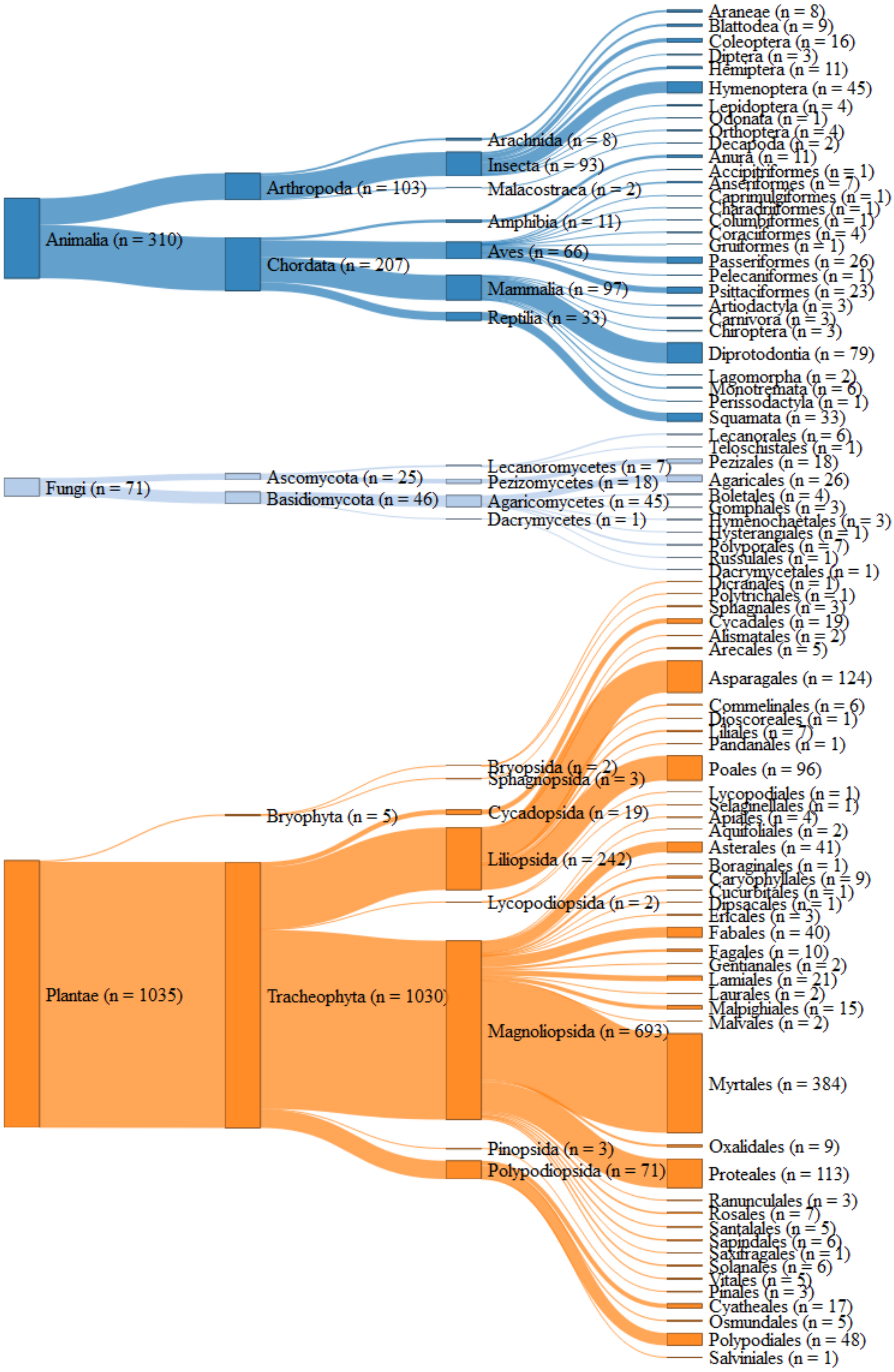

Figure 2. Taxonomic breakdown (kingdom, phylum, class, and order) and the number of identified observations (71% of the total observations were identified to order). There were two slime molds added to the project but not shown.

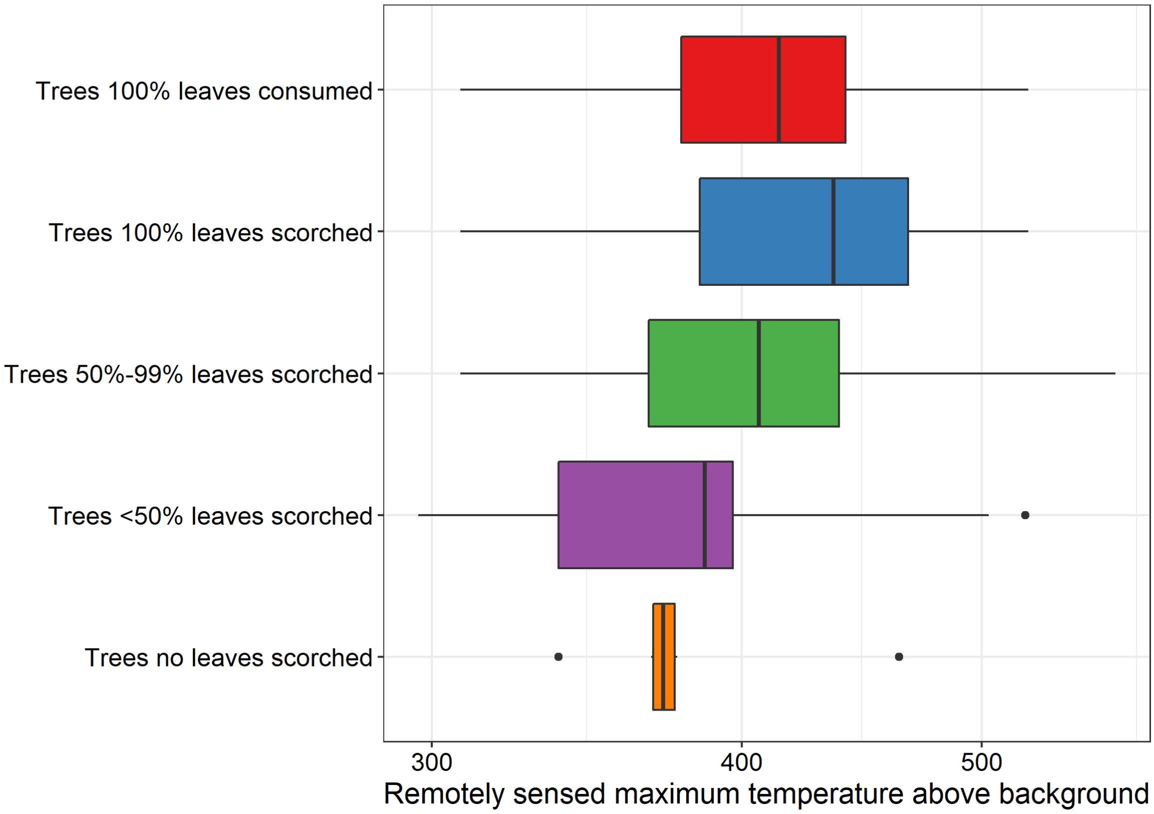

Figure 3. Relationship between the citizen science measure of burn severity and the remotely sensed temperature from the Digital Earth Australia hotspots data.

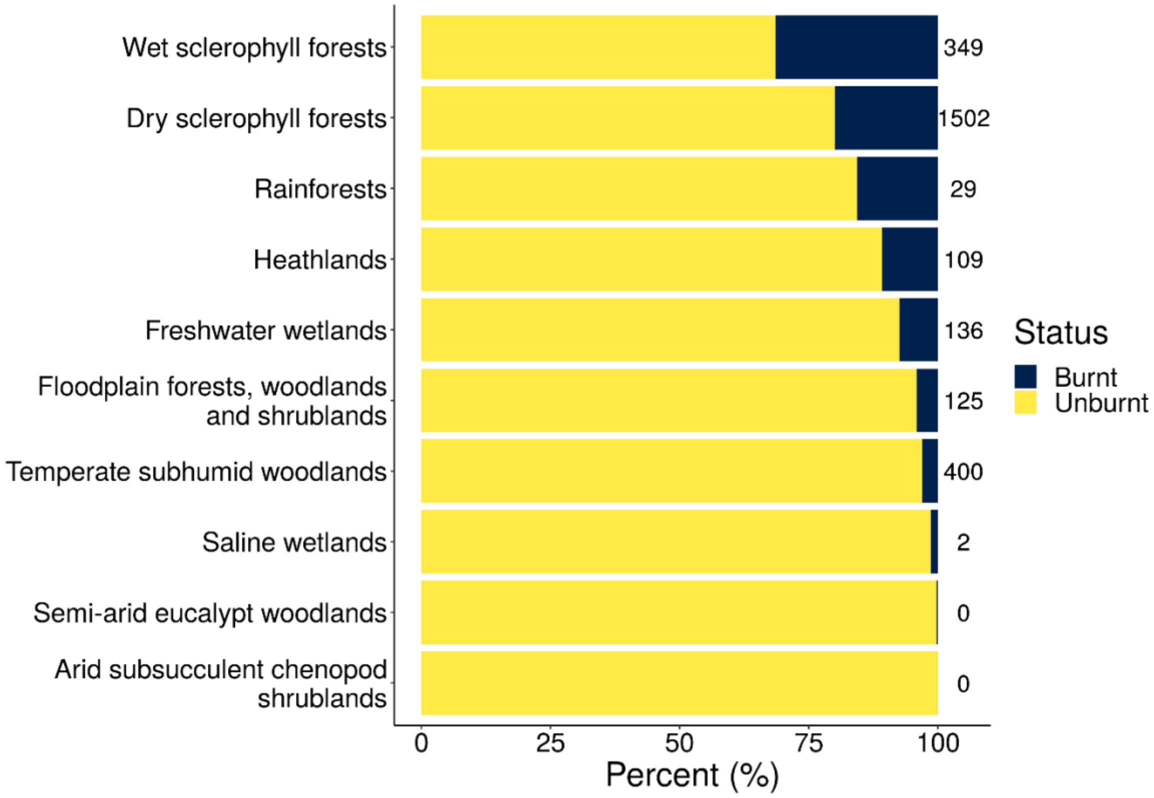

Figure 4. Percentage of burnt and unburnt area of affected national vegetation formations across temperate-subtropical south-east Australia during the 2019-2020 fire season. The number to the right of each bar indicates the number of iNaturalist observations recorded within that vegetation formation.

SUPPLEMENTARY FIGURES AND TABLES

Table S1. Pairwise effect sizes extracted from a linear model where the response variable was temperature and the predictor variable was our post-fire citizen science assessment of burn severity.

Contrast	Effect size	Standard error	Lower 95% CL	Upper 95% CL
Trees <50% leaves scorched - Trees 100% leaves consumed	-0.6609	0.1039	-0.8647	-0.457
Trees <50% leaves scorched - Trees 100% leaves scorched	-0.9720	0.0937	-1.1558	-0.788
Trees <50% leaves scorched - Trees 50%-99% leaves scorched	-0.5883	0.0938	-0.7724	-0.404
Trees <50% leaves scorched - Trees no leaves scorched	-0.1146	0.4152	-0.9292	0.700
Trees 100% leaves consumed - Trees 100% leaves scorched	-0.3111	0.0869	-0.4816	-0.141
Trees 100% leaves consumed - Trees 50%-99% leaves scorched	0.0726	0.0884	-0.1008	0.246
Trees 100% leaves consumed - Trees no leaves scorched	0.5464	0.4143	-0.2666	1.359
Trees 100% leaves scorched - Trees 50%-99% leaves scorched	0.3837	0.0750	0.2365	0.531
Trees 100% leaves scorched - Trees no leaves scorched	0.8574	0.4119	0.0493	1.666
Trees 50%-99% leaves scorched - Trees no leaves scorched	0.4737	0.4119	-0.3346	1.282