Global learnings for research impact in weed management in Australia

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Summary The Australian government is increasingly seeking evidence of a pathway to impact, and demonstration of impact, for research, as a measure of its return on invested taxpayer dollars. The government is seeking evidence of positive impact arising from research efforts, on society, the economy and the environment. This follows international efforts by countries such as the United Kingdom (UK), Canada and the Netherlands to do the same. In 2014, the UK Research Excellence Framework (REF) received 6679 case studies from UK Universities, demonstrating research impact on 'the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia', across individual and multiple disciplines.

Avenues of research impact can include results of collaborations with industry and community stakeholders. Demonstrating the impact of weed research, including management programs, is likely to become increasingly important in Australia. As such, active engagement in the development, or use of designated impact metrics from research idea to results adoption will become necessarily important, as will the development of case studies. This paper highlights some key international learnings for describing and/or measuring research impact as they relate to weed management.

Keywords Research impact, weed management, collaboration, industry, university, community, case studies, metrics, multidisciplinary.

INTRODUCTION

Sustainable weed management will be critical to global food security (Paini 2016, Westwood 2018) and natural ecosystem conservation (Pyšek *et al.* 2012) into the future. To be able to describe the value proposition of our weed research and management work to the public, as well as to policy makers and funders, the 'weeds community' needs to clearly articulate the positive and vital impacts we have on national and global production systems and the environment.

Increasingly, Australian research granting and investment bodies are seeking evidence of research impact (ARC 2018). This can either be retrospective, as is the case for the current ARC system, or as a forward forecast that sets out the business case for the research in competitive funding calls. This paper encompasses ideas for multiple uses of describing the positive real-world impact of weed research beyond academia.

There are many reasons for, and ways to assess, the complex mechanisms enabling the successful movement of knowledge from research to application and the delivery of tangible positive impact. For example, in utilising one such mechanism, (the Research Contributions Framework, Morton 2015), Morton (2017) and Morton and Casey (2017) found four lessons that could help maximise impact from future research. These would be equally applicable to weed research: '1. plan an impact strategy that addresses complexity from the start, and identifies key monitoring criteria, as well as risks and assumptions; 2. include stakeholder mapping to identify key actors who will be essential to taking recommendations forward, and allow time to build partnerships with them; 3. keep communication lines open from the start and throughout any project with partners and wider stakeholders; and 4. support and recognise key staff who act as knowledge-brokers.' This current paper investigates the ways authors of the 6679 Case Studies submitted to the 2014 United Kingdom (UK) Research Evaluation Framework (UK REF 2014) demonstrated positive impact on the environment, economy, society or technology from studies either directly about, or similar to, weed management research.

MATERIALS AND METHODS

The case studies in UK REF (2014) were searched employing the search terms 'weeds' and 'invasive alien species' in April 2018. Case studies identified under these search terms were evaluated and categorised into the pre-defined impact types of environmental, economic, societal or technological impact. Within these groups an analysis of actions leading to positive impact of the research in the real world was undertaken and is described.

RESULTS

A search of the UK REF (2014) database using the search term 'weeds' revealed 10 case studies, seven of which were directly relevant to weeds. Searches under the term 'invasive alien species' showed 617 case studies, of which case studies under the follow-

ing 'Units of Assessment' (UoA) are most relevant to weeds: Biological Sciences, 104; Agriculture, Veterinary and Food Sciences, 42; and Earth Systems and Environmental Sciences, 54. Within each UoA, it is possible to search for 'Impact Type' and the Impact Types evaluated as having most relevance to weeds are listed below for each of the three UoAs searched (Table 1).

Learnings and ideas for demonstrating the positive impact of research into weeds have been taken from both the case studies directly and also other similar case studies in the search results (Table 1).

DISCUSSION

The UK REF (2014) case study authors described and measured the positive impact of their research on society, the environment, and on both via improved technological solutions, at scales ranging from local to global. Advice to all levels of government and key non-government bodies improving policy, planning, strategy and action planning likewise were described at levels from influencing conservation plans covering target habitats, to advice imbedded in national and international policies such as those of the United Nations. These actions have led to widespread improved conservation status and farming practices. A wide range of media and public engagement activities has also been shown to increase public understanding and interaction in the scientific/management research area leading again to improved conservation and land use practices. Research advice was found to be included into policy and planning as an impact type of all three of the following: social; environmental; and technological areas. The impact activities learned from the case studies have been illustrated here as they would relate to weed management.

Social Impacts Research that resulted in changes in international and national public understanding of the research area and increased public actions towards the goals of the research area. Demonstrating social impact can include a measurement/estimate of the number of people exposed to various forms of media. Media included film production such as on nature channels, public lectures, images on stamps and focus images for parks signage. Media use examples described evidence of public discussion and debate through twitter, blogs, sharing of, and comments on, articles. Public awareness was also enhanced through numbers of books written for non-specialist audiences, and translated into multiple languages. Encouraging 'citizen science', using interactive websites, was an avenue for measuring public use and increased understanding, especially if the site invited public involvement in a project, for example, to count or monitor species spread or reduction.

Educational activities at primary and secondary levels illustrated research that had been used as building blocks for educational resources, with free lesson plans and linked multimedia resources. These case studies showed the resources had been used by large percentage of schools and had reached a large number of pupils in a given timeframe. The studies highlighted when the education resources were used internationally. At the tertiary education level, authors described impact in the context of inspiring young people to study their research area.

Research was shown to have had a broad impact once it had been incorporated into key public policies, planning, strategies and action plans.

Technological (often Economic) Impacts Some examples included commercialisation of a new method or diagnostic or treatment, and often the establishment of a spin out company. Technological impacts included improved manufacturing processes, and reduction in manufacturing wastage, leading to reduction in management costs in particular or improved conservation over multiple land uses. For technological equipment, the case studies described the number of units sold,

Table 1. 'Impact Types' relevant to weeds found in a search under the terms 'Invasive Alien Species' in three 'Units of Assessment' (UoA) on the UK REF (2014) Case Studies searchable database in April 2018, and for some, the percentage directly related to weeds.

Impact types	Biological Sciences	Agriculture, Veterinary and Food Sciences	Earth Systems and Environmental Sciences
Environmental	55(22%)	12(0%)	43(26%)
Economic	3	1	3
Social	4	5	3
Technological, also often Economic	30(0%)	18(0%)	3

including if the new method of making them/program/algorithm had been taken up by other major/global companies, which increased its usefulness and made it a mainstream tool. Research was classified as having high impact when it was used globally or across a range of crops/weeds/land management practices. Widespread or global use of knowledge and patented techniques, was therefore claimed by authors as having impacts on food security, sustainable crop production and farming profitability.

Predictive technology for growers was described, for example to sense disease/weeds and plan planting or treatments, as having positive impacts on decreasing both crop loss and use of herbicides. Along with these useful impacts, the author of this current paper would suggest also, technology that differentiates crops, native animals, insects, or whole of landscape sensitivity to weed control disturbance leading to the positive impact of improved timing and type of control on farms, and improved conservation. Biopesticides research was shown to have led to commercialised products that help farmers (and potentially others) overcome pest resistance. Whether similar avenues exist for the production and use of bioherbicides remains to be seen.

A technological impact was also the existence of a 'legacy' of young scientists trained by industry. Close collaborations between researchers, government bodies and scientific societies meant that research has been used by policy makers within that particular sector. Research was shown to contribute to weed control guidelines, regulations and policy planning in the UK, as well as abroad.

Environmental Impacts Use of research by government and non-governmental public bodies to produce targeted management plans or prescriptions was an indicator of environmental impact. Research also provided supportive evidence for management advice and advocacy work, and to inform government legislation and policy that led to incorporation into high level planning. This included scientific data on negative effects on biodiversity and economic costs resulting in increased general understanding of why weeds are problem species and need to be considered in a policy, planning strategy and legislation context. Robust scientific evidence was described as being used to underpin eradication and control programs, especially in complex land use systems. Similarly, research predictions of increased weed threats under climate change were incorporated into policy and planning documentation of various levels of government and peak environment bodies, especially in areas under threat from weeds. Evidence of environmental impact was also presented as improved control techniques that reduce negative environmental effects of existing techniques.

Case studies measured the extent of a natural ecosystem that had been restored utilising outputs from a particular body of research and plans developed using the research. They showed that researchers had improved conservation by providing expert advice and guidance on survey methodologies, taxonomy and basic biology, particularly if this advice had been widely adopted, regionally, nationally or globally. An important avenue of impact was where research influenced the 'management options' put forward under government schemes and grants by public and community bodies applying for funds to undertake biodiversity and weed projects. Overseas research investigating degradation caused by multiple land uses delivered impact by informing sustainable development plans across industry and the environment, and had increased use of 'Fairtrade' or equivalent certifications. Research was also shown to have underpinned the international agreement, the 'ICUN Red List of Threatened Species'.

Research to improve protocols for growth and use of biocontrol agents led to practice change at institutions/industries that produce/sell biocontrol agents. New genetic diagnostic tools for pest plant identification were shown, that led to improved plant tracking. Case studies described the assessment of risk to native or other species resulting in restrictions on imports of species known to be invasive and development of licensing arrangements to regulate the use of invasive species if for commercial purposes, and as a mechanism to impose penalties for misuse.

Research utilised in the above ways therefore led to best practice management for the target species and for whole landscapes. These kinds of activities by weeds researchers can lead to weed management that conserves species and ecosystems. This type of impact was described as a paradigm shift in weed prevention and management methods across the landscape, across land uses and between multiple partners.

Gaps Economic analysis methods used to assess degradation caused by weeds and amelioration in different systems were not directly described, although some case studies stated they had made a large contribution to the public and governmental understanding of the economic impact of invasive species.

CONCLUSION

The Australian and global 'weeds community', including researchers, industry members, policy makers and community land managers or practitioners need

to fully describe and measure, where possible, our efforts to improve weed biosecurity and management in Australia. As always, there is finite funding available from governments, industry and even individuals who volunteer their time, and this needs to be spent on the weed activities that result in the most positive outcomes for land conservation, farming practices, the amenities we all use, and the underlying environmental systems we all rely upon.

We need to embed the measurement and description of the positive impact of our weed research and management into our work. This will enable us to describe the value proposition of our work to funders, policy makers, planners and to the community in general. Our impact statements and examples will inevitably be used by funders for media commentary, and by others in social media posts. As such, impact measures need to be described with the intended audience and dissemination method in mind. This could build to create an improved cultural acceptance of the importance of weed biosecurity and management, which in turn will help those who are making strong weed management efforts in their industries, and in their policy and planning work. The increased literacy of our weed research community in defining our positive impacts gives us further license to operate. Therefore, if planning your research impact narrative becomes a core component of undertaking weed research work, it will give our community the mechanism to do more of the vital weed research that is needed to protect Australia's and the worlds ecosystems, farming systems and overall environments.

ACKNOWLEDGMENTS

Thank you to Cameron Begley, of Spiegare Pty Ltd for his continuing interest in the area of demonstrating the impact of research. Thank you also to all those who pursue a goal common to many of us, which is that our combined research and other work has meaning and use in the real world, as well as to those involved in basic research, who enable so much of what we know to be known.

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