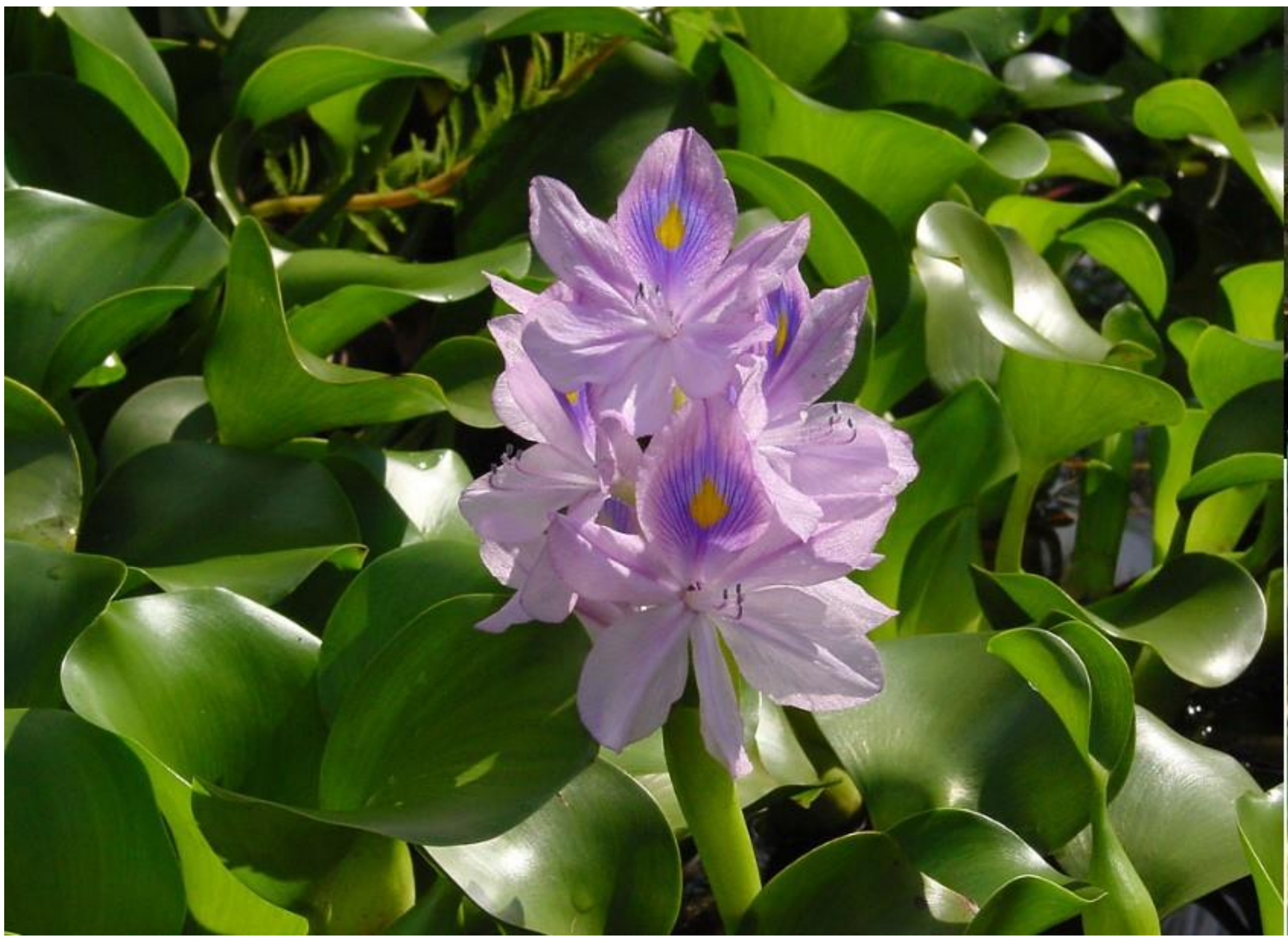
VOLUME 2, ISSUE 2, 2020



WEEDS

JOURNAL OF THE ASIAN-PACIFIC WEED SCIENCE SOCIETY

APWSS



EDITORIAL

'Alien' Species, 'Pertinacious Weeds' and the 'Ideal Weed' – Revisited

Nimal R. Chandrasena [1]

[1] Current Address: *Nature Consulting*, 1, Kawana Court, Bella Vista, NSW 2153, Australia

E-mail: **nimal.chandrasena@gmail.com**

Published: December 2020

Landmark Events in the evolution of *Weed Science*

A sound knowledge of the history of *Weed Science* – is essential for us weed scientists to adapt to emerging challenges and paradigm shifts in our dealings with weeds. It is helpful to know how we got to where we are in *Weed Science*.

This knowledge of history should include a good grasp of reflections and ideas of our founders, which defined the pathway for the discipline to evolve as an indispensable scientific endeavour it has now become. As in any discipline, there were seminal events, pivotal moments and key individuals whose efforts laid our foundations and pioneered a shared interest. In this Editorial, I wish to revisit a few of these.

Many of today's ecological and environmental issues are contentious, socially divisive, and appear intractable. They are, however, typical of complex issues that ecologists and natural resource managers have to deal with everyday and into the foreseeable future. Weed scientists are also continually exposed to complex issues related to pioneering species, or colonizing taxa (in other words, 'weeds') as they grapple with negative effects vs. positive effects of these extraordinary group of plants.

We must educate ourselves to interact and deal with weeds better while aspiring to protect our environment, biological diversity, and agricultural production. It is the responsibility of every weed scientist to study weeds to obtain meaningful information and provide critical analyses of weed-related issues to help inform and educate the public.

In this regard, Robert Zimdahl has elaborated on various moral, ethical, and contentious technical issues that have risen within the broader disciplines of agriculture and Weed Science, published in this journal (Zimdahl, 2019) and elsewhere (Zimdahl, 2010a; 2012; 2018). These analyses and viewpoints should be essential readings for the next generation of weed scientists.

Weedy colonizer species do pose significant challenges to some human endeavours, although not all such taxa are bad all the time, in all situations. Dealing with organisms that have colonizing capabilities is simply one element in our complex relationship with Nature.

As *Weed Science* took shape in the 1950s, our founding fathers, too, confronted challenges and issues, especially in understanding the ecological roles of pioneering species as part of plant succession. In the efforts to understand the roles of weedy species in nature and how they respond to human-caused disturbances, the direction of the discipline was almost certainly defined by growing concerns over the overuse of herbicides in the 1950s decade (Harper, 1956; 1957).

It is also true that *Weed Science* not only first emerged as a science, but also has continued to date under the dominating influence of discoveries and applications of a vast number of chemical herbicides.

Due to the strong marketing campaigns by herbicide manufacturers in the early days (1960s through 1990s), *Weed Science might have been properly called Herbicide Science* (Thill *et al.*, 1991). Lamenting on this negative perception, Donald Wyse (1992) stated:

> *"…A large portion of resources devoted to Weed Science have been devoted to herbicide research and promotion of their use. The over-emphasis on chemical weed control by many Weed Scientists will continue to retard the development of Weed Science as a balanced discipline…"* (Wyse, 1992).

Symposium on the *Biology of Weeds, 1959*

During the 1950s and 1960s, rumblings of trouble in the future were beginning to be heard (Duke, 2005). *Weed Science*, as a discipline, was heavily criticized as being a conduit for herbicide companies to market their products as they expanded.

Although the focus slowly changed to capture studies in weed biology, ecology, and non-herbicidal weed control methods, the negative perception that *Weed Science* was a discipline that was and remains focused on herbicides. Read any weed science journal - The dominant focus remains herbicides

Ideas and thoughts about '*know your enemy before you go to war*' and the need to better appreciate the biology and ecology of weeds came around that time. The need to '*know*' weeds better was of such importance that John Harper organized a symposium on the subject in 1959, under the auspices of the British Ecological Society at Oxford, April 2-4, 1959.

In the introduction to the symposium publication - *The Biology of Weeds* (Harper, 1960), he wrote that for many years, weeds had been regarded as inappropriate material for biological studies. Almost all of the weed biology studies, except for those causally related to weed control, had been severely neglected. Part of the problem why weeds were 'untouchables' among plants was the idea that the 'pure' botanist must be concerned only with 'natural' vegetation.

The standard view at that time was that these '*camp followers of cultivation'*, are the domain of Applied Botanists. Even as early as in the 1950s, only a decade after the first commercialization of 2,4-D (2,4-dichloro-phenoxy acetic acid), alarm bells were ringing loudly on its overuse. Harper warned that herbicide use was so widespread in Britain, Europe, and the USA that it ran the risk of potentially hijacking an emerging science. Introducing the 1959 symposium, he wrote, as follows:

> *"…this symposium has been concerned with the biology of weeds, which has been interpreted to exclude chemical control. This has been a deliberate policy, because symposia and conferences in weed control have been held in abundance. Herbicides are so widespread in use that they are beginning to form part of the 'normal' environment of weed populations.*
>
> *"...Already weed strains have been selected, which are resistant to some of the chemical herbicides. It will be a tragedy if the botanist does not take opportunities now offered to follow the influences of this most potent force on the distribution, frequency, evolution, and dynamics of weed populations…"*

The 1959 symposium turned the attention of weed researchers to focus on the taxonomy, biology, and ecology of weeds, including their reproductive systems, origins, habitat preferences, and evolution. It encouraged s the study of weed species from an individual perspective (autecology), and as part of plant communities (synecology).

Emphasizing the environmental harm that can result from the excessive use of herbicides, John Harper steered the directions weed research should take at this crucial meeting. This move was pivotal in the development of the discipline over the next 60 years. The scientific community listened because of the esteem with which Professor Harper was held. Three years earlier, Harper (1956; 1957) had prophetically warned of the likelihood of developing herbicide resistance in weeds.

History will record this 1959 symposium at Oxford as the first real attempt to broaden the framework for studying and understanding weeds, dissociating the subject from herbicide-dominated thinking.

Promoting ecology and biology, it paved the way for *Weed Science* to develop with confidence, as an important, multi-disciplinary science. Deliberations covered how weed management research is linked with other applied crop protection research, such as Plant Pathology and Entomology and also, the importance of population dynamics and taxonomy.

The attention of the gathering was also firmly on in-depth analyses of biological attributes that make species become weeds. There was emphasis on the quantitation of negative effects of a dominant, individual weed species, their populations, or mixtures of different species (communities), in food crops, or in other production systems (such as grazing and forestry), and on water resources.

The Symposium on the *Genetics of Colonizing Species, 1964*

A much more influential symposium – the *First International Union of Biological Sciences Symposia on General Biology* – was subsequently held in Asilomar, California, during 12-16 February 1964. The proceedings – *Genetics of Colonizing Species* - Edited by George Baker and Ledyard Stebbins, published in the following year (1965) must be regarded as the seminal landmark event in the evolution of *Weed Science*. The publication is recognized as one of the most widely read books in ecology and genetics (Barrett, 2001).

This is especially because it is at this symposium that several evolutionary biologists, such as Richard Lewontin and Ernst Mayr, made important contributions to the field of *Weed Science*, which, at that time, was struggling to find a firm scientific footing. I quote two examples below.

> *"…What would the ideal colonizer look like? That is pretty obvious; they would have effective dispersal mechanisms, high somatic plasticity, high inter-specific competitive ability; and the greatest degree of all three is most desirable…'* Lewontin (1965).

Lewontin, a Professor of Evolutionary Biology, answered the question, way back in 1965, at the Symposium, explaining what a good colonizer is. A crucial aspect of a good colonizer is the inherent, genetic variability available within the species and then, expressed in its population.

This variability in the genetic make-up, available within a population, rather than just in an individual, is what allows the species to respond well to variations in stressful environmental conditions they face during a colonization process. Different 'stress-tolerant' genes in the population get activated as a response to different environmental cues.

Their symposium deliberations shone a spotlight on how Darwin's theory of evolution via natural selection might be operating in Nature. As the Editors (Baker and Stebbins, 1965) stated:

> *"…the Symposium had as its object, the bringing together of geneticists, ecologists, taxonomists and scientists working in some of the more applied phases of ecology –such as wildlife conservation, weed control, and biological control of insect pests..."*

The explanation of possible genetic systems operating within 'colonizing species' brought the discourses within the discipline of *Weed Science* to a higher plateau than previous. Summarizing the famous 1964 symposium, Ernst Mayr, a renowned vertebrate zoologist, from Harvard, stated as follows:

> *"…Except for a few endemics, every species is a colonizer, because it would not have the range it has, if it had not spread there by range expansion, or 'colonization', from its place of origin..."* Ernst Mayr (1965)

Mayr's quote has gone mostly unnoticed in the history of *Weed Science*. However, it is significant as he highlights the similarities of 'weedy' pioneering plant species and other successful colonizers, such as house flies and rodents, and we humans.

All of the widespread species in the world have strong adaptations for range expansion. No species would be successful, from evolutionary or ecological viewpoints, *if they did not have some capability for range expansion from its place of origin*. Put simply, successful species <u>need</u> to have the biological attributes required and the capacity to colonize other suitable habitats.

Triumph after that depends on other factors that influence its reproductive success (inherent traits) and perpetuation of genes in the new environments through breeding and production of offspring.

✳✳✳✳

With a focus squarely on *Plant Science*, the symposium stimulated discussions on research on using weeds as model, experimental organisms to understand how plant populations behave over the next two decades. This emphasis, combined with studies on the biology, ecology and eco-physiology of individual weed species changed the direction of *Weed Scienc*e forever, which, up to that time, had an inordinately unbalanced focus on herbicides [1].

Concurrently, during this period of *ecological enlightenment*, the heightened awareness obtained on plant and animal population biology and ecological perspectives on weeds (i.e., related to succession, vacant niches, see Baker, 1965), brought in more 'science' to the *Weed Science* discipline.

By the early 1960s, other societies of biologists, especially, plant ecologists and taxonomists, influenced the directions of weed research significantly, across the globe. This brought about a change of focus of *Weed Science* from herbicides on to studies of weeds, as biological organisms, as well as correctly identifying individual species and their strengths and weaknesses (i.e., 'know your enemy before entering the battle').

---

[1] Robert Zimdahl offered a slightly different opinion (*personal communications*, Dec 2020) on the influence of the 1965 Symposium. While agreeing that Ernst Mayr's quote has hardly been quoted in the corpus of *Weed Science* literature, in his view, the symposium certainly stimulated discussions, perhaps more in the plant science world, but not necessarily, sufficiently, in the *Weed Science* world.

Stimulating the discourse on converting ecological theory into practical management of plant and animal populations, the *British Ecological Society* launched the *Journal of Applied Ecology*, in the heady days in the early 1960s. Launching the Journal in 1964, its first editors – Arthur Hugh Bunting and V. C. Wynne-Edwards - optimistically wrote as follows (see Ormerod and Watkinson (2000):

> *"…Ours is an age in which ecological thinking and methods can, more than ever before, contribute to the progress of mankind…'* (1964), Journal of Applied Ecology, 1, pp. 1-2*.*

Reviewing the literature, I find that the turnaround of focus to *understand weeds*, as purely a group of plants with special attributes for colonizing vacant niches, created by disturbances, was achieved in the late-1950s to mid-1960s period.

It is abundantly clear that the need to *understand weeds, as a basis for their control* was promoted by our founding fathers, at that time. They were also concerned about the potential for any 'new' technology, particularly, herbicide technology, to go wrong when it is used without an appreciation of unintended consequences and collateral damage.

Rachel Carson's *Silent Spring, 1962*

Apart from the *Genetics of Colonizing Spe*cies, we may also add Rachel Carson's major contribution, *Silent Spring*, published on 27 September 1962 (Carson, 1962) as a landmark, which influenced the development of *Weed Science*.

The book sounded an ominous warning to the scientific community and the public on the adverse effects of excessive pesticide use across USA. While the book's focus was largely on the persistent, organo-chlorine insecticides, such as DDT and its cousins (i.e., aldrin, dieldrin), Carson did touch on the potential negative effects of the large-scale use of herbicides as well.

The impact of *Silent Spring*, acknowledged as one of the most important and influential treatise of the 20th Century [2], was a vastly increased regulatory control of all pesticides, and the mandatory requirements of comprehensive research data on modes of action, efficacy, toxicology, and environmental fate of xenobiotics. The stringent approval requirements increased the research efforts on all pesticide applications. The additional costs for herbicide/pesticide evaluations slowed down new discoveries considerably.

On the positive side, the mandatory requirements for registration resulted in increased funding, which promoted closer working relationships between researchers, the pesticide and herbicide Industry, independent reviews, and efficacy evaluations.

In Zimdahl's view (*personal communications*, Dec 2020), the primary result of Rachel Carson's book was a steady and uniform desire among weed scientists, and especially the herbicide industry in the USA, to deny the legitimacy and correctness of her book. Many weed scientists dismissed her comments because she was, after all, only a botanist. According to at least a few detractors, she did not know any thing about weeds, or herbicides, and hence, her views did not apply to weed control with herbicides.

✻✻✻✻

With the recognition of the need to anchor *Weed Science* in its basic sciences – *Botany* and *Ecology*, over the next two decades, the emphasis shifted from herbicides to a more holistic approach to control and manage weeds. In many ways, in much the same way that dust storms in the 1930s galvanised action on the 'dust bowls' in the USA [3], a greater awareness of the problematic issue, raised with scientific data and information, spurred people on to find appropriate solutions. This change of focus led to the development of the now well-known Integrated Weed Management (IWM) approach (Thill *et al.*, 1991; Wyse, 1992; Zimdahl, 2012) and its wide-scale adoption, especially in the USA.

---

[2] (1) Griswold, E. New York Times (21 Sep 2012). How 'Silent Spring' Ignited the Environmental Movement (**https://www.nytimes.com/2012/09/23/magazine/how-silent-spring-ignited-the-environmental-movement.html**); (2) The *Discover Magazine* (8 Dec, 2006) listed *Silent Spring* as No. 16 of the 25 greatest science books of all time (**https://www.discovermagazine.com/the-sciences/25-greatest-science-books-of-all-time**).

[3] (1) 'Dust Bowls' is a term given to drought-stricken ~~southern plains~~ prairie states of the USA, particularly Oklahoma, which suffered severe *dust storms* during a dry period in the 1930s. As high winds and choking *dust* swept the region from Texas to Nebraska, people and livestock were killed and crops failed across the entire region, further aggravating the effects of the Great Depression (**https://en.wikipedia.org/wiki/Dust_Bowl**); (2) Fiona Harvey, 19 May 2020, The Guardian. Dust Bowl Conditions of 1930s US Now more than twice as likely to reoccur (**https://www.theguardian.com/environment/2020/may/18/us-dust-bowl-conditions-likely-to-reoccur-great-plains**).

Public concerns on the potential impacts of widespread pesticide use had also driven the science of managing insect pests towards integrated pest management (IPM) at that time. Following in the same direction, IWM was an effort to:

> *"…overcome the paralysis of the pesticide paradigm and conceive a Weed Science research program that addresses both society's perceptions of safety and the scientific community's perceptions of risks…"*
>
> Zimdahl (2012)

The discourses at that time responded to public pressure, and included scientific ideas on population and community ecology, the genetic basis of evolution, carrying capacity of ecosystems, limiting resources and limits of growth.

Arguments for reducing the large loads of herbicide and other pesticides used in agriculture swirled around in the 1960s and 1970s. A primary motivation was to achieve acceptable levels of environmental safety, while mitigating the negative economic impacts of weeds and pests with chemicals.

Whilst herbicide research continued on aspects, such as new discoveries, efficacy studies, reducing herbicide contamination of surface and ground water resources, and modifying application technology to increase weed control efficiency, IWM stimulated research and practical applications, incorporating all of the available weed control methods, based on ecological principles, weed thresholds, as well as economic goals of weed control (Thill, et al., 1991).

IWM also shifted the emphasis from 'weed control' to 'weed management', with the incorporation of knowledge of population biology (e.g., weed seed population dynamics; soil seed bank; species shifts over time) into control programmes. Aspects that our founders pushed for in the early 1960s.

Other vital elements in IWM included crop hygiene (preventative weed control); cultural practices (i.e., crop rotations, multiple cropping, and minimum tillage); and biological control. The primary intention of IWM was sustainable and ecological weed management, and large-scale reductions in the use of herbicides for weed control.

Conservation agriculture, with its emphasis on regenerating and retaining soil and crop health in an integrated manner, can be regarded as an off-shoot of sustainable agriculture, as well as an integration of principles of agro-ecology into IPM and IWM (Radosevich, et al., 1997; Altieri, 1999; Harker and Donovan, 2013).

However, away from agricultural fields, our knowledge about the ecological effects of colonizing species over long timeframes is quite limited. As a result, many of the claims against particular colonizing species, as the primary cause of biodiversity losses, are unsubstantiated allegations only.

✳✳✳✳

We must remember our founders for their contributions and the directions given at those seminal conferences to change course of Weed Science, as a discipline. We may also acknowledge the stimulation given by scientists, such as Rachel Carson, to look for ways reduce the overall use of pesticides and herbicides in managing pest species and thereby, lessen adverse environmental effects.

Nearly 70 years from our beginnings, *Weed Science* is now a mature science with a vast corpus of knowledge on specific, adverse effects of weeds in agricultural systems and other situations and how best to manage or mitigate such effects.

Even today, it is unfortunate that most published papers on weeds consider it an axiomatic truth that the presence of weeds, at whatever abundance, will always present a problem. This flawed thinking is what makes us fearful and ready to launch untenable offensives against the colonizing taxa.

If you were a real 'alien being', visiting the Planet Earth for the first time, looking around and perusing the literature on weeds, you would be thoroughly confused. All that this group of plants, branded as 'weeds', appear to be doing is to poison or hurt people, cause injury to livestock, reduce farmers' income, and agricultural productivity.

In some instances, they appear to, or are alleged to threaten other plant species and biodiversity and are blamed for it. The alien visitor would also hear some commentators deride colonizing taxa as some kind of '*alien invaders*' on the earth itself and 'as the second greatest threat to biodiversity' on the planet (see Chew, 2015).

It appears that weedy species cause a litany of other problems also to humankind, such as blocking waterways, prevent the growth of 'native' plant species, and reducing recreational opportunities, which are quite disturbing.

The alien visitor could be excused for being more frightened of meeting this group than an encounter with the human species!

Pioneering Thoughts

Humans have encountered pioneer species for millennia and have benefitted from them as plant resources. Until recent times, the interactions were without maligning of species. Ancient records indicate that humans have been using 'weedy' colonizing species for at least 10,000 years or more. The uses would have been primarily as edible food and sources of medicines and also as raw materials for various purposes including firewood. Weeds also featured strongly as fodder for domesticated animals in the past millennia, a practice that continues to date (see reviews by Altieri, 1999; Kim et al., 2008; Zimdahl, 2007; Chandrasena, 2008; 2014).

In those past millennia, weeds were not considered as major problem but only as an 'incidental issue' in cropping (Timmons, 1970). We also learnt to cope with them efficiently, as evident in the great successes of agricultural production.

The history of *Weed Science* documented so well elsewhere (Shaw, 1964; Timmons, 1970; Wyse, 1992; Evans, 2002; Appleby, 2005; Zimdahl, 2010a; Falck, 2010), demonstrates how the discipline helped to increase crop production and transform agriculture. This history also shows how the discipline then evolved and accumulated an impressive knowledge-base for dealing with colonizing plants, when and where they become problems.

∗∗∗∗

As I discussed (Chandrasena, 2020), since the early-1990s, the term '*Invasive Alien Species*' (IAS) has become familiar to a considerable segment of the scientific community and the public.

A significant portion of the *Weed Science* community has also adopted the IAS terminology, even though many ecologists are unconvinced about the underlying ecological concepts (Sagoff, 2002; 2009; 2019; Davis and Thompson, 2011; Davis et al., 2011; Guiaşu and Tindale, 2018). While debates about the appropriateness of the terminology still continue, the 'new' generation of weed researchers appear confused, as it is not always easy or possible to determine which species is 'native' or 'non-native' to a given region or continent.

The term '*alien*' is applied, nowadays, to both animals and plants with scant regard for what it means or why it was used by scientists of the past centuries.

One of the earliest Kew botanists who used the term '*alien*' was the British taxonomist Stephen Troyte Dunn (1868-1938) [4]. In introducing his book – *The Alien Flora of Britain* (1905), Dunn stated as follows:

> *"…The term alien is used here to designate any species which, though now spontaneous, originated in Britain through the human agency…".*
>
> *"...Now although alien plants are usually defined as above, and are frequently for that reason called "introduced plants" it is seldom possible to obtain any definite information as to the manner in which they actually arrived in the country..."*
>
> *"…The term "introduced plant", moreover, is not really distinctive, for all plants, native and otherwise, must have been originally introduced to their present habitats. In the great majority of cases botanists arrive at their conclusions as to the status of a species by a careful observation of its present circumstances in the British Isles, and also of its geographical distribution beyond them..."*
>
> *"…Thus, a species which exists in perfectly wild and natural surroundings, both here and in the neighbouring parts of the world, is deemed indigenous, for there is no reason to suppose that its presence is due to any agent but natural dissemination at the time when the flora of North-West Europe originated. If, on the other hand, a species is always found to be connected with artificial surroundings, it is classed as an 'alien'..."*

The early botanists of the 18th, 19th, and 20th Centuries recognized the role of humans in moving plants across biogeographical regions but also appreciated that natural agencies also cause long-dispersal of plants. Those days, as the human population grew and interactions across continents increased through trade, empire-building, conquests and colonization, many plant species spread widely through the human agency, partly by accident and partly by deliberate introductions.

It was important for botanists to understand and communicate to each other the factors that caused the changes in the biogeographical distribution of species, the agencies (both human and natural) and causes of spread and the habitat preferred by the species, which successfully established themselves in the new environments.

[4] Stephen Dunn served as the superintendent in the Department of Botany & Forestry (1903-1910) in Hong Kong. At Kew, before Hong Kong, Dunn had worked on compiling the 2nd supplement of the *Index Kewensis* (**https://en.wikipedia.org/wiki/Stephen_Troyte_Dunn**).

The early writings, particularly of Stephen Dunn, indicate a great deal of caution in categorizing plant species in this way, as it was difficult to assign any species as a '*native*' or '*introduced alien'* plant without historical knowledge.

As Marcus Hall, an environmental historian pointed out to me recently [5], Dunn's use of the term '*alien*' so clearly in his book's title suggests that the word had been around for some decades. This book appears to have put a stamp on use of the word '*alien*' for 'introduced' species, many of which had become weeds in Britain.

According to Marcus Hall, it is difficult to pinpoint the origin of the term. Variations of the English terms - *alien species, alien flora, alien fauna*, also appear in several foreign word equivalents. Certainly, the term '*alien species'* was well accepted by the 1930s, particularly in Britain, and in the USA, there are references to '*alien grasses'* as early as the 1910s. These terms date back in concept to the 19th Century. "*exotic*" is a much older term.

The word 'alien' (Latin, "*alienus*") means belonging to another, not one's own, unfamiliar, unconnected, strange, or foreign. And when *alienate* first appeared in English as a legal term in the mid-15th Century, it meant to transfer ownership of some property over to someone else, so that it is now 'foreign' or 'unconnected' to the transferee. It is unfortunate that it was used in reference to introduced plant and animal species.

As a botanist, Dunn would have dealt with large collections of specimens that had been stored at the Kew Herbarium. Subsequently, Edward James Salisbury (1886-1978) a Professor of Botany at the University College, London, popularized the use of the term '*alien*' in his book on "*Weeds & Aliens*" (1961). Salisbury was also the Director of Kew Gardens in London during 1943-56 and had access to century-old herbarium specimens. He also had a considerable interest in weeds [6].

A book, entitled "*Weeds and Aliens*", published while the discipline of *Weed Science* was taking shape, in the early-1960s, would have had an impact. However, as I stated earlier (Chandrasena, 2019), the term was cautiously avoided by others. The term was then, and is even now, superfluous to any sensible and enlightened discourse on weeds.

Of course, those 18th Century botanists knew that they were collecting specimens of common, as well as rare species and not aliens from another planet. Their purpose was not to slander plant species, but to caution other botanists on the risks of introducing plants across the continents, particularly with the exchanges of live specimens among botanic gardens.

Likely, they were also aware of spreading plant species along with movements of livestock, fodder, people, and military equipment, at that time, as Dunn has described in some detail his book (Dunn, 1905, Introduction, pp. xiii-xvi).

It is most likely that Salisbury followed Dunn's practice and used the term '*alien*' interchangeably with the term '*introduced*'. Nowadays, some authors use the term to refer to plants becoming weedy when transferred from their native to an *alien* environment, meaning a new environment. Here, while the emphasis is on the new environment, the organism is also regrettably branded as an *alien foreigner*.

The issue of whether, or to what extent, some 'non-native' species, introduced into a new environment, could cause harmful effects in the new home, are matters that Ecology and Weed Science can help resolve. Notwithstanding this, as a long-term 'weed watcher', I can emphatically state that calling all such species 'invasive', which is a keystone in the IAS terminology, is an unwarranted distraction.

Negative connotations of the term '*alien*' alienates people from potentially beneficial plant resources. It also prevents weed researchers from engaging with colonizing species appropriately. The IAS confusion has resulted in some scientists creating long lists of species as 'undesirable aliens' in different countries, which, it is alleged with no real evidence, may pose intolerable biosecurity risks.

Many potentially invaluable taxa have been maligned as 'unwanted plants' that can cause major problems not only in agriculture but also in the general environment. Ecological evidence, such as how a species behaves in one environment, is the basis of 'weed risk assessments' (WRAs), the primary tool for 'border control' in many countries.

However, the flip side of WRAs is that they have lead to the listing of potentially invaluable species as 'undesirable invasives', when such a calling is scientifically contestable. Also, the maligning of species as 'invasives' is at least partly based on human interests, life experiences, personal perceptions, 'likes' or 'dislikes' of species, all of which are subjective judgements, which are fraught with danger (see Harlan and de Wet, 1965; de Wet, 1966).

The flawed concept of IAS was, however, boosted through the 1990s decade, by discussion in the news media and in publications of such

[5] Marcus Hall (Institute of Evolutionary Biology & Environmental Studies, University of Zurich) *personal communication,* Oct 2020.

[6] E. J. Salisbury (Source: **https://en.wikipedia.org/wiki/Edward_James_Salisbury**).

organizations as the Nature Conservancy Council in the USA, and the National Geographic Society.

The incorporation of the notion '*alien*' species threaten ecosystems and biodiversity in the *UN Convention of Biodiversity* (1992) gave authority to this claim, without much scientific evidence [7]. My view is that Article 8 (h) of the CBD could have been better worded with a more detailed explanation and scientific qualification.

Despite the constant maligning of colonizing plant species by the alarmists ('invasion biologists') with a myth that '*invasive aliens may engulf the world*', we need not fear them. The better we understand weeds as a group of colonizing pioneers, the faster we relieve ourselves of such fears and anxieties. I re-iterate, to 'live with weeds', we must understand and respect them better than we have done so far (Chandrasena, 2014; 2019).

However, one of the desirable effects of the IAS debate is that it has created a greater awareness in the public of 'weeds' and their potential negative effects, as well as positive and beneficial effects.

We must thank George Baker and other botanists, such as Asa Gray, John Harper, Arthur Hugh Bunting and Jack Harlan, for describing in fairly accurate terms what colonizing plant species are. The contributions of evolutionary biologists, such as Richard Lewontin (1965) and Ernst Mayr (1965) are also important in characterizing successful plant or animal colonizers as pioneering and highly resilient species and not 'aliens'.

A dip into this history, which placed the discipline of *Weed Science* in its foundational footing, is important, so that the new generation of weed scientists would be better equipped to deal with contentious issues related to weeds.

Asa Gray and 'Pertinacity' in weeds

Ideas about botanical characteristics and behavioural aspects of weeds 'as a group' arose in the mid-to-late 19th Century. In this regard, the contributions of the renowned American Botanist- Asa Gray (Figure 1) need to be recognized by all weed scientists [8].

Gray's article (1879), on the '*predominance and pertinacity of weeds*', probably inspired others to look for botanical attributes that characterized weeds. In the article, Gray highlighted the close relationship between weeds and human endeavours, as follows:

> *"…A weed is any plant which obtrusively occupies cultivated or dressed ground, to the exclusion or injury of some particular crop intended to be grown. Thus, even the most useful plants may become weeds if they appear out of their proper place.*

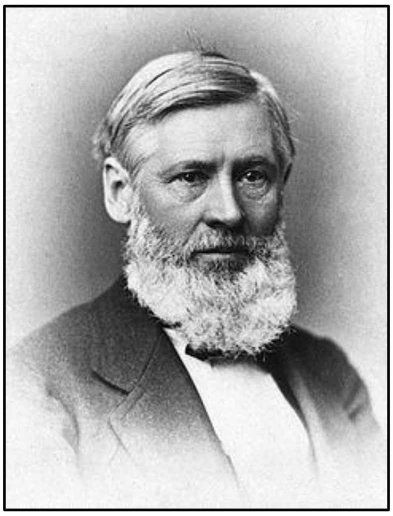


Figure 1. Asa Gray (1810-1888) (**https://en.wikipedia.org/wiki/Asa_Gray**)

> *"...The term is sometimes applied to any insignificant-looking or unprofitable plants which grow profusely in a state of nature; also, to any noxious or useless plant. This excludes predominant indigenous plants occupying ground in a state of nature. Such become weeds when they conspicuously intrude into cultivated fields, meadows, pastures, or the ground around dwellings..."*

> *"…Many are unattractive, but not a few are ornamental; many are injurious, but some are truly useful. White Clover is an instance of the latter. Bur Clover (Medicago denticulata) is in*

[7] The ***Agenda 21*** for Sustainable Development, drawn at the UN's famous *Earth Summit* (Rio Conference, held in Rio de Janeiro, Brazil, 3-14 June 1992), a 351-page document, mentions the terms - 'weeds' and 'herbicides', each, only once. However, the *Convention for Biological Diversity* (CBD), also drawn at the same Summit, gave the terminology related to '*invasive species*', its recognition (Source: **https://web.archive.org/web/20090510093432/http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm**).

[8] Asa Gray was Fisher Professor of Natural History, Harvard University, 1842–73. He wrote numerous botany textbooks and on the North American flora. He was also the President of the American Academy of Arts and Sciences (1863–73); of the American Association for the Advancement of Science (1872), Regent of the Smithsonian Institution (1874–88), and Foreign member, The Royal Society of London (1873) (Source: **https://www.encyclopedia.com/people/science-and-technology/botany-biographies/asa-gray**).

California very valuable as food for cattle and sheep, and very injurious by the damage which the burs cause to wool…"

"…In the USA, and perhaps in most parts of the world, a large majority of the weeds are introduced plants, brought into the country directly or indirectly by man. Some such as Dandelion, Yarrow, and probably the common Plantain and the common Purslane, are importations as weeds, although the species naturally occupy some part of the country..."

In my reading of history, Gray was the most eminent 19th Century botanist, who first questioned: "*Why are weeds so pertinacious, aggressive, and successful?* *Are their common characteristics that give weeds an advantage over others?*"

Gray used an unusual term - '*pertinacity*' to describe the attributes of weedy species, such as persistence, tenacity, and stubbornness. Although he called these specific 'weedy' attributes, such characteristics are behavioural, rather than truly botanical and heritable. Yet, he did recognize certain qualities in many weeds, which were better explained by George Baker and others in subsequent years.

The term **pertinacity** describes the quality of persistent tenaciousness, i.e., sticking with something, not giving up, no matter what. It is a type of persistent determination and is a mix of courage, conviction, and a little stubbornness.

Gray was also clear in his mind that some American weeds were immigrant species from the Old World, which originated in the 'forest-covered' regions of Europe. Naming several such species, he suggested that many such species followed 'husbandmen and flocks', and spread far and wide by sheep and cattle, as agriculture and pastoralism expanded in the continent, prior to migration to the New World via the human agency.

As far as Gray was concerned, the prevalence and dominance of both European weeds (Old World) and American weeds (New World) could be explained by the disturbances, caused by '*sudden*' land use changes and '*communication changes, such as the railroad*' that were occurring in the American continent, at that time.

Gray (1879) also highlighted the spread of both categories of weeds '*step by step, and somewhat in rapid strides'* across the USA, caused by livestock, movement of feedstock, people, and equipment associated with humans.

Writing 140 years ago, Gray also concluded that self-fertilization was not a prerequisite for plants to become aggressive and predominant weeds, whether they be European immigrants arriving in the Eastern States (of USA), or those spreading in the Western States, such as California (quote below).

"...Self-fertilization is neither the cause nor a perceptible cause of the prepotency of the European plants which are weeds in North America. A cursory examination brings us to a similar conclusion as respects the indigenous weeds of the Atlantic States, those herbs which under new conditions, have propagated most abundantly and rapidly, and competed most successfully for the possession of fields that have taken the place of forest..."

We now know that many colonizing taxa are adapted for both self-fertilization and cross-fertilization. A large number of taxa get cross-fertilized through wind (e.g., grasses) and those that produce attractive flowers, by insect visitors.

Gray's critical observations on the persistence, tenacity, and stubbornness of some weedy species, shed an early light on botanical attributes, ecological behaviour, and characteristics of weeds.

From a historical viewpoint, it is important to note Gray's writings, which also showed how weeds cross continents, and then spread following human immigration ('*weeds as shadows of men'*). He also understood and wrote about 'disturbances' and landuse changes, perhaps, the most important two key drivers, which assist weeds to be established.

George Baker and the '*Ideal Weed*'

Now I wish to revisit Dr. Herbert George Baker's characterization of the 'Ideal Weed' and discuss issues related to this enlightened understanding of colonizing species. I am motivated by the constant stream of articles that I read in the submissions received by this Journal. I am distressed that most papers appear to start with the premise that an all-out assault on weeds with herbicides is a must to increase crop production or manage our environmental assets. This highly questionable view needs to change.

In 1965, Herbert George Baker [9], from the University of California, Berkeley, provided what most weed scientists consider the most elegant ecological definition of what a weed is (Baker, 1965).

[9] H.G. Baker was a British-American botanist and evolutionary ecologist who was an authority on pollination biology and breeding systems of flowering plants. (Sources: H.G. Baker - In Memorium (**https://senate.universityofcalifornia.edu/_files/inmemoriam/html/bakerhg.htm**); and (**https://en.wikipedia.org/wiki/Herbert_G._Baker**)

"…A plant is a weed if, in any specified geographical area, its populations grow entirely or predominantly in situations disturbed by man, (without, of course, being a deliberately cultivated plant). Thus, weeds include plants which are called agrestals (they enter agricultural land), as well as those which are ruderals (and occur in waste places as well as along roadsides)…"

"…In many cases, the same species occupy both kinds of disturbed habitat. Ruderals and agrestals are faced with many similar ecological factors, and the taxa which show these distributions are in my usage, 'weedy. Such disturbed habitat is mostly, but not exclusively, associated with man's activities and are at least partially created by man…"

Figure 2. Herbert George Baker (1920-2001) (Source: https://en.wikipedia.org/wiki/Herbert_G._Baker)

Baker, then went on to produce a list of attributes (Table 1) that depicted a successful weed: an '*Ideal Weed*'. By comparing traits of 'weedy' and 'non-weedy' relatives of the same genus (called, 'congeners'), he proposed that species, which exhibit several of the traits would be significant weeds. In contrast, those that display a few of the traits would be minor weeds. Colonizing species possess some or most of these characteristics.

Baker explained that the more of these characteristics an individual species has, the 'weedier' it would be. *Fortunately, there is no single claimant weed owning all of these characteristics collectively.* Those that depend on seeds for will grow fast to reproductive maturity. They will produce large numbers of seeds, some of which live long buried in the soil. While some seeds may germinate quickly, a portion will remain dormant until conditions become favourable for germination.

At least 85 years after Asa Gray's observations, in describing '*The Ideal Weed'*, Baker recognized '*self-compatibility, but not complete autogamy or apomixy*'; and '*cross-pollination by unspecialized visitors or wind*' as major characteristics of such taxa, along with 'phenotypic plasticity' and 'environmental adaptability' (Table 1).

Baker proposed that colonization is likely to be more successful for species with an ability to self-fertilize, and thus, to establish new populations as single individuals. As a result, self-compatibility, he suggested, should be common among colonizing species.

Table 1 Baker's 'Ideal Weed' Characteristics

Category	Characteristic
Seed bank-related:	• Germination requirements fulfilled in many environments. • Discontinuous germination and great longevity of seed.
Vegetative growth-related:	• Rapid growth through vegetative phase to flowering. • If a perennial, vigorous vegetative reproduction or regeneration from fragments; • Brittlenenss, so as not to be drawn from ground easily. • Ability to compete interspecifically by special means (rosette, choking growth, allelochemicals).
Reproductive Phase:	• Continuous seed production for as long as conditions permit. • Self-compatibility, but not complete autogamy or apomixy. • Cross-pollination by unspecialized visitors or wind. • Very high seed output in favorable environments. • Production of some seed in wide range of environmental conditions; tolerance and plasticity. • Adaptations for short- and long-distance dispersal.

This idea, labelled by Stebbins in honour of Baker as ‘***Baker's Law***’, was influential in discussions of the evolution of sexual-systems and mating-systems in species, which are successful in establishing populations through long-distance dispersal in different environments.

Baker’s Law describes the benefits of self-compatible hermaphroditism in highly successful species for their establishment, following long-distance dispersal. In the 1950s and 60s decades, these ideas were important to understand not just island colonization by successful colonizers but also the constraints imposed by low-density conditions (lack of mates) on plant reproduction.

Baker was also the first to really stress life-history considerations and the importance of local environmental conditions for understanding the evolution of mating patterns in the successful colonizing plant species. In describing the characteristics of ‘*The Ideal Weed’* (Table 1), Baker recognized cross-fertilization by unspecialized insect visitors (such as ants) or wind-pollination, both of which are predominant in grasses (Poaceae) as important mechanisms for successful colonizers.

The effect of Baker, along with others, such as Stebbins, has been significant in Weed Science's evolution, even though the discipline has long suffered from being sucked into the vortex and belief that herbicides will solve all weed problems. Discussions on the evolution of weeds (see Baker, 1972; 1974) helped draw the emerging discipline away from herbicides into botany and ecology. The latter placed Weed Science within the realm of a broader scientific endeavour, incorporating research into plants' genetic systems and evolutionary biology.

In paying homage to these outstanding evolutionary biologists, Spencer Barrett (2001) explained that the tremendous interest in the ecology and evolution of plant reproduction during the 1980s, 90s decades is in no small way due to Baker’s early influence in stimulating research in this field.

Several of Baker’s reviews, such as ‘‘Reproductive Methods as Factors in Speciation’’ (Baker, 1960) and ‘‘Evolutionary Mechanisms in Pollination Biology’’ (Baker, 1963), promoted new research directions and influenced forging cross-disciplinary links between plant ecologists and those in genetics and evolutionary biology (Barrett, 2001).

Baker’s list has been heavily used in weed ecology studies and is often used to predict which weeds will become more problematic in different habitat. In my view, the fundamental proposition Baker made remains the keystone of *Weed Science*, and the list is where modern teaching of the discipline should also begin. Agricultural scientists, in particular, would benefit from such a deeply biological and ecological understanding of weeds, as species, before they attempt weed control.

As John Harper explained in *The Population Biology of Plants*, in disturbed habitat, weeds can be better managed by understanding how individuals in plant populations interact with each other and the environment, and by manipulating factors that maintain their field populations (Harper, 1977).

This, however, requires knowledge of both weed biology (life cycle strategies of individual species) and ecology (interactions of a weed with both its biotic and abiotic environment, including the soil environment).

Flexibility in reproduction is common in many weeds, as the subject specialists know well. Baker himself stated that “*weeds are excellent subjects for the study of microevolution*”. In any given species, genetic variations may not be present to control all of the ‘weediness traits’ equally.

In his contribution to *Weed Science*, Baker introduced the concept of ‘‘general-purpose-genotype’’ to refer to colonizing species that possess broad ecological tolerance to a wide range of environmental conditions but are often displaced from undisturbed communities by specialists with a high degree of local adaptation.

While confirmation of the existence of general-purpose-genotypes within plant or animal populations has remained elusive; this embryonic idea stimulated research on phenotypic plasticity and the evolution of specialist versus generalist strategies, to be successful colonizers (Barrett, 2001).

Individuals colonizing a new habitat often face the fundamental problem of a lack of mates. Baker hypothesized that species with the ability to reproduce uniparentally are more likely to successfully colonize new areas compared with species that rely on mates for propagation (Baker, 1955). While the scenario of island colonization and establishment originally influenced his thoughts, he later applied this concept to the evolution of weedy species that colonize agricultural landscapes (agrestals) and those that dominate in waste or poorly-managed areas, such as roadsides and railroad tracks (Baker, 1965).

The influence of Baker’s ideas on the origins and evolution of weeds and breeding systems of colonizing species has been quite significant over the past several decades, as shown in two such weed research studies, highlighted below.

In one study, on the genetic expressions of weedy traits in common morning glory (*Ipomoea purpurea*), Chaney and Baucom (2012) found increased ‘weediness’ in the species to occur through selection on the reproductive output and competitive ability, rather than through selection on growth rate. Such research shows which weedy traits are more significant in a given species in determining how it would respond to different environmental stresses.

In another study, Van Eten et al (2017) agreed with Baker's view (Baker, 1991) that weedy species were excellent models to examine the breeding systems that allow species to successfully colonize novel environments. Suggesting that '*not all weeds are created equal*', the authors examined the hypothesis that weedy plants have an increased likelihood of being self-compatible compared with 'non-weedy' plants, a hypothesis derived from the afore-mentioned Baker's Law.

The study used an analysis of a combined database of the weedy-status (weedy or non-weedy) and introduction-status (introduced or native) of plant species found in the USA with a database of plant sexual systems, to determine whether native and introduced weeds varied in their sexual systems compared with native and introduced non-weeds.

The results showed that introduced weeds were overrepresented by species with both male and female functions present within a single flower (hermaphrodites) whereas weeds native to the USA were overrepresented by species with male and female flowers present on a single plant (monoecious species). Overall, the results supported Baker's Law at the level of the sexual system, thus providing further evidence that uni-parental reproduction is an important component of being either a native American or introduced weed from overseas.

As Baker suggested, species that reproduced uniparentally were more likely to successfully establish in a new habitat, where, initially, mates may be lacking for reproduction (cross-fertilization).

Conclusions

A primary intent of this Editorial is to encourage weed scientist and weed managers, across continents, to think differently about weeds.

The collective wisdom of all weed scientists and other specialists, such as social scientists and those who specialize in ethnobotany appear important in this regard. We must aspire to bring about a change in farmers' mind set, as well as an attitude change among landholders and governments.

Relaxing the attitude towards colonizing species will come with time, but this can be hastened by economic incentives to manage weeds as part of the biodiversity within individual farmlands and vast farming landscapes, rural areas, or countryside. The recognition of biodiversity values of weeds and the tolerance of beneficial weeds in arable weeds has been recommended in Western European countries, including the UK (see discussions in Chandrasena, 2008; 2014).

I contend that revisiting the attributes of successful colonizers, as our founders did, would make us better understand weeds. Attention should focus on the processes by which weedy taxa 'colonize' new habitat.

If one understood the factors that determine the outcome - success or failure of those colonization attempts - that would undoubtedly be helpful in how we may respond to an undesirable colonization event, or perhaps, enhance our response to desirable colonization.

Baker, in his last decades of life did not get involved in the controversy created by the 'invasion biologists. Barrett (2001), who knew Baker well, wrote that Baker was one of the least judgmental people he had ever met as the latter rarely took a public stand on controversial issues. However, I have no doubt, that in discussing the breeding systems, pollination and evolution of weedy species, Baker avoided the use of the term 'invasion'. His preference was to use the more ecologically correct term 'colonization', which is a component of plant succession.

The resilience of weeds, their tenacity, and the capacity to adapt to environmental disturbances need to be recognized not just as harmful but also as potentially beneficial. It is clear that *the very success of these plant taxa in the environment is also their weakness.* Their verdant growth, abundance, and persistence, in some situations, is what brings them into conflicts with human objectives.

Perhaps, a deeper ecological understanding would help modify our attitudes allowing us to avoid conflicts with potentially useful colonizing plant taxa and getting into situations from which we cannot win.

✳✳✳✳

A critical issue for *Weed Science* is the persistent slandering of colonizing plants as 'invasives' by some. Such disparaging inhibits studying them and appreciating their redeeming values and thereby welcoming them into our lives and environment. The prevailing negative perception that all weeds are bad, under all circumstances, needs to change. Addressing this anomaly requires recognition of the beneficial effects and values of colonizing plants, as part of the Earth's rich bio-diversity.

Shifting the emphasis of weeds from '*foe' to friend*' requires vigorous campaigning by enlightened weed scientists and ecologists, working within or outside *Weed Science*. Presently, positive engagement with weedy species is championed only by popular websites and patrons of sustainable lifestyles and herbal medicine who are outside the *Weed Science* community.

There is also a question we must content with – *who would pay for long-term studies on the beneficial effects of colonizing species?* As the history of *Weed Science* shows, only chemical companies were willing to fund applied weed research, because of the profits they could derive from herbicides. Despite the alarming rise of herbicide-resistant weeds, across continents (Heap, 2020), funding for herbicide research continues unabated even today.

There is no simple remedy for weed problems in their many manifestations. Therefore, we need to continue our studies on the best management strategies and control tactics to manage their negative effects. Thanks to contributions from founders, such as Asa Gray and George Baker, *Weed Science* does understand quite well the reasons why colonizing species come to dominate landscapes. We also know a great deal about how to manage them.

Weed management approaches need to be designed to prevent the introduction of potentially problematic colonizing taxa to new habitats and to provide rapid responses to minimize undesirable effects where conflicts arise between man and colonizing species.

Alternatively, we must come to an accommodation that such an introduced species, may, perhaps, establish successfully and expand its territory, producing a variety of effects, some of which could be at least temporarily undesirable from a human point of view. It is my view that nearly all other plant and animal species will accommodate the 'foreigner' because that is how Nature responds.

I believe that management of colonizing species should be done best with a deep and proper ecological understanding of such species. Management should also be undertaken with a balanced view of economic, environmental, and social implications, but without dramatizing weed issues, and certainly avoiding messages that create a visceral dislike for the colonizing plant taxa.

As I have discussed in this Editorial, our founders were emphatic in explaining that weeds are botanically only 'colonizing plants', and their management will be best undertaken within an ecological framework. Wherever or whenever man disturbs a habitat, they will be among the first *pioneers* to make use of the opportunity of space ('pioneers of secondary succession', *sensu lato*, Bunting, 1960).

Downplaying this ecological emphasis, because of a focus on herbicide-based weed control, is disingenuous. In natural or man-made ecosystems, many weeds serve valuable ecological functions that need more recognition. Examples of their complex biological role, such as providing resources for wildlife, pollinating insects, slowing erosion, building soil, and generally enriching biological diversity, are abundant in global literature; these need to be studied more and given more extensive publicity.

In a strategic approach to managing weeds, more people – weed scientists and students – should explore different ways of using these taxa for improving not just the environment but also the 'human condition'.

A key to sustainable living is to *learn from weeds* to be more resourceful and *not ask for more*. If all men become thrifty, and asked for less, we could reduce our environmental impacts, both as individuals and as societies. Such a change would make our Earth a much safer place for all species.

Negative assumptions on weeds, formed over about two centuries in the field of agriculture, have inhibited ecologically-oriented weed research in areas outside agriculture. Such inhibitions need to be removed in the future to bring about a balance in the scientific discourses and messages to the public.

To end this Editorial, I would reiterate that insights about how our founders "saw" colonizing species are critically important for the next generation of weed scientists. As I said previously (Chandrasena, 2019), quoting Marcel Proust, '*without history man is nothing*'. Through a study of man's historical relationships with weeds, the next generation of weed scientists must realize that *weedy species are no more villainous than man himself*.

With or without the presence of humans on the planet, colonizing species will play vital roles in stabilizing the earth's damaged ecosystems. They will also survive any catastrophe on the earth much better than humans would.

Acknowledgements

I thank Robert Zimdahl, Raghavan Charudattan and David Low for reviewing this Editorial and providing valuable suggestions for improvement.

I also acknowledge the sources (Wikipedia), from which the photographs of Asa Gray and George Baker were obtained purely for educational purposes and not for any commercial gain.

Literature Cited

Appleby, A. P. (2005). A history of weed control in the United States and Canada—a sequel. *Weed Science*, 53: 762-768.

Altieri, M.A. (1999). *Agroecology: The Science of Sustainable Agriculture*. 2nd Ed. Westview Press, Colorado. 433 pp.

Baker, H. G. (1955). Self-compatibility and establishment after ''long-distance'' dispersal. *Evolution*, 9: 347–348.

Baker. H. G. (1960). Reproductive methods as factors in speciation in flowering plants. Cold Spring Harbour Symposium on. Quantitative Biology, 24: 177–191.

Baker, H. G. (1963). Evolutionary mechanisms in pollination biology. *Science*, 139: 877–883.

Baker, H. G. (1965). Characteristics and Modes of Origin of Weeds. *In*: Baker, H. G. and Stebbins, G. L. (Eds.) *The Genetics of Colonizing Species*. Proceedings 1st International Union of Biological Sciences Symposia (General Biology). Academic Press. New York. 147-169.

Baker, H. G. (1972). Human influences on plant evolution. *Economic Botany*, 26: 32–43.

Baker, H. G. (1974). The Evolution of Weeds. *Annual Review of Ecology and Systematics*, 5: 1-24.

Baker, H. G. (1991). The continuing evolution of weeds. *Economic Botany*, 45 (4): 445-449.

Baker, H. G. and Stebbins, G. L. (Eds.) (1965), *The Genetics of Colonizing Species*. pp. 147–172, Academic Press, New York.

Barrett, S. C. H. (2001). The Baker and Stebbins Era comes to a Close. *Evolution*, 55 (11): 2371–2374.

Bunting, A.H. (1960). Some reflections on the ecology of weeds. *In*: J. L. Harper (Ed.) *The Biology of Weeds.* Blackwell Scientific, Oxford. pp. 11-25.

Carson, R. (1962). *Silent Spring*. Houghton Mifflin Company, Boston, New York, 367 pp.

Chandrasena, N. R. (2008) Liabilities, or Assets? Some Australian Perspectives on Weeds, *In*: Utility of Weeds as Bio-Resources (Eds. K. U. Kim, D. H. Shin & I. J. Lee), Kyungpook National University, Daegu, Korea, 9-56.

Chandrasena, N. R. (2014). Living with weeds – a new paradigm? *Indian Journal of Weed Science*, 46(1): 96-110.

Chandrasena, N. (2019). Seeing 'Weeds' with New Eyes. *Weeds*, 1 (2): 1-12.

Chaney, L. and Baucom, R. S. (2012). The Evolutionary Potential of Baker's Weediness Traits in the Common Morning glory, *Ipomoea purpurea* (Convolvulaceae). *American Journal of Botany*, 99 (9): 1524–1530.

Chew, M. (2015). Ecologists, Environmentalists, Experts, and the Invasion of the 'Second Greatest Threat'. *International Review of Environmental History* (Ed. Beattie, J.). pp. 7-40. ANU Press, The Australian National University, Canberra, Australia (**http://www.environmentandsociety.org/mml/ecologists-environmentalists-experts-and-invasion-second-greatest-threat**).

Davis, M. A. and Thompson, K. (2001) Invasion terminology: should ecologists define their terms differently than others? No, not if we want to be of any help. *ESA Bulletin*, 82: 206.

Davis, M. et al, (2011). Don't judge species on their origins*. Nature*, 474: 153-154.

De Wet, J. M. J. (1966). The Origins of Weediness in Plants. *Proceedings of the Oklahoma Academy of Sciences, 1966*. 14-17.

Duke, S. (2005). Six decades of Weed Science since the Discovery of 2,4-D and Challenges for the 21st Century. Proceedings of the 20th Asian-Pacific Weed Science Society (APWSS) Conference, 7-11 November, 2005, Ho Chi Min City, Vietnam, pp. 3-11.

Dunn, S.T (1905). *The Alien Flora of Britain*. London, West, Newman and Co. pp. 236 (Available at: **https://archive.org/details/alienfloraofbrit00dunn/page/n5/mode/2up**).

Evans, C. (2002). *War On Weeds in the Prairies West: An Environmental History*. University of Calgary Press, Calgary, Alberta, 309 pp.

Falck, Z.J. S. (2010). *Weeds: An Environmental History of Metropolitan America*. University of Pittsburgh Press. 256 pp.

Gray. A. (1879). The Predominance and pertinacity of weeds. *American Journal of Science and Arts*, 85 (2): 161-167 (Republished by: Sargent, C.S. (1889). *Scientific Essays of Asa Gray*. Vol II. Essays and Biographical Sketches, 1841-1886. Houghton Mifflin, NY, pp. 234-243) (Available at: **https://www.semanticscholar.org/paper/The-pertinacity-and-predominance-of-weeds-Gray/1d0eee0b8bac1152ba5db00cf1d1ff6a76d92b33**).

Guiaşu, R.C. and Tindale, C.W (2018). Logical fallacies and invasion biology. *Biology & Philosophy*, 33: 34 (**https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6133178/pdf/10539_2018_Article_9644.pdf**).

Hall, M. (2003). Editorial: The native, naturalized and exotic – plants and animals in human history. *Landscape Research*, 28(1): 5–9.

Harker, K. N. and Donovan, T. O. (2013). Recent Weed Control, Weed Management and Integrated Weed Management (Editorial). *Weed Technology*, 27: 1-11.

Harlan, J. R. and De Wet, J. M. J. (1965). Some thoughts about weeds. *Economic Botany*, 19: 16-24.

Harper, J. L. (1956). The evolution of weeds in relation to resistance to herbicides. *Proceedings of the British Weed Control Conference*, 3: 179.

Harper, J. L. (1957). Ecological aspects of weed control. *Outlook on Agriculture.* 1 (5): 197-205.

Harper, J. L (Ed.) (1960). *The Biology of Weeds*. A Symposium of The British Ecological Society. April, 1959. Blackwell Scientific Publications, Oxford. pp 256.

Harper, J. L. (1977). *Population Biology of Plants*. Academic Press, London. pp. 892.

Heap, I. (2020). The International Herbicide-Resistant Weed Database. Online. Accessed: 26 December 2020 (**www.weedscience.org**).

Kim, K. U., Shin, D. H. and Lee, I. J. (Eds.) (2008). *Utility of Weeds and Their Relatives as Bioresources*. Kyungpook National University, Daegu, Korea.

Lewontin, R.C. (1965). Selecting for Colonizing Ability. In: H.G. Baker & G.L. Stebbins (Eds.), *The Genetics of Colonizing Species*. pp. 147–172, Academic Press, NY.

Mayr, E. (1965). Summary (p. 553). In: Baker, H. G. and Stebbins, G. L. (Eds.), *The Genetics of Colonizing Species*. Academic Press, NY. 588 pp.

Ormerod, S. J. and Watkinson, A. R. (2000). Editorial: The Age of Applied Ecology. *Journal of Applied Ecology*, 37, 1-2.

Radosewich, S. R., Holt, J. S. and Ghersa, C. M. (1997). Ecology of Weeds and Invasive Plants – Relationship to Agriculture and Natural Resource Management. 3rd Edition. Wiley-Interscience, USA. 589 pp.

Thill, D. C., Lish, J. M., Callihan, R. H. and Bechinski, E. J. (1991). Integrated Weed Management – A Component of Integrated Pest Management: A Critical Review. *Weed Technology*, 5: 648-656.

Timmons, F. L. (1970). A history of Weed Control in the United States and Canada. *Weed Science*, 1970. 18 (2): 294–307) [Republished: 2005. Weed Science, 53: 748-761].

Sagoff, M. (2002). What's Wrong with Exotic Species? In: Galston, W. (Ed.) *Philosophical Dimensions of Public Policy*, Routledge, NY, pp. 349 (Chapter 34, 14 pp.).

Sagoff, M. (2005). Do non-native species threaten the natural environment? *Journal of Agricultural and Environmental Ethics*, 18: 215-236.

Sagoff, M. (2009). Who is the invader? Alien species, property rights, and the police power. *Social Philosophy and Policy*, 26: 26–52.

Sagoff, M. (2019). Fact and value in invasion biology. *Conservation Biology*, 34 (3): 581-588.

Salisbury, E. (1961). *Weeds & Aliens*. The MacMillan Co., New York. 384 pp.

Shaw, W. C. (1964). Weed Science—Revolution in Agricultural Technology. *Weeds*, 12: 153-162.

Van Eten, M. L., Conner, J. K., Chang, S-M. and Baucom, R. S. (2017). Not all weeds are created equal: A database approach uncovers differences in the sexual system of native and introduced weeds. *Ecology and Evolution*, 7: 2636–2642 (Available at: **https://doi.org/10.1002/ece3.2820**).

Wyse. D. L. (1992). Future of Weed Science Research. *Weed Technology*, 162-165.

Zimdahl, R. L. (2007). *Fundamentals of Weed Science*, Third Edition. Chapter 4 – Ethnobotany, pp. 59-78. Academic Press.

Zimdahl, R. L. (2010a). *A History of Weed Science in the United States.* Elsevier, London, 224 pp.

Zimdahl, R. L. (2010b) Ethics for Weed Science. *Pakistan Journal of Weed Science Research*, 16 (2): 109-121.

Zimdahl, R. L. (2012). *Weed Science: A Plea for Thought - Revisited*. Springer Briefs in Agriculture. Springer. 73 pp.

Zimdahl, R. L. (2018). Agriculture's Moral Dilemmas and the Need for Agroecology. *Agronomy*, 8, 116; doi:10.3390/agronomy8070116.

Zimdahl, R. L. (2019). Some Thoughts About Ethics for Agriculture. *Weeds*, 1 (1): 17-22.

ORIGINAL RESEARCH

Plant Invasion Research in Nepal: A Review of Recent National Trends

Mohan Pandey[1], Khum Bahadur Thapa-Magar[2], Buddhi Sagar Poudel[3], Thomas Seth Davis[2], Bharat Babu Shrestha[4, *]

[1] KTK-BELT, Inc., Kathmandu, Nepal,

[2] Department of Forest and Rangeland Stewardship, Warner College of Natural Resources, Colorado State University, Fort Collins, USA.

[3] REDD Implementation Centre, Ministry of Forests and Environment, Kathmandu, Nepal

[4] Central Department of Botany, Tribhuvan University, Kathmandu, Nepal

Corresponding Author E-mail: shresthabb@gmail.com

Received: 31 May 2020

Accepted for publication: 28 September 2020

Published: 30 December 2020

Abstract

Research interests in Invasive Alien Plant Species (IAPS) have expanded globally, and nationally in Nepal, over the last few decades. Here we provide a systematic compilation and analysis of the scientific literature to explore research trends and identify research gaps in plant invasion biology in Nepal. We compiled and examined journal publications retrieved from Web of Science (WOS) and other databases (NepJOL, Google Scholar, and other bibliographies) using specific search keywords. The search yielded 86 research studies on IAPS, published between 1958 and 2020 (up to August 2020) that met our pre-determined criteria.

The number of publications in national journals that focused on IAPS increased, starting in 2000, but this increase was not notable in international journals, until 2010. Nearly 91 % of the studies that appeared in international journals were published after 2010. A majority of the studies focus on biology, ecology, and ecological impact studies of a few selected IAPS, especially mile-a-minute (*Mikania micrantha* Kunth), parthenium weed (*Parthenium hysterophorus* L.), and crofton weed (*Ageratina adenophora* (Spreng.) R.M. King & H.Rob.), mostly in Nepal's forest ecosystems. Eighty-four percent (84%) of field-based studies have been conducted in the central region of Nepal (Bagmati and Gandaki provinces together). Tribhuvan University, a Government-funded, National University of Nepal, was the largest contributor to IAPS related research and our analysis revealed that international grants were the primary funding sources for this research.

We conclude that future regional research should be prioritized on thematic areas focusing on: (a) understudied phytogeographic regions, (b) impacts on protected areas, (c) under-studied invasive and naturalized species, (d) IAP dispersal mechanisms, and (e) economic impacts. Additional research in these priority areas will help to focus our understanding of IAPS in Nepal and will be important for mitigating ecological and economic damages from IAPS. Also, funding from government agencies for research, and incentives for graduate students to publish their theses, may improve the knowledge-sharing aspects related to the above themes and reduce biases in areas that we identified in this review.

Keywords: Invasive Alien Plant Species, IAPS, Web of Science, research trends, research gaps

Introduction

Biological invasions are one of the five major impacts of anthropogenic activities on the global environment (IPBES, 2019). Invasive alien species are a serious threat to native species biodiversity (Blackburn et al., 2019), ecosystem function (Ehrenfeld, 2010), and ecosystem services (Vila and Hulme, 2017). Invasions by alien species can ultimately damage the economy and livelihoods of people (Reid et al., 2005; Pimentel et al., 2005) at both local and global scales (Bellard et al., 2016; Doherty et al., 2016).

Systematic reviews are often used in invasion ecology research to understand the spatial, temporal, and subject-based research trends and identify key knowledge gaps (Kettenring and Adams, 2011; Lowry et al., 2013). In recent years, several global systematic review papers on invasive plant ecology have focused on specific invasive species (Yu et al., 2016; Maharjan et al., 2019a), taxonomic groups (Thomaz et al., 2014), environmental impacts (Nelson et al., 2017), dispersal pathways and mechanisms (Ansong and Pickering, 2013), and management options (Esler et al., 2010).

Biological invasions in Nepal has been identified as one of the emerging threats to biodiversity and ecosystem services (Shrestha, 2019) and is one of the major underlying causes of habitat degradation in Nepal, along with unsustainable harvesting practices, environmental pollution, overgrazing, and infrastructure developments (Chaudhary et al., 2016). The number of invasive alien plant species (IAPS) in Nepal has increased over time (Shrestha, 2019) and the range of climatically suitable areas for most of the IAPS of Nepal is likely to expand and shift upslope under climate change scenarios in the future (Shrestha and Shrestha, 2019).

These current and future scenarios suggest that issues surrounding biological invasions are likely to escalate. Current management and policy responses to these problems are inadequate in Nepal (Shrestha, 2019), although considerable efforts have been made by researchers to generate new knowledge, related to biology and ecology of individual IAPS (Maharjan et al., 2014), their diversity (Bhattarai et al., 2014), distribution (Shrestha et al., 2019a; Maharjan et al., 2019b), impacts (Murphy et al., 2013; Bhatta et al., 2020; Thapa et al., 2020), management and control (Shrestha et al., 2011; Rai et al., 2012), and socioeconomic aspects (Rai and Scarborough, 2013; Shrestha et al., 2019b).

Despite the increasing number of research publications on IAPS of Nepal, there is a need to critically review regional research on IAPS in order to identify priority areas for future work and provide direction to managers concerned with mitigating the effects on IAPS.

Thus, we aimed to conduct a comprehensive, systematic review of studies related to the IAPS of Nepal to answer the following questions: (1) How has the rate of publication in IAPS research in Nepal changed over time? (2) Are different regions of Nepal reasonably represented in ecological sampling? (3) How wide is the difference between basic and applied research in terms of research effort? (4) Which species and habitats have been prioritized for IAPS research? and (5) Who is studying IAPS of Nepal and who funds this research?

The information compiled here creates a knowledge-base to identify current research trends and gaps for future research of IAPS in Nepal. Our hope is that this information would influence invasive alien species policies, funding priorities, and management options, across the country.

Methods

Literature searches were conducted from the following sources: (a) Institute for Scientific Information (ISI) Web of Science Database (WOS), an international database; (b) Google Scholar; (c) a bibliography of invasive species in Nepal (DFRS, 2011); and (d) NepJOL, a Nepalese journal database, following standard procedures for a systematic review (Pullin and Stewart, 2006). In ISI WOS, we identified papers on August 19, 2020, using search keys: Topic: 'Nepa*' OR 'Nepal hima*' AND 'inva*' OR 'alien' OR 'exotic' OR 'naturalized' AND 'plant' OR' weed' followed by the 'refine' function to eliminate non-biological topics.

We searched literature from Google scholar and NepJOL up to August 20, 2020, using search keys: 'IPS Nepal', 'Invasive species Nepal', 'invasive plants Nepal', the scientific, common, and local name of each IAPS (e.g. Lahare Banmara for *Mikania micrantha*, Kalo Banmara for *Ageratina adenophora*, Seto Banmara for *Chromolaena odorata*, Jalkumbhi for *Eichhornia crassipes*, etc.). Studies published in some bulletins (e.g. Bulletin of Department of Plant Resources) were also included.

After the literature search from multiple resources, we collated the results, and an additional screening step was performed that included reading the title and abstract of each paper. From the screening process papers were further filtered and papers were excluded on the basis of: (1) studies of irrelevant topics (e.g. invasive fauna, native weeds), (2) unrelated locations (i.e. outside Nepal), and/or (3) duplicate publications and publications other than journal research articles (e.g. newsletter, proceeding, global systematic review articles, theses, books, and book chapters) (See Supplement 1 for diagram showing article filtering process).

After exclusion, we extracted the following information from the remaining papers: (1) first two author's names, (2) types of databases, (3) publication year, (4) institution of main and corresponding author/s, (5) research theme, (6) funding source, (7) types of research, (8) focus species, (9) habitat, and (10) study location (see Supplement 2 for details).

A distribution map of IAPS field studies was constructed using the coordinates of the study area in R software using package "sf" (Pebesma, 2018). The required GIS layers (district boundary, road system, physiographic region) were extracted from the regional database system of the International Centre for Integrated Mountain Development (ICIMOD) (https://rds.icimod.org/). For studies that did not have geographic data, we used Google Maps (https://www.google.com/maps) to specify the boundary according to the textual description of the study area and extracted latitude and longitude using mid-point of delineated boundaries. The elevation of the respective locations was extracted from the Digital Elevation Model of Nepal (USGS, 2000).

Results

We retrieved 267 publications, of which 102 were from WOS and 165 from other databases (NepJOL, Google scholar, bibliography, and others). After refining 3 biological studies in WOS, we reduced the record to 99. We did not use any refine function to publications retrieved from other sources but removed non-relevant publications manually.

A total 181 studies (75 from WOS and 106 from other databases) were excluded that were unrelated to the topics of our interest after reading the titles, abstracts, and full texts (if needed), duplicate papers (17), and publications which could not be accessed for data compilation (1). Eventually, we included 27 and 59 papers for the systematic review, which met our criteria from WOS and other databases, respectively (see Supplement 1). The list of the selected 86 papers has been provided as Supplementary Information (see Supplement 3).

Sources and year of IAPS publications

About one-third (27) of total studies (86) were retrieved from WOS while the remaining two-thirds (59) retrieved from other databases. The WOS extracted the papers that were published in international journals after 2000. The trend of publication in a national journal (n=40) showed an increase in research effort beginning in 2000s, while research effort published in international journals (n=46) abruptly increased after 2010.

Locations of research study areas

Field studies (N = 59 sites) have been undertaken in Tarai (n = 12), Siwalik (21), Middle Mountain regions (24), and High Mountains (2) but there were no studies related to IAPS in the High Himalaya ecoregion. More than four-fifths (84%) of the studies were conducted in Bagmati (e.g. Chitwan, Kathmandu, Nuwakot districts) and Gandaki Provinces (e.g. Kaski, Tanahu districts) which are located in central Nepal (approximate region: 83° to 86.5° E longitude) (Figure 2).

Nearly half (49%) of the study sites were inside the protected areas, with 62% of them focused to Chitwan National Park. There was no study reported from Karnali and Sudurpaschim Provinces.

Research themes, type of research, focus species and habitats

The highest proportion of studies were investigations of the ecological impacts of IAPS, followed by studies on the biology and ecology of IAPS (Figure 3A). These two research themes accounted for 55% of all studies, while studies related to socio-economic aspects were the least abundant. About 85% studies were observational (Figure 3B) and within this category, two-thirds were observational field studies.

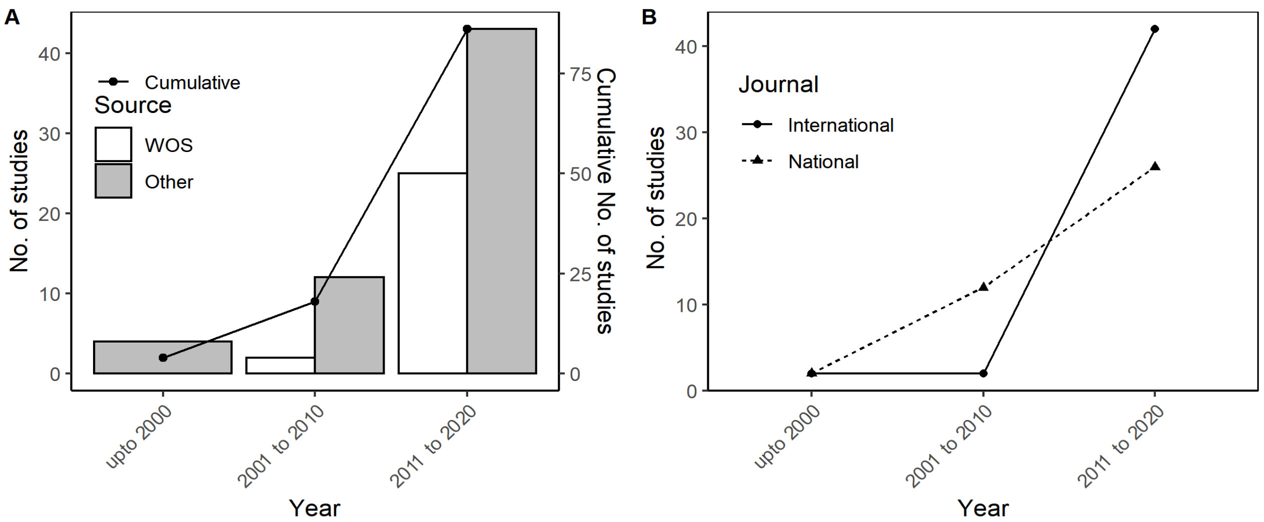


Figure 1. Number of studies, over time (N=86). A. Studies extracted from WOS and other sources. B. Studies published in national and international journals. In 2020, studies published until August 2020 were included.

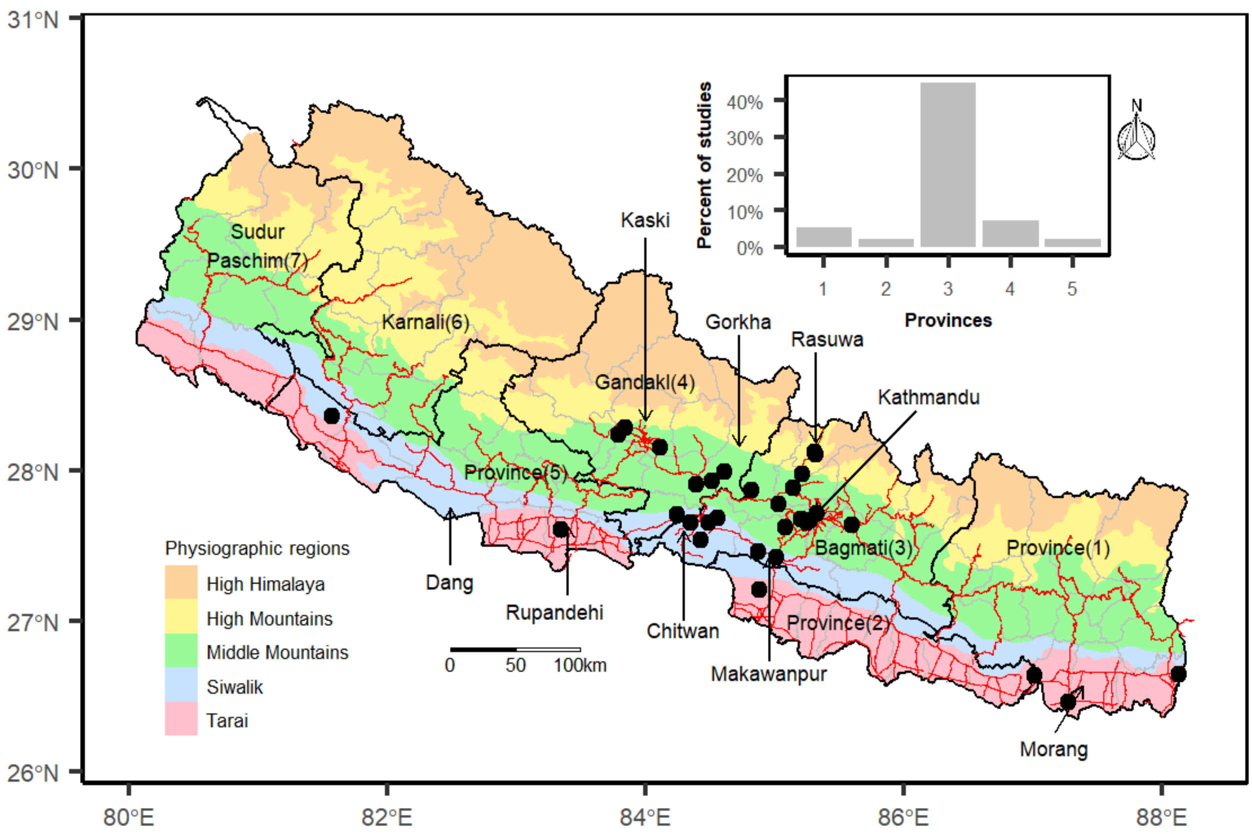


Figure 2. Location of study areas in publications based on field studies (N=59, denoted by black dots; the smaller number in the map is because of overlap). Black, grey, and red lines in the map represent province boundary, district boundary, and primary road systems (including highways), respectively.

Out of 27 IAPS reported from Nepal, 11 species were the subject of at least one study, suggesting that there is no existing research on ~59% of IAPS in Nepal. Among these species, mile-a-minute (*Mikania micrantha* Kunth), crofton weed (*Ageratina adenophora* (Spreng.) R. King & H. Rob.), and parthenium weed (*Parthenium hysterophorus* L.) were commonly studied (Figure 3C). These three IAPS represented nearly three-fifth of the total studies that we evaluated. Out of 43 field studies that had identifiable habitat types, about half of the studies were conducted in forest ecosystems (Figure 3D). By comparison, relatively few studies were from grasslands, wetlands, or roadside areas.

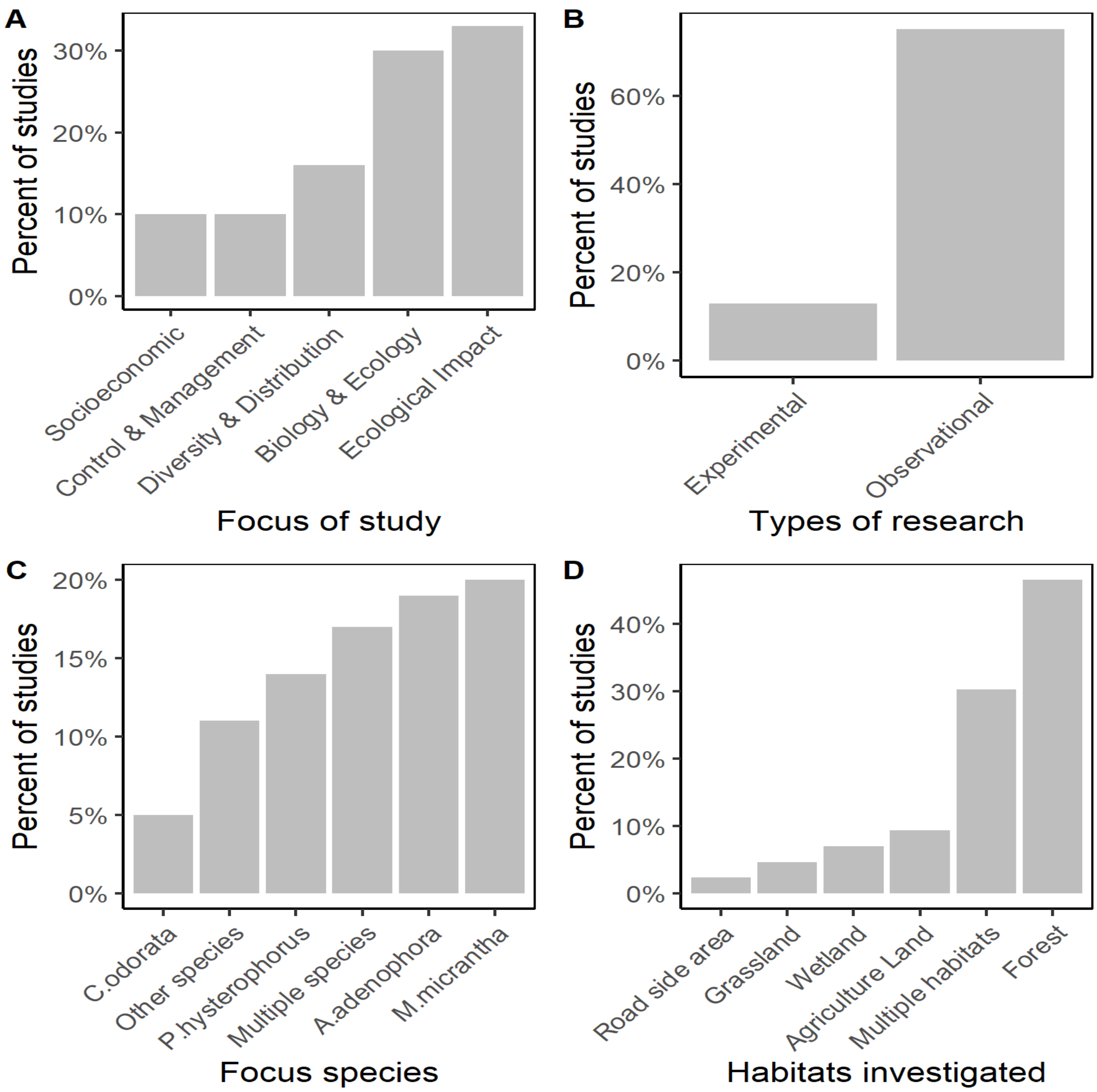


Figure 3. Number of studies on invasive alien plant species of Nepal (N = 86). A) Theme of study, B) Types of research, C) Focus species (*Chromolaena odorata*, *Ageratina adenophora*, *Parthenium hysterophorus*, *Mikania micrantha*; 'other species' included *Ageratum houstonianum*, *Alternanthera philoxeroides*, *Amaranthus spinosus*, *Lantana camara*, *Mimosa pudica*, *Eichhornia crassipes*, and *Mimosa diplotricha*), and D) Habitats investigated (N=43).

Contributing institutions and funding sources

Universities were found contributing two-third of total publications in which Tribhuvan University (a national university of Nepal) alone represented 41% of all authors (Figure 4A). Nearly one-fourth (24%) of the total authors were affiliated to foreign universities while 15% were Nepal Government officials.

Forty-seven studies (54% of total) mentioned the funding sources in their publications; of these, 38% of studies were funded from international grants while the Nepal Government funded only 19% of studies (Figure 4B).

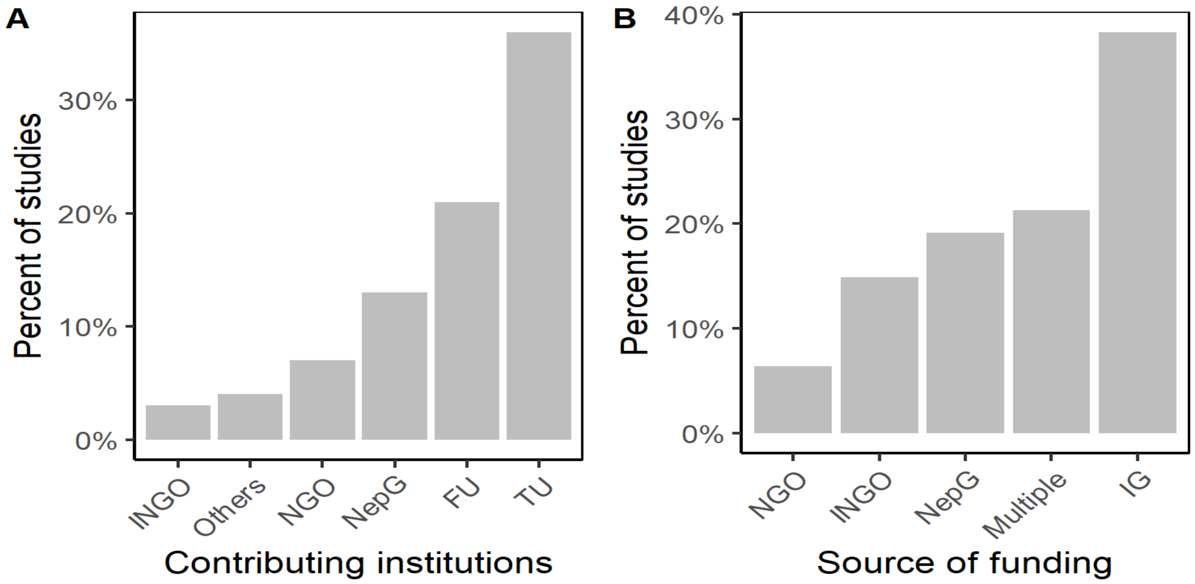


Figure 4. Number of studies according to the author's institutions and funding sources. A) Categories of institutions to which authors were affiliated (N=86), and B) Categories of funding institutions (N=47). Abbreviations: FU- Foreign universities, IG - International grants including funding from foreign universities, INGO - International Non-governmental Organizations, NepG - Nepal Government, NGO- Non-governmental Organizations, TU - Tribhuvan University

Discussion

How has the rate of publication in IAP research in Nepal changed over time?

The trend of IAPS related publications from Nepal differs from global trends of biological invasions related publications and suggests that IAPS in Nepal has only recently become a subject of considerable research interest. Globally, rapid increase in publications related to biological invasions was observable in the 1990s (Lowry et al., 2013), but this was not the case in Nepal until approximately 2010. The global rise of biological invasions publications is attributed to a SCOPE (Scientific Committee on Problems of the Environment) Program on the Ecology of Biological Invasions, which produced a series of publications during the late-1980s and early-1990s (Simberloff, 2011). Similarly, the reported post-2010 increase in IAPS publications in Nepal is concomitant with the timing of a national assessment and publication, reporting 21 IAPS by IUCN Nepal (Tiwari et al., 2005). Other contributing factors might be linked to (1) Nepal National Biodiversity Strategy and Action Plan (MFSC, 2014) and National Wetlands Policy (2003), which identified IAPS as a major threat to biodiversity; (2) increased funding on IAPS research after 2005; and (3) an increase in research activities at national universities such as Tribhuvan University (TU), where research has become a mandatory requirement for graduate students of botany, environmental science, forestry, and agriculture in recent decades. Some of these dissertation research have led to publications (e.g. Timsina et al., 2011; Bhatta et al., 2020), while others have not.

The WOS, as a large international database, was not able to extract the research studies that were published in national journals as *Scientific World* (Ministry of Education, Science and Technology), *Botanica Orientalis* (Tribhuvan University), *Banako Janakari* (Forest Research and Training Center of the Ministry of Forest and Environment), etc. which are published by government agencies and universities in Nepal.

Previous studies have also revealed that the WOS and other big databases are biased in terms of language, national, and subjective matters of data storage (Mongeon and Paul-Hus, 2016) and therefore insufficient to generalize research findings (Yu et al., 2016). Therefore, we note that systematic reviews relying only on data compilation from big international databases could be a significant limitation and may not reflect the state of knowledge generation at the national level, particularly in underdeveloped regions.

Are different regions of Nepal appropriately represented in ecological sampling?

There was a clear geographical bias on IAPS studies, with greater overall research effort in the Siwalik and the Middle Mountain regions of central Nepal. This difference is likely attributable to a higher diversity and abundance of IAPS and general habitat suitability in these regions as compared with the High Mountains and High Himalaya (Shrestha, 2016; Shrestha and Shrestha, 2019). Further, there was an observable effect of proximity to the capital city (Kathmandu), where most researchers and research institutions are concentrated.

We also report a higher number of studies in the Chitwan National Park and Buffer Zone (CNPBZ) areas, in Central Nepal. As most research funding awards for Nepali scientists are small, researchers often strategically choose to focus their efforts on species that are distributed in nearby areas to reduce fieldwork and travel expenses (Wilson et al., 2007). Such geographical biases in biological invasion studies have been reported previously in Nepal (Poudel and Thapa, 2012), and also in other countries, such as Brazil (de Andrade Frehse et al., 2016), as well as globally (Pysek et al., 2008).

These biases in research may have at least two critical management implications at local levels: (1) there is a risk of extrapolating results of a relatively few studies to a broader context by ignoring context-specific phenomena of biological invasions, and (2) bias in research focus could delay study of control methods for some IAPS at early stages of invasion in vulnerable habitats (Bellard and Jeschke, 2016).

Prioritization of future research in eastern and western Nepal will reduce existing geographic biases of IAPS relevant knowledge and provide balanced scientific information for policy and management decisions.

Which research theme, species and habitats are prioritized for IAPS research?

In recent years, research priorities have been expanding from observational and ecological impact studies to topics including distribution mapping (e.g. Shrestha et al., 2019a) and projection of future species' distribution under climate change (e.g. Shrestha and Shrestha, 2019), control of IAPS (e.g. Rai et al., 2012), and socioeconomic effects of IAPS invasions (e.g. Rai and Scarborough, 2013; Shrestha et al., 2019b).

About 95% of the studies were focused on basic research that includes studies reporting distribution, biology, ecology, impacts, etc. with very less prioritization on applied aspects such as reporting of control and management. This is in line with global literature (Esler et al., 2010) whereas it is in contrast to the findings in Mexico (Espinosa-Garcia and Villasenor, 2017). In our view, this wide research gap, due to lack of adequate knowledge generation in management and control, may critically affect the timely preparation of national level IAPS management protocols for Nepal and prompt implementation of the protocols at the local scale.

Mostly studies have prioritized widespread species that pose a substantial threat to biodiversity and agricultural livelihoods (Reid et al., 2005; Pysek et al., 2008) and rarely emphasize co-occurring, but still potentially problematic, invasive species (Kuebbing et al., 2013).

We found that the IAPS research in Nepal was primarily focused on some widespread and economically injurious species, such as mile-a-minute, parthenium weed and crofton weed. Among the three most studied species, mile-a-minute is one of the world's worst invasive species (Lowe et al., 2000). In Nepal, recent national inventories rank mile-a-minute and crofton weed as posing 'high-risk' and 'medium risk', respectively, to native ecosystems (Tiwari et al., 2005). As a species, mile-a-minute has significant negative impacts on wildlife forage by covering and out-competing palatable forage plants in broadleaf ecosystems in Chitwan National Park

(Murphy et al., 2013), whereas crofton weed often colonizes forest edges and shrublands, where it may be ingested by livestock.

Similarly, parthenium weed is rapidly expanding from peri-urban grasslands and roadside verges to agro-ecosystems and natural habitats including protected areas (Shrestha et al., 2015; Shrestha et al., 2019a). Several other invasive species such as lantana (*Lantana camara* L.*),* Siam weed (*Chromolaena odorata* (L.) R. King & H. Rob.), and water hyacinth (*Eichhornia crassipes* (Mart.) Solms), which are globally infamous (Lowe et al., 2000) and high risk posing IAPS in Nepal (Tiwari et al., 2005), are relatively less studied by comparison.

Non-invasive but naturalized species have not been an object of research from the perspective of biological invasions. Forest ecosystems were reported as the most studied habitats in a systematic review of crofton weed and Siam weed using the WOS database (Yu et al., 2016). A similar result in the present analysis may be related to the institutional and policy framework of Nepal that prioritizes forests over other ecosystems (BB Shrestha and BS Poudel, *personal observations*).

More frequent IAPS studies in forests are also linked to the colonization of degraded forests and forest edges with mile-a-minute and crofton weed, the two most heavily researched IAPS in Nepal (Tiwari et al., 2005; Shrestha, 2019).

Although agriculture is also a dominant regional land cover type (Uddin et al., 2015) that is highly vulnerable ecosystem to IAPS infestation (Paini et al., 2016), we did find 37% fewer studies in agroecosystems represented in the literature than in forests. Yet, several IAPS including bluemink (*Ageratum houstonianum* Mill.) and water lettuce (*Pistia stratiotes* L.) are considered by farmers as highly problematic in agroecosystems in Nepal (Shrestha et al., 2019b). These species may also pose serious challenges for cropping systems by having an impact on the herbicide application rates.

Identification of IAPS as an emerging threat to the agriculture sector by Nepal Government (PQPMC, 2019) can help promote IAPS research in the agricultural sector and ensure food security.

Who is studying IAPS of Nepal and who funds this research?

Tribhuvan University (TU) is a major contributor to the existing scientific literature on plant biological invasions in Nepal, partly because graduate students in the biological sciences at TU and affiliated institutions must complete and report on original research to meet degree requirements. Several of these graduate research projects have been conducted without financial supports (e.g. Balami et al., 2019). However, the number of publications from funded-research increased since 2015 (e.g. Shrestha et al., 2019a) while studies conducted by international universities notably increased following 2012, indicating recent collaborative research efforts in this sector.

Although there are various research-based institutions and environmental departments in Nepal, government funding for IAPS research remains low and is erratic in comparison to international funding sources such as international grants. The government generally places low funding priority on the environmental sector, with an estimated allocation of only about 1% of the total annual budget (GoN, 2019). Globally, recent data also show that developing countries tend to spend less on research and innovation (UNESCO, 2020).

However, the large number of self-funded studies from university students (e.g. Balami et al., 2019) suggests that scientists continue to conduct research independently despite limited available government funding. This trend indicates a growing public interest in academics and a grassroots commitment to improving the management of IAPS in Nepal. Nevertheless, gross domestic expenditure on research and development as a percentage of GDP is increasing in Nepal (Katsnelson, 2016), which is promising for the future IAPS research funding needed to cover broad geographic regions, understudied species, and ecosystems, and elucidate the socioeconomic impacts of IAPS in Nepal on public and private stakeholders.

Despite the low national funding for research in universities of Nepal, TU continues to be the largest academic institution publishing IAPS research in Nepal. We excluded graduate theses from our analysis but Poudel and Thapa (2012) reported that graduate theses accounted for 60% of all kinds of biological invasion related literature in Nepal.

We are aware that many M.Sc. graduate theses end up without publication. For example, 32% of 54 M.Sc. graduate theses, supervised by one of the authors (BB Shrestha) between 2003 and 2018 have not yet been published in peer-reviewed journals. It could, at least partly, be attributed to personal lack of motivation, as most of the students after graduation obtain some employment which leads to a lack of motivation to publish. Any incentive from universities, whether monetary reward or certificate of merit, may also encourage graduate students to publish their theses. Publications of graduate thesis in standard journals, rather than predatory ones, not only showcase the academic excellence of the graduates but also enrich essential knowledge base, such as of IAPS and improve research impacts of universities with the potential of attracting additional funding from various sources.

Conclusions and future directions for IAPS research in Nepal

Our review not only highlights geographic, taxonomic, and habitat biases in IAPS research in Nepal, but also documents a recent increase in research output despite limited available governmental funding. Accordingly, we recommend that future regional IAPS research should be prioritized to under-studied phytogeographic regions, such as eastern and western Nepal.

As most previous studies have focused on only a few species, new research should focus on other widespread but under-studied species such as lantana, water hyacinth, bluemink, and others including invasive and non-invasive naturalized species. Research on IAPS ecology in wetland, grassland, and agroecosystem habitats are also comparatively underrepresented in the literature and studies in these systems could inform new weed management practices. Although protected areas were the context for slightly less than half of the identified field studies, they were mostly confined to the Chitwan National Park and not broadly representative of conservation efforts in Nepal. Future research incorporating additional protected areas is essential to understand the extent and severity of IAPS problems and should be considered in ecosystem management plans of protected areas at the national level.

Some of the key information essential for effective policy and management responses are also missing in the IAPS literature that we reviewed. For example, identifying dispersal mechanisms and pathways (both internationally as well as within-country) and movement vectors is indispensable for the management of invasive alien species (Hulme, 2009) but none of the literature we identified examined these crucial issues. Similarly, economic impacts in terms of direct damage and cost of management have never been quantified in Nepal, although such quantification is available for other countries (e.g. Pimentel et al., 2005; Xu et al., 2006) as well as at regional (e.g. Nghiem et al., 2013) and global scales (Pimentel et al., 2001).

Economic valuation of IAPS-related impacts provides the most compelling justification for policy and management responses and can help to clarify the economic rationality of various management applications. Furthermore, knowledge generated from applied research on the effectiveness of different control strategies for IAPS requires more consistent outreach to agriculturalists and land managers in order to enhance general applicability and integration of effective methods.

Acknowledgements

We would like to acknowledge the assistance provided by Dr. Nimal Chandrasena, the Editor-in-Chief of the 'Weeds' journal. His insights, critical comments and editing of the early drafts of the manuscript are highly appreciated. Authors are also thankful to other anonymous reviewers for their comments and suggestion on the manuscript.

References

Ansong, M. and Pickering, C. (2013). Are weeds hitchhiking a ride on your car? A systematic review of seed dispersal on cars. *PLOS ONE*, 8 (11): 1–11.

Balami, S., Thapa, L. B. and Jha, S. K. (2019). Effects of invasive *Ageratina adenophora* on mycelial growth of some important soil fungi. *Songklanakarin Journal of Science and Technology*, 41 (2): 464–469.

Bellard, C., Cassey, P. and Blackburn, T. M. (2016). Alien species as a driver of recent extinctions. *Biology Letters*, 12 (4).

Bellard, C. and Jeschke, J. M. (2016). A spatial mismatch between invader impacts and research publications. *Conservation Biology,* 30 (1): 230-232.

Bhatta, S., Joshi, L.R. and Shrestha, B.B. (2020). Distribution and impact of invasive alien plant species in Bardia National Park, western Nepal. *Environmental Conservation*, 47 (3): 197-205.

Bhattarai, K. R., Måren, I. E. and Subedi, S. C. (2014). Biodiversity and invasibility: Distribution patterns of invasive plant species in the Himalayas, Nepal. *Journal of Mountain Science*, 11 (3): 688-696.

Blackburn, T. M., Bellard, C. and Ricciardi, A. (2019). Alien versus native species as drivers of recent extinctions. *Frontiers in Ecology and the Environment*, 17 (4): 203-207.

Chaudhary, R. P., Uprety, Y. and Rimal, S. K. (2016). Deforestation in Nepal: Causes, consequences, and responses. In: Shroder, J.F., Sivanpillai, R. (Eds.), Biological and Environmental Hazards, Risks, and Disasters. Elsevier, San Diego, United States. pp. 335–372.

de Andrade Frehse, F., Braga, R. R., Nocera, G. A. and Vitule, J. R. S. (2016). Non-native species and invasion biology in a megadiverse country: scientometric analysis and ecological interactions in Brazil. *Biological Invasions*, 18 (12): 3713-3725.

DFRS. (2011). A Bibliography of the Invasive Alien Species in Nepal. Department of Forest Research and Survey (DFRS), Kathmandu, Nepal. 15 p.

Doherty, T. S., Glen, A. S., Nimmo, D. G., Ritchie, E. G. and Dickman, C. R. (2016). Invasive predators and global biodiversity loss. *Proceedings of the National Academy of Sciences of the USA*, 113(40): 11261-11265.

Ehrenfeld, J. G. (2010). Ecosystem consequences of biological invasions. *Annual Review of Ecology, Evolution, and Systematics*, 41: 59-80.

Esler, K. J., Prozesky, H., Sharma, G. P. and McGeoch, M. (2010). How wide is the “knowing-doing” gap in invasion biology? *Biological Invasions*, 12 (12): 4065-4075.

Espinosa-García, F. J. and Villaseñor, J. L. (2017). Biodiversity, distribution, ecology and management of non-native weeds in Mexico: a review. *Revista Mexicana de Biodiversidad*, 88: 76-96.

GoN. (2019). Budget Speech of Fiscal Year 2019/20. Government of Nepal (GoN), Ministry of Finance, Singha Durbar, Kathmandu (Available at: https://mof.gov.np/uploads/document/file/budget_speech_website_20190619052055.pdf)

Hulme, P. E. (2009). Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *Journal of Applied Ecology*, 46 (1):10–18.

Katsnelson, A. (2016). Big science spenders. *Nature*, 537 (7618), S2-S3.

Kettenring, K. M. and Adams, C. R. (2011). Lessons learned from invasive plant control experiments: a systematic review and meta-analysis. *Journal of Applied Ecology*, 48 (4): 970-979.

Kuebbing, S. E., Nuñez, M. A. and Simberloff, D. (2013). Current mismatch between research and conservation efforts: The need to study co-occurring invasive plant species. *Biological Conservation*, 160: 121–129.

IPBES (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. S. Díaz, et al. (Eds.). Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) secretariat, Bonn, Germany. 56 p.

Lowe, S., Browne, M., Boudjelas, S. and De Poorter, M. (2000). 100 of the world's worst invasive alien species: a selection from the global invasive species database (Vol. 12). Auckland, New Zealand: Invasive Species Specialist Group. 11 p.

Lowry, E., et al. (2013). Biological invasions: a field synopsis, systematic review, and database of the literature. *Ecology and Evolution*, 3 (1): 182-196.

Maharjan, S., Joshi, S., Shrestha, B. B., Devkota, A. and Jha, P. K. (2014). Life History Traits and Invasion Success of *Parthenium hysterophorus* L. in Kathmandu Valley, Nepal. *Nepal Journal of Science and Technology*, 15 (1): 31-38.

Maharjan, S., Shrestha, B. B., Devkota, A., Muniappan, R. and Jha, P. K. (2019a). Temporal and spatial patterns of research on a globally significant invasive weed *Parthenium hysterophorus* L.: A bibliographic review. *Crop Protection,*135: 104832.

Maharjan, S., et al. (2019b). Predicting suitable habitat of an invasive weed *Parthenium hysterophorus* under future climate scenarios in Chitwan Annapurna Landscape, Nepal. *Journal of Mountain Science*, 16 (10): 2243–2256.

MFSC. (2014). Nepal National Biodiversity Strategy and Action Plan 2014-2020. Ministry of Forest and Soil Conservation (MFSC), Government of Nepal, Kathmandu. 200 p.

Mongeon, P. and Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: a comparative analysis. *Scientometrics*, 106 (1): 213–228.

Murphy, S. T., et al. (2013). Invasive mikania in Chitwan National Park, Nepal: the threat to the greater one-horned rhinoceros *Rhinoceros unicornis* and factors driving the invasion. *Oryx*, 47 (3): 361-368.

Nelson, S. B., et al. (2017). Patterns and mechanisms of invasive plant impacts on North American birds: a systematic review. *Biological Invasions*, 19 (5): 1547–1563.

Nghiem, L. T., et al. (2013). Economic and environmental impacts of harmful non-indigenous species in Southeast Asia. *PLoS ONE*, 8(8): e71255.

Paini, D. R., et al. (2016). Global threat to agriculture from invasive species. *Proceedings of the National Academy of Sciences of the USA*, 113(27): 7575-7579.

Pebesma, E. (2018). Simple Features for R: Standardized Support for Spatial Vector Data. *The R Journal*, 10 (1): 439–446.

Pimentel, D., et al. (2001). Economic and environmental threats of alien plant, animal, and microbe invasions. *Agriculture, Ecosystems and Environment,* 84 (1): 1-20.

Pimentel, D., Zuniga, R. and Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, 52 (3): 273-288.

Poudel, B. S. and Thapa, H. B. (2012). An assessment of existing studies on invasive alien plant species of Nepal. *Banko Janakari*, 22 (1): 28-36.

PQPMC. (2019). Invasive Alien Species: An emerging threat to agriculture and biodiversity in Nepal. Plant Quarantine and Pesticide Management Center (PQPMC), Ministry of Agriculture and Livestock Development, Nepal. 52 p.

Pullin, A. S. and Stewart, G. B. (2006). Guidelines for systematic review in conservation and environmental management. *Conservation Biology*, 20 (6): 1647–1656.

Pysek, P., et al. (2008). Geographical and taxonomic biases in invasion ecology. *Trends in Ecology and Evolution*, 23 (5): 237-244.

Rai, R. K., Sandilya, M. and Subedi, R. (2012). Controlling *Mikania micrantha* HBK: How effective manual cutting is? *Journal of Ecology and Environment*, 35 (3): 235-242.

Rai, R. K. and Scarborough, H. (2013). Economic value of mitigation of plant invaders in a subsistence economy: incorporating labour as a mode of payment. *Environment and Development Economics*, 18 (2): 225-244.

Reid, W. V., et al. (2005). Ecosystems and human well-being-Synthesis: A report of the Millennium Ecosystem Assessment. Island Press, Washington, DC. 137 p.

Shrestha, B. B., Shabbir, A. and Adkins, S. W. (2015). *Parthenium hysterophorus* in Nepal: A review of its weed status and possibilities for management. *Weed Research*, 55(2):132–144.

Shrestha, B. B. (2016). Invasive Alien Plant Species in Nepal. In: P.K. Jha, M. Siwakoti and S. Rajbhandary (Eds.), Frontiers of Botany. Central Department of Botany, Tribhuvan University, Kathmandu, Nepal. pp. 269–284.

Shrestha, B. B. (2019). Management of invasive alien plant species in Nepal: current practices and future prospects. In: S.C. Garkoti, S. van Bloem, P.Z. Fule and R.L. Semwal (Eds.), *Tropical Ecosystems: Structure, Functions and Global Change*. Springer Nature Singapore. pp. 45-68.

Shrestha, B. B., et al. (2019a). Distribution of *Parthenium hysterophorus* and one of its biological control agents (Coleoptera: *Zygogramma bicolorata*) in Nepal. *Weed Research*, 59 (6): 467-478.

Shrestha, B. B., et al. (2019b). Community perception and prioritization of invasive alien plants in Chitwan-Annapurna Landscape, Nepal. *Journal of Environmental Management*, 229: 38–47.

Shrestha, B. B., Thapa-Magar, K. B., Paudel, A., & Shrestha, U. B. (2011). Beetle on the battle: Defoliation of *Parthenium hysterophorus* by *Zygogramma bicolorata* in Kathmandu valley, Nepal. *Botanica Orientalis: Journal of Plant Science*, 8: 100-104.

Shrestha, U. B. and Shrestha, B. B. (2019). Climate change amplifies plant invasion hotspots in Nepal. *Diversity and Distributions*, 25(10): 1599–1612.

Simberloff, D. (2011). Charles Elton: neither founder nor siren, but prophet. In: D.M. Richardson (Eds.), Fifty years of invasion ecology: The Legacy of Charles Elton, Wiley-Blackwell Publications, UK. pp. 11-24.

Thapa, L. B., Kaewchumnong, K., Sinkkonen, A. and Sridith, K. (2020). “Soaked in rainwater” effect of *Ageratina adenophora* on seedling growth and development of native tree species in Nepal. *Flora: Morphology, Distribution, Functional Ecology of Plants*, 263: 151554.

Thomaz, S. M., Kovalenko, K. E., Havel, J. E. and Kats, L. B. (2014). Aquatic invasive species: general trends in the literature and introduction to the special issue. *Hydrobiologia*, 746 (1): 1–12.

Timsina, B., Shrestha, B. B., Rokaya, M. B. and Münzbergová, Z. (2011). Impact of *Parthenium hysterophorus* L. invasion on plant species composition and soil properties of grassland communities in Nepal. *Flora-Morphology, Distribution, Functional Ecology of Plants*, 206 (3): 233-240.

Tiwari, S., Siwakoti, M., Adhakari, B. and Subedi, K. (2005). An inventory and assessment of invasive alien plant species of Nepal. IUCN Nepal. 115 p.

Uddin, K., et al. (2015). Development of 2010 national land cover database for Nepal. *Journal of Environmental Management*, 148: 82-90.

UNESCO. (2020, May 9). How much does your country invest in R&D? (Retrieved from http://uis.unesco.org/apps/visualisations/research-and-development-spending/)

USGS. (2000). Nepal Digital Model Elevation (DEM). US Geological Survey.

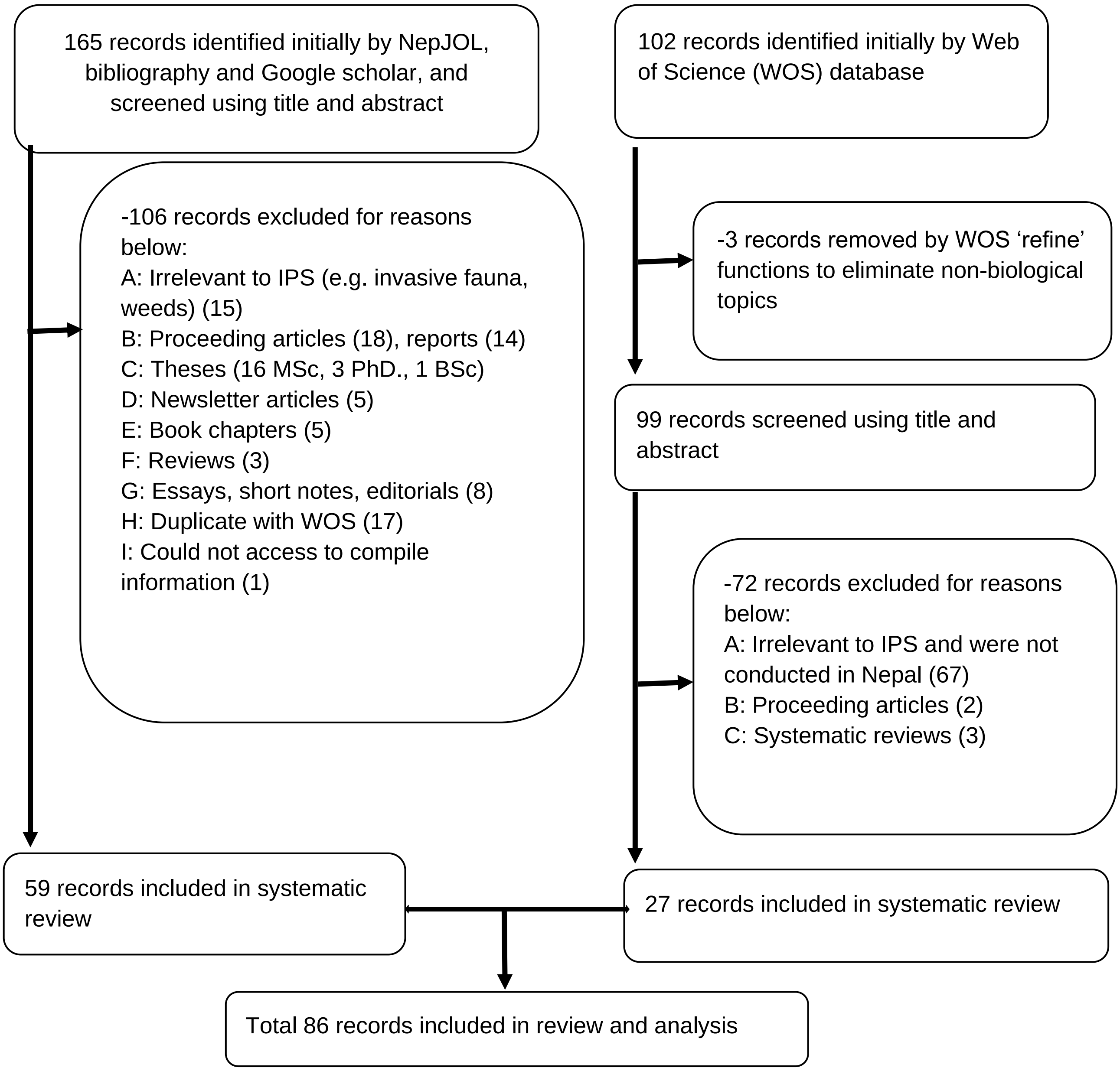
Vilà, M. and Hulme, P. E. (Eds.). (2017).*Impact of biological invasions on ecosystem services* (Vol. 12). Cham: Springer. 354 p.

Wilson, J. R., Procheş, Ş., Braschler, B., Dixon, E. S. and Richardson, D. M. (2007). The (bio) diversity of science reflects the interests of society. *Frontiers in Ecology and the Environment*, 5 (8): 409-414.

Xu, H., et al. (2006). The distribution and economic losses of alien species invasion to China. *Biological Invasions*, 8(7): 1495-1500.

Yu, F., Akin-Fajiye, M., Thapa Magar, K., Ren, J. and Gurevitch, J. (2016). A global systematic review of ecological field studies on two major invasive plant species, *Ageratina adenophora* and *Chromolaena odorata*. *Diversity and Distributions*, 22 (11): 1174–1185.

Supplement 1. Diagram showing article filtering process



Supplement 2. Selected publication attributes with categories and description

Attributes	Categories	Description
Authors institution	1) First author 2) Corresponding author	Corresponding author over the first author for analysis in case they differed from each other
Types of databases	1) WOS 2) Other sources	Other sources (e.g. Google scholar, NepJOL, bibliography published by DFRS 2011).
Research Theme	1) Diversity and Distribution 2) Biology and Ecology 3) Socioeconomic Aspect 4) Ecological Impact 5) Management and Control	1) Studies on species diversity, distribution, abundance, modelling, reviews 2) Studies on trait characteristics (morphological, anatomical, biological, and chemical features; adaptation for environmental gradients); phytochemical screening 3) Perception of local people, impact on local economy and livelihood 4) Studies related to impact on biology and ecology of other species - species distribution, regeneration, occurrence; habitat alteration due to invasion; allelopathy; effect on ecosystem and habitat attributes 5) Studies on management aspects; policy and institutions
Research types	1) Observational 2) Experimental	1) Studies that do not have control over the factors and distribution modelling studies are considered as observational. 3) Studies that have been done by controlling the environmental factors with the experimental design is considered as experimental studies.
Funding resources for research	1) Nepal government 2) Non-Governmental Organizations 3) International Non-Governmental Organizations 4) International Grants 5) Multiple funding sources	1) Organizations/Departments governed by Nepal government. 2) Non-profit citizen-based national organizations registered in Nepal. 3) International non-profit organizations 4) International charitable trusts, governments, and foreign universities. 5) Studies with more than one funding sources
Contributing institution	1) Nepal government 2) Tribhuvan University 3)Non-Governmental Organizations 4) International Non-Governmental Organizations 5) Foreign University 6) Others	2) Tribhuvan University and its constituent institutions. 5) Universities outside Nepal 6) Any organizations/institutions other than mentioned above
Study locations	1) Protected areas 2) Outside protected areas	1) Buffer zone and core areas of national park, wildlife reserve, conservation area; Ramsar sites; protected forests; world heritage sites 2) All other areas other than protected areas

Supplement 3. List of publications selected for inclusion in analysis

Balami, S. and Thapa, L. B. (2017). Herbivory damage in native *Alnus nepalensis* and invasive *Ageratina adenophora*. *Botanica Orientalis: Journal of Plant Science*, 11:7–11.

Balami, S., Thapa, L. B. and Jha, S. K. (2017). Effect of invasive *Ageratina adenophora* on species richness and composition of saprotrophic and pathogenic soil fungi. *BIOTROPIA-The Southeast Asian Journal of Tropical Biology*, 24(3):212-219.

Balami, S., Thapa, L. B. and Jha, S. K. (2019). Effects of invasive *Ageratina adenophora* on mycelial growth of some important soil fungi. *Songklanakarin Journal of Science and Technology*, 41(2):464–469.

Banerji, M. L. (1958). Invasion of *Eupatorium glandulosum* HB & K. in East Nepal. *Bulletin of Botanical Society*, 10(1/2): 14-18.

Baral, B. and Maharjan, B. L. (2011). Antagonistic characteristics and phytochemical screening of invasive alien species of Nepal Himalaya. *International Journal of Pharmaceutical & Biological Archives*, 2(5): 1444–1450.

Baral, B. and Vaidya, G. S. (2011). Biological and chemical assessment of water hyacinth (*Eichhornia crassipes* (mart.) Solms.) of Phewa Lake, Nepal. *Scientific World*, 9(9):57-62.

Baral, B., Bhattarai, N. and Vaidya, G. S. (2011). Pharmacological and Antagonistic Potentials of *Mikania micrantha*. *Nepal Journal of Science and Technology*, 12:75–84.

Baral, B., Vaidya, G. S. and Bhattarai, N. (2011). Bioactivity and biochemical analysis of water hyacinth (*Eichhornia crassipes*). *Botanica Orientalis: Journal of Plant Science*, 8:33–39.

Baral, S., et al. (2017). Invasion of alien plant species and their impact on different ecosystems of Panchase Area, Nepal. *Banko Janakari*, 27(1):31–42.

Basnet, S., Chand, D. B., Wagle, B. H. and Rayamajhi, B. (2016). Plant diversity and stand structure comparison of *Mikania micrantha* invaded and non-invaded tropical *Shorea robusta* forest. *Banko Janakari*, 26(1):78-81.

Bhargava, D., Mondal, C. K., Shivapuri, J. N., Mondal, S. and Kar, S. (2013). Antioxidant properties of the leaves of *Chromolaena odorata* Linn. *Journal of Institute of Medicine*, 35(1):53-57.

Bhatta, S., Joshi, L. R. and Shrestha, B. B. (2020). Distribution and impact of invasive alien plant species in Bardia National Park, western Nepal. *Environmental Conservation*, 47(3):197-205.

Bhattarai, K. R., Måren, I. E. and Subedi, S. C. (2014). Biodiversity and invasibility: Distribution patterns of invasive plant species in the Himalayas, Nepal. *Journal of Mountain Science*, 11(3):688–696.

Bhattarai, N. and Shrestha, G. (2009). Antibacterial and Antifungal Effect of *Eupatorium adenophorum* Spreng against Bacterial and Fungal Isolates. *Nepal Journal of Science and Technology*, 10:91–95.

Chaudhary, R., Shrestha, B. B., Thapa, H. and Siwakoti, M. (2020). Status and impacts of invasive alien plant species in Parsa National Park, central Nepal. *Banko Janakari*, 30(1):21-31.

Dai, J., et al. (2020). Mapping understory invasive plant species with field and remotely sensed data in Chitwan, Nepal. *Remote Sensing of Environment*, 250:1-12.

Devkota, A. and Sahu, A. (2018). Antimicrobial activities and phytochemical screening of leaf extract of Mikania micrantha H.B.K. *Journal of Natural History Museum*, 30:274–286.

Dhakal, S., Shrestha, B. B. and Siwakoti, M. (2018). Comparisons of Invasive Alien Plant Species Richness between Tarai and Siwalik Regions of Central Nepal. *Journal of Plant Resources*, 16(1):119–123.

Dyola, N., et al. (2020). Growth pattern of *Pinus roxburghii* under different regimes of invasive species in Panchase, Nepal Himalayas. *Pakistan Journal of Botany*, 52(1):261-270.

Everard, M., et al. (2018). Can control of invasive vegetation improve water and rural livelihood security in Nepal? *Ecosystem Services*, 32:125–133.

Gaudel, G., Hui, Z. W., Hung, D. Q. and Hien, L. T. (2016). Assessment of Invasive Alien Plant Species : Impact on Carbon Sequestration. *Imperial Journal of Interdisciplinary Research,* 2(10):51-65.

Gautam, D. and Pathak, A. (2020). Status and Impact of Invasive Alien Plant Species in Jyamire Bufferzone Community Forest of Parsa National Park, Nepal. *International Journal of Forestry and Horticulture*, 6(1):2454–9487.

Gurung, H. B., Shrestha, N. P., Chemjong, P. B., Neopnae, S. P. and Aryal, I. K. (1996). Effect of feeding banmara (*Eupatorium adenophorum*) [*Eupatorium trapezoideumon*] on the reproductive performance of goats in the eastern hills of Nepal. *Veterinary Review (Kathmandu)*, 11(2):48-50.

Joshi, C., van Andel, J., Skidmore, A., De Leeuw, J. and Duren, I. V. (2011). Morphological plasticity of corms in enhancing invasion of *Chromolaena odorata*. *Banko Janakari*, 21(2):3–12.

Joshi, C., et al. (2006). Indirect remote sensing of a cryptic forest understorey invasive species. *Forest Ecology and Management*, 225(1–3):245–256.

Sharma, K. C. and GK, K. C. (1977). Reports on studies on the biological control of *Eupatorium adenophorum* [by the gallfly *Ecidochares utilis*, in Nepal]. *Nepalese Journal of Agriculture*, 12:135-58.

K.C., U. and Shrestha, B. (2019). Invasion of *Parthenium hysterophorus L .* across land use types in Kirtipur Municipality. *International Journal of Human Capitals on Urban Management*, 4(4):259–268.

Kafle, M. R., Kafle, G., Balla, M. K. and Dhakal, L. (2009). Results of an Experiment of Preparing Compost from Invasive Water hyacinth (*Eichhornia crassipes*) in Rupa Lake Area, Nepal. *Journal of Wetlands Ecology*, *2*:17–19.

Khadka, A. (2017). Assessment of the perceived effects and management challenges of *Mikania micrantha* invasion in Chitwan National Park buffer zone community forest, Nepal. *Heliyon*, 3(4):1-14.

Khanal, D. P., Raut, B. and Dangol, K. S. (2015). Phytochemical Screening, Pharmacognostic Evaluation and Biological Activity of *Amaranthus spinosus* L. *Journal of Manmohan Memorial Institute of Health Sciences*, 1(4):29–34.

Khaniya, L. and Shrestha, B. B. (2020). Forest regrowth reduces richness and abundance of invasive alien plant species in community managed *Shorea robusta* forests of central Nepal. *Journal of Ecology and Environment*, 44(1):1-8.

Lamsal, A., Devkota, M. P., Shrestha, D. S., Joshi, S. and Shrestha, A. (2019). Seed germination ecology of *Ageratum houstonianum*: A major invasive weed in Nepal. *PLoS ONE*, 14(11):1–14.

Maharjan, R. B. S. and Ming, C. L. (2012). The Potential Role of Water Hyacinth in Wastewater Treatment in Nepal. *Hydro Nepal: Journal of Water, Energy and Environment*, 10(10):36–41.

Maharjan, S., Joshi, S., Shrestha, B. B., Devkota, A. and Jha, P. K. (2014). Life History Traits and Invasion Success of *Parthenium hysterophorus* L. in Kathmandu Valley, Nepal. *Nepal Journal of Science and Technology*, 15 (1):31–38.

Maharjan, S., Shrestha, B. B. and Jha, P. K. (2007). Allelopathic Effects of Aqueous Extract of Leaves of *Parthenium Hysterophorus* L. on Seed Germination and Seedling Growth of Some Cultivated and Wild Herbaceous Species. *Scientific World*, 5 (5):33–39.

Maharjan, S., et al. (2019). Predicting suitable habitat of an invasive weed *Parthenium hysterophorus* under future climate scenarios in Chitwan Annapurna Landscape, Nepal. *Journal of Mountain Science*, 16(10):2243–2256.

Maharjan, S., Shrestha, B.B., Devkota, A., Muniappan, R. and Jha P.K. (2020). Seed biology of summer and winter generations of *Parthenium hysterophorus* L. *Journal of Environment Science*, 6:112-118.

Mishra, K. K. (1991). Parthenium hysterophorus LINN.-a new record for Nepal. *Journal of the Bombay Natural History Society*,88 (3):466-467.

Murphy, S. T., et al. (2013). Invasive mikania in Chitwan National Park, Nepal: The threat to the greater one-horned rhinoceros *Rhinoceros unicornis* and factors driving the invasion. *Oryx*, 47(3):361–368.

Niroula, B. (2012). Phenology, biomass, and associated species of alligator weed at Biratnagar, Nepal. *Nepalese Journal of Biosciences*, 2:148–150.

Niroula, B., Parajuli, D. and Jha, S. (2009). Ecophysiology of *Mimosa pudica* L. at Biratnagar, Eastern Nepal. *Our Nature*, 7 (1):177–181.

Pandit, N. R., et al. (2018). Biochar improves maize growth by alleviation of nutrient stress in a moderately acidic low-input Nepalese soil. *Science of the Total Environment*, 625:1380–1389.

Pandit, N. R., Mulder, J., Hale, S. E., Schmidt, H. P. and Cornelissen, G. (2017). Biochar from “Kon Tiki” flame curtain and other kilns: Effects of nutrient enrichment and kiln type on crop yield and soil chemistry. *PLoS ONE*, 12 (4):1–18.

Paudel, V. R. and Gupta, V. N. P. (2008). Effect of some Essential Oils on Seed Germination and Seedling Length of *Parthenium hysterophorus* L. *Ecoprint: An International Journal of Ecology*, 15:69–73.

Paudel, V., Gupta, V. and Agarwal, V. (2009). Effect of Diffusates of *Parthenium hysterophorus* on Seed Germination of *Raphanus sativus* L. *Scientific World*, 7(7):29–32.

Rai, R. K. and Rai, R. (2013). Assessing the Temporal Variation in the Perceived Effects of Invasive Plant Species on Rural Livelihoods: A Case of *Mikania micrantha* Invasion in Nepal. *Conservation Science*, 1(1):13–18.

Rai, R. K. and Scarborough, H. (2013). Economic value of mitigation of plant invaders in a subsistence economy: Incorporating labour as a mode of payment. *Environment and Development Economics*, 18(2):225–244.

Rai, R. K. and Scarborough, H. (2015). Understanding the Effects of the Invasive Plants on Rural Forest-dependent Communities. *Small-Scale Forestry*, 14(1):59–72.

Rai, R. K., Sandilya, M. and Subedi, R. (2012). Controlling *Mikania micrantha* HBK: How effective manual cutting is? *Journal of Ecology and Field Biology*, 35(3):235–242.

Rai, R. K., Scarborough, H., Subedi, N. and Lamichhane, B. (2012). Invasive plants - Do they devastate or diversify rural livelihoods? Rural farmers' perception of three invasive plants in Nepal. *Journal for Nature Conservation*, 20(3):170–176.

Rokaya, M. B., Khatri-Chettri, J., Ghimire, S. R. and Shrestha, B. B. (2020). Vegetation and soil seedbank dynamics in *Parthenium hysterophorus* L. invaded subtropical grassland in Nepal. *Tropical Ecology*, 61(2):238-247.

Rymer, C. (2008). The effect of wilting and soaking *Eupatorium adenophorum* on its digestibility in vitro and voluntary intake by goats. *Animal feed science and technology*, 141(1-2):49-60.

Sahu, A. and Devkota, A. (2013). Allelopathic Effects of Aqueous Extract of Leaves of *Mikania Micrantha* H.B.K. on Seed Germination and Seedling Growth of *Oryza Sativa* L. and *Raphanus Sativus* L. *Scientific World*, 11(11):91–93.

Sahu, A. and Devkota, A. (2016). Antimicrobial Activity of Leaf Extracts of Some Invasive Alien Plant Species of Aster Family against Clinical Bacteria. *Ecoprint: An International Journal of Ecology*, 23:1–12.

Sapkota, L. (2007). Ecology and management issues of *Mikania micrantha* in Chitwan National Park, Nepal. *Banko Janakari*, 17(2):27–39.

Schmidt, H., et al. (2015). Fourfold Increase in Pumpkin Yield in Response to Low-Dosage Root Zone Application of Urine-Enhanced Biochar to a Fertile Tropical Soil. *Agriculture*, 5(3):723–741.

Sharma, K. R. (2020). In-vitro antioxidant, antidiabetic, and toxic effect of *Ageratum houstonianum* from Chitwan district Nepal. *Journal of Balkumari College*, 9(1):48-54.

Sharma, L. N., Adhikari, B., Bist, M. R. and Shrestha, B. B. *Mimosa diplotricha* (Fabaceae): A New Report of Invasive Weed from Eastern Tarai of Nepal. *Journal of Plant Resources*, 18(1): 1-5.

Sharma, M. and Devkota, A. (2018). Allelopathic Influences of *Artemisia dubia* Wall. Ex. Besser on Seed Germination and Seedling Vigor of *Parthenium hysterophorus* L. *Journal of Institute of Science and Technology*, 22 (2):117–128.

Sharma Poudel, A., Shrestha, B. B., Jha, P. K., Baniya, C. B. and Muniappan, R. (2020). Stem galling of *Ageratina adenophora* (Asterales: Asteraceae) by a biocontrol agent *Procecidochares utilis* (Diptera: Tephritidae) is elevation dependent in central Nepal. *Biocontrol Science and Technology*, 30 (7):611-627.

Shrestha, B. B., et al. (2019). Distribution of *Parthenium hysterophorus* and one of its biological control agents (Coleoptera: *Zygogramma bicolorata*) in Nepal. *Weed Research*, 59(6):467–478.

Shrestha, B. B., et al. (2010). Fortuitous biological control of *Parthenium hysterophorus* by *Zygogramma bicolorata* in Nepal. *Journal of Natural History Museum*, 25:332-337.

Shrestha, B. B., et al. (2019). Community perception and prioritization of invasive alien plants in Chitwan-Annapurna Landscape, Nepal. *Journal of Environmental Management*, 229:38–47.

Shrestha, B. B., Thapa-Magar, K. B., Paudel, A. and Shrestha, U. B. (2011). Beetle on the battle: Defoliation of *Parthenium hysterophorus* by *Zygogramma bicolorata* in Kathmandu valley, Nepal. *Botanica Orientalis: Journal of Plant Science*, 8:100–104.

Shrestha, B. K. and Dangol, D. R. (2014). Impact of *Mikania micrantha* H.B.K. Invasion on Diversity and Abundance of Plant Species of Chitwan National Park, Nepal. *Journal of Institute of Science and Technology*, 19(2):30–36.

Shrestha, K., Wilson, E. and Gay, H. (2008). Ecological and Environmental Study of *Eupatorium adenophorum* Sprengel (Banmara) with Reference to its Gall Formation in Gorkha-Langtang Route, Nepal. *Journal of Natural History Museum*, 23:108–124.

Shrestha, S. (2019). Distribution, effect, and utilization of Mikania micrantha on livelihood: Case study of Janakauli buffer zone community forest of Chitwan National Park. *Journal of Agriculture and Natural Resources*, 2(1):95–108.

Shrestha, U. B. and Shrestha, B. B. (2019). Climate change amplifies plant invasion hotspots in Nepal. *Diversity and Distributions*, 25(10):1599–1612.

Shrestha, U. B., Sharma, K. P., Devkota, A., Siwakoti, M. and Shrestha, B. B. (2018). Potential impact of climate change on the distribution of six invasive alien plants in Nepal. *Ecological Indicators*, 95:99–107.

Singh, A. G. and Sharma, A. (2014). Documentation of Invasive Alien Plants Species of Rupandehi District, Western Nepal. *International Journal of Applied Sciences and Biotechnology*, 2(2):168–175.

Singh, R. M. and Poudel, M. S. (2013). Briquette Fuel - An Option for Management of *Mikania micrantha*. *Nepal Journal of Science and Technology*, 14(1):109–114.

Siwakoti, M. (2007). Mikania Weed: A Challenge for Conservationists. *Our Nature*, 5(1):70–74.

Subba, B. and Kandel, R. C. (2012). Chemical Composition and Bioactivity of Essential Oil of *Ageratina adenophora* from Bhaktapur District of Nepal. *Journal of Nepal Chemical Society*, 30:78–86.

Sullivan, A., An, L. and York, A. (2018). Which perspective of institutional change best fits empirical data? An agent-based model comparison of rational choice and cultural diffusion in invasive plant management. *Journal of Artificial Societies and Social Simulation*, 21(1).

Sullivan, A., York, A. M., An, L., Yabiku, S. T. and Hall, S. J. (2017). How does perception at multiple levels influence collective action in the commons? The case of *Mikania micrantha* in Chitwan, Nepal. *Forest Policy and Economics*, 80:1–10.

Sullivan, A., York, A. M., White, D. D., Hall, S. J. and Yabiku, S. T. (2017). De jure versus de facto institutions: Trust, information, and collective efforts to manage the invasive mile-a-minute weed (*Mikania micrantha*). *International Journal of the Commons*, 11(1):171–199.

Suwal, M. M., Devkota, A. and Lekhak, H. (2010). Allelopathic Effects of *Chromolaena odorata* (L.) King & Robinson on Seed Germination and Seedlings Growth of Paddy and Barnyard Grass. *Scientific World*, 8 (8):73–75.

Thapa, L. B., Kaewchumnong, K., Sinkkonen, A. T. and Sridith, K. (2016). Plant communities and *Ageratina adenophora* invasion in lower montane vegetation, central Nepal. *International Journal of Ecology and Development*, 31 (2):35-49.

Thapa, L. B., Kaewchumnong, K., Sinkkonen, A. and Sridith, K. (2016). Plant invasiveness and target plant density: high densities of native *Schima wallichii* seedlings reduce negative effects of invasive Ageratina adenophora. *Weed Research*, 57(2):72–80.

Thapa, L. B., Kaewchumnong, K., Sinkkonen, A. and Sridith, K. (2016). Impacts of invasive *Chromolaena odorata* on species richness, composition, and seedling recruitment of *Shorea robusta* in a tropical sal forest, Nepal. *Songklanakarin Journal of Science and Technology*, 38(6):683–689.

Thapa, L. B., Kaewchumnong, K., Sinkkonen, A. and Sridith, K. (2020). “Soaked in rainwater” effect of Ageratina adenophora on seedling growth and development of native tree species in Nepal. *Flora: Morphology, Distribution, Functional Ecology of Plants*, 263-151554.

Thapa, L. B., Kaewchumnong, K., Sinkkonen, A. and Sridith, K. (2020). Airborne and belowground phytotoxicity of invasive *Ageratina adenophora* on native species in Nepal. *Plant Ecology*, 221:883-892.

Thapa, S., Chitale, V., Rijal, S. J., Bisht, N. and Shrestha, B. B. (2018). Understanding the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *PLoS ONE*, 13(4):1–16.

Timsina, B., Shrestha, B. B., Rokaya, M. B. and Münzbergová, Z. (2011). Impact of *Parthenium hysterophorus* L. invasion on plant species composition and soil properties of grassland communities in Nepal. *Flora: Morphology, Distribution, Functional Ecology of Plants*, 206 (3):233–240.

Vaidya, G. S. and Bhattarai, N. (2009). Antagonistic study of *Lantana camara* (Linn) against with pathogenic bacteria. *Scientific world*, 7 (7):64-67.

Vaidya, G. S. and Bhattarai, N. (2014). Efficacy of invasive green manures and mycorrhiza on growth and yield of different legumes crops and study their antimicrobial properties. *Scientific World*,12 (12):65-69.

TECHNICAL PAPER

Design and testing of field application tools for a bioherbicide with a plant virus as active ingredient

Raghavan Charudattan [1] Ernest Hiebert [1] Wayne Currey [2] Mark Elliott [1] James DeValerio [1] and Gabriella Maia [1] [1]

[1] BioProdex, Inc., 3131 NW 13th Street, # 54, Gainesville, FL 32609-2183
[2] Weed Systems, Inc., Hawthorne, Florida

Corresponding Author E-mail: rcharudattan@bioprodex.com.

Received: 8 August 2020

Accepted for publication: 3 October 2020

Published: 30 December 2020

Abstract

SolviNix LC is a novel commercial bioherbicide containing a plant virus as the active ingredient (ai). It is registered in the USA for the control of tropical soda apple (*Solanum viarum,* TSA), an invasive weed of pastures and woodlands. As no prior example or experience exists for the application of a plant virus as an herbicide, we devised and tested tools and methods for field application.

Our objectives were to design a practical, economical, and effective tool and method that could be easily melded into weed management practices. This should be accomplished by delivering a minimal effective amount of the ai (in dosage and rate). As TMGMV, like all plant viruses, requires physical damage to the plant by abrasion or wounds to enter the tissues, we designed, assembled, and tested four tools and a few modifications thereof that simultaneously abraded and applied the bioherbicide to the leaves. We also tested two commercially available herbicide wipers and modifications to them to treat individual plants. Of the tools tested, high-pressure sprayers, either a backpack sprayer or an all-terrain vehicle (ATV) mounted sprayer, delivering the herbicide at $\geq$ 0.55 MPa ($\geq$80 psi), provided the desired level of weed kill (85% or higher). Here we describe the different application tools, the test results, and the rationale for the application tool/method presently included in the label, a backpack sprayer. Given the novelty of the application systems we tried, this report could be instructive to others facing a similar challenge.

Keywords: *Tobacco mild green mosaic tobamovirus,* TMGMV, plant virus, tropical soda apple, *Solanum viarum*, SolviNix, bioherbicide.

Introduction

Solanum viarum Dunal (tropical soda apple, TSA) is a serious weed in pastures and surrounding woodlands in the USA and several other countries. It is a species native to Argentina, Brazil, Paraguay, and Uruguay and is a designated Noxious Weed in the USA (e-CFR, Part 360 Noxious Weed Regulations, 2020). Following its introduction into Florida in 1984, TSA spread rapidly to several south-eastern U.S. states in the 1990s (CABI, 2020). Following several years of coordinated, aggressive management by these states, TSA is now confined to Florida where it is a recurring problem in cattle pastures and surrounding woodlands.

[1] RC and EH, Emeritus Professors, University of Florida, Plant Pathology Department, Gainesville, Florida (UF PPD); ME, former Senior Biological Scientist (UF-PPD); JD, former Senior Biological Scientist (UF PPD), Emeritus Agriculture & Community Development Agent (UF) and now Laboratory Technician IV, Bureau of Citrus Budwood Registration, Division of Plant Industry, Florida Department of Agriculture and Consumer Services, LaCrosse, Florida; and GM, former Lab Technician (UF PPD).

TSA has been introduced into 19 countries of which 10 have reported it to be invasive, including Australia (reported from New South Wales [NSW WeedWise, 2018] and Queensland [Csurhes, 2012]), India, Myanmar, Nepal, Vietnam, and others (CABI, 2020). In New South Wales, TSA is under a Biosecurity (Tropical Soda Apple) Control Order (Christie, 2017). The biology, distribution, economic and environmental impacts, and management of TSA have been well studied and published (e.g. Cuda et al., 2000; Mullahey et al., 1993, 1994a, 1994b; Salaudeen et al., 2013).

In our search for a biological control agent for TSA, we discovered an unusual but previously known phenomenon of virus-elicited systemic necrosis that consistently killed this plant. The virus is a naturally occurring (non-engineered, unmodified) Tobacco mild green mosaic virus Strain U2 (TMGMV U2). In December 2014, the U.S. Environmental Protection Agency (EPA) granted an unrestricted registration for our product SolviNix LC as a bioherbicide for TSA and TMGMV U2 as an herbicide active ingredient (ai). It is the world's first example of an herbicide ai that is a plant virus. To assemble the registration data package, we researched the biology of the host-virus interaction, sequenced an isolate of the registered strain, screened 435 plant species to delineate the host range of the virus, and developed a process to mass-produce the virus for commercial use.

With no prior example or experience to guide us in the application of a plant virus as a commercial herbicide, we devised and tested several tools and methods for field application. The method had to be practical, effective, and easily melded into weed management practices. As TMGMV, like all plant viruses, requires physical damage to the plant by abrasion or wounds to enter the plant tissues, the challenge was to design a tool that *simultaneously abraded and applied the bioherbicide to the leaves*. This should be accomplished by delivering a minimal effective amount of the ai (in dosage and rate) to render the herbicide economical and environmentally acceptable. Here we describe the different application tools, the test results, and the rationale for the application tool/method included in the label.

Tobacco mild green mosaic virus (TMGMV) (scientific name: *Tobacco mild green mosaic tobamovirus*, is a species of *Tobamovirus.* It was previously called Tobacco mosaic virus U2 (TMV U2) and is worldwide in distribution wherever tree tobacco (*Nicotiana glauca* Graham), an occasional ornamental and more commonly a naturalized weed, and cultivated tobacco, *N. tabacum* L., are grown.

As the name implies, TMGMV causes a mild mosaic symptom in tobacco compared to the closely related TMV. Also, compared TMV, TMGMV attacks fewer hosts (a narrower host range) (Description of Plant Viruses [DPV], 2020).

Unlike animal viruses that infect their hosts through receptors on host cells, for TMGMV to be effective as a bioherbicide, the virus particles (the ai in the bioherbicide) have to be introduced into living TSA cells through microscopic or macroscopic injuries to the cell walls. The virus can then infect the cells, replicate, and move from cell to cell, triggering the systemic lethal necrosis, a form of severe hypersensitive response to the virus from TSA (Charudattan and Hiebert, 2007).

TMGMV and other tobamoviruses are called "mechanically transmitted" viruses. They have no known natural vectors such as arthropods or nematodes that transmit the virus and must be physically inoculated into the plant cells to cause disease. On a small scale in the laboratory and greenhouse, rubbing individual leaves with a piece of sterile cheesecloth dipped in a virus extract is used, which is impractical to use on a field scale. Hence, it was necessary to design and test a new equipment or modify conventional herbicide applicators.

Our priorities were to devise an equipment/tool that is effectively inoculates the plants, was easy to operate, and could be purchased from us or self-assembled by the users. Moreover, the application should ensure a consistently high level of control (weed kill) while delivering only a small amount/volume of the virus. The method must injure the foliage mildly without tearing off the inoculated leaves or breaking the branches, which would preclude virus replication and triggering of the lethal host reaction. The challenge was enormous due to the lack of prior art to such a method of herbicide application.

Background

From the start, field-wide application of the bioherbicide was not contemplated as TSA occurs in patches rather than in large monocultures. It was equally important to avoid non-target application, i.e., leaving virus residues in pasture areas devoid of TSA. The cost of the bioherbicide to the user was another important consideration. Therefore, we attempted to design an application tool to treat scattered TSA patches and areas inaccessible to larger equipment, such as in wooded areas. Based on our prior work (Charudattan and Hiebert, 2007), we decided that two methods of application would be necessary: 1) spot application to treat plants in sites inaccessible to spray vehicles and 2) an ATV (all-terrain vehicle) mounted sprayer to treat scattered, patchy infestations in open fields. Also, from the earlier work it was established that more than 85% TSA control could be obtained using 10 µg of ai per ml applied at the rate of about 5 ml per plant in spot treatments.

Materials and Methods

Unless stated otherwise, the following application tools/systems were conceptualized and developed jointly by the authors and custom designed and assembled by Dr. Wayne Currey from commercially available components. A liquid concentrate of a purified preparation of TMGMV U2, the registered bioherbicide formulation of SolviNix LC, was used (SolviNix Labels, **www.bioprodex.com,** 2014).

The tools and methods were tested and validated under an Experimental Use Permit (EUP) issued to BioProdex, Inc. by the EPA. The trials were done in approximately 18.45 hectares (45.6 acres) at six sites in six Florida counties (see details in **Tables 1 and 2**).

As a standard practice, the SolviNix LC was mixed with a volume of water required to provide the chosen ai/ml and the approximate volume for the area or number of plants to be treated. No adjuvant, surfactant, or abrasive such as carborundum power was used. Indeed, none of these additives should be used (SolviNix Labels, 2014) as they will either render SolviNix to be noninfective (adjuvants/surfactants) or could be unsafe to applicators (carborundum). The effects of virus inoculation on disease development and symptoms sequence are presented under Results in **Figure 11** (see later).

The timing of application is critical to assure efficacy: SolviNix should be applied from spring to fall in subtropics and from late spring to late summer in temperate zones. So, these trials were done between late March and early September. Each of the following systems (except S-4 M-1, S-6 and its two modifications, **Table 1**) was tested at least twice at two or more sites to confirm consistency of results. As this was a qualitative comparison intended to select tools and methods that consistently provided 85% or higher levels of TSA kill, no statistical analysis was deemed necessary.

System 1 (S-1): This system consisted of a MeterJet™ spray gun (Spraying Systems Co., Glendale Heights, IL, USA, **https://www.spray.com** having a TeeJet 0001 nozzle (TeeJet Technologies, Glendale Heights, IL, USA, **https://www.teejet.com**) set to deliver 2 mL of SolviNix per discharge at 0.55 MPa (80 psi) force at the point of discharge (**Figure 1**). The sprayer was connected to a high-pressure backpack cylinder containing CO_2 as the propellant. The spray gun was attached to the cylinder with a high-pressure hose fitted with a Series 2 HKGL Eaton Hansen quick-disconnect coupling (Eaton, Jacksonville, Florida, **https://www.eaton.com**).

Figure 1. The S-1 sprayer gun for spot- spraying with a pre-set 2-mL volume of SolviNix per discharge at 0.55 MPa (80 psi).

S-2: Like S-1, S-2 was operated with a backpack high-pressure CO_2 cylinder but unlike S-1, it had a meter-long) wand with a TeeJet nozzle having a D-1 or D-2 orifice plate in a Quick Cap and an extra gasket (**Figure 2**).

Also, unlike S-1, S-2 was not designed to discharge a pre-set volume of SolviNix; the discharge duration was used to regulate the volume sprayed. The SolviNix was sprayed at 0.41 to 0.55 MPa (60 to 80 psi) forcing it to penetrate the leaves.

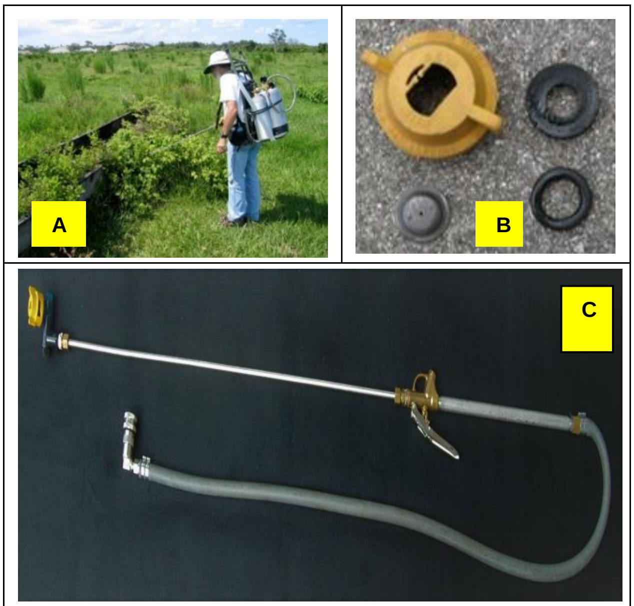


Figure 2. (**A**) S-2 backpack sprayer with an herbicide tank and a pressurized CO_2 cylinder.(**B**) Parts of the nozzle assembly consisting of (clockwise from top left) Quick Cap, a standard washer, an extra washer, and a TeeJet D-2 orifice plate. (**C**) A fully assembled trigger-controlled wand with the nozzle assembly and a Series 2 HKGL Eaton Hansen quick-disconnect coupling to connect the hose to the tank.

S-3: This system was similar to S-2 but was operated with a 12-volt battery-powered electric pump mounted on an all-terrain vehicle (ATV) (**Figure 3**). It could also be operated off the battery of a pickup truck. It was designed to generate a spray stream at 0.48 to 1.38 MPa (70 to 200 psi). Unlike S-2, S-3 was attached to a long pressure hose to reach sites inaccessible to the ATV or a truck.

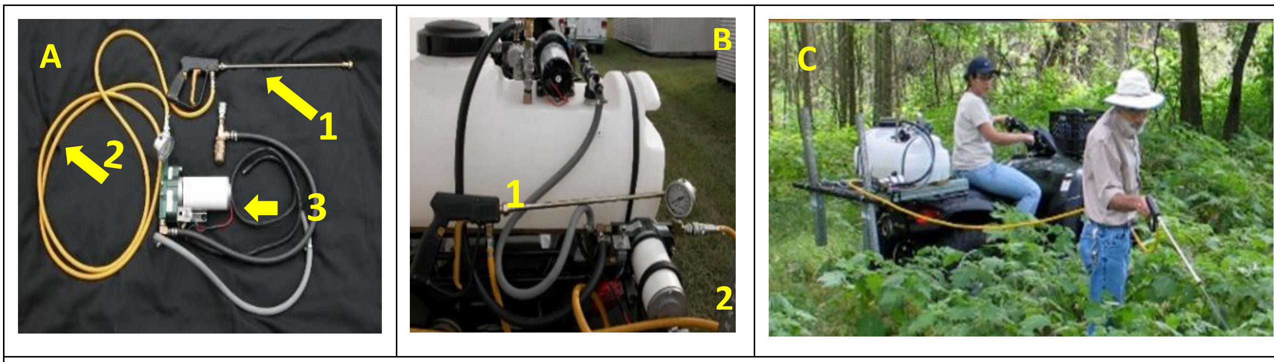


Figure 3. (**A**) The high-pressure, trigger-controlled spray wand of S-3 (arrow 1) fitted with the TeeJet nozzle assembly (**Figure 3 B, C**), a long hose (arrow 2), and a high-pressure electric pump (arrow 3). (**B**) A fully assembled S-3 with an ATV-mounted tank, the spray wand (arrow 1), and the high-pressure electric pump with a pressure gauge (arrow 2). (**C**) The mobility and reach afforded by S-3 is shown.

S-4: The S-4 was designed with a 3.05-meter-wide (10-foot) spray boom providing a 3.7-meter (12-foot) swath coverage. The system was mounted on an ATV as shown in **Figure 4**. The spray boom was designed to work with a row of plastic doormats (available in local hardware stores), 46 cm width by 56 cm long, hung from a metal rod mounted about 8 cm behind the boom.

Figure 4. (**A**) The S-4 with a spray boom and abrasive mats fitted on one side of the ATV with the tufted, abrasive side of the mats facing forward and hung from a bar about 8 cm (3 inches) behind and below the spray boom. (**B**) The row of mats (shown back side facing the camera) were flexible as they passed over the TSA canopy. (**C**) Frontal (**C1**) and rear views (**C2**) of S-4 making passes over TSA plants.

The mats were intended to abrade the leaves as they passed over the TSA foliage (**Figure 4 B**). The spray boom was fitted with seven TeeJet Airmix 110-03 flat fan nozzles and the system was fed with SolviNix from a spray tank by a CO_2 high-pressure cylinder, both housed in a fiberglass crate mounted on the ATV (arrow, **Figure 4 A**).S-4 was first tested twice in a replicated study at the University of Florida field research station (site details in **Table 2**).

The test site was prepared by tilling and treatment with a preplant chemical herbicide approved for use for this site. The plots were 3.05 m^2 (10 ft^2) and each plot was transplanted with 24 TSA seedlings in four rows each with six seedlings. The transplants were allowed to grow for approximately 12 weeks to reach maturity to the pre-flowering stage at inoculation.

S-4 was tested by applying six treatments of 0 (water control) and, 3.12, 6.25, 12.5, 25, or 50 µg/ml of SolviNix with five replicates plots per concentration. The study was concluded 44 days (first trial) or 34 days (second trial) after the treatments were applied at which time the final counts of living plants per plot were taken and percent TSA kill was calculated The results are presented in **Table 2**.

Figures 5 illustrates the effectiveness of the S-4 system and that of SolviNix as an herbicide. The system was tested in a replicated field trial and further modified to improve efficacy.

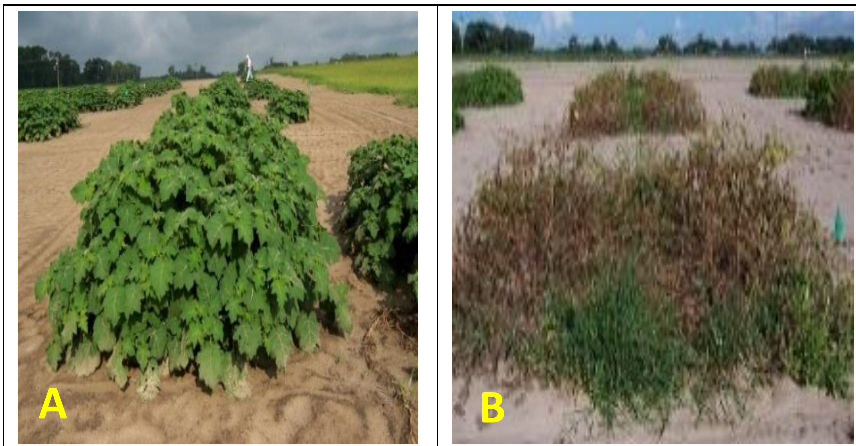


Figure 5. Replicated plots of TSA plants treated with SolviNix using the S-4 system (**Figure 5**). (**A**) The TSA plants had been treated two days before this picture was taken. (**B**) The plots to the left of the centre row show untreated (green, alive) TSA; the row of plots in the middle and the two plots to the right were treated with SolviNix (brown, dead). Grass weeds (green) are seen in the foreground plot (21 days after treatment).

The system was modified three ways to improve leaf abrasion. Modification 1 (M-1) consisted of using 11 cm (4.5 inch) wide strips of the plastic mats (compared to the 46 cm wide mats in S-4) (**Figure 6 A, B, C**).

It was conjectured that the narrower strips unlike the broader mats would pass through the TSA canopy and abrade the leaves from different angles unlike the wider mats that tended to simply ride over the canopy and miss wiping a large proportion of the lower leaves.

Figure 6. In M-1 modification of S-4, the mats were vertically cut into 11-cm (4.5-inch) strips, front (**A**) and back (**B**) views. The strips were attached and hung from a metal bar on an ATV as in S-4. (**C**) Application of SolviNix with M-1 in a TSA-infested mixed pasture-pecan grove.

In the second modification M-2, the 11-cm wide plastic mats were replaced with a row of 0.76-meter (2.5-foot) lengths of 5.1-cm (2-inch) width double-loop chain (**Figure 7A**). The chain lengths were hung 2.5 cm (1 inch) apart, from a 3.05-meter metal bar about 8 cm (3 inches) behind the spray boom.

It was thought that the metal links would help abrade the leaves as the chain lengths passed through TSA canopy, amidst the branches. In M-3, the spray boom of S-4 was fitted with a section of chicken-mesh fencing weighted down with a galvanized metal bar (**Figure 7B, 7C**), assisting the chicken-mesh to abrade the leaves as it passed over TSA canopy.

Figure 7. Field use of M-2 and M-3 modifications of S-4 showing the chain lengths (**A**) and the chicken-mesh fencing material (arrow, right), a metal bar to weigh down the mesh (arrow, left) (**B)**, and the spray boom (**C**).

<u>**S-5**</u>: A commercial wiper system developed for chemical herbicide applications called the Alley Cat Herbicide Wiper (Alley Cat Farm Equipment, Boynton Beach, Florida (**www.weedwipe.com**) was tested.

The wiper system consisted of a row of water-permeable synthetic fibre mats backed with plastic mats with both fitted with tubes delivering measured volumes of herbicide (**Figures 8 and 9**).

The flow rate was controlled by a pressure regulator attached to an ATV-mounted 56.8 litter (15-gallon tank). As the wiper passed over the TSA foliage, the mats abraded the leaves and deposited a liquid film of SolviNix on the leaves (**Figure 9**).

S-5 was tested at delivery rates of 28 L/ha to 131 L/ha (3 to 14 GPA), and further improvements were tried to increase abrasiveness. This was done by (1) placing a stretch of chicken-mesh fencing in front of the wiper pads (modification M-1a) (**Figure 8A)** or (2) behind the pads (modification M-2a; image not shown), or (3) by adding a section of galvanized reinforcement mesh to the chicken-mesh fencing in front of the wiper pads (M-3a) (**Figure 8B**). These additions were made without interfering with the wiper's designed fluid delivery system.

Figure 8. (**A**) Application system S-5, Alley Cat Herbicide Wiper. Water permeable material (blue) that allows flow-through while remaining moist with *SolviNix* LC and rubber backing material. (**B**) Attached with fluid-delivery tubes. (**C**). The S-5 wiper system in use in the field.

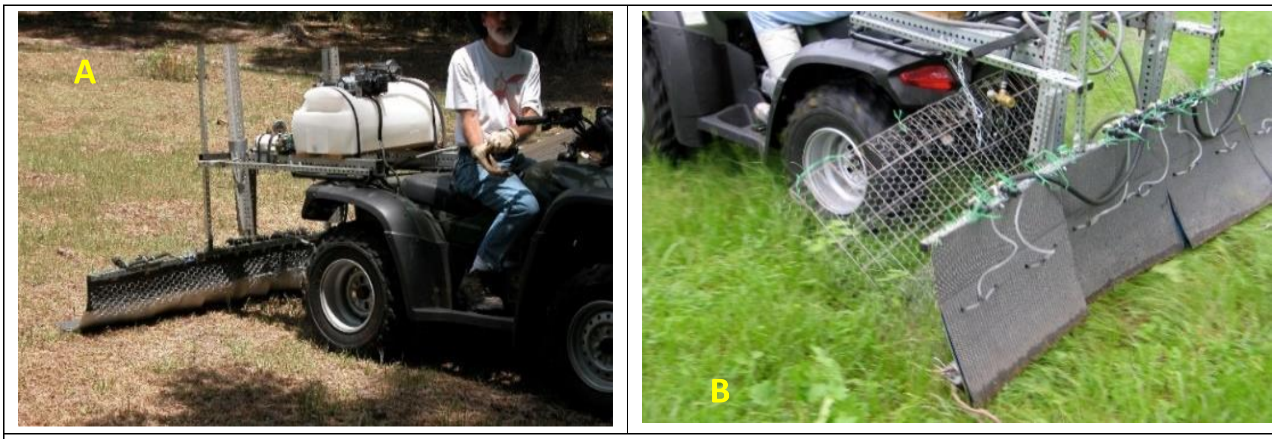


Figure 9. Modification M-1a to the Alley Cat herbicide wiper (S-5) with chicken-mesh fencing placed before the pad (**A**) and M-3a with galvanized reinforcement mesh and chicken-mesh before the pad (**B**), both modifications shown fully assembled and ready to be used.

S-6: The S-6 was the Microwipe (**Figure 10**) herbicide wiper made by the Micron Group (Micron Group, Bromyard Industrial Estate, Herefordshire, U.K., https://www.Microngroup.com/microwipe).

We tested it as a hand-held "clean-up" tool for scattered TSA plants. It is made of plastic tubes in the shape of a "T", with the see-through long end doubling as the handle and herbicide reservoir and the wick looped from the opaque top of the "T" (**Figure 10A, 10 B**). The wick, when fully wet, enabled the herbicide to be wiped on the foliage. To add abrasiveness to the tool, we wrapped chicken-mesh fencing or drywall sanding and plastering screen around the top of the "T", behind the wick (**Figure 10C**).

Results

Once infected by TMGMV, the TSA plant invariably dies following a typical disease development and symptoms expression sequence; the different results reported here were due to the variable efficacy of the tools and methods in delivering the virus into the leaves. The virus-host reaction in these field trials mirrored the repeated observations from greenhouse trials (Charudattan and Hiebert, 2007), but at a slightly slower speed (**Figure 11**).

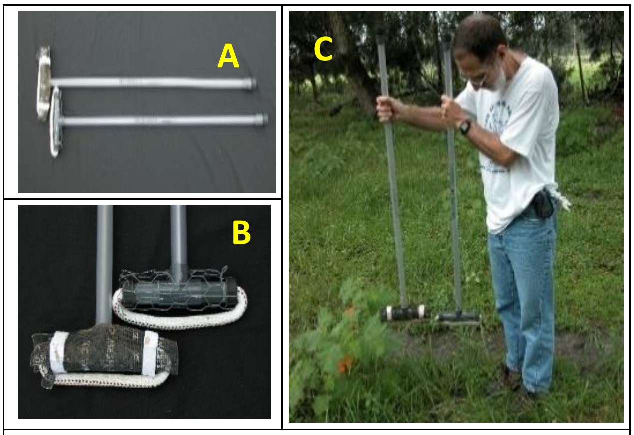


Figure 10. (**A**) S-6 Microwipe applicators with chicken-mesh fencing (**B right**), or drywall sanding screen wrapped behind the wick to improve abrasion (**B, left**). The reservoir (the long handle) is filled with an appropriate dilution of SolviNix LC and after the wick is fully moist, TSA plants are rubbed and scoured as shown in **C**.

The appearance of necrotic local lesions, an expression of host resistance reaction, is the first symptom seen around 14 days (usually on the eighth day in the greenhouse) following infection (**Figure 11 B**). Since the lesions are expressed only in infected leaves, they are not easy to find in the field. Easier and more widely seen is systemic chlorosis of the plant and epinasty and wilting in apical shoots (**Figure 1 C**), the second step in the symptom sequence.

This is followed by the onset of wilting of the entire plant (**Figure 1 D),** progressive death and drying of leaves and branches (**Figure 1 E**), and complete death with the dried plant left standing until trampled by cattle or brought down by natural forces (**Figure 1 F**). Mature green fruits present when the plant is treated may mature and turn yellow carrying viable seeds. Alternatively, if the fruits are immature, they may rot and shrivel up in time (**Figure 11 G)**.

The relative efficacies of the application systems along with site and application details are provided in Table 1. Although S-1 precisely delivered the pre-set volume, it was difficult to aim and consequently gave poor results (<10% TSA kill, results not shown). It was difficult to hit the leaves with brief spurts of fluid as the stream tended to miss the leaves by passing through open spaces between leaves. Therefore, S-1 was not considered suitable and it was not tested further.

S-2 and S-3 systems were highly effective and were considered suitable SolviNix application tools. The average level of efficacy of SolviNix applied with high-pressure spot sprays (S-2 and S-3) averaged 89% (range 58-100% in 12 trials). Both systems performed equally well.

The boom sprayer system S-4 without modifications gave an average of 75% TSA kill in two trials averaged across SolviNix treatments (control not included). The TSA kill ranged from 13% to 96% in the two trials without the expected correspondence between ai/ml concentration and percent kill (Table 2). Hence, to improve efficacy and consistency of S-4, modifications were tried. Of the tree modifications, M-1 gave 50% kill in a single trial and it was not tested further. M-2 and M-3 yielded, respectively, 54% (43-65%, five trials) and 60% (53-66%, four trials) TSA kill.

Likewise, the efficacy of the Alley Cat wiper system, S-5, without modification, was also only fair (61%, 50-73%, three trials). The modifications M-1a (45%; 40 and 50%, two trials), M-2a (45%; 40 and 50%, two trials), and M-3a (40%, one trial) were also not efficacious (Table 1).

The S-6, Microwipe, without modifications was not effective (no data taken). With modifications, it provided 75% TSA kill (with chicken mesh or drywall sanding screen). The addition of the chicken mesh and/or the reinforcement mesh to S-4 or S-5 modifications introduced a major drawback: the meshes severely tore the TSA leaves or broke off the branches, removing them from being the virus replication sites.

Discussion

We screened three Solanaceae-adapted tobamoviruses for infectivity and possible usefulness as biological control agents for TSA: Tomato mosaic virus (ToMV), Tobacco mosaic virus U1 (TMV U1), and TMGMV U2 as these were available to us to study. As previously reported (Charudattan and Hiebert, 2007), TMGMV U2 killed all inoculated TSA plants in repeated greenhouse trials whereas the other two viruses elicited only nonlethal systemic mosaic or systemic mosaic and mottling in this host.

Thus, by pure chance, we discovered that TMGMV U2 elicited systemic necrosis and killed TSA, an invasive weed of interest to us. This host-virus interaction underlines the novelty of SolviNix; there is no similar example among herbicides.

However, we are not the first to consider TMGMV U2 for biological control of a weed; in 1986, Professor J. W. Randles, The University of Adelaide, Waite Agricultural Research Institute, proposed that TMGMV U2 (referred to in the paper by its older designation as TMV U2) could be used as a biological control agent for *Echium plantagineum* (Paterson's curse, purple viper's-bugloss; Boraginaceae) in Australia (Randles, 1986).

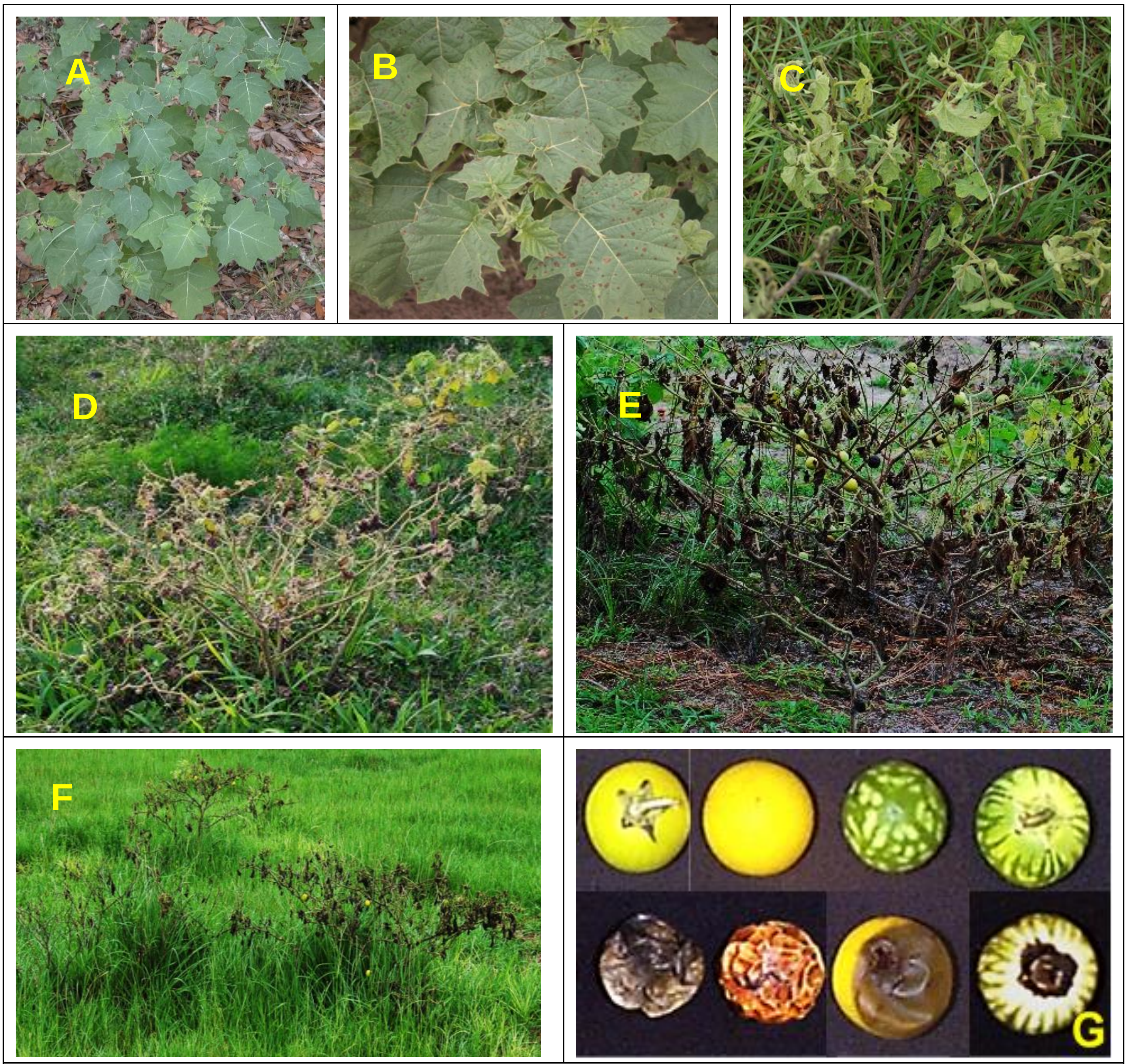


Figure 11. Sequence of disease and symptoms development in TMGMV U2-infected TSA plants in the field. A healthy, uninfected plant (**A**); foliar necrotic local lesions (**B**); chlorosis of the plant with epinasty in shoot apices and onset of wilting (**C**); wilting of the entire plant (**D)**; advanced wilting and drying of the plant with partially green branches (**E**); fully wilted, dried plants (**F**); and the effects on fruit: top row, right to left: unaffected mature green fruit and mature, ripe, yellow fruit; fruit viewed from adaxial (stalk) and abaxial sides; bottom row, right to left: mature green fruit with rotting around the stalk, rotting of mature yellow fruit, and two stages of dead, dried fruit (**G**).

In this plant, TMGMV U2 elicited yellowing and systemic mosaic and reduced leaf production and increased leaf senescence in pot trials. It reduced seed production in inoculated plants in the field. However, unlike in the TMGMV U2-TSA interaction, the virus did not kill *E. plantagineum*.

It is the invariable causation of 100% mortality of infected TSA, leaving no living, systemically infected plants in the field, was the prime consideration on which the SolviNix registration decision was based. For, it was reasoned that with no surviving, systemically infected TSA plants left to serve as virus reservoir, there is no danger of virus spread to other susceptible species. Therefore, the use of TMGMV U2 as a bioherbicide was acceptable.

TMGMV is readily transmitted mechanically in the laboratory by abrading the leaf with virus solution. Therefore, we expected all tools/methods to perform relatively well. Yet, none of the tools/methods we developed to abrade the leaves while delivering the virus solution was as effective in the field as spraying with a high-pressure sprayer. It was unexpected, particularly since this experience was contrary to the belief that TMGMV, like TMV, is highly contagious.

In fact, in field trials, we observed many cases of healthy TSA plants growing in contact with TMGMV-infected plants that failed to become infected. Also, there was no evidence of virus spread within the field following SolviNix applications.

The results from these EUP trials were used to develop label directions for application of SolviNix LC. As spot spraying is generally the prevailing TSA control method used in Florida and a high level of TSA kill of 85% or higher was consistently obtained by high-pressure (0.55 MPa, 80 psi) spraying of TSA canopy with a backpack or ATV-based sprayers, only these methods were considered for listing in the label.

However, initially, only the high-pressure backpack sprayer, which can be more easily cleaned and is cheaper to buy and use than an ATV-mounted system, was approved for listing on the SolviNix label (see Labels under Products, **www.BioProdex.com**). We are testing an ATV-mounted boom sprayer like the S-4 capable of spraying at pressures higher than in the trials reported here for possible future addition to the label.

Conclusions

SolviNix LC reliably provides $\geq$85% TSA kill when spot-sprayed with a high-pressure (> 0.55 MPa) backpack sprayer, which is listed in the label. SolviNix LC performs effectively and satisfactorily in commercial usage.

Acknowledgements

The authors express their sincere thanks to Dr. John W. Randles, Emeritus Professor, Waite Agricultural Research Institute, School of Agriculture, Food and Wine, University of Adelaide, Australia and Dr. Louise Morin, Research Scientist and Project Leader, Weed Biological Control, CSIRO, Canberra, Australia for their excellent, helpful critiques and suggestions for improvement of the paper. We also thank anonymous reviewers for their comments.

Our special thanks to the Journal Editor Dr. Nimal Chandrasena for his extraordinary efforts with the layout and formatting of the manuscript and editorial recommendations.

The work reported herein is based on research supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture Small Business Innovation Research (SBIR) Program, Award Number 2006-33610-17183.

We also thank the Plant Pathology Department, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida, our former employer, for enabling this work.

References

CABI (2020). *Solanum viarum* (tropical soda apple). Invasive Species Compendium (Online: **https://www.cabi.org/isc/data sheet/ 50562**. Accessed June 9, 2020).

Charudattan, R. and Hiebert. E. (2007). A plant virus as a bioherbicide for tropical soda apple, *Solanum viarum*. *Outlooks on Pest Management,* 18: 167-171.

Csurhes, S. (2012). Tropical Soda Apple *Solanum viarum*. Invasive Plant Risk Assessment. Department of Agriculture and Fisheries, Biosecurity Queensland (Online: **https://www.daf.qld. gov.au/_data/assets/pdf_file/0014/72140/IPA-Tropical-Soda-Apple-Risk-Assessment.pdf.** Accessed Sep 13, 2020).

Cuda, J. P., et al. (2002). Tropical soda apple, wetland nightshade, and turkey berry. Pages 293-309. In: R. Van Driesche, et al. (Eds.), Biological Control of Invasive Plants in the Eastern United States. Forest Health Technology Enterprise Team, Technology Transfer-Biological Control, FHTET-2002-4, U.S. Dept. Agric., Forest Service, Morgantown, WV.

DPV Web. (2020). Descriptions of Plant Viruses (**http://www.dpvweb.net/** Accessed June 16, 2020).

e-CRF (Electronic Code of Federal Regulations), (2020). Part 360 Noxious Weed Regulations. **https://www.ecfr.gov/cgi-bin/text-idx?SID=c77fd6d3e6ee23739 c063074d572a6f4&mc=true&node=pt7.5.360&rgn=div5)**. Current as of July 21, 2020.

Mullahey, J. J., Charudattan, R., Medal, J. and Pitelli, R. (1994a). Tropical soda apple in Brazil. *Florida Cattleman Livestock Journal,* 59: 34.

Mullahey, J. J. and Cornell, J. (1994b). Biology of tropical soda apple (*Solanum viarum*), an introduced weed in Florida. *Weed Technology,* 8: 465-469.

Mullahey, J. J., Nee, M., Wunderlin, R. P. and Delaney, K. R. (1993). Tropical soda apple (*Solanum viarum*): a new weed threat in subtropical regions. *Weed Technology,* 7: 783-786.

NSW WeedWise. (2018). NSW Government, Department of Primary Industries. Online: **https://weeds.dpi.nsw.gov.au/Weeds/Details/186**. Accessed September 13, 2020.

Randles, J. W. (1986). Susceptibility of *Echium plantagineum* L. to tobacco mosaic, alfalfa mosaic, tobacco ringspot, and tobacco necrosis viruses. *Australasian Plant Pathology*, 15: 74-77.

Salaudeen, T., Thomas, M., Harding, D. and Hight, S. D. (2013). Economic impact of tropical soda apple (*Solanum viarum*) on Florida cattle production. *Weed Technology,* 27:389–394.

SolviNix Labels (2014). BioProdex Home, Products. **www.BioProdex.com**.

Table 1. Efficacy of SolviNix and application systems in field trials.

Application type; System used	Area treated (ha)	Applied Dose (µg a.i/mL)	Rate (L/ha)	Number of days after treatment	% TSA kill
Site designation, County, site description: C Cowart, Flagler county, cattle, and blueberry farm: GPS coordinates: N29°28.619; W081°23.405. Total area treated at this site: 0.81 ha, 2 ac.					
Spot spraying; S-3	2	10	N/Ap	37	98
Site designation, County, site description: Dinner Island Wildlife Management Area, Hendry county, Cypress dome: GPS coordinates: N 26°28.55; W 081°10.289. Total area treated at this site: 2.02 ha, 5 ac.					
Spot spraying; S-2	4.76	10	N/Ap	34	99
Spot spraying; S-2	0.24	10	N/Ap	34	100
Site designation, County, site description: D Crawford, Hendry county, wetland pasture in a homestead: GPS coordinates: N26°32.349; W081°23.730. Total area treated: 4.05 ha, 10 ac.					
Spot spraying; S-3	2.0	10	N/Ap	53	90
Large-area application; S-4: M-2	2.0	10	22.5	53	65
Large-area application; S-4: M-2	2.0	5.7	35	53	58
Large-area application; S-4: M-3	2.0	10	22.5	53	59
Large-area application; S-4: M-3	2.0	5.7	35	53	66
Site designation, County, site description: M Dunn, Alachua county. GPS coordinates: N 29°38.564; W 082º06.676. Total area treated: 0.03 ha (0.07 ac).					
Spot spraying; S-3	N/Av	10	N/Ap	46	90
Spot spraying; S-3	N/Av	10	N/Ap	21	90
Large-area application; S-4: M-1	1.2	50	20	26	50
Large-area application; S-4: M-2	0.96	10	20	46	54
Large-area application; S-5	0.28	10	2.14	46	60
Large-area application; S-5	0.5	10	5.4	46	73
Large-area application; S-5: M-1a	0.63	10	10.8	24	50
Large-area application; S-5: M-1a	0.63	50	10.4	22	40
Large-area application; S-5: M-2a	0.63	10	14.4	21	50
Large-area application; S-5: M-2a	0.63	50	10.4	22	40
Large-area application; S-5: M-3a	0.63	50	10.4	22	40
Microwipe; S-6	N/Av	50	N/Ap	N/Ap	N/T
Microwipe; S-6, Chicken-mesh	N/Av	50	N/Ap	22	75
Microwipe; S-6, Drywall sanding screen	N/Av	50	N/Ap	22	75
Site designation, County, site description: R Crawford, Collier county, open pasture. GPS coordinates: N26°24.081 W081°26.343. Total area treated: 6.07 ha (15 ac).					
Spot spray; S-2	2.87	10	N/Ap	36	96
Spot spray; S-3	2.87	10	N/Ap	36	96
Large-area application; S-4: M-2	0.88	10	22.5	35	52
Large-area application; S-4: M-2	0.88	5.7	35	35	43
Large-area application; S-4: M-3	0.88	10	22.5	35	61
Large-area application; S-4: M-3	0.88	5.7	35	35	53
Large-area application; S-5; site disturbed	5.73	10	3.5	48	N/T
Site designation, County, site description: E Tucker, Elkton, St Johns county, cull pile/cattle feed. GPS coordinates: N29°46.527; W081°25.540. Total area treated: 3.08 ha (7.6 ac).					
Spot spraying; S-2	1.26	10	N/Ap	24	80
Spot spraying; S-2	1.26	10	N/Ap	21	85
Spot spray; S-3; nozzle with D-2 orifice plate	1.26	10	N/Ap	36	85
Spot spray; S-3; with an 80-03 flat fan nozzle	1.26	10	N/Ap	36	58
Large-area application; S-5	1.26	20	5	49	50
N/Av = Not available; N/Ap = Not applicable, ~5 mL per plant; N/T = data not taken; test abandoned.					

Table 2. Efficacy of S-4 in a replicated field trial applying six SolviNix concentrations

Treatments:	SolviNix a.i. µg/mL						Average of all treatments by trial:
	0 (control)	3.1	6.3	12.5	25	50	
	Percent TSA Kill						
Trial 1:	0	92	71	92	96	96	89
Trial 2:	0	13	38	86	79	83	60
	Average of all treatments from two trials:						75
Site designation, County, site description: Plant Science Research and Education Unit, University of Florida, Marion county. GPS coordinates: N 29°24.624; W 082º10.201. Total area treated: 0.03 ha, 0.07 ac.							

PERSPECTIVE

Publications of W.M. Porterfield Jnr. on Weeds of Shanghai: A Review

Peter W. Michael[1]

[1] Current Address: 5, George Street, Epping, NSW 2121, Australia

E-mail: **pwjemichael@hotmail.com**

Received: 22 November 2020

Accepted for publication: 10 December 2020

Published: December 2020

Abstract

This paper provides a brief review of the botanical contributions of W. M. Porterfield (1893-1966), focusing on a list of 115 plants, including many weeds, 75 of which he described and illustrated in a series of articles and later published in a book with descriptions of an additional 40 plants. His meticulous observations are of great interest in the study of weed biology and history. All plants were collected in Shanghai.

Key words: W. M. Porterfield, Botanist, Shanghai

Introduction

Willard Merritt Porterfield (1893–1966) received his M.A. in 1915 from Franklin & Marshall College, Lancaster, Pennsylvania, USA, and began his career as a teaching missionary in China, where he served in the faculty of St. John's University of Shanghai. His biographical details have been obtained from Merrill and Walker (1938); The NY Times (1966) and Stafleu and Cowan (1983).

It was in China that he developed his strong interest in plants. He wrote on trees, shrubs and herbs, and a booklet on bamboo. One of his earliest publications (Porterfield Jr., 1922) was concerned with algae in the Chinese classics. After his experiences in China, he returned to the USA, where he worked at Vermont University Agricultural Research Station, the New York Botanical Garden, and the Soil Conservation Service of the US Department of Agriculture.

Porterfield wrote a number of articles on Chinese food plants in *The Journal of the New York Botanical Garden*, which are all referenced in Porterfield Jr. 1951. He is most cited for his paper on the botany and utilization of Sponge gourd or loofah – *Luffa cylindrica* Roem. (Porterfield Jr 1955).

There are two of his works to which I wish to draw special attention. They are:

1. A series of ten articles entitled "Lawn and Roadside Plants of Shanghai", which appeared across 10 instalments in Volume 16 (pp. 32–40,95–100, 140–145, 197–204), Volume 17 (pp. 136–142, 238–244, 305–314) and Volume 19 (pp. 82–90, 145–151, 259–267) of *China Journal* (Shanghai), published in 1932 and 1933.

2. The book *Wayside Plants and Weeds of Shanghai*, published by Kelly & Walsh in Shanghai, Hong Kong, and Singapore in 1933.

The series covers 75 different plants, each with illustrations. I used the series during my preparation of a Working List of Weeds of the Asia-Pacific Region, which I prepared for the 7th Asian-Pacific Weed Science Society (APWSS) Conference in Sydney in 1979 (Michael, 1979), and again, recently, during a search for early Chinese records of *Oxalis debilis* Kunth (syn. *O. corymbosa* DC., *O. martiana* Zucc.).

These plants are listed again in Porterfield's book, along with 40 additional plants, bringing the total number to 115, all with illustrations according to descriptions of the book in the bibliography of Needham's *Science and Civilisation in China* (Vol. VI, Part 1) and notes about the book in the National Library Board Catalogue, Singapore. This rare book is an important early work in English referring to weeds in China, which, regrettably, I have not been able to see.

Porterfield obviously had a strong feeling for weeds as he often regretted not getting to the fields soon enough to collect plants before they were mown or slashed. He took identification of his plants very seriously. In his descriptions of plants, he always mentions the date of collection, and he needed good specimens for his illustrations.

I do not know whether his collections of Chinese plants are held in Chinese herbaria. He made good use of important botanical publications dealing with far eastern plants, especially Bentham's *Flora Hongkongensis* (Bentham, 1861) and Merrill's *Flora of Manila* (1912). Porterfield also sought help from many other botanists concerned with plants in China, notably A. N. Steward in Nanjing (Nanking), the author of *Manual of Vascular Plants of the Lower Yangtze Valley, China* (Steward, 1958) [1]. He also drew attention to Nathaniel Gist Gee (1876-1937), sometime Professor of Natural Science at Suzhou (Soochow) University.

In this brief article, I list the 75 plants featured in the series. In cases where the botanical name has changed, I list the current name first, followed by the name as it appeared in Porterfield's article. It has been difficult at times to be sure of the identity of the plants. Sometimes the Chinese characters presented by Porterfield have been helpful.

After accessing a digital copy of Porterfield's "Systematic Classification of the Species", the list that introduced his book, I have also been able to add the names of the 40 additional plants, to present the complete listing of **115** (Table 1). The additions from the book are marked in Table 1. I have again noted changed names, listing the current names above those, as noted by Porterfield (1933).

Table 1. List of Plant Species

LAWN AND ROADSIDE WEEDS OF SHANGHAI		
# = plants listed in Porterfield's book, additions to original list in article series		
Monocotyledons		
Araceae		*Pinellia ternata* (Thunb.) Breitenbach, as *Arum ternatum* Thunb.
Commelinaceae		*Commelina communis* L.
Cyperaceae		*Cyperus eragrostis* Vahl
		C. rotundus L.
Iridaceae	#	*Iris japonica* Thunb.
Liliaceae		*Allium chinense* G. Don
		Barnardia japonica (Schult.f.) Roemer & Schultes, as *Scilla chinensis* Benth.
Orchidaceae		*Spiranthes australis* Lindl.
Poaceae (Gramineae)	#	*Alopecurus aequalis* Sobol., *as A. geniculatus* L.
		Cynodon dactylon Pers.
		Digitaria ciliaris (Retz.) Koeler, as *D. sanguinalis* Scop. var. ciliaris Doell
	#	*Echinochloa crus-galli* (L.) Beauv.
		Eleusine indica Gaertn.
	#	*Elymus caninus* (L.) L., as *Agropyron caninum* (L.) Beauv.
		Eragrostis cilianensis (All.) Link
		Eremochloa ophiuroides Hack.
	#	*Imperata cylindrica* (L.) Beauv.

[1] For details on Albert N. Steward – see: (1) http://scarc.library.oregonstate.edu/findingaids/?p=collections/findingaid&id=1052; and (2) H.M. Gilkey (1959). "Albert Newton Steward", Bulletin of the Torrey Botanical Club, 86(5): 342-344.

Table 1 (continued). List of Plant Species

LAWN AND ROADSIDE WEEDS OF SHANGHAI		
# = plants listed in Porterfield's book, additions to original list in article series		
		Paspalum scrobiculatum L.
		Pennisetum alopecuroides (L.) Spreng.
		Poa annua L.
		Setaria viridis Beauv.
		Zoysia japonica Steud., as *Z. pungens* Willd.
Dicotyledons		
Acanthaceae		*Rostellularis procumbens* (L.) Nees, as *Justicia procumbens* L.
Amaranthaceae		*Amaranthus cruentus* L., as *A. paniculatus* L.
		A. spinosus L.
		Achyranthes bidentata Blume
Apiaceae (Umbelliferae)	#	*Cnidium monnieri* (L.) Spreng., as *Selinum monnieri* L.
	#	*Torilis japonica* (Houtt.) DC., as *T. anthriscus* (L.) Bernh.
Asteraceae		*Artemisia vulgaris* L.
		Carpesium cernuum L.
		Chrysantheumum indicum L.
	#	*Cirsium arvense* (L.) Scop.
	#	*C. japonicum* DC.
	#	*Conyza bonariensis* (L.) Cronq., as *Erigeron linifolius* Willd.
		C. canadensis (L.) Cronq.
	#	*Crepis japonica* Benth.
		Eclipta prostrata (L.) L., as *E. alba* Haenk.
		Erigeron annuus (L.) Pers.
		Eupatorium japonicum Thunb.
	#	*Hieracium crocatum* Fries
	#	*Inula britannica* L.
		Kalimeris indica (L.) Schultz-Bip., *as Boltonia indica* Benth.
		Lactuca indica L.
	#	*Saussurea carthamoides* Benth.
	#	*Sonchus asper* (L.) Hill
		S. oleraceus L.
		Taraxacum officinale Weber
Boraginaceae		*Trigonotis peduncularis* (Trevir.) Benth.
Brassicaceae (Cruciferae)		*Capsella bursa-pastoris* (L.) Medikus
	#	*Cardamine flexuosa* With., as *C. hirsuta* L. var. *sylvatica* Hook.
	#	*Lepidium didymum* L., as *Coronopus didymus* (L.) Smith
		L. virginicum L.
		Rorippa indica (L.) Hieron., as *Nasturtium montanum* Wall.
	#	*Thlaspi arvense* L.
Caryophyllaceae		*Arenaria serpyllifolia* L.
		Cerastium glomeratum Thuill. as *C. viscosum* L.
	#	*Sagina japonica* (Sw.) Ohwi as *S. maxima* Gray
		Stellaria alsine Grimm. var. *undulata* (Thunb.) Ohwi as *S. uliginosa* Murr. var *undulata* Fzl.
		S. aquatica (L.) Scop.

Table 1 (continued). List of Plant Species

LAWN AND ROADSIDE WEEDS OF SHANGHAI		
# = plants listed in Porterfield’s book, additions to original list in article series		
		S. media (L.) Cirillo
Chenopodiaceae		*Chenopodium album* L.
Convolvulaceae		*Calystegia hederacea* Wall.
Cucurbitaceae		*Melothria indica* Lour.
Euphorbiaceae		*Euphorbia helioscopia* L.
Fabaceae (Leguminosae)		*Astragalus sinicus* L.
	#	*Medicago minima* (L.) Bartal.
	#	*M. polymorpha L.,* as *M. denticulata* Willd.
		Melilotus officinalis (L.) Lam.
		Trifolium repens L.
	#	*Vicia faba* L.
	#	*V. sativa* L.
	#	*V. tetrasperma* (L.) Schreb.
Lamiaceae (Labiatae)	#	*Ajuga genevensis* L.
		A. pygmaea A. Gray
		Glechoma hederacea L. as *Nepeta hederacea* Trev.
		Lamium amplexicaule L.
		Mentha arvensis L.
		Perilla frutescens (L.) Britt., as *P. ocymoides* L.
	#	*Prunella asiatica* Nakai, as *P. vulgaris* L.
Oxalidaceae		*Oxalis debilis* Kunth, as *O. martiana* Zucc.
		O. corniculata L.
Papaveraceae	#	*Corydalis incisa* (Thunb.) Pers.
Piperaceae		*Houttuynia cordata* Thunb.
Plantaginaceae		*Plantago major* L.
Polygonaceae		*Persicaria longiseta* (de Bruyn) Kitag., as *Polygonum caespitosum* Blume var. *longisetum* Steward
		Persicaria jucunda (Meisn.). Migo, as *Polygonum jucundum* Meisn.
		Persicaria lapathifolia L. var. *salicifolia* Sibth., as *Polygonum lapathifolium* L. var. *salicifolium* Sibth.
	#	*Rumex acetosa* L.
Portulaceae		*Portulaca oleracea* L.
Primulaceae	#	*Androsace umbellata* (Lour.) Merr. as *A. saxifragaefolia* Bunge
Ranunculaceae		*Isopyrum adoxoides* DC.
		Ranunculus acris L.
	#	*R. japonicas* Thunb.
		R. pensylvanicus L.
		R. ternatus Thunb.
Rosaceae	#	*Duchesnea indica* (Andr.) Focke
	#	*Potentilla kleiniana* Wight & Arn.
Rubiaceae	#	*Galium aparine L.*
		Paederia scandens (Lour.) Merrill, as *P. foetida* L.
Scrophulariaceae	#	*Lindernia crustacea* (L.) F Muell., as *Vandellia crustacea* Benth.
		Mazus miquelii Makino and *M. stachydifolius* (Turcz.) Maxim, as *M. rugosus* Lour. and *M. stolonifer* Maxim.

Table 1 (continued). List of Plant Species

LAWN AND ROADSIDE WEEDS OF SHANGHAI		
# = plants listed in Porterfield's book, additions to original list in article series		
	#	*Veronica agrestis* L.
		V. persica Poir., as *V. tournefortii* Gmel.
	#	*V. serpyllifolia* L.
Solanaceae		*Physalis minima* L.
		Solanum nigrum L.
Verbenaceae	#	*Verbena officinalis* L.
Violaceae	#	*Viola alba* Besser
		V. diffusa Ging. in DC.
		V. japonica Langsd.
		V. odorata L.
		V. patrinii DC.
		V. patrinii var. *chinensis* DC.
Vitaceae	#	*Cayratia japonica* (Thunb.) Gagnep.

Examples

Fortunately, Porterfield's articles are accessible in the relevant volumes of the *China Journal* (Shanghai), held by the University of Sydney and I present two of his descriptions and illustrations in full, as examples to show the quality and detail of his work.

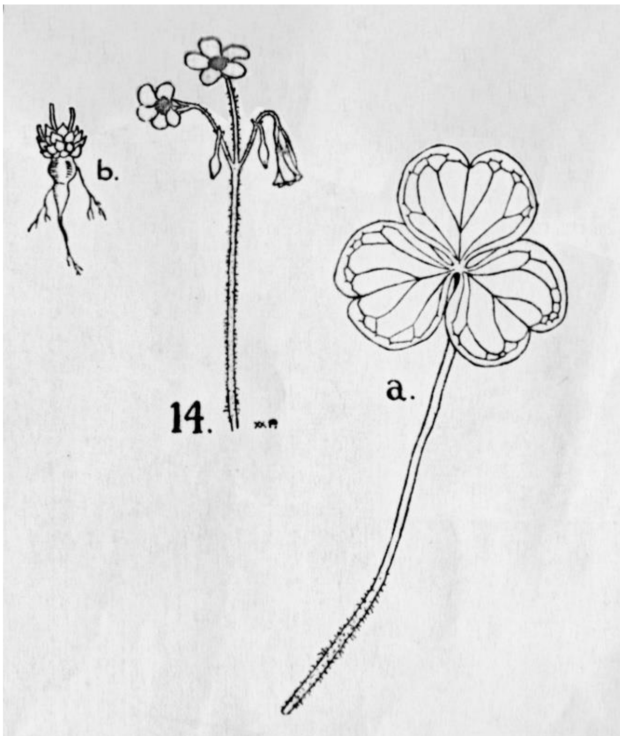


Figure 1. Illustration of *Oxalis martiana* Zucc. [*O. debilis* Kunth.]

a. A leaf showing the long petiole partly hairy and the broad obovate leaflets

b. The tuberous rhizome

Stemless herbs with compound tuberous rhizome. Leaves radical, trifoliately compound, 6 cm. across. Leaflets broadly obovate-emarginate. Petioles 21 cm. long with scattered hairs below. Peduncles also radical and hairy, longer than the petioles, and bearing a cymose cluster of pale pinkish-purple flowers.

A common wanderer about the cultivated borders of the lawns having to be weeded continually from the violet beds. The petals are three times as long as the sepals, each of which have [*sic*] two small glands at the tip. (Collected Jun 28, 1931)

References: *Flora Hongkongensis* (Bentham, 1861), p. 56
Flora of Manila (Merrill, 1912), p. 265.

China Journal, vol. XVI, March 1932, no. 3, pp. 141, 142 (text)

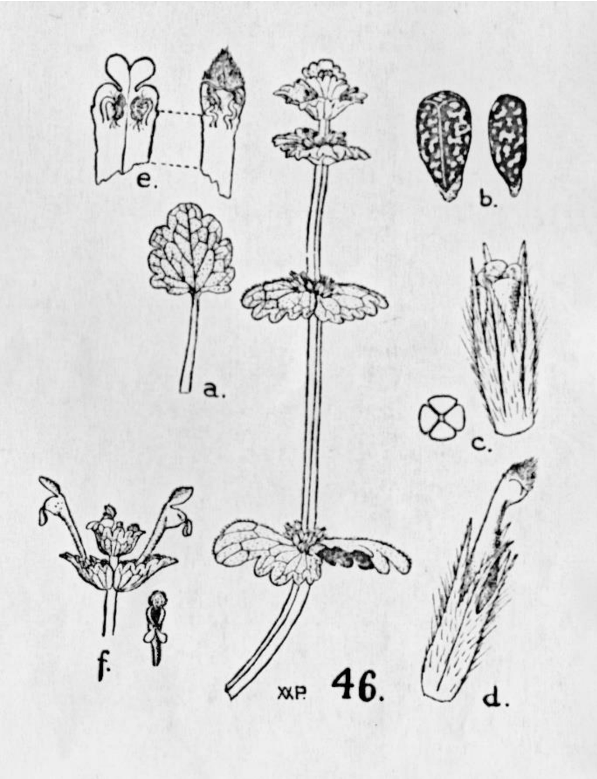


Figure 2. Illustration of *Lamium amplexicaule* L.

a. Long-petioled leaf of the lower part of the stem
b. Seeds, enlarged
c. Magnified view of nutlets maturing within calyx tube
d. A cleistogamous flower enlarged
e. A dissection of the same showing stamens
f. Characteristic later flower

A decumbent annual with opposite rounded deeply crenate-toothed leaves, the upper ones clasping, the lower ones petiolate. Flowers purple, early ones cleistogamous; later ones with long corolla tube dilated at the throat, arched upper lip, spreading lower lip with truncate lateral lobes, the middle lobe notched and contracted at the base. Seeds splotched with white and black.

One of the early mints to spring up on the borders of the lawn. The first flowers do not open, are smaller, but, nevertheless, produce seed. (Collected March 12, 1932).

References: Gray's New Manual (Robinson and Fernald, 1908). p. 700.

China Journal, XVII, December 1932, no. 6, pp. 309 (text), 311.

Conclusion

Porterfield's contribution to the knowledge of plants in the Shanghai area was considerable and made more effective by his contacts with other botanists. His first-hand observations of weeds are an important resource in the study of weed biology and history. He throws light on botanists poorly known, for example N. G. Gee (1876–1937), an early influential teacher of biology in China.

Porterfield's experience in China undoubtedly equipped him well for serving the CIA for a time during the Second World War (The New York Times, 1966).

Acknowledgements

I am grateful indeed for the help of my daughter Linda in preparing this manuscript. I also acknowledge some helpful comments by Dr. Nimal Chandrasena (Editor-in-Chief) and an anonymous reviewer that improved the manuscript.

All reproductions have been credited to the original 1932 sources and are used here for educational purposes only.

References

Bentham, G. (1861). *Flora Hongkongensis: A Description of the Flowering Plants and Ferns of the Island of Hongkong*, London: L. Reeve, pp. 482 (Available for download: **https://archive.org/details/florahongkongen00bentgoog**).

Merrill, E. D. and Walker, E. H. (1938). *A Bibliography of Eastern Asiatic Botany*, Jamaica Plain, MA: Arnold Arboretum of Harvard University, p. 719.

Merrill, E. D. (1912). *A Flora of Manila* [First Edition, Philippine Islands. Bureau of Science. Publication No. 5, p. 490], Palala Press, p. 508. (Available for download: **https://www.biodiversitylibrary.org/item/42008#page/7/mode/1up**).

Michael, P. W. (1979). Working List of Weeds of the Asian-Pacific Region (with some Australian common names). 7^{th} APWSS conference Sydney, Australia, November, !979 [2].

[2] A 36-page handout of a list given to all participants at the 7^{th} APWSS Conference in Sydney. Prepared from many sources by P. W. Michael, University of Sydney, with financial support from Japan Association for the Advancement of Photo-Regulators (JAPR).

Needham, J (1986). *Science and Civilization in China*, Vol. VI, Part 1, Cambridge, UK, London & New York: Cambridge University Press.

The New York Times (1966). "Dr. William [*sic*] Porterfield Jr. Dies; Ethnobotanist Served the C.I.A.", 27 March, 1966.

Porterfield, W.M. (1922). "References to the algae in the Chinese classics", *Bulletin of the Torrey Botanical Club*, 49: 297–300.

Porterfield, W.M. (1932–33). "*Lawn and Roadside Plants of Shanghai*," A series of articles in China Journal (Shanghai), Vols. XVI, XVII & XIX (contents list only available for download: **https://oregondigital.org/downloads/oregondigital:df72d548k**).

Porterfield, W. M. (1933). *Wayside Plants and Weeds of Shanghai*, Kelly & Walsh, Shanghai, Hong Kong and Singapore, 1933, pp. xvii–xxi.

Porterfield, W. M. (Jr.) (1951). "The principal Chinese vegetable foods and food plants of Chinatown markets". *Economic Botany*, 5, 3–37.

Porterfield, W. M. (1955). "Loofah: The sponge gourd" *Economic Botany*, 9: 211–223.

Stafleu, F. A. F. and Cowan, R. S. (1983). *Taxonomic Literature: a selective guide to botanical publications and collections with dates, commentaries and types*, 2nd Edition, Vol. IV, Utrecht: Bohn, Scheltema & Holkema, 1976–88.

Steward, A. N. (1958). Manual of vascular plants of the lower Yangtze valley, China. Corvallis, Oregon State College. pp. 621.

Robinson, B. L. and Fernald, M. E. (1908). Gray's New Manual of Botany. 7th Edition. American Book Co. pp. 926.

PERSPECTIVE

On the difficulty of being a 'Weed' ....

David Low [1]

[1] Current Address: *PO Box 415 Moorabbin Vic 3189, Australia*

E-mail: **david.low7@bigpond.com**

Submitted: 01 September 2020

Accepted: 23 October 2020

Published: 30 December 2020

Prelude: Weeds as Grotesque

"...There are no Grotesques in Nature…"
Thomas Browne, Religio Medici, 1642

Native and cultivated plants are protected, both by warrant of their being culturally valued and by virtue of their being a form of life that is culturally remembered for their continuity within a specified landscape – 'that plant has grown here for thousands of years!' (Chandrasena, 2014). On the other hand, a weed is not valued positively at all, or at most, valued only grudgingly. The weed is a cultural 'invader'.

Therefore, the weed has no claim to cultural landscape continuity in any positive sense, either from the point of view of production, or conservation. Indeed, it is often a 'declared pest' and must be killed, usually by poison. As an unwanted visitor to 'our' world, the opportunistic weed is feared and maligned – it gets what it deserves.

To hunt down and kill weeds is, therefore, to avenge culturally on two levels. The weed disrupts our sense of commodified agri-ecological continuity (both the farmers and the ecologists say, 'it is evil'), so the weed must be destroyed for its affront to the interests of those who control culturally 'productive' land. This is understandable and straightforward, but there is something more.

The weed must also be killed because it *represents* something else. Weeds present, or are used strategically to represent, all the unmanageable forces that challenge our known social 'order of things'. Indeed, as the 'war on weeds' rhetoric would have us believe, national security priorities are at stake, and national security demands a compellingly lethal response [1].

But can we kill them all? 'Unwanted plants', that is, weeds, move. It is their nature to 'invade' - to move as pioneers into vacant spaces disturbed and laid bare by our human interventions (Baker, 1965). As such, weeds are *not wild*, as they are not considered to be 'native', and simultaneously, they *are wild*, because they are undomesticated [2].

As a hybrid being neither genuinely wild, nor truly domesticated, the 'weed' is something 'in-between'. As neither a commercially valued domesticated plant, nor a 'naturally' wild plant, the weed is a blended creature.

To understand what the weed represents as a 'blended creature', the literary concept of grotesque realism might give us a hold (cf. Bakhtin, 1968). Grotesque realism is a literary genre in which the proper order of things is challenged or parodied by virtue of being different, primarily through being contrasted with its opposite.

The grotesque form, however, is not just a simple inversion. The grotesque form goes deeper still. Grotesque realism is used to deconstruct and mobilise binary classificatory categories for a *cultural* purpose. Hence, if the purpose of killing weeds is culturally determined, we can also legitimately explore the grotesque mark of the weed. We can then see '*the difficulty of being a weed*' within the socially constructed frameworks that weeds must live within (cf. Fisher, 1996).

In the present context, then, the weed represents our power (or lack of power) to domesticate nature for our mundane purposes. Simultaneously, *the weed represents domestication's disfigurement.* As Figuié, Binot and Caron (2015) put it, "…*the distance between man and [plant] relies on the distance between wild and domestic..."* and, "…*for men to stay men and not to go back to animality, they must contain wild and domestic [plants] at their respective place*…"

If we are right about the above, the internal symbolic separation of 'wild' and 'domesticated' is also an external *biopolitical* separation: a separation that maintains, strengthens, or extends political and economic alliances.

The 'weed', being neither iconic native plant, nor beloved domesticated crop, is, therefore, a plant that can be harnessed by stakeholders to embody the high-status city dweller's self-image of righteousness and benevolence toward nature (exemplified in "the protection of native plants"). The 'weed' can also represent city folk's neglect and disregard of the farmers and agri-businesses that depend on the land for their survival (exemplified in the expression "living off the land") (cf. Fortmann, 1990; Donahue, 2005).

The grotesque bodies of weeds are therefore real, but also symbolic. Weeds are 'pests' that can embody an elites' supposed moral and intellectual superiority and simultaneously embody an ideological counter (or critical) expression of this assumed superiority. As such, the grotesque form 'weed' can function as a botanical critique of the dominant symbolic order. In doing so, the form exposes the disunities that underlie social tensions and contradictions.

In other words, it is the weedy plant's potential to unsettle the culturally determined norms of inclusion, exclusion, and domination that make the management of weeds so vexing to government policymakers, weed scientists, and the public.

None of the above would have mattered much had it not been that what the weed *represents* is used to gain political support amongst those who *commodify* land to serve 'growth' (Daly, 2020). Therefore, hunting the weed down is a way for businesses and politicians to suture a social rupture and encourage our natural capital to be taken to the 'other side' and domesticated for profit. This leads to self-serving admonishments to hunt the 'evil weed' down, or it shall destroy 'us'.

The problem is that 'we' are in fact hunting down something that helps to keep us constituted, so we are in effect at war with ourselves, a profoundly, untenable delusion (Low and Peric, 2011; Dwyer, 2011; Larson, 2005).

Let me try to explain how this works at a community level.

[1] Consider, for example, Australia's "32 Weeds of National Significance", the secure management of which requires "…coordination among all levels of government, organisations and individuals with weed management responsibilities." (cf. **http://www.environment.gov.au/biodiversity/invasive/weeds/weeds/lists/wons.html**)

[2] In an important sense, so-called 'native plants' are domesticated plants because they are cared for and protected, while weeds are not.

Community participation in weed management

To encourage the community to hunt down weeds, governments have traditionally been intensely focused on compliance programmes. In this approach, the government's role is to enforce legislation. Land managers (including private land managers) must take responsibility for eradicating, as far as reasonably possible, noxious, or 'declared' weeds on the land they own or manage.

In the case of weeds, however, a focus upon regulatory enforcement is challenging to implement. Weeds live on both public, and private land, so affected communities commonly refer to weeds as "invading plants". This labelling occurs because weeds that live on somebody else's land only move onto a property through somebody else's inaction or negligence, or they just move in 'naturally' on the wind, so the story goes. Seen from the weed's perspective, however, we might also legitimately ask, as Stengers (2019) has, what makes us "so obviously invasive" in our preoccupation with blaming the plants for the conditions we have created for them to live in?

The usual government policy response to the above problematization is to ignore most of what is problematic about weeds in crafting care for our natural capital, and instead, argue for and support a 'cross-tenure approach' to weed management at 'landscape-scale'. The policy intends to allow local communities to collaborate with government land managers, to address weed issues across all land tenures cooperatively.

Called a "community-led approach", the government's legitimized policy 'infrastructure' (cf. Metzger, Soneryd and Linke, 2017) is designed to enable land management participants to simplify the scope of the weed issue collectively.

The community is then expected to implement the best practice management techniques, and level of intervention and resourcing required to deal with the problem, as defined.

Hunt (2005) described the process in detail:

"…The nil-tenure approach highlights the benefit of focusing on the 'common problem' rather than criticizing the efforts of adjoining land managers. The implementation of the simple approach has negated over twenty years of poor relations between private and public land managers … More importantly, it has had a positive impact on the emotional well-being of farmers … who now feel that something positive is being done to address the constant financial and emotional impact of [weeds]. Through this truly consultative process, local land managers have not only taken "ownership" of the issue but have identified and pursued the resources required to successfully implement a local solution. (n.p.)…"

As noted by Hunt above, a "community-led approach" to weed management aims to allow weed affected communities to 'take ownership' of adverse effects of weeds at a landscape scale. A '*war on weeds*' is declared by the government to encourage community development and participation.

However, what if some property owners want to craft a different story for themselves and do not want to participate in landscape-scale weed control? The result is called 'neighbour-to-neighbour spillovers' (Fenichel, Richards and Shanafelt, 2014). For example, when one farmer uses poisons to manage the ingress of weeds onto her property, this 'pushes' the weeds toward her neighbours' property, who may not use poisons, creating what is known in economics as a 'spillover'. The result is that due to a neighbour's action (or inaction), a bordering neighbour becomes more heavily affected by weeds.

However, the above is a biased view (or, in economic terms, we might say, a 'dominated evaluation'). Another view is that one neighbour values weeds and chooses not to kill them, partially or wholly. For example, some organic cattle farmers value certain weeds for their nutritional content and resistance to drought and varied soil conditions, and do not want herbicides drifting across their paddocks. Thus, the spillover is reversed.

Either way, at the landscape scale, the nil-tenure approach holds that unless *all* land managers regionally coordinate *all* of their weed management practices, weed effects (positive or negative) will only be 'moved on' from one landholder to another. This causes a 'ripple effect' among those involved and those not involved (Ainsley and Kosoy, 2015; Southwell et al., 2013; Allen, 2016).

Note too that the above dynamic also applies to government efforts to kill weeds on government land. Because weeds cannot be eradicated at the landscape scale and have 'no respect' for borders, they circulate or 'spillover' from one area to another. Landscape control almost wholly fails in managing weeds on public land.

According to traditional, rational choice economics, the above spillover effects occur because an individual, disconnected land managers are unable to make socially optimal decisions. For example, individual landholders may be limited by a lack of information on the benefits of landscape-scale pest management. Stakeholder agencies, too, suffer either from apathy, funding, and resourcing deficiencies compounded by lack of clarity on jurisdictions and when to do what regarding weeds (Harper and Chandrasena, 2018).

The information-related limitations of rational choice economic theory have given rise to an alternative framework called "behavioural economics" (Gsottbauer and van den Bergh 2011). In this new approach, economic decisions incorporate social mechanisms. For example, through communication about spillovers' effects, individual landholders might begin to consider whether it is fair to disregard the needs of their neighbours when choosing what to do, or not do about weeds. They may want to enhance their social standing and feelings of solidarity with the community by supporting community-led action on weed management (cf. Hunt,2005).

Alternatively, they may want to support environmental conservation and not poison their land with herbicides. Similarly, government policy makers will feel neighbour pressure to kill weeds on public land, and 'be a good neighbour', while simultaneously feeling a contradictory pressure to refrain from using polluting poisons in natural or recreational areas.

Irrespective of which economic theory is used, the outcome is that, in a community-led approach, all landholders must agree to participate in weed control, for the 'greater good' which is dictated by a shared, coordinated understanding. In this unique, restricted sense, a community-led approach to weed management is supposed to use the input of the communities affected by weeds to consider different points of view and different ways of managing the situation into a unified system within which there is a shared sense of 'knowing is doing' (Ison, 2008).

In the above manner, a community-led approach generates a *distributed* form of best practice that is adaptive to all the community's diverse needs (Maran, 2015). Government is then positioned to recognise and legitimise these adaptive landscape achievements as an outcome of its "community-led approach", chiefly because the outcome is judged to conform to governments' pre-existing weed policy commitment to community action and community self-regulation.

The above arguments reveal why appraisal of the weed issue is often thought to be 'complex' or 'messy'. In practice, the weed management *system* can only be partially known to its participants because the appraisal of other possible methods of weed management are "closed down" (Stirling, 2008) or sometimes only partially opened. For example, a participant who advocated for weed/human co-existence and tolerance would be seen as a dissident at a meeting convened to explain how herbicides can be used to the best effect. A savvy and non-confrontational person would spare themselves the trouble of their view being automatically rejected and not bother to attend.

Paradoxically, this "closing down" of participation occurs in a process committed to "opening up" participation. Put another way, gains in the visibility of marginalised concerns are seen to involve a loss of legitimacy or standing by the incumbent, dominant interest, and are eschewed (Metzger, Soneryd and Linke, 2017). Similarly, assisting some stakeholders to gain increased influence may lead to a decrease in engagement or participation by others who feel any opening up of appraisal would not be in their interest.

A more balanced community-led approach, on the other hand, would set out to create a plan of action to bring those involved together in an even-handed manner. It would seek to move forward, within a shared understanding of the dynamic nature of the boundary of the issue, making the journey forward something, "more lively, more commercial, more usable, more user friendly, more acceptable, more sustainable"(Latour, 2008, p. 5). It could be all of the above, depending on the full range of government policy and political commitments to which a weed management programme is asked to answer

In the present dominated context, however, the policy commitments are framed very narrowly. The pertinent policy constraints are that weed programmes should aim to achieve *pesticide-based* landscape-scale participation across *all land tenures*. The most powerful stakeholders (government and the agrochemical industry) cooperated to be seen to be working hard to 'kill more weeds'. Indeed, in Australia, a State government has extended this logic to an extreme level and takes the number of 'herbicide treatments' as a key measure of the government's environmental performance (Commissioner for Environmental Sustainability Victoria, 2018).

Under the above conditions, the shared commitment can only be 'common' if the method used to achieve it is dominated and is *lethal for weeds*. If participation is not aligned with lethal chemical control, this interest is marginalised.

Another factor influencing the current weed framing is that government and government stakeholders' primary focus is on pest management methods that can be 'sold' (Morales, 2002). The development of chemicals (herbicides) that can kill plants is of interest economically. This is again paradoxical because, if we could find a 'market failure' rationale for government intervention, it would be to encourage the economic use of weeds, not lethal poisoning, as the latter techniques presently operate successfully in a market. Simultaneously, the former is belittled by the government as too 'fringe' to attempt to improve. There is no market failure with respect to herbicide-based weed control, so there is no justifying market failure for governments to support such methods financially, indeed, quite the reverse.

Making use of the beneficial aspects of weeds, however, relies mostly on local knowledge and these techniques are currently not well legitimated by national frameworks (Morales 2002, p. 157).

Where traditional or local uses of pioneering species are practised, the techniques are rarely intentionally diffused to other areas. Given this, Morales (2002) recommends that policy makers should encourage and support organisations that recognise farmers who utilise weeds beneficially, document the limitations, and assist farmers to improve on their beneficial uses of the maligned species.

Rationales for community participation

There have been a host of commissions and enquiries into weed programmes over the years all around the world. Each has concluded that previous landscape-scale efforts for weed control have failed *due to a lack of community participation.* Landscape-scale weed control is a policy failure, Allen (2016) argues, as it results in a mosaic of controlled and uncontrolled areas. Indeed, and as argued earlier, efforts directed at landscape control construct *the exact conditions necessary for neighbour-to-neighbour spillovers*.

Allen (2016) also argues that the pest issue needs "reframing" to address the above strategic policy-relevant issue. Allen points out that when pests are framed as a serious *generic* problem, only then are they a landscape-scale problem. However, when a pest issue is framed as one in which the problem is about locally situated pest situations, the issue becomes more narrowly focussed.

This latter alternative framing allows the policy to focus on why *this* particular pest-plant's death is necessary (Steer, 2015). In other words, weed policy, in this alternative framing, can function to *target* where weed management of a specific plant is needed, and why, and can leave aside areas in which there is no weed issue. An example would be in public land areas where weeds are not part of the commodified landscape, provide positive ecosystem services, and can potentially be well-tolerated.

The above alternative framing is essential because it can be used to influence policy options, such as whether to use landscape-scale weed management that draws on community-led action to assist in the management of weeds. As Wesselink et al. (2011) have pointed out, without a clear understanding of why community action is needed, hard-won community-led participation soon loses momentum and support. This occurs mainly when public participation is structured by governments merely to bolster an already decided policy position (that lethal control by poisoning is good for business).

An alternative participatory rationale is what Wesselink et al. (2011) called *substantive.* Within a substantive rationale, the purpose of community-led participation is to involve 'non-experts' who can see issues and ways of doing things that the experts miss. Under this rationale, participants can more or less ignore the central policy directives and introduce ways of moving forward that reframe or re-contextualise policy goals to suit their *particular* purpose(s).

In other words, a substantive rationale for community-led participation incorporates and explores disagreement with the incumbent policy, it works to accommodate compromises, and is *remedial*. As such, its purpose is to address policy-driven shortcomings and *find a cure for the local situation*. This outcome achieves a *horizontally*-broadened and deepened participation by stakeholders, especially in their *local* pest and conservation issues (cf. Stirling, 2008).

Given the above, and as Wesselink et al. (2011) also point out, the solutions that community-led participation methods generate and foster will depend on the *local* contexts and contingencies of the participants, not on the forced imposition of 'best practice' weed control methods by those in power (stakeholder businesses and governments). The operative mode of action is, therefore, *integrative* rather than 'command and control'.

In the above sense, the policy framing is 'local management action', not 'landscape-scale control' driven by vested interests. However, as noted earlier, given that dominant current government policy is that weed control should aim at lethal *landscape-scale control*, it was earlier argued that landscape-scale weed control by community-led action is *sure to fail*. This is because local participants' needs, and methods are fundamentally different from those of the government for two key reasons.

First, landscape-scale weed control aims primarily to fund pesticide-based control of weeds on public land, not private land. Thus, the constraints on change are very much contingent on government management priorities, which, as argued above, are both dominated by a pesticide focus, and therefore captured and limiting (Moran,2015).

Second, but associated with the first, weed policy is controlled by well-entrenched constituencies with political 'clout', for example, the farming and chemical industry interest lobby. As a consequence of both these factors, local initiatives that make use of the beneficial properties of weeds, or encourage nature to left alone, will appear at best to be mere 'tinkering' at the edges. Such approaches gain little substantive support from central policy makers (cf. Thompson and Warburton, 1985). The difficulty, then, is not whether the *closure* of the current weed policy commitments is good or bad, but rather, whether the present closures are *privileged* and unable to be effectively challenged or changed.

Participation to address capture?

Given the preceding arguments, it would seem that a community-led approach to weed management can *potentially* be used by the government to address programme capture issues and simultaneously foster the social or 'other regarding' side of the weed issue. This potential, however, is limited by political and economic interest capture. As Paavola (2007) has also concluded, the choice to use community-led action should be aimed at addressing political capture and social justice issues, rather than economic efficiency *per se*.

However, and as also noted earlier, this more strategic aim still begs the question: *Whose interests and whose values will be recognised in government-led actions to promote community-led action*? Put the other way around: *Whose interests would a government be willing to reduce or sacrifice to achieve a broadened community-led approach to the generation of public value?*" For example, would a government be willing to weather the push back from the incumbent interests if current funding allocations were changed to favour the protection of natural capital? Indeed, would a government be willing to expose an existing weed programme to an open and transparent public value appraisal?

The above questions are germane here because *any* challenge to the incumbent sectional interest of weed control policies will be seen as a threat and will be vigorously opposed by the present beneficiaries of those policies.

In other words, the real issue to be managed is political and economic, a situation in which power constrains the choices and options available to policymakers to implement changes in weed management that would favour the generation of natural capital. Therefore, the reframing of weed management programme, recognizing social and/or environmental values and natural capital, without also creating excessive oppositional lobbying, is a central issue for consideration in the immediate future.

To achieve the above reform outcomes, the necessary reframing will need to be supported by forward-looking policy commitments supported by government-led technical assistance. As Mitchell, Florin, and Stevenson (2002) have found, technical assistance efforts typically underpin community-led approaches to pest management. They warn, however, that technical assistance systems must strike an important balance.

For example, it would be unreasonable to expect weed stakeholders (present and future) to make individual behaviour changes towards weed prevention, rather than chemical-based management, when such behaviour would, in some crucial respects already discussed, be seen to be counter to a government's landscape-scale, cross-tenure policy approach to weed management. In this situation, information on the beneficial uses of weeds would be quickly disabled by existing generic weed management policy commitments.

Seen from the opposite extreme, in an environmentally literate, community-led approach, new weed management policy commitments must be careful not get 'too far in front' of the communities they wish to build weed prevention capacity within. The community will determine its own (multiple, diverse) needs, and it will have its own (multiple, diverse) technical assistance requirements, based on what the community knows and learns. This is a significant constraint, as pesticide-based control methods have been the central commitment of the most influential and privileged segment of the communities living in weed affected areas for almost two hundred years (Fleming et al., 2014).

What we do know for sure, however, is that, to date, pesticide-based weed control approaches have broadly failed to manage weeds sufficiently to satisfy the affected landholders who hold the biggest vested interest in weed control. Agri-businesses who are locked into technical uses of herbicide to kill unwanted vegetation are, therefore, likely to continue to lobby and harass governments to do more to support the herbicide-pesticide industry and its forward trajectory with agri-business.

There is, therefore, a substantial 'sunk investment' in herbicidal-based control and the overreach of the technologies used to facilitate it. Consider, for example, Bayer's recent willingness to pay out billions of dollars in cancer claims against glyphosate, rather than change the thinking and techniques that enable chemicals to be used in a perilous manner.

According to traditional economic theory, a 'sunk investment' should have no bearing on decisions regarding future weed management investments, but the analysis here has shown it does. As argued earlier, a landscape-scale, community-led approach is presently framed to address a persistent failure. It admonishes and cajoles the community to do more and to kill enough weeds to create a stable level of biosecurity assurance *for those who benefit from selling herbicides*.

Indeed, even in cases where local management of weeds has been obtained to an acceptable level of control for crucial chemical stakeholders, the management effort often does not end up being a good story. It leads to other environmental issues and difficulties, such as the loss of production, due to soil and groundwater contamination; surface water pollution due to persistent chemical residues; the development of herbicide-resistance in weeds, and a myriad of known and unknown, non-target effects on beneficial microorganisms and other fauna.

The solution to these well-known issues is also captured by the same interests that created these unwanted social, environmental, and economic externalities, most of which affect the poor and what is left of a damaged and polluted environment. The solution to problems caused by the excessive and unwarranted use of chemicals cannot be more of the same.

The 'weed problem' is, therefore, at the core, a human political issue. Politically privileged stakeholders need to loosen their grip on the dominance of lethal, herbicide-based weed control in favour of an evidence-based appraisal of a broader set of plant-based interests, for example, organic farming, land reclamation, weeds as providers of ecosystem services and bio-resources for all animals (Chandrasena, 2014; 2019).

Given the above, a government's role in community-led weed management should not be to dictate to affected communities what the weeds' effects are, nor what the 'best' weed management/eradication techniques are (i.e., 'lethal best practice'), let alone attempt to enforce these herbicide-based control measures at the landscape-scale via inspections and fines. In other words, a 'speaking to' approach to community participation cannot encompass the necessary sense of the other's point of view to reach a steady-state outcome concerning weed management at the landscape-scale (cf. Daly, 2020).

In contrast, a 'listening' approach would assume a need for some receptivity from the government regarding its policy and programme commitments (Bodie and Crick, 2014) [3]. A system strengthening process for community-led weed management that 'listens' would, therefore, need to actively encourage compromise, especially with respect to the beneficial uses of some colonizing species. It would do this by designing in a commitment to encouraging community-led action that sustains natural capital, rather than telling the community how to best contribute to the dominant policy of unjust and environmentally destructive herbicidal weed control.

Finding the right technical assistance balance will also require a 'programme logic' to be developed for setting out what a community-led weed programme expects to achieve and how its successes will be measured. Without these, both community and government may feel over-burdened as they attempt to respond to multiple areas of concern and multiple requests for expertise (Mitchell, et al., 2002, p. 625).

Further, and as noted earlier, community requests for assistance will seem 'polluting' or 'unacceptable' to the current chemical-based weed programmes, that is, unless the dominant policy commitments of the current weed programmes are made amenable to genuine community inputs that would realistically influence policy change.

A community-led approach may mean, for example, that programme support staff will need to actively *encourage* input from the perspectives of those most often presently affected and excluded from weed management decision-making processes, for example, input from organic producers, or input from those who currently use weed prevention methods and do not participate in community weed poisoning. These 'outsider' perspectives will initially be quite challenging to the power of the *status quo* for

[3] Included here would be efforts to 'listen' to the weeds that are being unjustly persecuted simply because they have been listed as 'pest' species.

reasons already noted. However, the theory underpinning a community-led approach holds that such conflict will, on balance, be beneficial, especially if structured and supported by government policy.

The situational reading of present policy processes undertaken here suggests the above may require *re-framing the impossible as possible*. From a pragmatic viewpoint (Kevelson, 1998), whether a possible new way of doing weed management, for example, making use of weeds rather than poisoning them, is impossible is presently determined by reference to existing, chemical-based weed policies. In other words, the appraisal of *what is possible or impossible* is made in respect to what is currently known.

An 'impossible change' is therefore just a euphemism for a lack of trust in the capacity of the community to contribute to the shared task of seeking out and implementing improvements to weed management, especially those methods that seek to protect and enhance natural capital. As argued above, this lack of trust by government is understandable, given the present dominated policy commitments to herbicidal control, and how governments currently respond to any threat to herbicidal priorities.

To achieve the desired revisions, systems thinking practitioners, such as Checkland and Poulter (2006), found that the 'command and control' style of thinking associated with goal-oriented behaviour (such as those that occur under a landscape scale approach to weed management discussed earlier) are largely unhelpful with respect to *dynamic* systems.

Like Allen (2016), Checkland and Poulter (2006) sought a method to re-frame issues of concern, but in a manner that would assist all those involved to move away from goal-oriented, or 'fixed' thinking. Thus, instead of 'herbicide treatment 'goals or 'performance targets', Checkland and Poulter (2006) argued for a move towards thinking in terms of *learning*, for example, learning how to 'live with weeds' (as proposed by Chandrasena, 2014), or by learning how to prevent weeds from affecting farming operations in a manner that complements the sustainable use of natural capital.

The above cannot be achieved by reference to what is currently known, but rather, it can be achieved by learning how the known can be carried forward in new ways, in order to encompass new concerns, bought to the table via community leadership.

However, and as Fox and Murphy (2016) have argued persuasively, when a government agency engages in robust public participation to learn, this interaction will be seen to be placing existing bureaucratic policies and operational systems at risk. Paradoxically, then, and as discussed earlier, government agencies claiming to want to use a community-led approach may only *really* use it if an increase in participation assists the agency to become *more* perfectly inflexible in the longer run. Thus, unless a government's weed programme has a genuine policy commitment to a *transformational* vision for weed management, most of its effort directed at community engagement will be seen to be "mere window dressing" (ibid. p. 218).

In the above sense, then, what is first needed in a community-led approach is an *institutionally* supportive environment that will create the conditions necessary for learning to take place within. This environment will enable a weed programme to learn more and more about the multiple issues people in different situations are wanting to learn more about. This learning will have to occur not only in the terms acceptable to the local participants (Thomas and Warburton, 1985), but more importantly, in terms acceptable to the *system of weed bureaucracy itself* (Fox and Murphy, 2016).

If the additionality of community-led weed management is not made amenable to a government's weed programme itself, the weed programme will instead remain fixed on higher level aims, such as weed 'population control' at 'landscape scale', which, as argued earlier, leads to the allocation of more and more resources and technical support to achieving an aim that is largely "symbolic" (Newig, 2007).

I use symbolic above as, in the face of the persistent historical failure to eradicate weeds, Newig (2007) has argued that there is a tendency for politicians to enact "symbolic legislation". Symbolic legislation, refers to, "laws which despite their often ambitious officially declared objectives are designed to remain ecologically ineffective" (Newig, 2007, p. 277, see also Vasiliy 2020).

In the current view, symbolic policies are designed to deflect attention away from chemical capture and the expansion of agribusiness into larger and larger areas of the environment, furthering the erosion of natural capital that it is mistakenly alleged, 'invasive' weeds are supposed to cause.

Note too that symbolic policy actions are implemented from an *ex ante* positioning – the decision maker *already knows* that the response will fail to address its declared objective, other than symbolically. Put bluntly, the real aim of the herbicidal control of plants is to 'solve' the weed problem from a purely *politically captured* point of view. The political motivation is a desire to respond effectively and immediately to the urgent needs of an influential constituency, that is, agribusiness.

The implementation of assistance to community-led chemical weed control stakeholders demonstrates a government's genuine desire to be responsive to a community's expressed concerns. The trouble is, as a *symbolic* policy response, herbicidal control of weeds is designed to *manage* a persistent failure rather than *resolve* it (Newig, 2007). A failure to control weeds favours chemically-based land management. It appeases some powerful agribusiness interests and their constituents, at the expense of the broader living environment.

As a codicil to the above claim, then, we should also note the effect of an information asymmetry in relation to herbicidal weed control. Due to a focus on sunk investments in chemical control any effort from a government to find out whether herbicides are truly safe and effective would be seen to be an overly time consuming and prohibitively costly process.

Realising this, and given no other viable option, due to factors already discussed, governments and their chemical regulators generally overlook the ineffectiveness of the policies it puts in place to encourage the herbicidal control of weeds. Why? Herbicides are *designed* to meet an important 'emotional need'; the need to kill something and feel safe, but they will not dissolve the weed 'problem', as what is problematic also involves poisoning life as a means to secure life.

Because herbicides offer a 'quick fix', criticisms of herbicidal methods are also usually easy to deflect on another basis. The issues are complex, and the causal connections between herbicide use and pollution are deliberately kept opaque. There is also 'scientific uncertainty' surrounding the long-term effectiveness of herbicides because there is no effort to create a scientifically informed agreement on their longer-term effects. Indeed, as Newig (2007) argues, the more complex and opaquer a problem issue is, the *more likely* it is to be addressed through symbolic political action.

Based on Newig's (2007) research, symbolic policy responses, such as financial and policy assistance for the community to wage a herbicidal 'war on weeds', are instituted when the following conditions exist:

- A high level of public concern or controversy exists, forming acute, value-laden conflict patterns (e.g., 'rent seeking' behaviours, such as lobbying to benefit agri-chemical interests).
- Addressing the issue substantially would involve high regulatory costs, while at the same time yielding low or no regulatory benefit (in present case, primarily because weeds cannot be 'eradicated' with chemicals).
- There is an asymmetrical distribution of information (e.g., the difficulty of determining the spread of weeds over relatively large areas, abundances and densities).
- There is a high level of issue complexity (e.g., considerations of the overlaps between 'native' vs. 'non-native' or 'introduced' species and colonizing, pioneer plants, and how these species influence the preservation of natural capital).

The above analysis might be interpreted as suggesting that one of the central purposes of a symbolic policy response is deception. The aim of funding a 'war on weeds' might be said to be 'to fool' the public into believing something 'real' is being done, while it is known beforehand that the intervention will not be effective, other than at a symbolic level. While that is a possibility, the issue may go deeper. The present paper follows Newig's thinking and proposes the use of a landscape-scale 'war on weeds' is a *shared* self-deception, which functions to fulfil a *shared* need.

Self-mortifying policy/responses to complexity

While some landholders manage to negotiate their way through the weed policy morass and find satisfaction (mainly by implementing various weed prevention methods), a substantial number of stakeholders are less successful because they follow government (i.e., agribusiness) advice to keep it simple and chemically 'treat' life that is problematic in the dysfunctional sense discussed so far here.

Doerner (1980) has identified several common mistakes that are made by decision-makers when they are dealing with complex systems in this manner. For example, decision-makers commonly give *insufficient consideration to understanding processes in time*. This simplifying tendency, as applied with respect to weeds, is compounded and entrenched in policy by 'rent seeking' behaviours that stress a need for 'immediate action', even though many potential environmental harms that some weeds may cause in specific situations are largely unknown, or may even resolve themselves naturally without any chemical intervention.

Another factor identified by Dorner (1980) is the *tendency to think in causal series rather than in causal nets*. In this situation, there is a tendency to focus on the main effect while surrounding causal factors are ignored, impoverishing the number of options available. As Lourey et al. (2011) found, 'pest management' stakeholders usually have a very high involvement and commitment to their preferred method of pest management. While deciding to commit to a new method, they may consider alternatives, but once committed, there is a considerable 'sunk investment' in the decision, which as already argued, they are reluctant to release. This inhibits consideration of further options or influences, including consideration of whether the 'invested-in' method really works. Alternatively, if the initial assessment identifies any situation that constrains their efforts to manage weeds, this too will remain an inhibiting factor when additional complexity is confronted.

If Dorner's (1980) findings are applied to a weed management policy system, then, it may be possible to better understand the nature of the system. The continued failure of a weed management programme to reduce weed abundance to a level that inhibits further weed infestations suggest a lack of control, which, for the decision-maker, implies that they have no control over weeds.

The loss of control that is implicit to the application of herbicides, therefore, implies fear; a fear of further loss of control, credibility and the consequences that will follow. Thus, the feedback-loop that chemical weed control creates, in turn, weakens a person's feelings of control and safety, creating as Derrida (2001) argued, a kind of "auto-immunity" response in which the protective behaviour destroys its own protection (p. 94). This is doubly unfortunate in the present context, as it suggests that government weed programmes are in effect designed to create feelings of vulnerability and a dependence on goods supplied by the chemical industry.

Promoting generic weed killing is therefore likely to cause stakeholders to experience and express feelings of being at an even *greater* level of risk. Thus, the peripheral conditions that limit the possible success of chemical weed management, such as the rapid development of herbicide resistance in innumerable weeds (Heap, 2019), and changes in the weed floras, are increasingly ignored, and all weed issues are attributed to an over-abundance of 'threatening' weeds, when in fact*, it is the failure of chemical control that is doing the threatening*.

Autoimmunity consequences

Under conditions of failure, then, government weed programmes are in fact creating their own self-defeating conditions that take the form of a general reduction hypothesis: "*the programme would work if only we could kill more weeds*". This degeneration of scope and purpose is natural in an emotional sense, but in a practical sense, it inhibits us and overrides other issues that might be considered important, for example, our environment (cf. Ahmed, 2005).

As a symbolic response to dealing with an overburden of complexity, then, a herbicide-focussed weed programme creates an associated complex of decision-making restrictions, for example, a reduction in the number of alternative methods considered by stakeholders, leading to the further entrenchment of pesticide-based (but ineffective) methods over non-chemical methods.

Or the above failure might lead to a 'fortification' tendency that only considers one option in isolation (cf. Doerner, 1980). Or it might lead to a decomposition of social cohesion into a focus on individual action – a frame within which individuals must face an impending personal catastrophic weed attack alone (Brown and Nettleton, 2017).

The above mechanisms come about because most weed programmes focus on the chemical control of weeds at landscape scale, which leads to a persistent failure, which then leads to the entrenchment and repetition of the same failure, generating more fear.

If the argument made so far is right, land managers are having difficulty dealing with the complexity of their situation. The difficulty of avoiding unpleasant consequences (a failure to deal with weeds) depletes their ability to cope effectively, causing a further depletion in their decision-making resources, leading to even worse decisions being made (cf. Oertig et al., 2013). This process is perhaps best exemplified by farmers who report spending 'all their money and time' on weeds.

As found by Doerner (1980), when the complexity of a situation creates an 'intellectual emergency', a common reaction is to reduce the number of conditions considered. In the case of weed management, the options are effectively reduced to two: participation in government supported herbicidal control, or non-participation and ridicule.

Conclusion

We have argued in this paper that most government landscape-scale weed interventions will continue to under-perform if they do not consider that weeds may, in certain circumstances, provide positive ecosystem services for the planet, not just disservices (Chandrasena, 2014; 2019; Altieri et al, 2015). Therefore, weeds are not plants that should *necessarily* be killed with chemicals (Vaz et al., 2017).

We further suggest that there is an optimal scale of herbicide-based weed management beyond which weed management becomes uneconomic. Killing weeds with chemicals increases social costs and environmental damage faster than it creates production or conservation benefits (cf. Daly, 2020). Based on our reasoned arguments, the time for a change and modified approach is upon us.

Governments are failing to recognise this limitation sufficiently. Consequently, killing weeds with herbicides has itself become a dysfunctional 'growth industry'. Indeed, poisoning life has become big business – even in so-called 'natural' landscapes, the government encourages chemical weed control and commodifies the natural landscape unnecessarily, leading to a depletion of natural capital.

The failure of weed management approaches in Australia, for example, was recently discussed by Harper and Chandrasena (2018). They placed the blame mainly on changing and confusing policy back-flips of various governments, inadequate funding, accountability, and the lack of on-ground, performance-based monitoring regimes.

In contrast, the leading cause of the dislocation in the present view is that governments generally hold the view that the chemical control of plants can *substitute* for the services that plants perform for us. For example, the ways colonising species (weeds) can rejuvenate and replenish areas that have been damaged and laid bare by humans. As such, this paper has argued that weeds are *complementary* to ecological health and, if we attempt to eradicate them with chemicals, the services weeds provide will be needlessly lost, impoverishing our 'stock of natural capital', possibly irreversibly.

In this paper, we critically viewed the above line of thinking through the lens of community participation. The community is generally very keen to do weeding. Indeed, there is currently wide-spread support in the community for 'lethal weed control'. The public is, for the most part, keen to 'kill more weeds'.

However, whether the current, dominant lethal weed policy framing meets our broader *public value* and *environmental* expectations, is uncertain, especially from a policy development perspective.

Our analysis suggests that a dominant government policy that aims to kill enough weeds to obtain '*a reasonable level of landscape control'* is bound to fail. Indeed, we have argued that this doomed lethal objective is inconsistent with, or ignores entirely, locally-led initiatives that more cost-effectively 'manage' any adverse effects of weeds, for example, via a significantly increased emphasis on weed prevention methods, or via the tolerance of some innocuous and beneficial weeds, or even via ecological 'learnings' that aim at achieving weed-human co-existence (e.g., letting weeds grow on field borders to nurture beneficial insects for crop pest control and the provision of other ecosystem services, such as pollination services and soil erosion control).

As Fox and Murphy (2016) have explained, bureaucratic systems have particular virtues. When excesses and deficiencies are identified, an authoritarian system may seek short-term collaboration with a broader set of stakeholders to redress some of the identified imbalances.

What remains to be seen, therefore, is whether there really is any appetite in government circles for 'open' community participation, that is, participation that would generate genuine improvements to weed management, or, whether the call for community-led participation in weed management will remain merely 'symbolic', pursued to satisfy 'emotional' purposes only (cf. Newig, 2007; Hunt, 2005), or more negatively, to aid the interests of the billion-dollar chemical industry.

There are more positive ways forward. Allen (2016), for example, reported that in Australia sheep farmers can organise themselves to protect the welfare of their livestock via pest-prevention measures, such as fencing and guard dogs, rather than via the lethal control of native dingoes. Further, as sheep farmers are quite capable of organising themselves to protect their assets in this manner, there is no 'market failure'; therefore, there is no need for government-led, funded, landscape-scale interventions that aim to kill dingoes at landscape scale. Such efforts are doomed to fail.

Thus, to address the '*difficulty of being a weed*", there may be some hope if government policy aims *not* to achieve a landscape-scale level of herbicide-based weed management, but instead, aims to work with the community to *reduce* the unwanted, effects of weeds at local scale. It will be a bonus if the policy aims to *protect* the community's sense of well-being and focus on outcomes that can be achieved in a manner that the affected communities understand and will broadly support. Such a policy aim would reveal and celebrate the ways colonising species can also be valued for what they do to support life on this planet.

This is not a new call. Numerous authors have been arguing for recognising biodiversity values and ecosystem services provided by weeds for some time (cf. Hillocks, 1998; Marshall, 2003; Jordan and Vatovec, 2004). Indeed, Chandrasena (2014; 2019) has extended this insight to propose a paradigm of 'living with weeds' as a solution.

As noted in our opening remarks, weeds usually appear somehow 'malformed and grotesque' to us, both physically and conceptually. They blend that which is wild with that which is domesticated. They emerge persistently from the crevices and temporal interstices we create for them in the name of 'growth'. Our point, however, is that their remarkable botanical attributes and ecological capacities, (cf. Baker, 1965), generate 'threshold' situations for us – moments when the factors that cause environmental degradation are for a time reversed. We can take advantage of these moments.

Weeds can turn the plant world on its head and make a genuine dialogue with all that is 'still wild' possible. The overlap of natural and human capital is indeed a clash of worlds, and the result often appears grotesque. Yet, from this weird blend, new value can emerge.

Acknowledgements

Thank you to my family for your encouragement and support in writing this paper. I would also like to thank my former policy colleagues in government for their contributions to the thinking covered in this article.

A thank you to the Journal's Editor - Dr Nimal Chandrasena for encouraging me to write what I learned about weed management from my involvement in government policymaking and submit the result to a wider critical appraisal. In this latter respect, I would like to thank him and two other anonymous reviewers who offered helpful suggestions for improving the paper.

References

Ahmed, S. (2004). Affective economies. *Social Text*, 22 (2): 117-139.

Ainsley, M. & Kosoy N. (2015). The tragedy of bird scaring. *Ecological Economics*. 116: 122-131.

Allen, L. (2016). Is landscape-scale wild dog control the best practice? *Australian Journal of Environmental Management.* 24 (1): 5-15.

Altieri, M.A. et al. (2015). *Crops, Weeds and pollinators. Understanding ecological interaction for better management*. Food and Agriculture Organization (FAO). p 106 (**http://www.fao.org/3/a-i3821e.pdf**).

Baker, H.G. (1965). Characteristics and modes of origin of weeds. *In*: H. G. Baker & G. L. Stebbins (Eds.), *The Genetics of Colonizing Species*. pp. 147–172, Academic Press, NY.

Bakhtin, M. (1968). *Rabelais and His World*. Trans. Helene Iswolsky. Cambridge: The Massachusetts Institute of Technology Press. 496 pp.

Bodie, G. D. and Crick, N. (2014). Listening, hearing, sensing: three modes of being and the phenomenology of Charles Sanders Peirce. *Communication Theory*, 24: 105-123.

Brown, N. and Nettleton, S. (2017). Bugs in the blog: immunitary moralism in antimicrobial resistance (AMR), *Social Theory and Health*, 15: 302–322.

Chandrasena, N. (2014). Living with Weeds: A New Paradigm*. Indian Journal of Weed Science*, 46 (1): 96-110.

Chandrasena, N. (2019). [Editorial]. Seeing 'Weeds' with new Eyes, *Weeds.* 1 (2): 1-12.

Checkland, P.B. and Poulter, J. (2006). *Learning for Action : A Short Definitive Account of Soft Systems Methodology and Its Use for Practitioners, Teachers and Students*. Chichester: John Wiley & Sons. p. 226.

Commissioner for Environmental Sustainability Victoria (2018). *Framework for the Victorian State of the Environment (SoE) 2023 Report*. Victorian Government, Melbourne, (**https://www.ces.vic.gov.au/reports/framework-victorian-state-environment-soe-2023-report**).

Daly, H. (2020). A note in defense of the concept of natural capital. *Ecosystem Services*, 41: 1-2.

Derrida, J. (2001) Philosophy in a time of terror. In G. Borrador (2003). *Autoimmunity: Real and Symbolic Suicides*. University of Chicago Press: Chicago. p. 224.

Doerner, D. (1980). On the difficulties people have in dealing with complexity. *Simulation and Games*, 11(1), 87-106.

Donahue, D. L. (2005). Western grazing: the capture of grass, ground and government. *Environmental Law*, 35: 721-806.

Dwyer, J. (2011). Weed Psychology and the war on Weeds. *Plant Protection Quarterly*, 26 (3): 82-86.

Fenichel, E. P., Richards, T. J. and Shanafelt, D. W. (2014). The control of invasive species on private property with neighbor-to-neighbor spillovers. *Environmental Resource Economics*, 50: 231-255.

Figuié, M., Binot, A. and Caron, A. (2015). Wild and domestic, human and animal: colonial and post-colonial surveillance policies in Zimbabwe. *Review d'Anthropologie des connaissances*, 9: 163-188.

Fisher, F. (2006). *Response Ability: Environment, Health and Everyday Transcendence.* Vista Publications, Melbourne. 315 pp.

Fleming, P. J. S., et al. (2014). Management of wild canids in Australia: free-ranging dogs and red foxes. In Alister Glen & Christopher Dickman (Eds.) *Carnivores of Australia*. Canberra: CSIRO. 448 pp.

Fortmann, L. (1990). Locality and custom: non-aboriginal claims to customary usufructuary rights as a source of rural protest. *Journal of Rural Studies*, 6 (2): 195-208.

Fox, C. and Murphy, P. (2016). The paradox of bureaucratic collaboration: Government bureaucracies in robust collaboration with the public. *Journal of Sustainable Development*, 9 (1): 217-228.

Gsottbauer, E. and van den Bergh, J. (2011). Environmental policy theory given boundary rationality and other-regarding preferences. *Environmental Resource Economics*, 49: 263-304.

Harper, P. and Chandrasena, N. (2018). Weed Management is Not Quite 'Bush Regeneration' – An Opinion Proc. 21st Australasian Weeds Conference, Sydney, NSW, Australia, 9-13 Sep 2018, 273-279.

Hillocks, R.J. (1998). The potential benefits of weeds with reference to small holder agriculture in Africa. *Integrated Pest Management Reviews*, 3: 155-167.

Heap, I. (2019). The International Survey of Herbicide Resistant Weeds (www.weedscience.org).

Hunt, R. (2005). The nil tenure approach to a landscape issue (wild dogs). Proc. Of the third NSW Pest Animal Control Conference 4th – 7th July, NSW DPI.

Ison, R. L. (2008). Systems thinking and practice for action research. in P. Reason & H. Bradbury (Eds) *The SAGE Handbook of Action Research Participative Inquiry and Practice.* 2nd Ed., SAGE Publications, London UK, pp. 139 - 158.

Jordan, N. and Vatovec, C. (2004). Agroecological Benefits of Weeds. Chapter 6, pp. 137-158. *In*: Inderjit (Ed.) *Weed Biology and Management*. Kluwer Academic Publishers

Kevelson, R. (1998). *Peirce's Pragmatism: The Medium as Method*. Peter Lang: New York. p. 204.

Larson, B.M.H. (2005). The War of the Roses: Demilitarizing Invasion Biology. *Frontiers in Ecology and the Environment*, 3(9): 495-500.

Latour, B. (2008). A cautious Prometheus? A few steps toward a philosophy of design (with special attention to Peter Sloterdijk). Keynote lecture for the *Networks of Design* meeting of the Design History Society Falmouth, Cornwall, 3rd September 2008 (**http://www.bruno-latour.fr/sites/default/files/112-DESIGN-CORNWALL-GB.pdf**).

Lourey, R., Kaine, G., Davies, A., Young, J. (2011). *Landholder responses to incentives for wild dog control.* Service Design Research Working Paper 08-11, Department of Primary Industries: Melbourne (**https://www.ecologyandsociety.org/vol22/iss2/art2/**).

Low, D. and Peric, Z. (2011). An Ecosemiotic Approach to Weed Biosecurity. Proceedings 23rd Asian-Pacific Weed Science Society (APWSS) Conference, Cairns, 26-29 Sep. 2011, pp. 78-86.

Marshall, E. J. P., et al. (2003). The role of weeds in supporting biological diversity within crop fields. *Weed Research*, 43:77–89.

Metzger, J.; Soneryd, L. and Linke, S. (2017). The legitimization of concern: A flexible framework for investigating the enactment of stakeholders in environmental planning and governance processes. *Environment & Planning A*, early view online, 49(11):2517-2535.

Morales, H. (2002). Pest management in traditional tropical agroecosystems: Lessons for pest prevention research and extension. *Integrated Pest Management Reviews*, 7: 145-163.

Moran, D. (2015). Carceral geography: spaces and practices of incarceration. Ashgate: Farnham (UK). p. 194.

Newig. J. (2007). Symbolic environmental legislation and societal self-deception. *Environmental Politics*, 16(2), 276-296.

Oertig, D., et al. (2013). Avoidance goal pursuit depletes self-regulatory resources. *Journal of Personality*, 81 (4): 365-375.

Paavola, J. (2007). Institutions and environmental governance: a reconceptualization. *Ecological Economics*, 63: 93-203.

Southwell, D., et al. (2013). Understanding the drivers and barriers to participation in wild canid management in Australia: implication for the adoption of a new toxin, para-aminopro-piphenone. *International Journal of Pest Management*, 59 (1): 35-46.

Steer, J. E. S. (2015). The reconciliation of introduced species in New Zealand: Understandings from three 'exceptional' case studies. Unpublished Ph.D. Dissertation, University of Auckland (**https://www.academia.edu/22033695/The_reconciliation_of_introduced_species_in_New_Zealand_Understandings_from_three_exceptional_case_studies**).

Stengers, I. (2019). Putting problematization to the test of our present. *Theory, Culture & Society* (**https://doi.org/10.1177/0263276419848061**)

Stirling, A. (2008). "Opening Up" and "Closing Down": Power, participation, and pluralism in the social appraisal of technology. *Science Technology & Human Values*, 33 (2): 262-294.

Thompson, M. and Warburton, M. (1985). Knowing where to hit: a conceptual framework for the sustainable development of the Himalaya. *Mountain Research and Development*, 5 (3): 203-220.

Vasiliy, T. et al. (2020). An Analysis of US State Regulated Weed Lists: A Discordance between Biology and Policy, *Bioscience*, 70(9): 804–813.

Vaz, A. S.; et al. (2017). Integrating ecosystem services and disservices: insights from plant invasions. *Ecosystem Services*, 23: 94-107.

Wesselink, A., Paavola, J, Fritsch, O and Renn, O. (2011). Rationales for public participation in environmental policy and governance: practitioners' perspectives. *Environment and Planning A*, 43: 2688-2704.

PERSPECTIVE

Dragon Trees, Von Humboldt, and Napoleon: Water Hyacinth's Journey to Africa

Jeremiah M. Kitunda [1]

[1] Current Address: Appalachian State University, Department of History

224 Joyce Lawrence Lane, Boone, NC 28608, USA

E-mail: kitundajm@appstate.edu

Submitted: 30 November 2020

Accepted: 22 December 2020

Published: 30 December 2020

Abstract

This paper provides an account of the German naturalist and explorer - Alexander von Humboldt's role in the migration of water hyacinth ([*Eichhornia crassipes* (Mart.) Solms], from its native range in the Amazon to other parts of the world between 1800 and 2000 [1]. Humboldt (1769-1859), an avid plant collector, transplanted this free-floating aquatic species, renowned for its beauty as a wildflower, from its natural habitat in the Orinoco River in the Amazon Basin, first to the botanical gardens in North America and Europe at the beginning of the 19th Century. By the mid-19th Century, his network of scientists had already transferred the plant from European botanical gardens to Asia, Australia, Oceania and Africa, as a fish-breeding facility, an ornamental beauty, and a plant of interest to botanical research. By the last quarter of the 19th Century, the plant had become well-adapted to conditions in countries where it had been introduced, and spread aggressively, especially in Egypt, South Africa, and the USA. Its fame rose as both an obnoxious aquatic weed and multipurpose plant. During the imperial wars of the early 20th Century, European colonial armies used mats of water hyacinth as screens against enemy detection.

In recent decades, water hyacinth has been declared the worst aquatic weed ever seen in Africa's watercourses. It challenges navigation in natural and artificial waterways. Nonetheless, Africans turned this ecological disaster into an economic asset with the guiding spirit – 'if you can't beat the mats, join them'. The narrative of water hyacinth, therefore, represents one of the yardsticks with which to measure the depth and extent of Humboldt's influence in both temporal and geographical space. Based on his personal accounts, herbaria data, and published literature, this paper provides a brief introduction to the role of this German naturalist in the migration of water hyacinth and perspectives on the influence of plant collectors of the past centuries on the spread of species during the colonial era.

Key words: Water hyacinth, *Eichhornia crassipes*, African lakes and rivers, Dragon tree, Alexander Von Humboldt, Napoleon, ecology, environment, aquatic weeds.

---

[1] The article is a brief account based in part on the author's recent book on *A History of Water Hyacinth in Africa: The Flower of Life and Death from 1800 to the Present* Published in 2018 by Lexington Books - Rowman & Littlefield Press.

Introduction

As Alexander Von Humboldt tells us in *Cosmos,* childhood tales of a colossal African Dragon tree [*Dracaena draco* (L.) L.] in the old tower of the Berlin Botanical Garden stimulated his desire for adventure (Gendron, 1961; Humboldt,1858). The Nile River Basin was Humboldt's first target for adventure and exploration, but Napoleon's military occupation of North Africa, from 1797 to 1801, shattered this dream, forcing Humboldt to opt for exploring Western Africa and South America.

The dragon tree, a native of the Western African islands and western Morocco, occupied a considerable space in his exploration accounts. Humboldt's botanical curiosity, applied to exotic plant and botanical gardens, signifies several things. First, it signifies the ways in which botanical gardens of the 18th and 19th Centuries inspired the naturalists' travels in search of exotic plants for transportation beyond the native ranges. Second, it points to the role African plants played in inspiring botanical curiosities in Europe during the early modern period. That inspiration, however, as the case of Humboldt illustrates, spiralled, and transformed Africa from a source of botanical curiosities into a recipient of exotic plants in the 19th Century. Thirdly, it points to the fact that the science and history of introduced plants are to be found in travel accounts and in botanical gardens' records.

This is why a focus on Humboldt's exploits is beneficial to the study of the plants that he collected and transferred to Africa. It is not just his exploration of Africa and African dragon trees that made him important, but his transfer of a major aquatic weed - water hyacinth [*Eichhornia crassipes* (Mart.) Solms] and many other plants from South America to Africa.

Furthermore, what makes Humboldt so important in the history of water hyacinth is the fact that before him, naturalists had described water hyacinth purely for botanical knowledge. He was also instrumental in contributing to the early development of plant ecology as a new branch of botany and made a significant impact by laying the foundations and scientific methodologies of climatology, limnology, geology and environmentalism (Huxley, 2007).

Between 1793 and 1813, Humboldt's pioneering ideas of environmentalism crystallized in *Florae Fribergensis Specimen,* in which he argued that altitude, climate, temperature, and geography determine where plants grow and become geographically distributed (Humboldt, 1793).

It is, therefore, significant that if the Greek word *Oikos* (from which the term *ecology* derives) means "*house"*, then Humboldt not only transplanted and physically housed water hyacinth in botanical seed banks, but also intellectually housed it in the science of plant ecology—where later generations cultivated and discoursed about it in abundance.

Expounding his views of humans and nature as integrated halves of a single whole, Humboldt (1858) inspired the theories of George Perkins Marsh that predominate current environmental studies. Leading environmental historians, such as Alfred Crosby (2004) drew heavily on this Humboldtian tradition. Most aggressively colonizing aquatic species in African watercourses today are linked to Humboldt's South American plant collections that reached European botanical gardens between 1800 and 1805. Subsequently, many were transferred to Africa through the agency of people and institutions linked to Humboldt and his plant collections.

On June 5, 1799, aboard the *Pizzaro*, a Spanish ship, Humboldt, and his French botanist Aimé Bonpland sailed from Spain through the West African coast to South America. On July 16, 1799, they landed at Cumana (Venezuela) where they stayed for several weeks collecting plants (Adams, 1969; Helferich, 2004).

Humboldt then spent five years collecting plants and botanizing through Venezuela, Ecuador, Colombia, Peru, Mexico, and the Caribbean Islands. Travelling overland, his party entered the Orinoco River at its confluence with Rio Apure [2], working their way upstream, collecting a considerable menagerie of species. Humboldt's accounts show that, during the exploration of the Orinoco's middle course, he collected only a few specimens, due to clouds of stinging insects and the unattractiveness of the riverine flora (Stearn, 1968).

However, the enchanting beauty of a floating herb that blocked the passage of his boat could not escape his attention. In April 1800, Humboldt recorded encountering "floating gardens which, in the tangle of the river's tributaries, covered mile-upon-mile with what we were sure were hyacinths, water

[2] The Orinoco is one of the largest rivers of South America. Its basin covers an area of about 990000 km², covering most of Venezuela and eastern Colombia (source: **https://en.wikipedia.org/wiki/Orinoco**. See also Bonnie Hamre, *Orinoco River*. About.com: South America for Visitors. Retrieved December 25, 2020).

lilies, and fantastically coloured heliotropes" (Duval, 1982).

This was a remarkable moment in the history of water hyacinth. Humboldt collected specimens, labelling them as "floating wood". He pressed, sketched, and sealed the plants in boxes and conveyed them down the Orinoco to Havana (Cuba) for shipment across the Atlantic to Europe in three consignments. We could safely presume water hyacinth was a dominant plant species among the species shipped across to Europe.

Historians can track these plant collections to Europe-based institutions and individual naturalists who subsequently transferred the plants to Africa for scientific experiment and acclimatization purposes.

In my recent book — *A History of the Water Hyacinth in Africa: The Flower of Life and Death from 1800 to the Present* (Kitunda, 2018), I have traced the origin of water hyacinth, as described above, from the watercourses of South America, to European botanical gardens, and then, further afield to Africa.

For safety, Humboldt divided his collections into three large consignments. One consignment was left in the care of friends in Cuba, while a box of manuscripts of herbals and collection of insects, under the care of a Franciscan monk was sent to France via Spain. This, unfortunately, was shipwrecked off the coast of West Africa.

The third consignment of 1,600 specimens, in the care of one James Fraser, reached King Charles IV of Spain, the Royal Society, and the Kew botanical garden in Britain. Then, from England, the last part of the consignment reached Humboldt's mentor, Carl Ludwig Willdenow, the Director of the Berlin Botanical garden (1801-1812).

In 1801, with the help of the Swedish taxonomist Olof Swartz, Willdenow published Humboldt's 'floating woods' as *Pontederia azurea*, a name that persisted for the next 80 years until the species was renamed as *Eichhornia crassipes,* (Mart.) Solms (Gopal, 1987). Botanists in all three countries immediately transferred the plant to Africa for scientific research and acclimatization. The botanist William Aiton Townsend carried some of it from Kew to the Cape for those purposes.

Centrally, *A History of the Water Hyacinth in Africa* (Kitunda, 2018) draws attention to an innovative methodology of tracking down the origins, collection, distribution, and ecological transformation of introduced plants using herbaria data of past collections. Most museums and botanical facilities hold varying sizes of herbaria and data on plants. These scientifically valuable source materials, rarely used in historical inquiry, carry copious notes and information that botanists have left behind. They show details of collectors of a given plant, location(s) where the plant was collected, date(s) of collection, reasons for collection, details of its natural habitat, uses and relationship with new environments.

The use of herbaria data and travel accounts of naturalists, such as Humboldt, allowed the reconstruction of the history of water hyacinth from South America to Africa via the European botanical gardens from the 18th to the 21st Century (Kitunda, 2018). The analysis of such information shows not just the history, but also the changing perceptions and responses to species, such as water hyacinth, among ordinary people, scientists, conservationists and policy makers, over the last 200 years.

In discussing the history of water hyacinth, several important questions arise. Rather than a pernicious legacy of "the white man's burden" introduced to beautify Africa, could water hyacinth actually be one of the means of rethinking discussions about biological imperialism and ecological mismanagement?

Could species, such as water hyacinth, be even beneficial to underdeveloped African economies? Water hyacinth and its behaviour in countries to which it has been introduced, also raises the question of whether aggressive colonizing species are truly dangerous and whether they should be relentlessly maligned. Does water hyacinth represent an example of a potentially beneficial effect of ecological imperialism? (*sensu lato* Crosby, 2004)

The historical analysis shows that water hyacinth was originally viewed positively for many decades until its abundance and aggressiveness forced changes in perception. However, in the latter half of the 20th Century and most certainly in the 21st Century, African countries seem to be realizing that the species can be extremely beneficial.

Many African countries, for instance, Rwanda, Burundi, Kenya, Ethiopia, Sudan, and Niger, now reclaim and utilize water hyacinth for a wide variety of uses, including extracting pollutants from sewage and industrial effluents, and for crafts, paper industries, biogas production, and animal feed resources.

Water hyacinth is now perceived not as an ecological disaster, but an economic opportunity if harvested and handled properly and managed in the waterways it occupies. The Lake Victoria and the Niger River Basins are good instances of this changing view of water hyacinth. Cottage industries of all kinds have mushroomed in these two basins all centred on exploitation of water hyacinth as raw material for production of a wide range of valuable goods (Kitunda, 2018).

Such utilization approaches have been captured very much in poetry. In 1985, as water hyacinth aggressively invaded the Niger River Basin a renowned Nigerian parapsychologist-cum-astrologer, Dr. Okunzua recovered the following communication from the plant[3]:

> *"I am the leaf, the leaf of blessings and fortune. I have brought with me fortune and wealth to Nigeria. I am the leaf, I am full of wealth and blessings." (Edewor, 1988)[4]*

This epigrammatic passage encapsulates the precise perceptions among Africans of water hyacinth as potentially beneficial to land and people. Despite the claim that water hyacinth is a pest, it can potentially be dealt with in ways that poses no threat to the environment, but which may even be beneficial.

In their obsession with eradication of what have been dubiously labelled "invasive alien plants", the media, policymakers, and scholars appear to have failed to see the ambivalence of biological and ecological success of introduced species in their new environments.

By extension, new plants in new places may potentially constitute 'a boon not doom' to the area. It all depends on perceptions. As William Beinart and Peter Coates argued,

> *"...It is difficult to sustain an argument that all botanical immigrants should be uprooted and repatriated. If this were done the United States would have to subsist on tortillas and refried beans, South Africa on springbok burgers. . . Frangipanis and loquats, eastern exotics which have long beautified Cape gardens would disappear.*
>
> *"…So, would the vineyards of California and the Cape. But just as these countries' biological diversity has probably been enriched by importation, the success of particular plants threatens the variety of indigenous life. So, there must be a strong case for control of rampant invaders, even for eradication in niches specially set aside for attempts to nature indigenous splendor…"* (Beinart and Coates, 1995).

The above quotation reflects a discourse defining environmentalism from its beginnings as a scientific study in the mid-19th Century. Diverging from the Humboldtian view of plant transfers, George Perkins Marsh, America's first environmentalist, recognized the irreversible impact of man's actions on the earth. His 1864 book, *Man and Nature* had a global impact, setting the tone that gave rise to the twin concept of conservationism and sustainability:

> *"…Whenever man plants his foot, the harmonies of nature are turned into discords. Indigenous vegetable and animal species are extirpated and supplanted by others of foreign origin with new and reluctant growth of vegetable forms and with alien tribes of animals. These intentional changes and substitutions constitute indeed great revolutions…"* (Marsh, 1864).

These remarks may have influenced other environmental historians, such as Alfred Crosby and William Cronon, who also pointed out the unintended impacts of the botanical activities of naturalists and networks of institutions who transferred exotic plants across continents. New World plants would have not reached Africa without the actions of specific naturalists crisscrossing the Atlantic between the Eastern and Western Hemispheres. Humboldt's story, and water hyacinth's history, illustrate this point while providing an example of a discourse that we may call the "Botanical Atlantic".

Focusing on Humboldt as the principal carrier of Amazonian aquatic plants to African waterscapes illuminates the Botanical Atlantic connection across continents in the late 18th Century. Humboldt's discovery of water hyacinth in the Orinoco River of Venezuela's Amazon basin in 1800 falls within the narrative of a network of botanists and savants. Historians today will do well to not ignore these linkages between scientists and their influences on different corners of the globe.

[3] In the African worldview, nature speaks like humans! Indeed, there is a huge discourse on speech in animals, plants, and inorganic nature (see Margo DeMello, *Speaking for animals: Animal Autobiographical Writing* (New York: Routledge, 2012); Arien Mack, *Humans and Other Animals: Cross-Cultural Perspectives on Human-Animal Interactions* (Columbus: Ohio State university press, 1999).

[4] Poem of Dr. Okunzua quoted in J. O. Edewor, "Developing water hyacinth from menace status to national profitability level," In O. L. Oke, A.M.A. Irnevborc and T.A. Farri (Eds), Proceedings of the International Workshop on Water hyacinth," *FMST* (1988), l75-178; P. L. Bolorunduro, "Water Hyacinth Infestation: Nuisance or Nugget," *National Agricultural Extension Research and Liaison Services* (*NAERLS/ABt1)* Zaria, Kaduna State, Nigeria.

While we know much about the movement of peoples (associated with Humboldt) and ideas (associated with botanists, explorers, military officers, and others), water hyacinth easily moved across the Atlantic, from botanical collections to herb gardens to watercourses in Africa. Imperial networks of botanical and leisure gardens, fish hatcheries, experimental stations, museums, imperial armies and much else, served as the main vehicles through which hyacinth spread from Humboldt's collections to Africa.

The plant's introduction into Africa was part of the extraordinary movement of species between Africa, Europe and the Americas that accompanied the expansion of European political and economic systems in conquered territories over the last five centuries. The period of water hyacinth's transfer between South America and Africa, coincided with the rise and retreat of the "New European Imperialism"—a 19th Century movement in which seven European nations (Belgium, Britain, France, Germany, Italy, Portugal, and Spain) projected their political, economic, botanical, and cultural influence towards Africa and other large territories, such as India and Australia.

Water hyacinth's transformation during its long journey to Africa makes it an important part of the ecological dimension of imperialism and the Atlantic botanical connection of the Western and Eastern Hemispheres. However, the existence of multiple conduits of biological transfers speaks against a purely imperialist narrative of water hyacinth colonization of Africa's watercourses.

After the initial deliberate introduction, the species infiltrated African waterways through accidental and intentional human and non-human actions, some having nothing to do with empires. For instance, during the high floods in the 1950s, water hyacinth spilled over the Congo-Nile River divide into the Upper Nile. The resulting massive infestation of the White Nile within Sudan backed up the tributaries and eventually contaminated the Blue Nile in Ethiopia. These events had no direct connections with the previous human conquests and colonization events and European Empires (Kitunda, 2018).

The Dispersal of Water Hyacinth – Jefferson, Aiton, Delile, Napoleon, and Josephine

In 1804, when the United States President Thomas Jefferson (1746-1823) hosted Humboldt for six weeks on his voyage back to Europe, water hyacinth was not well known in the USA. Jefferson, an acute gardener, appear to have acquired water hyacinth from Humboldt and cultivated it in several places in the USA (Figure1).

Figure 1. Thomas Jefferson (left) and Alexander Von Humboldt (right)[5]

Living in revolutionary societies, both men were deeply concerned with the human condition, and each vested hope in the new American nation as a possible answer to many of the deficiencies characterizing European societies at the time. Subsequently, water hyacinth reached the Congo through missionaries (Patterson, 1983) and South Africa through travellers returning from the USA botanical exhibition fairs. Such historical facts indicate the connection between Jefferson, Humboldt and water hyacinth's spread far away from its original home in South America.

From July 9, 1804 to August 3, 1804, Humboldt sailed from Philadelphia to France with "forty-two-boxes containing an herbal of six thousand equinoctial plants and seeds from the rivers of the Amazon (Helferich, 2004) (see Map in Figure 2).

While more than 6000 botanical specimens went to the French *Muséum National d'Historire Naturelle*, a special collection went to the *Jardin des*

[5] For more details on the relationship between Jefferson and Humboldt, see Sandra Rebok's 2014 book: *Humboldt and Jefferson: A Transatlantic Friendship of the Enlightenment*. Charlottesville; London: University of Virginia Press, 220 pp. The book explores the warm relationship between two fascinating personalities in the wake of Humboldt's famous expedition through the Spanish colonies in the spring of 1804. The two men corresponded a good deal over the years, speculating together on topics of mutual interest, including natural history, geography, and the formation of an international scientific network.

Plantes (also known as *Jardin du Roi*—the King's Garden) in Paris. Whereas Aimé Bonpland, Carl Sigismund Kunth and Auguste de Saint-Hilaire worked the collections into several publications, the Court botanist Alire Raffeneau Delile (1778-1850), a long-time associate of Humboldt and a member of Napoleon's expedition to Egypt shipped water hyacinth to acclimatization stations in Africa (Stoddard, 1869; Gendron, 1961).

Figure 2. A Map showing Von Humboldt's expeditions (1799-1804) and possible routes of water hyacinth's travels (Source: By Alexrk translated by Cäsium137 (T.) </span, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=7249639).

Moreover, Aimé Bonpland impressed Empress Joséphine with a gift of flower-seeds from the Amazonian basin certainly including water hyacinth. Joséphine, an ambitious horticulturist, was delighted:

> *"…I am happy to see these foreign plants flourish and multiply. I wish Malmaison soon to offer a model of good cultivation and become a source of riches for the rest of France. It is with this in mind that I am having a very large quantity [from South America].*
>
> *"…I want each department within ten years to possess a collection of rare plants to have originated from my nurseries…"* (Bonaparte and Redouté, 1982).

Joséphine cultivated varieties of exotic plants in the greenhouses at Malmaison and later introduced them to France and French African dependencies between 1805 and 1810. She spent much time establishing extensive gardens of flowering plants, collecting and planting every kind of native and exotic flowering plant. Subsequently, following her example elite families established similar gardens at notable houses throughout Europe. Eventually these pursuits "trickled down to the masses" and gardening with exotic flowering plants became fashionable throughout Europe and colonial outposts in Africa

(Roebuck, 2007). The French court botanists classified most of Malmaison's garden plants with Joséphine's name.

The ten-volumes of *Jardin de la Malmaison* contains 502 plates of *Liliacées* and as proof of how important these plants were to the imperial class Napoleon bought eight copies as gifts for his guests. It is evident that the botanical passion of this French Empress supplemented the imperialist zest of her husband to bring water hyacinth to Africa.

Historical records also indicate that it was Alire Raffeneau Delile, a long-time associate of both Humboldt, Napoleon's family, and a member of Napoleon's expedition to Egypt, who pioneered modern Egyptian botany.

From 1799 and 1849, Delile maintained a botanical foothold in the Nile Delta in spite of the British overthrow of the French in Egypt. He also created the first French botanical gardens to cultivate and study floating plants on the Nile. More than 12,000 packets of seeds were shipped annually from Humboldt's Amazonian collections held in Joséphine's nurseries and the King's garden to the French botanical gardens in Egypt, Algeria, Tunisia, Morocco, West Africa, and the East African islands of Madagascar, the Seychelles, Mauritius, and Reunion (Duval, 1982).

Several developments made Delille the pivot of water hyacinth dispersal to Africa. He ascended to the position of the manager of the French Agricultural Garden at Cairo, the Director of the King's Garden, and professor of Botany at the University of Montpelier. Besides, in 1827, Humboldt himself settled at the Berlin Botanical Garden, giving Delile access to the garden. Delile thus could work closely with global botanical institutions that superintended transfer of Eichhornia to Africa.

In the 1850s, the spread of water hyacinth across the continents gained momentum with the rise of geographical exploration and acclimatization societies across Europe. Although Portugal, Spain and Holland had much earlier set the pace of plant acclimatization, it was the French (with greater imperial clout from Napoleon and Joséphine) who popularized the acclimatization movement across Europe and Africa.

The operations of French botanic gardens became the specialty of the *Société zoologique d'Acclimatation* which established branches in Africa (Gendron, 1961). The acclimatization program called on all Western countries to collaborate in populating European and colonial lands with new inhabitants as means of increasing productivity.

As a result, a succession of similar societies across Europe moved not just water hyacinth but hundreds of other plant species to Africa (Sonberg, 1990; Bright, 1999). In fact, it was through the British Acclimatisation Society that botanists in Egypt and South Africa were able to bring a variety of foreign plant species, perceived as beneficial, to these two important colonies (Anderson, 1992; Osborne, 1991 and 2000).

Receptions and Perceptions in the recent era

On May 6, 1859, Humboldt died leaving water hyacinth enjoying a high place among flowering plants in European royal gardens, private leisure pools and scientific institutions. The species was treasured as an indispensable, beautiful ornamental plant for European waterscapes and tropical pools.

As one of his contemporaries said, the introduction of a new plant in a country was more valuable than the discovery of a gold mine and more enduring than a pyramid. An appraisal of colonial botany of the 18th and 19th Centuries shows that water hyacinth has carried on and spread the legacy of Humboldt in Africa in its botanical complexity.

Among Africans the plant was well received as part of nature despite its immigrant status, just as European immigrant settlers were locally accommodated to blend and give birth to an African triple heritage of Asiatic, European, and African traditions (Mazrui, 1986)[6]. Nevertheless, between 1863 and 1889, two German scientists, Paul Friedrich Augus Ascherson and Georg Schweinfurth, reported that water hyacinth had run wild since the introductions by Delille (Ascherson and Schweinfurth, 1889).

Water hyacinth's innate capacity to be successful in a variety of environments was possibly not an important consideration in those early centuries when it was introduced across continents. However, as its aggressive growth and behaviour expanded, the species quickly became a concern and

[6] See also Mazrui, A. (1986). *The Africans [videorecording]: A Triple Heritage: A commentary* / by Ali A. Mazrui; a co-production of WETA-TV and BBC-TV; written and presented by Ali A. Mazrui; produced by Peter Bate. [Indianapolis, IN]: Annenberg Media, [1986]. 5 videodiscs (ca. 522 minutes): sd., col.; 4 3/4 in. Videodisc release of a 9-part television series originally broadcast in 1986. Mazrui, Ali Al'Amin, Screenwriter, Host, Narrator.

was perceived as a nuisance. Gopal (1987) argued that introduced 'exotic' plants are not necessarily undesirable unless they effectively compromise human interests.

In 1879, twenty years after the death of Humboldt, water hyacinth escaped from Egypt-based French and British botanical gardens, the Khedival gardens and plant acclimatization stations to become abundant everywhere in the Nile valley.

This was not only a turning point but also another remarkable moment in the history of water hyacinth which deserves explanation. The explosion of water hyacinth was aided by the 1870s floods, which struck Sudan and Egypt during an unsettled political climate owing to Anglo-French competition over control of the Nile valley (Muschler, 1970).

The transition of water hyacinth from a treasured ornamental plant to a "problematic aquatic weed" was a figurative convergence of its 'beauty-turned beast' character. The transition is linked with both political turmoil and natural catastrophes in the African continent. The narrative of a potentially aggressive species that can spread widely with or without the human agency had been written thus.

The lesson here is, after human introduction for botanical interests a strong colonizer species could escape from control due to external factors, such as a natural disaster or political turmoil in a country. The loss of ecological control and management could then lead to situations where the aggressive nature of the species may cause potential economic harm.

At the beginning, there was clearly a human aspect to this nexus of nature, turmoil, and spread of colonizing species. Hydrological changes, chemical-based farming, urbanization, and industrialization were key factors behind the transformation of introduced aquatic plants into problematic species.

As I have pointed out, in some cases, at least, such transformations were initiated during the era of colonial empires. During the 1870s, at least 80 years after Humboldt's introduction, water hyacinth was identified as an ecological pest for the first time outside its native range. Egypt assumed the reputation of being the first country where water hyacinth initially exhibited its capacity to be an aggressive colonizer.

The beauty Humboldt had seen in water hyacinth in April 1800 in the Orinoco River had made a remarkable transition within less than a century along the Nile River Basin, now seen not as an epitome of beauty but as a 'beast' that smothered other aquatic species and spelt doom for various human economic activities using waterways in part created by imperialism.

During the imperialist era channels were constructed for navigation and easy transportation of goods throughout Africa, and other occupying countries. These waterways provided a conducive way for aquatic species to spread. Africa's interconnected water bodies enabled water hyacinth to proliferate naturally and spread quickly, defying a purely imperialistic explanation of biological invasion.

It could be argued that water hyacinth overcame imperialism and charted its own course in Africa, and elsewhere because it is such a successful colonizing species.

From the second half of the 19th Century to the end of the Second World War, perceptions of water hyacinth remained capricious. However, in the second half of the 20th Century, water hyacinth became increasingly a subject of poetry and science. In the 1980s for instance, Evangeline Paterson's poem (1983), *Bringing Water Hyacinth to Africa,* captured water hyacinth's perceived impact on the African environment:

"…And who is to blame?
Some say a priest, Homesick of Florida
Some say a Belgian lady, all Africa
Or her backyard, set out
To prettify the Congo..."

"…And who's to say?
But pity whoever it was, who meant
No harm, and left, as monument
A thousand miles of curses and jammed
propellers (Patterson, 1983).

The poem illustrates four key points: firstly, water hyacinth's arrival and fecundity in colonizing African waterways; second, the plant's arrival via the agency of an American missionary or a female Belgium gardener; thirdly, the perception of the plant's beauty —to prettify the Congo and fourthly, that beauty can also be a problematic curse.

Once in the waterways of Africa, water hyacinth changed from an object of beauty into a species that caused obstruction of maritime activities and potentially, economic wellbeing. The mats clogged engines and propellers of commercial ships, transport and fishing vessels crippling local and regional economies and traffic. This was the refrain across the continent from the late 19th Century to the end of the Second World War.

The post-war era marked yet another intersection of the plants, political chaos, and natural disasters. Remarkable political changes, especially in the 1950s and 1960s, swept away European colonial empires as African nationalists took leadership of their countries. This regime changes forced many European botanists and horticulturalists to abandon their water hyacinth-infested pools. Nevertheless, African regimes also continued the legacy of colonial environmental changes in the continent's waterscape that constitutes what Marsh and Crosby have termed 'disturbed environments', conditions, which are conducive to water hyacinth proliferation (Chandrasena, 2020).

From the 1960s to 1990s, military coups across Africa diverted attention from surveillance over water hyacinth. Issues of water hyacinth infestations and general environmental care took a back-seat. In the process, water hyacinth's history and science of control and utilization were lost as the expatriates fled. Archives and libraries containing records on water hyacinth were destroyed or left to decay.

This lost memory, perhaps, helps explain anxieties of the late 1980s when water hyacinth appeared with renewed strength to shock the 1990s generations, which viewed it as an 'alien' species with the potential to destroy African watercourses and human life. Inaction and disagreements in this discourse gave water hyacinth the best opportunity to expand further before African politicians and environmentalists began to realize the menace the species portends if unmanaged and ignored.

While the ecological imperialism thesis sees all this as a negative outcome of the "colonization process", a deeper historical analysis would support the view that other factors contributed to consequences of plant introductions. The evidence is that there are strong linkages between political turmoil, stable societies and economies and water hyacinth proliferation. Each country involved in the "perceived water hyacinth crisis" has also clashed with multinational companies operating within their boundaries.

While governments and institutions struggled to find a way out of the problem, riparian communities, for example those around Lake Victoria, devised their own means of coping with the invasive plant. Eventually, through a largely 'trial and error' approach, they have turned an ecological disaster into an economic asset. Fishermen have learned to co-exist with the movements of water hyacinth. Where floating aquatic species oscillate between river banks and lakeshores, depending on wind and water current, fishermen and sailors have adjusted their waterborne activities to the wind patterns (Kitunda, 2018).

History demonstrates that water hyacinth can be adopted and turned into an economic opportunity rather than an ecological-cum-economic peril in African watercourses. What is more, the connection between water hyacinth and disease is not clear. Iqbal (2009) questioned the same issue in Bengal and provided evidence that there is no connection between water hyacinth and human ailments, as claimed by the media.

Lakeshore residents of Lake Victoria have taken advantage of water hyacinth in planning their fishing, navigation, and water use activities. Moreover, jobless women and handicapped people have also come together to form community-based organizations to harvest water hyacinth and turn it into compost, animal feed, and biogas production. Others used water hyacinth as raw materials for weaving, manufacturing paper and pulp, furniture and other products that have attracted tourists.

A new economy based on water hyacinth has since been in the making— one could say, thanks to Humboldt. Kitunda (2018) reviewed considerable literature on this matter (See also Onyango, J., and Ondeng, M. 2015 and Segbefia, A. et al. 2019b).

Conclusions

There are several important conclusions one can draw from this analysis and account. Most importantly, the presence of water hyacinth in African waterways serves as the yardstick with which to measure the depth and extent of Alexander von Humboldt's legacy of plant collection and influence across the globe.

Regardless of their nationality, all human agents and carriers of water hyacinth to Africa were in one way or another connected to Von Humboldt, his plant collections, and botanical gardens associated with him. Secondly, the narrative of water hyacinth illustrates the fact that although environmental problems in the current era are often perceived as sudden and new manifestations of human destructiveness, the processes of environmental change we see nowadays are generally deeply-rooted in the past.

The history of water hyacinth in African waterways, currently viewed as a novelty, is deeply imbedded in the century-old course of European imperialism and botanical activities in Africa (Beinart and Coates, 1995). They are relics of a colonial past.

Yet imperialism was not the only factor that converted a plant introduced for beauty to one that has entered into a conflict with humans.

As demonstrated, the plant was initially useful as an ornamental plant for private citizens, a military asset to imperial soldiers in the tropics, and an economic asset to botanists and fish hatcheries. In the second half of the 19th Century, its immense proliferation transformed it into an ecological and economic problem, as it has been perceived to tamper with the wellbeing of native species and to impede human activities.

No doubt, the species has indeed been a problem in many situations as the vast literature on water hyacinth shows (Gopal and Sharma, 1981; Gopal, 1987).[7] However, in my view, the way forward, as illustrated in the African case, is to use historical sources to understand the implications of and solutions to such problems.

The ideal future scenario would be to balance the negative effects with positive benefits of introduced species and develop ways by which human societies can utilize the abundance provided by such species. As Chandrasena (2014) pointed out, not all such aggressive colonizer species are bad all the time. Negative impacts of colonizer species depend very much on circumstances and situations.

The science on the relationship between water hyacinth and fisheries exhibits unresolved tensions. From the late 18th Century to the end of the 19th Century, water hyacinth was viewed as a fish breeding facility and certainly, not as the killer of fish. However, there is now a large volume of literature that condemns water hyacinth as a killer of fish (due to oxygen depletion and other effects) and an obstacle to fishing in lakes, rivers and artificial reservoirs. At least in some cases, the evidence for such claims is unproven.

According to oral and written sources from Lake Victoria, for example, the advent of water hyacinth brought back indigenous fish species that were driven to the brink of extinction following introduction into the lakes of the exotic Nile perch fish species during the colonial era (Ayodo, 2008). Fishermen explained (and marine biologists concurred) that the mats of water hyacinth, unfavourable to the predatory perch, provided greater shelter and breeding facilities for indigenous fish than any vegetation before (Kateregga and Sterner, 2009; Segbefia, et al. 2019a; d).

There is consensus that the plant slowed fishing and navigation activities, as Patterson (1983) points to in her poem, allowing targeted fish to recoup their populations during the grace period when the riparian nations were fighting over what to do with hyacinth and during which the plant colonized large lake portions. This reflects the power of nature's resilience in the face of human-induced environmental mishap.

Grand attempts to use water hyacinth as a source of industrial raw materials may constitute not only an ecological revolution in Africa, but also a revolution in the legacy of Humboldt's water hyacinth in Africa. They could transform perceptions and thus trigger a sort of gold-rush scenario to possess the plant as a vital industrial resource. This would shift the nature of the current controversy from what to do with water hyacinth to one over who should own and protect it from illegal exploitation (Bolorunduro, 2002; Hauser, Wernand, Korangteng, Simpeney, and Sumani, 2014).

These are not speculative postulations, but assumptions based on the history of other plants in Lake Victoria, which were eventually cleared out of the lake after local people adopted them as raw materials (Kitunda, 2018).

Giving prominence and adapting the utilization approach is one way of reclaiming the beauty of water hyacinth by using it to mitigate deforestation, save indigenous species and provide for local economies a sustainable resource for developing the riparian regions of waterways. In doing so, we will, in a muted way, release and redeem water hyacinth 'history from the ecological imperialist paradigm.

Comparing the acclimatization movement of the 19th Century which saw the introduction of species as acts of heroism, and contemporary conservationism that sees species introductions as

[7] Contemporary weed scientists, especially those interested in water hyacinth and other aquatic weeds, should be aware of the important works of the Indian biologist - Brij Gopal. His monographs, published in 1981 (co-authored with K. P. Sharma) and 1987, have remained inaccessible to many since publication. Gopal reviewed exhaustively the literature on water hyacinth and other introduced aquatic species from all parts of the world listing all the sources from news paper reports, articles, herbaria specimens to monographs, from which I have drawn heavily. My book (Kitunda, 2018) contains a comprehensive bibliography of water hyacinth, relevant to Africa, as well as the scientific literature related to the historical journey of *Eichhornia.*

detrimental to local ecosystems, we can appreciate the complexity of issues related to once favoured colonizing species and plant transfers.

Acknowledgements

I would like to thank my colleagues Professor Scott Jessee and Ralph Lentz for reading draft manuscripts of this article. I also thank Thomas McLamb for helping with the photographs and maps.

Above all I would like to thank Dr Nimal Chandrasena, Editor-in-Chief, for inviting me to write about water hyacinth from a historical perspective in a journal that is usually the preserve of weed scientists and readers in ecology and environmental science. Not the least I thank him for valuable insights on the history of water hyacinth's botanical naming and other aspects.

I also thank a second anonymous reviewer who offered helpful suggestions for improving the paper.

References

Adams, A. (1969). *Eternal Quest: The Story of the Great Naturalists*. G. P Putnam's Sons, New York. 509 Pp.

Altieri, M. et al. (2015). Crops, Weeds and pollinators. Understanding ecological interaction for better management. *Food and Agriculture Organization (FAO)*. pp. 106 (**http://www.fao.org/3/a-i3821e.pdf**).

Anderson, W. (1992). Climates of Opinion: Acclimatization in Nineteenth-Century France and England. *Victorian Studies*. 35 (2): 135-157.

Ayodo, H. (2008). Water hyacinth brings back long-lost fishes. *The Standard*, July 17.

Ascherson, P. and Schweinfurth, G. (1889). *Illustration de la Flore d'Egypte. Mémoires présentés à l'Institut Egyptien*. *L'Institut,* Le Caire. 643 pp.

Baker, H. (1965). Characteristics and modes of origin of weeds. In: H. G. Baker & G. L. Stebbins (Eds.), *The Genetics of Colonizing Species*. pp. 147–172, Academic Press, NY. 588 pp.

Beinart, W. and Coates, P. (1995). *Environment and History: Taming Nature in the USA and South Africa*. Routledge, NY.

120 pp.

Bolorunduro, P. (2002). Water hyacinth infestation: nuisance or nugget. In: Proceedings of the International Conference on Water Hyacinth, 27 Nov. - 01 Dec., 2000, New Bussa, Nigeria, pp. 111-121.

Bonaparte, J. and Redouté, P. (1982). *Roses for an Empress*. Translated by Anna Bennett. Sidgwick & Jackson, London.117 pp.

Bright, C. (1999). *Life Out of Bounds: Bioinvasion in a Borderless World*. W.W. Norton, NY. 294 pp.

Brizicky, G. (1958). The introduction of Centrolobium ochroxylum into Africa. *Brittonia* 10(July): 104-109.

Burdick, A. (2005). *Out of Eden: An Odyssey of Ecological Invasion*. Farrar, Strauss and Giroux., New York. 354 pp.

Chandrasena, N. (2014). Living with Weeds: A New Paradigm. *Indian Journal of Weed Science*, 46: 96-110.

Chandrasena, N. (2019). [Editorial]. Seeing 'Weeds' with new Eyes. *Weeds*, 1 (2): 1-12.

Chandrasena, N. (2020). 'Seeing Weeds with New Eyes' Part II—Some Historical Perspectives and 'Proto Weeds'. *Weeds*, 2 (1): 1-16.

Cronon, W. (2003). *Changes in the Land: Indians, Colonists, and the Ecology of New England*. Hill & Wang, New York. 284 pp.

Crosby, Alfred. (2004). *Ecological Imperialism: The Biological Expansion of Europe 900-1900*. Cambridge University Press, NY. 390 pp.

Crosby, Alfred. (2020). *The Columbian Exchange*. ABC-CLIO, LLC, Santa Barbara, CA. 320 pp.

Delile, A. R. (1824). *Flora de Egypte*. Imprimerie Impériale, Paris. 113 pp.

Delile, A. R. (1826). *Centurie de Plantes d'Afrique*. Imprimerie Impériale, Paris. 111 pp.

DeMello, M. (2012). *Speaking for animals: Animal Autobiographical Writing*. Routledge, New York. 288 pp.

Drayton, R. (2000). *Nature's Government: Science, Imperial Britain, and the "Improvement" of the World.* Yale University Press, New Haven. 354 pp.

Duval, M. (1982). *The King's Garden*. University of Virginia Press, Charlottesville. 214 pp.

du Toit, R. (1938). Water Hyacinth. *Borderij in Suid Afrika (Farming in South Africa)*. (13):16-17.

Edewor, J. (1988). Developing water hyacinth from menace status to national profitability level. In O. L. Oke, A.M.A. Irnevborc and T.A. Farri (eds.). Proceedings of the International Workshop on Water hyacinth. FMST, pp. l75-178.

Gendron, V. (1961). *The Dragon Tree: A life of Alexander, Baron von Humboldt*. Longmans, New York. 214 pp.

Gopal, B. and Sharma, K. (1981). *Water hyacinth (Eichhornia Crassipes), The Most Troublesome Weed of the World*. Hindasia, New Delhi. 227 pp.

Gopal, B. (1987). *Water Hyacinth*. Elsevier, Amsterdam. 471 pp.

Grove, R. (1995). *Green Imperialism: Colonial Expansion, Tropical Island Edens and the Origins of Environmentalism 1600-1860*. Cambridge University Press, New York. 560 pp.

Harper, J. (1960). *The Biology of Weeds*. Blackwell, Oxford. 256 pp.

Helferich, G. (2004). *Humboldt's Cosmos: Alexander Von Humboldt and the Latin American Journey that Changed the Way we see the World*. Penguins, New York. 358 pp.

Holm, L., Doll, J., Holm, E., Pancho, J., and Herberger, J. (1997). *World weeds: natural histories and distribution*. John Wiley, New York. 1152 pp.

Humboldt, A. (1793). *Florae fribergensis specimen, plantas cryptogamicas praesertim subterraneas exhibens*. H. A. Rottmann, Berolini. 190 pp.

Humboldt, A. (1960). Humboldt's Essai Sur la Géographie des Plantes. *Journal of the Society of the Bibliography of Natural History* (3): 351-57.

Humboldt, A. (1858). *Cosmos: A Sketch of a Physical Description of the Universe*. Translated by E. C. Otté and W. S. Dallas. Henry G. Bohn, York Street, Convent Garden, London. 424 pp.

Huxley, R. (2007). *The Great Naturalists*. Thames & Hudson, New York. 304 pp.

Igbal, I. (2009). Fighting with a Weed: Water Hyacinth and the State in Bengal, 1910-1947. *Environment and History*, 5 (1):35-59.

Kateregga, E. and T. Sterner. (2009). Lake Victoria fish stocks and the effects of water hyacinth. *The Journal of Environment and Development*, 18, 62-78.

Kitunda, J. (2018). *A History of the Water Hyacinth in Africa: The Flower of Life and Death from 1800 to the Present.* Lexington Books, Boulder. 337 pp.

Ludwig, E. (1937). *The Nile: The Life Story of a River.* London: Unwin. 640 pp.

Mack, A. (1999). *Humans and Other Animals: Cross-Cultural Perspectives on Human-Animal Interactions*. Ohio State university press, Columbus. 272 pp.

Marsh, G. P. (1864). *Man and Nature: Or Physical Geography as Modified by Human Action*. Sampson Low, London. 578 pp.

Mazrui, A. (1986). *The Africans: A Reader*. Praeger, New York. 336 pp.

Muschler, R. (1970). *A Manual Flora of Egypt*. R. Friedlaender & Sohn, Karlstrasse, Berlin. 1312 pp.

Obeid, M. (1975). Aquatic Weeds in the Sudan: With Special Reference to Water Hyacinth. Background for the problem in the Sudan. A paper prepared for 'The Workshop on Aquatic Weed Management and Utilization' organized by The National Council for Research, Sudan and National Academy of Science, U.S.A., 24-29 November 1975. Khartoum. 156 pp.

Hauser, L., Wernand, A., Korangteng, R., Simpeney, N., and Sumani, A. (2014). Water hyacinth in the Lower Volta Region: Turning aquatic weeds from problem to sustainable opportunity by fostering local entrepreneurship. Retrieved from **http://www.academia.edu/8766399/** December 25, 2020.

Onyango, J. P., & Ondeng, M. A. (2015). The contribution of the multiple usage of water hyacinth on the economic development of riparian communities in Dunga and Kichinjio of Kisumu Central Sub County, Kenya. *American Journal of Renewable and Sustainable Energy*, 1(3), 128–132.

Osborne, M. (1991). A collaborative dimension of the European empires. In Home, R. W. and Hohlstedt, S. G. (eds.). International Science and National Scientific Identity. *Australasian Studies in History and Philosophy of Science*. 9. pp. 87–119.

Osborne, M. (2000). Acclimatizing the World: A History of the Paradigmatic Colonial Science. *Osiris.* 15: 135–151*.*

Paterson, E. (1983). *Bringing the Hyacinth to Africa*. Taxus Press, Durham. 64 pp.

Roebuck, F. (1932). *Complete Roses: Featuring 100 Easy-Growing Features—A Foolproof Guide to Homeowners.* Creative Homeowner, Upper Saddle River. 176 pp.

Segbefia, A., Honlah, E., Appiah, D., and Mensah, M. (2019). Effects of water hyacinth invasion on sustainability of fishing livelihoods along the River Tano and Abby-Tano Lagoon, Ghana. *Cogent Food & Agriculture*, 5(1), 1-19.

Segbefia, A., Honlah, E., Appiah, D., and Mensah, M. (2019d). The utility of water hyacinth in communities along River Tano and Abby-Tano Lagoon, Ghana. *American Journal of Social Science Research*, 5(1), 1-9.

Honlah, E., Appiah, D., & Segbefia, A. (2019b). Coping strategies to water hyacinth invasion among riparian communities in Ghana. *American Journal of Environment and Sustainable Development*, 4(1), 12–25.

Simpson, N. (1932). *A Report on the Weed Flora of the Irrigation Channels in Egypt*. Ministry of Water Resources & Irrigation, Cairo. 124 pp.

Sonberg, S. (1990). *A Reunion of Trees*. Cambridge University Press, Cambridge. 270 pp.

Stearn, W. (1968). *Humboldt, Bonpland and Kunth: A Miscellany on the "Nova Genera et Species Plantarum".* Cramer, Lehre. 159 pp.

Stoddard, R. (1859). *The Life, Travels and Books of Alexander Von Humboldt*. Sampson Low, Sons and Company, 352 pp.

Thyagarajan, G. (1984). Proceedings of International Conference on Water Hyacinth. Hyderabad, India, February 7-11, 1983. *United Nations Environment Programme, 1984—Aquatic Weeds*. 1005 pp.

Vasiliy, T. et al. (2020). An Analysis of US State Regulated Weed Lists: A Discordance between Biology and Policy. *Bioscience*, 70 (9): 804–813.

Verdcourt, B. (1968). *Flora of Tropical East Africa-Pontederiaceae*: 2 (3). Crown Agents, London. 4 pp.

Addendum I – The Naming of Water Hyacinth and an Update

The historical nomenclature of water hyacinth, as well as the early descriptions of the species, have been somewhat confusing, from the time of 18th Century Swedish Carl Linnaeus to the days of the 19th Century German botanist - Hermann Zu Solms-Laubach. The historical information is available in the Biodiversity Heritage Library, BHL), which is freely available online (**https://www.biodiversitylibrary.org/**).

The genus *Pontederia*, within which water hyacinth is housed, was originally named by Linnaeus in his *Species Plantarum* (1753) (available at: **https://www.biodiversitylibrary.org/item/84235#page/5/mode/1up**; see p. 288). In 1801, two botanists— Olof Peter Swartz (1760-1818, Swedish) and Carl Ludwig Willdenow (1765-1812; German) in an update to Linnaeus' *Species Plantarum* used the name *Pontederia azurea* to describe Humboldt's collections at the Berlin Botanical Garden. Willdenow had been a mentor to Alexander Von Humboldt and examined many plants that the explorer had collected in South America and sent to Berlin.

In 1824, the German botanist and explorer- Carl Freidrich Philipp von Martius (1794-1868), who brought to Europe immense collections of water hyacinth and other Amazonian plants, described water hyacinth as *Pontederia crassipes* in *Nova Genera et Species Plantarum* (Volume 1: p. 9. Available at: **https://www.biodiversitylibrary.org/item/9619#page/13/mode/1up**).

In 1843, the German botanist – Carl Sigismund Kunth, split the Linnaean genus *Pontederia* and created *Eichhornia* (in honour of Friedrich Eichhorn, an iconic Prussian Minister of Education) to cover species with trilocular ovary and numerous ovules. He ignored the epithet '*crassipes*', which von Martius had given, and gave the species the name *Eichhornia speciosa* Kunth.

In the second half of the 19th Century, European botanists reached consensus that all species that had been described as *Pontederia azurea*, *Piaropus crassipes*, *Pontederia crassipes*, and so on, were in fact the same species. Ignoring numerous combinations that had been previously applied by different authors, in 1883, Zu Solms-Laubach (1842-1915) established the name *Eichhornia crassipes* (Mart.) Solms by which the species became universally known (Gopal, 1987).

The revision of genus and specific names of plants is a continuous process and water hyacinth's name has been the subject of many such revisions. Water hyacinth is also described on page 527-528 of Alphonse De Candolle and Casimir De Candolle (Eds.) *Monographiae Phanerogamarum*, Volume IV. Sumptibus G. Masson, Paris, (1878-1896) (**https://www.biodiversitylibrary.org/item/100881#page/528/mode/1up**).

According to the *Kew Science Plant Index*, the accepted and preferred botanical name now is *Pontederia crassipes* Mart. although the synonym *Eichhornia crassipes* (Mart.) Solms is also accepted. The species has also been known under various other synonyms (see Kew Science, *Plants of the World* (**http://www.plantsoftheworldonline.org/?f=%2Caccepted_names&q=Eichhornia%20crassipes**).

Recent genetic analyses and a 'total evidence phylogenetic study' have placed the species under the genus - *Pontederia* but under a sub-genus *Oshunae*. Sub-genus *Oshunae*, is monospecific, being composed solely by *Pontederia crassipes* [See: Pellegrini, M., Horn, C. and Almeida, R. (2018). The 'total evidence phylogeny' of Pontederiaceae (Commelinales) sheds light on the necessity of its re-circumscription and synopsis of *Pontederia* L. PhytoKeys 108: 25–83].