EDITORIAL

The Paradox of Weeds

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Abstract

Weeds do present a paradox for humans. On the one hand, they bother us by being aggressive habitat colonizers that can adversely affect agricultural production or interfere with human activities. As pioneering species, the presence of weeds is inevitable in environments disturbed by humans or other forces. Nevertheless, the sheer abundance of some weedy species makes them undesirable in human-disturbed environments. Some of the highly aggressive weeds cost substantial money and effort to manage. The simple habitat occupation and 'colonization' of available 'ecological niches' by these highly successful plants gets them into trouble in the minds of some, who prefer to attribute other meanings, such as 'invasions' to these "alien and foreign" species.

A dip into history shows that, like humans, colonizing taxa are good at what they are genetically predisposed to do, i.e., adapt and survive even in the most stressful environments, with or without the presence of human-caused disturbances and areas where our crops would not do well. A balanced look at weedy species – '*Seeing Weeds With New Eyes*' – would show that many of these species can be put to incredibly beneficial societal uses. The adaptive characteristics that make many species so successful are well understood within the corpus of Weed Science, yet they are much undervalued.

I contend that many species undisputedly possess the strengths and attributes that humans desperately need in an uncertain future. To exploit the benefits of weedy species, we need to change our deeply entrenched negative perceptions about weeds and modify how we interact with other successful species. *Weeds are no more 'alien' than we are. They are also no more 'invasive' than we are*. As one historian (Alfred Crosby, 1986) noted, these species may even help heal the wounds on the earth, torn apart by the real 'invaders' – those '*wretched ingrates*' (humans).

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The Paradox of Weeds

The adverse environmental, social, and economic effects of the excessive growth of some colonizing taxa cannot be doubted (Muencher, 1935; Harper, 1960; Salisbury, 1961; Radosevich and Holt, 1984; Altieri and Liebman, 1988; Zimdahl, 1999; 2010; Leibman et al., 2001). Evidence of harmful effects comes from both within and outside agriculture and has been known since William Darlington first wrote about them in the mid-1800s. Darlington (1847; 1859) was the first to stress the relationship between human and plant immigrants: "*wherever humans go, some plants follow them like their shadows"*.

His views reflected the reflects the violent time he lived, just before the *American Civil War* (1860-65), when life was tough, and agriculture was '*a constant struggle*' and not an easy task.

> *"…Weeds are unwelcome intruders with no value; they also persist in growing where they are not wanted. As the aborigines disappeared with the advance of the whites, so do the native plants generally yield their possessions as cultivation extends, and the majority of the plants to be met along the lanes and streets of villages, and upon farms, are naturalized strangers, who appear to be quite at home, and are with difficulty to be persuaded or driven away…"*

Unfortunately, it was William Darlington who also started the use of war imagery in dealing with weeds (Chandrasena, 2023). Man has been waging a '*War With Weeds*' (Evans, 2002; Chew, 2006; Falck, 2010; Dwyer, 2011), which continues unabated now for several centuries without an end in sight!

The war metaphor believes *humans could win a war against weedy enemies*. The slogan has now become a *mantra* for many weed scientists, public officials, and enthusiastic volunteers, all wanting to wage a war on weeds! It is wrong to believe that we may win this war against weeds because we have in our possession the arsenal of herbicides and sophisticated machinery. The invasion story of weeds engulfing the world is also a myth (Hall, 2003; Chew, 2006; Guiaşu and Tindale, 2018).

However, as discussed in the large corpus of *Weed Science* literature, in most cases, the undesirable effects of weed abundance depend on *situations* (such as the *scale* of infestations, its *location* in the vegetation community) and the species with which one is dealing. If infestations are large and persistent, the effects of colonizing taxa can be quite disruptive and costly to manage (Harlan and De Wet, 1965; King, 1966; Zimdahl, 2010).

Some weeds are truly bothersome, especially in agriculture. Globally, the crop yield losses due to weeds are in the ballpark of 15-40%, but could be much higher if the farmers neglect their fields. Weeds cause losses in grain quality if the weed seeds contaminate the harvest. Another loss occurs if the dairy cows grazing on some weeds taint the milk they provide. Add to those the injuries caused to animals by thorny weeds, such as blackberry (*Rubus fruiticosus* L.) thickets of briar rose (*Rosa rubiginosa* L.), and aquatic weeds, such as hydrilla [*Hydrilla verticillata* (L.f.) Royle] and ribbonweed (*Vallisneria americana* Michx.) clogging up boat propellers. In other instances, dense mats of water hyacinth (*Pontederia crassipes* Mart.) or salvinia (*Salvinia molesta* D. S. Mitchell) could choke rivers and navigation canals. Some weeds also act as hosts for parasitic insects or plant diseases, while others cause harm by being parasitic on crops.

Through these direct or indirect effects, weeds increase the cost of farming and decrease the value of the land. In some situations, they may even threaten the existence of some slow-growing native plants in bushlands. Although the evidence of weeds causing irreversible and large-scale biodiversity losses is scanty, yes, they do cause real problems.

The scale of negative effects from weeds strictly depends on <u>time</u> and <u>space</u>, influencing both agricultural systems and natural ecosystems. The timing of weed emergence relative to a crop is paramount. Weeds that emerge alongside or slightly before crops during the ***critical period for weed control*** cause the most severe yield penalties through early resource capture and depletion and potential other effects, such as the release of allelochemicals (Zimdahl, 1999).

The "*critical period for weed control" defines the period when weeds present from the beginning of the crop cycle must be removed or the point after which weed growth no long affects crop yield. It is usually the early weeks of crop growth, roughly the first third of a crop's life cycle"* (Zimdahl, 1980, p. 91).

Life cycle characteristics, such as the seasonal emergence and reproductive timing of weeds, dictate their persistence in any disturbed system, such as a cropping field, a roadside or a backyard. For example, annual weeds rapidly produce and disperse seeds, which remain in the soil (seed bank), ensuring emergence and growth in future growing seasons. Weeds are also more capable than other slow-growing species in responding to temporal changes in the environment, such as elevated CO_2 levels or changes in rainfall and temperature patterns, by altering their growth responses, reproductive output, and seed dormancy. In so doing, weedy species have abundantly demonstrated how they can increase their resistance to herbicides and other control methods.

The spatial dimension of weed impacts arises because weeds are rarely distributed uniformly; they typically cluster in patches where local conditions (e.g., moisture, soil compaction and nutrients) are highly favourable for plant growth. As *pioneers of secondary succession*, weeds are also better adapted to grow in disturbed habitat and occupy vacant spaces much faster compared with other species (Harper, 1960; Baker, 1965; Bunting, 1965).

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The global figures from herbicide sales reflect our dislike for weeds and desire for profit. In 2005, the global herbicide market was US $15.39 billion. This figure rose to US $17 billion in 2016. By 2020, the market, dominated by glyphosate, was about US $31 billion, growing at a rate of 5.4% per year from 2014 to 2020. Much of this growth was not just in the dominant US market; it was international.

This market was predicted to grow at about 6% per year, from 2017 to 2025, to be worth around US $29 billion by 2025, with most of the herbicides likely to be used in agriculture, followed by forestry and waterways. However, the global herbicide market grew more than predicted and was valued at US$ 32.2 Bn in 2023. It is now expected to grow at a Compound Annual Growth Rate (CAGR) of 6.3% from 2024 to 2034. The market is likely to reach US$ 63.0 Bn (a doubling!) by the end of 2034 (Transparency, 2026).

The use of vast amounts of herbicides is incompatible with the UN's *Millennium Development Goals* (UN, 2026), which expect to make drastic adjustments in the way terrestrial and aquatic ecosystems are managed for a sustainable future. Instead of over-reliance on chemicals, better management and protection of biodiversity and ecosystems are expected in future scenarios [1].

Despite such incredibly high amounts of money spent on killing weeds, the case against weeds – *that they are harmful elements in our environment* - is not proven. Weeds have many redeeming values. Ecologically, weeds serve as a tool to understand how plant populations interact with each other and how plant communities stabilize through co-existence (Harper, 1958; 1960; 1977; Baker, 1965). Weeds also shine a spotlight on the mistakes humans regularly make in managing land, water, plants, animals, and other natural resources, causing continuous habitat disturbances (Harlan and De Wet, 1965)

From various viewpoints, people find weeds hard to live with because it is quite a challenge to manage some species. But, when the evidence is assessed, while most farmers consider weeds to be *timeless and unforgiving enemies* of agriculture, people may agree that: *Not all weeds are bad all the time, and certainly not under all circumstances*!

Humans – Not Weeds - Are the Primary Cause of Biodiversity Losses

Most weeds are *unremarkable* in many ways; they are ubiquitous, always present in the background of human-modified spaces, and they become problems only under certain conditions. Although the negative effects of weeds may creep up on you, they are not as dramatic as those brought about by disease or plague, caused by a pathogen or pest organism. While the adverse effects are readily visible, weeds present us with a paradox because they serve so many important functions within the same disturbed ecosystems. As photosynthetic organisms, pioneer species are a part of Nature's rich biodiversity. These taxa are critical biological resources. All that weeds are doing is taking the opportunity, when presented, to grow, survive, succeed, and reproduce (Harper, 1960; Baker, 1965; Bunting, 1965).

In 1859, Darwin called this a '*Struggle for Existence*' in Chapter 3 of his *'On the Origin of Species'*. Darwin stressed the vital role of competition among organisms as the driving force of natural selection and biological evolution. Colonizing taxa will often win in these 'struggles' with other species because they are better adapted by millions of years of evolution to do so. In so doing, they are perpetually engaged in the biological conservation of their own identity and kind. As Darwin (1859) explained, "*in biological evolution, that is precisely what all successful organisms are supposed to do"*.

The species disparaged as *'damned weeds'* were here on earth before us, and they will be here well after us. They are simply an essential part of the earth's rich biological diversity, just as much as we humans are! The future of humankind will depend on how well we manage our relationships with the environment, especially with all plants, which are our primary food producers.

Blaming weeds for biodiversity losses is a myth spread mainly by the media, vested interests and non-science commentators. Some concerns may be genuine, but often, the link between weeds and biodiversity losses is unsubstantiated. In some instances, the exaggeration of issues about a specific weed or a group of weeds, causing problems at a specific site, helps win funding. Sometimes, public servants may also overstate weed issues because it makes them look good in the public eye. At the extreme, some media outlets say that weeds are *engulfing our world*, in much the same way as weeds were depicted in the USA, 80-90 years ago.

In my view, the aggressive and persistent growth of colonizing taxa may be one contributory factor causing biodiversity losses at a specific location or ecosystem. In some rare cases, such as a particular ecosystem (a bushland remnant, a wetland, or a grassland), the dominant colonizers may appear to displace some other plant species. But mostly, such changes are transient. It is rare to find extreme cases where other plant or animal species may disappear from that local ecosystem for perpetuity because of a weed infestation.

Weeds are no match for humans when it comes to being the primary cause of damage to natural ecosystems. Human activities - vegetation clearing, unsustainable farming and other land-degrading activities diminish biodiversity by removing critical habitat elements for both plants and animals.

In the Asian-Pacific region, land clearing is alarmingly high, as in Australia. This is especially true for Indonesia, Malaysia, Myanmar, Thailand and Vietnam. Countries like Cambodia and Laos have hardly any old-growth forests left. Only a few years ago, the world watched in horror the destruction caused by fires in the vast Amazonian biomes – the world's largest rainforests (Gibbens, 2019). Recent research shows that the South-East Amazonian region is no longer a carbon sink (Amigo, 2020; Denning, 2021). Such non-natural disturbances entirely destroy the habitat structure, composition and ecological processes within those biomes (**Figure 1**).

[1] The United Nations. *Millennial Development Goal* 15 of the 2030 *Agenda for Sustainable Development* is devoted to: "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss".

Many animal and plant species are sensitive to the speed at which large-scale vegetation clearing occurs because there is no time for them to adapt to the changes, in most cases. They also may not have time to emigrate from the affected areas, even if they find other reasonably suitable habitats.

Figure 1. Destruction of the Amazonian forests. A photograph from 2019 (Phillips and Camargos, 2020; *The Guardian*, 5 May 2020)

The destruction of the Amazon rainforests in South America and those in Borneo and Sumatra in the Asian-Pacific region (Butler, 2014; Gaveau et al., 2018) must rank among the most incredible habitat devastations humans have caused (**Figure 2**). These vast tropical rainforests are the planet's 'lungs'. Their destruction is likely to have global repercussions, causing an imbalance in Nature from which the planet may not easily recover. Uncontrolled population growth, greed and indifference towards Nature are the primary reasons for this unfolding catastrophe, which appears unstoppable (Laurance et al., 2020). Among those who would suffer most are subsistence farmers and indigenous communities, whose existence is unlikely to have devastating, irrecoverable effects on the environment.

Satellite studies indicate that intact lowland forests in Borneo have declined drastically, with around 19.5 million hectares of old-growth forest destroyed between 1973 and 2016 (ca. 50 years). The justification for vast-scale deforestation and conversion of land to quick profit-making ventures, such as palm oil plantations, is the myth that it can deliver rapid economic development in developing countries (Uryu et al., 2008; IUCN, 2018).

Another prevailing myth is that, at a future unknown date, the devastated land brought under agriculture will somehow recover and restore itself into some stable ecosystems. Ecology and plant succession, in particular, teach us that this would take a very long time. Once large areas of previously forested lands have been brought under monoculture farming, the disturbances are likely to be long-lasting, most likely for several centuries. In such situations, biodiversity losses and disturbance of animal-plant interactions are inevitable, with potential losses of habitat for iconic species.

Long after the current generation has passed, the planet will suffer because of this wilful destruction for human greed and wants. Many animals and humans, especially indigenous groups, will pay the ultimate price – death by starvation, diseases and lack of shelter. Land-grab in these biomes, under the guise of development, is possibly a crime against humanity. The future of some of our most iconic species (such as the critically endangered orangutan, *Pongo abelii* and the Borneo pygmy elephant, *Elephas maximus borneensis*) is dire, unless these countries wake up and change their attitudes. Even promoting the values of natural ecosystems and demanding the protection of the great tropical forests in these regions and iconic species is beset with difficulties. All of this happens while weeds are being blamed for biodiversity losses!

Figure 2. Destruction of Rainforests in Borneo for Oil Palm plantations. [About 30% of tropical rainforests have been destroyed within the past 20 years (Butler et al., 2014)].

Losses of vast areas of mature trees lead to the homogenization of forests in their composition and structure. Simplifying the vegetation displaces animals and plants, which then have to move to different areas and re-establish new relationships. Weeds do not cause such harm; indeed, not at the scale and magnitude that some people claim.

Some countries in the Asian-Pacific, for example, Indonesia and Malaysia, will pay a heavy price in the future for this narrow focus at the expense of Nature. Unfortunately, the repercussions will be felt far and wide and are for the whole world. Some of the most destructive activities on the planet's 'lungs' (tropical rainforests) are currently felt in the islands of Borneo and Sumatra. The devastation left behind by abandoned oil-palm plantations in previously thickly forested areas would take several centuries to recover. In the meantime, some robust colonizing taxa, including most certainly perennial grasses (such as cogongrass), will move into the damaged landscapes. Both human and animal populations will suffer from such devastation.

It is also possible that under a rapidly changing global climate, other disasters (such as floods, cyclones and volcanic eruptions) would disrupt human activities and may even drive human populations away from the destruction that such disasters are likely to cause in heavily populated regions. If human interferences wane, the resilient pioneering and colonizing taxa will still be the *flag-bearers* who would lead the natural regeneration and restoration processes in badly deforested or devastated areas abandoned by humans.

Furthermore, if and when our planet has to deal with catastrophes, such as nuclear plants breaking down (such as Chernobyl in Ukraine and Fukushima in Japan) and their dire consequences, weeds will help us. Following any atomic fallout, colonizer taxa will undoubtedly be the '*Ecological Red Cross*', arriving as first responders to start the process of decontamination of affected areas before anyone else. In this regard, I agree with what Alfred Crosby said in his landmark book, *Ecological Imperialism*, 1986: "*Weeds are the Red Cross of the plant world; they deal with ecological emergencies. When the emergencies are over, they give way to plants that may grow more slowly but grow taller and sturdier*"

The widespread introduction of tree species (primarily for shade and fodder), leguminous cover crops, and pasture grasses, across continents, for pasture improvement and other benefits, often leads to those species becoming entrenched in new environments. The initial addition of fertilizers to promote plant growth expedites their establishment. Landscape transformations then inevitably follow.

The introduced species would be free, at least initially, of the natural enemies it had in its native range. They may also be free of other obstacles (such as a variable climate) in their new landscapes. Such favourable changes of circumstances play a role in 'disturbed' environments in which newly-arrived species with 'weedy' characteristics will thrive (Baker, 1965). While growing faster and more profusely, they may displace slow-growing native species at least for some time. Opportunistically capturing habitat, the newcomers often change the original composition and structure of the vegetation, altering the habitat even for the fauna, which may have been adapted to and associated with the previous vegetation.

All such plant species, introduced and exploited for benefits, get branded as undesirable 'invaders' of the habitat when they get established. Some of the most talked-about examples in Australia are the nitrogen-fixing legumes - prickly acacia [*Vachellia nilotica* (L.) P. J. H. Hurter & Mabb.], parkinsonia (*Parkinsonia aculeata* L.) and leucaena [*Leucaena leucocephala* (Lam.) de Wit]. Others like mesquite [*Neltuma juliflora* (Sw.) Raf.; syn. *Prosopsis juliflora* (Sw.) DC] and neem (*Azadirachta indica* A. Juss.) are also in the same category. It took only about 70 years, since the introduction of these species, for the Australian landscape managers and farmers to start blaming them for decreases in agricultural productivity and associated landscape issues.

Such species have incredible biodiversity values for the environment and bio-resource values for human societies. The farmers know that well. To blame the introduced species with 'weedy' characteristics for harming the environment is unfair. With extraordinary colonizing power, they grew well in hot and harsh environments and also added much-needed organic matter to the soil, transforming the Australian landscapes, which were otherwise unproductive. For the animals, the species provided fodder, as well as shade from the heat in arid and drought-prone parts of Australia, allowing livestock farming to expand.

Continuing to blame introduced species for land degradation, especially in NSW and Queensland, the Australian States that have such appalling records for land clearing, is dishonest. Blaming colonizing taxa for causing land degradation is common in Australia. Farmers, politicians, and even a few scientists form a united front in this regard. Much taxpayer funds are then wasted in poorly coordinated attempts to subdue these highly resourceful species through costly control programmes. So much for their much-admired beneficial values! Individually, in most situations, these species are still precious, providing the previously mentioned range of services to humans and animals. Once introduced into a new environment, they also know how to spread, conserve their gene pools and escape human folly.

Australians have indeed learned some bitter lessons about landscape-related environmental issues. Much of this vast continental landmass receives less than 500 mm of annual rainfall, and many areas are arid. Excessive grazing by large armies of livestock is a primary factor in many problems in such areas. The unfortunate animals often roam around in arid lands, looking for water and food, decimating grasslands and compacting the soil.

The destruction of the understorey vegetation and its protection leads to massive erosion and losses of soil through rainfall runoff. The resultant adverse effects, including nutrient enrichment in waterways and microbial contamination of water supplies, are all directly related to excessive pastoralism in Australia. Populations of introduced animals, such as rabbits, foxes, hares, horses, goats, and camels, and a host of native herbivores (kangaroos), also add foraging pressure across vast Australian landscapes. When the populations of such animals are excessively high, their foraging will reduce the quality of bushlands and grasslands, along with biological diversity. Surely, colonizing plant species cannot be solely blamed for such transformations. Ecologically, the introduced species are most likely the 'saviours' in those landscapes. With their extraordinary resilience, they would hold food webs together where conditions are tough for many native species and nothing else could grow, survive and perpetuate.

The Emergence of Weed Science

For more than 40 years, at many weed conferences, I have listened to what people say about weeds without hearing much discussion about their positive ecological roles. Regrettably, deep ecological discussions do not fit the agendas of weed conferences. When the focus is so much on 'Weed Control', papers that espouse any virtues of weeds are scarce. *More than 95% of all papers on weeds in the vast corpus of Weed Science publications take it for granted that they are bad news all the time*.

The historical mandate of professional weed societies in the world and their journals continues to be the development of tools to manage weeds effectively and economically. This justifiable focus, however, dissuades research that espouses any values of weeds to be undertaken or articles to be published in those journals. Time will tell whether public opinion will force a change for all organizations and agencies to consider the value of pursuing the utilization of colonizing taxa as biological resources.

During the 1920s and '30s, agriculturists spent a great deal of time improving cultural weed control practices. This was the real beginning of modern *Weed Science*. The discipline expanded after discovering the auxin herbicide 2,4-D in 1944. In those early days, it was all about cost-effectively managing weeds rather than understanding the biology and ecology of weeds.

The need to '*know*' weeds better before hitting them with herbicides was so important that John Harper, an Oxfordian Plant Ecologist, organized a special symposium on *The Biology of Weeds* in 1959. Under the auspices of the *British Ecological Society*, it was held at Oxford from 2 to 4 April. Introducing the symposium publication, Harper (1960) wrote that for many years, weeds were regarded as inappropriate material for biological studies, except for those *causally* related to weed control. Part of the problem with why weeds were '*untouchables*' among plants was the idea that the '*pure*' botanist must be concerned only with *natural* vegetation. and these '*camp followers of cultivation'* were the domain of Applied Botanists. The nature of 'weeds' in Britain was well understood by this time (Godwin, 1960), which gave impetus to the emergence of the scientific discipline. Some ecologists at the Symposium called them just 'harmless vagabonds'!

The 1959 symposium at Oxford encouraged weed researchers to focus on the taxonomy, biology, ecology and population dynamics of weeds, including their reproductive systems, origins and evolution. It impressed the scientific community to study weed species from an individual perspective (*Autecology*), populations, and as part of plant communities (*Synecology*) [2]. Emphasizing the environmental harm resulting from the excessive use of herbicides, Harper steered the direction of weed research at this crucial meeting. The scientific community listened because of the esteem with which he was held. He convinced the scientific community that *Weed Science* should not be only about weed control, but should focus on understanding individual weeds, their life cycle strategies, and how weeds interact with other species in natural and man-made ecosystems. Three years earlier, Harper (1956) had prophetically warned of the likelihood of herbicide resistance in weeds.

A decade after 2,4-D was commercialized, Harper (1956; 1958) warned that herbicide use was so widespread that it "*ran the risk of hijacking an emerging science*". He also wrote that "*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 herbicides*".

History will record this 1959 *Oxford Symposium* as the first attempt to dissociate *Weed Science* from herbicide-dominated weed control thinking that began initially in the U.K. but spread much more widely in the USA in the 1950s. By promoting ecology, the symposium paved the way for the *Weed Science* discipline to develop as a multi-disciplinary science, with a firm focus on biological and ecological attributes that make species 'weedy'.

'Weedy' species were understood to be nothing but those possessing characteristics of 'pioneers' or 'colonizers' (Bunting, 1960; Baker, 1965; Harlan and De Wet, 1965). Beginning from this point, over seven decades, the discipline has learnt a great deal about specific, adverse effects of weeds in most cropping systems. However, away from agricultural fields, knowledge of the ecological effects of colonizing taxa over long periods remains limited. As a result, many claims against particular species as causing biodiversity losses are unsubstantiated.

[2] *Autecology* is the study of how a species population interacts with the environment and its resulting dynamics. In contrast, *Synecology* refers to the study of groups of organisms (populations of one species, or communities, comprising species mixtures) within their environment.

Weeds Get a Bad Name

Weeds got a seriously bad name, i.e. *Invasive Alien Species* (IAS) after the emergence of *Invasion Biology* only 30 years ago. A search of literature will show that this dubious term was appropriated and popularized firstly by Edward Salisbury's 1961 book titled: *Weeds and Aliens*. However, the term was not used in the 1959 '*Biology of Weeds'* Oxford Symposium (Harper, 1960), which was a founding event in the emergence of Weed Science.

As discussed previously (Chandrasena, 2020; 2021), the term '*Alien*' was avoided in the proceedings of an even more influential and important symposium in Weed Science, held in the USA in 1965. This was the *First International Union of Biological Sciences Symposium on General Biology*, held in Asilomar, California (12-16 February 1964). The proceedings, '*Genetics of Colonizing Species'*, edited by George Baker and Ledyard Stebbins (1965), published in 1965, are one of the most widely read books in ecology and genetics (Barrett, 2001).

As Chandrasena and Rao (2017) pointed out, published proceedings of numerous global weed conferences, held over four decades (from the 1960s to 1990s, including the papers presented at the *Asian-Pacific Weed Science Society* (launched in 1967) Conferences, also do not contain the term, *Alien*. This means that until *Invasion Biology* really turned the tables and opinions about weeds, they were dealt with more sensibly as a part of a constraint in agriculture and other human-disturbed situations.

However, the term that Salisbury (1961) used was resurrected in the 1990s (Binggeli, 1994). Incorporating the notion that '*Alien*' species threaten biodiversity in the *UN Convention of Biodiversity* (CBD, 1992) gave authority to this claim despite the shaky evidence. The CBD was drawn up in 1992 at the UN's famous *Earth Summit*, under *Agenda 21 for Sustainable Development*. The idea was to increase the awareness of problems species introductions cause in different countries and consider the risks of spread and costs for their management [3].

The CBD, which entered into force in December 1993, is an important international treaty for biodiversity conservation. Sustainable use of biological and genetic resources and equitable sharing of the benefits derived from them are key components. The number of signatories has increased to about 196 countries, which means the Convention has near-universal participation.

Any reading of the CBD (1992) will show that it sought to address the threats to biodiversity and ecosystem services, particularly from human activities and climate change. It aimed to manage such adverse impacts felt across the globe through a broad framework that combined scientific assessments, incentives and the transfer of technologies. It also sought the active involvement of all stakeholders in the signatory countries in managing human-caused problems, including species introductions across continents. *Unfortunately, in all of the above noble intentions, colonizing taxa got blamed as Aliens!*

The Virtuous Weeds

Over the past 70 years, during which *Weed Science* took shape, ideas about *virtuous weeds* have been hard to sell. Nevertheless, there are also some farmers who truly believe that a good case can be made for defending colonizing taxa against modern-day human armies and their weapons. Blaming weeds as the reason why we cannot increase food production or manage our land better is an easy road to travel for many. It is also a good way to sell a Weed Conference! Our region, the Asian-Pacific, must also carry some blame. Despite the efforts of a few, the APWSS Conference also tend to be focused on easy solutions to weedy problems in their various manifestations (Chandrasena and Rao, 2017).

In-depth discussions on the paradox weeds present and examining how people can benefit from weeds are much-neglected aspects within *Weed Science*. Reviewing the information on the subject will help redress this inadequacy, as has been done in the case of biodiversity values of harmless species (Storkey, 2006; Storkey and Westbury, 2007; Storkey and Neve, 2018). Only about 10 years ago, the strong linkages between bees, weeds and pollination were highlighted in an FAO-sponsored major review (Altieri et al., 2015) and other research (Potts et al., 2016), which I reviewed for this journal (Chandrasena, 2022).

Such research and messages may counteract the overwhelming negative publicity on weeds and, more importantly, stimulate people to think differently and develop a healthy relationship with all plants and animals. Perhaps, some people may at least avoid treating Nature as something that can be exploited endlessly to benefit just one greedy species, while pushing the planet towards peril.

Despite conflicts and violence in the past millennia, ancient civilizations instinctively knew that human well-being depended on '*wild plants*'. There are many examples of '*extant*' and mature cultures, including First Nations people in the Americas and Australia, which value weeds as biological resources (Ens et al.,

[3] The *Earth Summit* (Rio Conference) was held in Rio de Janeiro, Brazil, 3-14 June 1992. The Conference gave rise to the United Nations *Convention of Biological Diversity*, 1992. The text is available at: **https://www.cbd.int/convention/text/**.

2017). *Weeds are not insulted in such societies, certainly not with the contempt as in modern Australia and many other affluent countries.*

Broadly, ancient civilizations continue to be '*gatekeepers of ecological knowledge*'. preserving traditional knowledge that allowed human societies to thrive within local ecosystems without destroying resources. The ecological knowledge they passed through generations was essential for their survival. Plant foods supplemented their meat diet. Many weeds served as medicines, and innumerable other practical purposes, including rituals. The economic rationalist approach, with an unrelenting emphasis on '*markets*', putting a dollar value on everything, hardly works in Nature. Over the past 100 or so years, there is clear evidence that measuring everything by market value has impeded our appreciation of the values and virtues of weedy species, as well as Nature.

Historical records indicate that people of ancient cultures, from the Old World (Europe, Africa, Asia and Australia) to the New World (The Americas), had healthy relationships with plants. All plant and animal species were universally valued by ancient societies, even during major conflicts over the past 5000 years. Many of today's weeds feature strongly in the records of ancient Greek and Roman scholars, such as Theophrastus (371–287 BC), Pliny the Elder (23-79 AD) (Siegfried, 2023), and others.

Buddhism, a much-revered religion and a moral code for a good life, taught by *Lord Buddha* 2600 years ago, recognized the values of all life forms. *Respect for plants is a constant theme in Buddhism*. Buddhism, in its oldest traditions and in newer interpretations, influences a vast region of Asia and its population. Along with Buddhism, the moral code of *Confucianism* also influences China and East Asia. In these much-respected and ancient philosophies, *all living things are valued and appreciated, not just for their innate qualities and practical reasons, but also from rational, moral, and ethical viewpoints*.

There are also many success stories relating to utilizing weeds as bio-resources to benefit societies. The examples of utilization of weeds in various cultures come from numerous cultures (Chandrasena, 2007; 2023b). Both *Ayurveda*, the traditional medicine system in India and Sri Lanka, and the *Chinese Traditional Medicine* system, use a large array of medicinal herbs, which are weeds. Herbaceous, edible weeds have also been a part of the African and Asian diets for millennia. Raw materials from colonizing taxa are utilized in many developing countries across the globe for a multitude of small-scale cottage industries, including paper and pulp, weaving, dye, oil and resin extraction, etc. (Chandrasena, 2023b).

Beginnings of efforts to promote Weed Utilization

The human adversaries of weeds are very good at blaming others for their follies. The winds of change are blowing, albeit slowly. Scientists seriously considered the prospects of utilizing colonizing aquatic weeds as far back as the early 1960s. In those days, aquatic weeds were widely regarded as a "*constraint to human development*".

Aquatic weeds interfered with local economies, prevented waterways from being used for navigation and fisheries and were mosquito breeding grounds. They also polluted drinking water supplies (Pirie, 1960; Mitchell, 1974; Pieterse and Murphy, 1990).

By the mid-1970s, excited by the utilization potential of water hyacinth and other aquatic weeds, the *US National Academy of Sciences* (1977) assigned a panel of experts to come up with ideas on how to integrate 'control' (or management) of water hyacinth and other problematic aquatic species with 'utilization'. The panel concluded that the conversion of the aquatic weed biomasses for feed, food, fertilizer, and energy would greatly benefit the economies of developing countries. Stressing the advantages of utilization, the panel said: "*aquatic weeds can be an important part of producing valuable end products: meat, eggs, fish, edible vegetables, fertilizers, animal feed, energy, paper pulp*".

The report was influential in directing people worldwide to think about the potential economic uses of aquatic weeds. In my reading of history, the term '*utilization of weeds*' was formally recognized, within *Weed Science*, only at this point, in the mid-1970s, beginning with the colonizing aquatic species. However, the interest in weed utilization in the Asian-Pacific region, especially in India (Bengal), Indonesia, Thailand and the Philippines, dates back to the late 1960s, as noted by Gopal (1987).

In the new millennium, launching the Japanese Journal - *Weed Biology and Management* in 2001, the President of the *Weed Science Society of Japan,* Kozo Ishizuka (2001), appealed to broaden weed research to capture weed biodiversity and utilization of weeds. He also emphasized the need to integrate *Weed Science* with other disciplines, such as social sciences and economics. In the same launch, Jiro Harada (2001) appealed to the new journal to promote the utilization of weeds. Both scientists argued for priority to be given to recording how weeds were used by traditional cultures in the Asian-Pacific region, especially the Far-East (China, Japan and Korea) and focus on the socio-cultural and historical aspects, not just weed management.

Recognizing that weeds have beneficial values has been an uncomfortable position to take for some weed scientists and professional weed societies. Only a small group of ecologists and weed scientists have been convinced that the utilization of colonizing taxa as bioresources is a pragmatic approach and an effective tool for their management in most situations. In this regard, a commendable early effort was made by Kil-Ung Kim's monograph (2007) from South Korea (Chandrasena, 2007).

If there is a doubt that the utilization of weedy taxa will encourage such species to go rampant, it is not backed by scientific evidence. We know that introducing species to new environments for societal benefits must be done with some care and consideration for future naturalizations and their effects on ecosystems. Nevertheless, we also know how to 'manage' species in most situations where their excessive growth may require such control.

Much of the research and reviews on the utilization of weeds as biological resources are published in journals dealing with economic botany, bio-engineering, resource utilization, environmental remediation and similar. The everyday weed researcher does not read such journals. More publicity, via articles in weed journals, is one way to rally the weed research troops towards utilizing colonizing taxa. Future weed conferences should also dedicate sessions to exploring utilization as a management tool.

An example of the large-scale commercialization of the biomass of saltmarsh cordgrass [*Spartina alterniflorus* (Loisel.) P.M. Peterson & Saarela] on an industrial scale comes from China. Saltmarsh cordgrass, a native of the New World, was introduced to China to prevent coastal erosion. Unsurprisingly, with extensive spread, it became a problem within a few decades in many coastal areas on the eastern coastline (**Figure 3**).

Greg Duns (2020), an industrial engineer, working in China, highlighted the usefulness and potential of converting cordgrass biomass to manufacture pulp-based products (such as egg cartons, cardboard and packing material), which are globally in very high demand. Cordgrass was particularly attractive for a range of industries and products because its large biomasses were freely available. Duns (2020) also discussed how to overcome the technical limitations of industrial-scale use of such biomasses with chemical or biological transformations.

Figure 3. (a) Cordgrass infestations in China, (b) Wheel hub packing container (top) and back of fruit tray (bottom) made of mixed pulps containing smooth cordgrass fibres

In India, there is also much interest in the utilization of weeds, especially for using weeds for compost, fodder and various other uses. In 2015, the Asian-Pacific Weed Science Society's *25th Silver Jubilee Conference* (APWSS, 2015), held in Hyderabad, organized a symposium on *Utilization of Weeds as Bio-resources*. Highlighting many examples, the symposium noted the opportunities, as well as challenges, in attempting to promote weeds as bioresources in many Asian-Pacific countries. Subsequently, Sharma and Pant (2018) discussed in some detail the opportunities in India for utilizing weed species as sources of pharmaceuticals, industrial chemicals, essential oils, biochar, biofuel and for soil carbon sequestration.

Since around 2008-09, there have been commendable efforts to utilize the vast infestations of lantana (*Lantana camara* L.), which infest many forested regions in India. Lantana has been a valuable resource for rural communities that live in forested areas and depend on forests for non-timber resources. There are now well-published examples of utilizing lantana for generating income for rural communities in the forest villages in the Western and Eastern Ghats (Kerala, Karnataka, Tamil Nadu) and Uttar Pradesh (Bhagwat et al., 2012; Singh and Singh, 2015; Kannan et al., 2016).

The concept of '*living with lantana'* in India took hold after several non-governmental organizations got involved. These include the *Ashoka Trust for Research in Ecology and Environment (*ATREE) and *The Shola Trust*. The NGOs put effort towards training the local villagers to harvest lantana for various purposes, including making attractive furniture and briquettes for fuel (**Figure 4**).

The community-oriented projects also show how various and complex socio-economic issues could arise when income can be generated at the village level (such as competition for resources, resentment, land ownership and leadership). Lantana infestations in the forests of South India have become an important source of biochar [4], which is widely used to improve soil fertility and reduce synthetic fertilizer use in plantation crops.

Figure 4. Lantana infestations converted to furniture and other products.
The following quotation is from *The Shola Trust* in India **http://www.thesholatrust.org/lantanaproject/**:
"*The furniture looks exactly like the bamboo or cane furniture, but is more durable. The cost of lantana furniture is also much less than bamboo furniture, as the raw material is available for free".*

As discussed by Ajitheram et al. (2020) and Chandrasena (2024), water hyacinth in India and elsewhere provides the same opportunities for a large range of uses that could generate considerable income. These eco-friendly opportunities need to be relentlessly pursued as part of water hyacinth management, especially in Africa and India (also see Yaduraju et al. 2026 – in this Issue).

People in South and South-East Asia and Africa have mastered many applications for aquatic weeds, such as water hyacinth, using its biomass for various products. These include making paper, fibreboard, and yarn. In Vietnam, Indonesia, Thailand, China, and the Philippines, long petioles of water hyacinth form the basis of various cottage industries. These include the weaving of dried petioles into baskets, picture frames, and furniture.

Woven water hyacinth 'furniture' is now globally popular. People in Western countries are fascinated by the use of plant materials in this way. In China and Africa, water hyacinth is used as a filler in making clay bricks for housing. It is also a significant animal feed in many countries. In Bangladesh, India, China, and the USA, water hyacinth is commercially used to generate biogas and remove nutrients from sewage and industrial effluents (Chandrasena, 2023a; b).

In recent years, water hyacinth has drawn considerable attention for the quality of its rich cellulose fibres that can be blended with other fibres. The vast abundance of water hyacinth and its fibre characteristics (low density and biodegradability) make it ideal for '*bio-composites*'. Such polymer fibres have various industrial applications, including bricks and other construction materials. In the real world, the additional income from water hyacinth enterprises makes a huge difference for poor people trying to escape poverty.

Despite this knowledge, the utilization of weeds as bioresources has been challenging to promote, even in the Asian-Pacific region. While it is human nature to aspire for a comfortable living, the way to achieve such a state varies among cultures. Many societies place too much focus on the illusion of prosperity and making money through any means possible. A resource-rich country like Australia is a fine example of this attitude, where protecting and conserving Nature for the sake of future generations is secondary to one's own mundane comforts.

These utilization efforts with weedy species are steps in the right direction. However, research on utilization, traditional knowledge, and socio-cultural aspects of weeds remains sparse. They are mostly written in local languages in most non-English-

[4] Biochar is produced by thermo-chemical conversion, the baking of organic material using no oxygen (pyrolysis) or gasification (limited oxygen). Biochar is a cost-effective option for reducing the volumes of organic materials currently sent to landfills. In India, Lantana and several other species have now become important source material for biochar (**https://www.thesholatrust.org/about-4-1**).

speaking countries. There are many books commending the virtues of weedy species in India, Sri Lanka, Thailand, China and Japan, written in local languages. Such research does not get read by the rest of the world. This communication gap limits the knowledge of beneficial weeds among different societies. Investing time to popularise this knowledge is, therefore, timely. Perhaps, weed scientists, who focus wholly on weed management, should pay attention to these aspects. Careers in *Weed Science* that began by tackling weeds and the problems they cause in various manifestations should not deter individuals from looking for opportunities to integrate utilization as a management option.

An attitude change in people can only be achieved if people realize that colonizing taxa are vital elements in Nature from which societies can benefit. In farming, where they need to be managed, action must be taken to prevent crop losses in production systems. But this must be done while recognizing the worth of the individual species. Outside of agriculture, many colonizers will also need to be managed where they impede slow-growing natives trying to establish in any given area. Such 'interferences' with human affairs are not the colonizers' fault. *Weeds are just incredibly good at* what they are doing.

More than 70 years of weed research show considerable uncertainty regarding the levels of adverse effects weeds have on ecosystems. Weeds certainly make their presence strongly felt in agricultural environments; there is no denying that. However, away from agriculture, in the broader environment - forests, grasslands, wetlands, and similar natural ecosystems - there is very little evidence that competition or other effects from colonizing taxa lead to irreversible and permanent vegetation community changes.

The *spatial scale* is crucial in assessments of weed impacts - whether adverse effects are measured on local ecosystems (paddock-level) or on a broader local catchment scale. Negative effects could also be considered on a broader scale (region or country level). The *time scale* is also vital because vegetation communities are resilient.

With or without human interference, they have an uncanny capacity to rejuvenate themselves, even after significant disturbances. In most cases, colonizing taxa may temporarily suppress a given vulnerable species but not subjugate it to a level that it may disappear entirely from a given habitat. Nature does not work like that. Plant ecology is full of cases that show species coexist in assemblages in both relatively undisturbed systems and disturbed ecosystems. It is scientifically challenging to show from localized and relatively short-duration studies that weeds cause irrecoverable losses of native plants and the biodiversity of vast landscapes.

Weed Science is now quite a mature discipline. It knows that the outcomes of weed competition are site-specific (Zimdahl, 2010). Weed scientists should explain to the public not to assume that weeds are bad all the time and cause permanent biodiversity losses across landscapes. However, the public must understand that weeds may play a small disruptive part in some situations. If colonizing taxa are dominant, their sheer numbers could cause short-term disruptions in any ecosystem. Annihilation and decimation of another species to its extinction do not occur in animal and plant interactions in Nature *unless humans are involved*.

Ecology teaches us that all plant species, populations and communities have innate abilities to share resources. They are good at '*co-existence*', tolerating varying levels of competition amongst themselves. Plants know how to make adjustments through '*give and take*' and live in harmony with others. Their unique '*modular*' construction gives them the flexibility to adjust their form and habit. Unfortunately, most animals can't do this.

As John Harper explained in his monumental treatise *Plant Population Biology* (Harper, 1977), each plant can be considered as made up of vast numbers of modules, each comprising a leaf, bud, and a part of the stem. Depending on the conditions they face, plants adjust the number of these modules. This flexibility is evident in many global weeds, such as lantana, water hyacinth and alligatorweed [*Alternanthera philoxeroides* (Mart. Griesb.]. It is a primary reason why such species are so successful. If we humans do not *add* to natural disturbances, in the longer term, interactions between different plant species will lead to relatively stable communities.

Plant Ecology has taught us that the capacity to reach new equilibria with component species, adjusting to sharing vital resources, is an admirable attribute of the Plant Kingdom. These *natural* relationships are dominated by beneficial, symbiotic, and mutualistic relationships between plants, and between plants, animals and microorganisms.

Learning from Nature

As far back as 1864, George Perkins Marsh, in his book on *Man and Nature*, wrote copiously about human activities that were having a major impact on the physical geography of the planet. He alerted that through large-scale forest and land clearing, pastoralism and expanded agricultural enterprises, humans were making an extraordinary change to the planet's landscapes. Marsh also gave examples of the healing power of Nature if we left areas undisturbed long enough.

As Jon Marshall and colleagues (2003) in the U.K.K said two decades ago, "*A culture, which* *encourages respect for Nature and wildlife is preferable to one that does not*". An emerging idea – of *Nature's Contributions to People* (NCP) – was recently highlighted by Pascual and co-workers (2017). It is a conceptual framework that fits the world of colonizing taxa and how we may strive to create a sustainable future for the present and future generations. As the authors explain:

> *"…Nature's contributions to a good quality of life are often perceived and valued by people in starkly different and often conflicting ways. People perceive and judge reality, truth, and knowledge in ways that may differ from the mainstream scientific lens…"*

> *"…Hence, it is critical to acknowledge that the diversity of values of nature and its contributions to people's good quality of life are associated with different cultural and institutional contexts and are hard to compare on the same yardstick…".*(Pascual et al., 2017).

The NCP concept has been developed within the context of the *Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES).* It is proposed as a pluralistic approach, widely applicable to knowledge–based policy initiatives.

The NCP platform recognizes the benefits of embracing the diversity and power relationships across stakeholder groups that hold different values on human-nature relationships. Resonating with the term *Ecosystem Services*, the NCP concept includes all of the positive benefits and occasionally negative contributions, losses, or detriments that people obtain from Nature (*anthropocentric values*). It also captures a *non-anthropocentric value* as a value centred on something other than human beings. These values can be *non-instrumental* (e.g. a value ascribed to the existence of a specific species for its own sake), or *instrumental* to non-human ends (for example, the instrumental value a particular habitat type may have for a species that is well-adapted to it).

Other knowledge systems, such as '*Nature's Gifts*', prevalent in many indigenous and traditional cultures, are recognized within the NCP concept. In a sympathetic worldview, colonizing taxa, which are accused of causing adverse effects on biodiversity and people, fall within the milieu of NCP and are most certainly '*Nature's Gifts*'. *A flexible mind will allow us to seek clarification on this viewpoint*.

An Eco-Literate and 'Weed-Literate' Society?

In many journal articles, it is common to find statements that "*we do not have much of an understanding of weeds and that all weeds are bad news"*. Such statements are indeed an insult to our founding fathers. *Within the discipline, a great deal is known about colonizing taxa and their biology and ecology*. In the early days, our founders sought answers to the questions - *why, how and what weeds are about and why they behave the way they do*. One reason for the emergence of *Weed Science* was to seek those answers, through biology, ecology and evolution. Herbicides were the other reason.

The central challenge in *Weed Science* presently is not a *knowledge gap* but a *translation deficit* in converting knowledge into practice. This deficit could also be a '*knowledge neglect*' because weed researchers appear to fail in applying previously known knowledge appropriately to find solutions to weed problems. The human brain seeks easy options. Scientists, with rational and well-trained minds, are also no exception; they, too, cut corners, often conducting research for the sake of it rather than to solve a real-world problem.

When bombarded with the news that weeds are always bad news, some will accept this flawed view without questioning. This may be a *confirmation bias* because they've been told so for decades. The message echoed repeatedly like a mantra, which appears to validate their preconceived notions.

Literacy is the ability to read and write. However, a fully literate person will have not just the ability to read and write but also to place the written material into the correct context of its meaning. *Understanding is the key here.* Environmental literacy – an extension of literacy - is the awareness of Nature, its complexities, intricacies, and wonders.

It teaches us that we are only a single and highly vulnerable species in the world, albeit the cleverest one, with a unique brain. *We are also the species that has the most profound impact on Nature.* Recent debacles with droughts, floods, cyclones, and bushfires, as well as losses of iconic animal species across the globe, are a testament that the natural world does not work by human rules. We will have to exist within its laws to survive as a species.

If the concept of environmental literacy is extended to weeds, we will be well on the way to creating a '*weed literate*' society. Such a community will reduce the current attitudes that blame weeds for everything wrong in our world. Instead, it will better appreciate plants in general, colonizing plants in particular, and their life-supporting roles in Nature. At the same time, changing our attitudes will help us *to manage colonizing taxa much better and save ourselves some trouble on the way* [This was a frequent comment made by Geoff Sagar, my mentor, at the Plant Population Biology School in North Wales, Bangor].

Knowledge about weeds has been tainted for decades with prejudices and half-truths. The public has been brainwashed by misleading information on weeds. These can only be counter-balanced by promoting 'weed-literacy' within the context of ecological literacy ('eco-literacy').

To be 'eco-literate', one needs to understand the structure and function of ecological communities (ecosystems). If we were more eco-literate, we would be more likely to respect the limits of those systems and engage sympathetically with the natural world. A 'weed-literate' society will find relief in realizing that not all weeds are bad all the time. It will aim to deal with weeds, not in isolation, but within the proper ecological and cultural context.

A possible cause of the prevailing 'weed illiteracy' is the shallowness of the discourses on weeds in different countries. Evidence must be discussed that, in the proper context, many weeds do have practical values from which societies should benefit. For many species, the opportunities for utilization can be made purely on simple economic arguments and common sense. Despite some reticence from researchers who may still believe in winning the war against weeds, future weed conferences would benefit from either special symposia or sessions dedicated to utilization.

Weed scientists must clarify to the public that we are not at a '*war with weeds*', but we recognize the benefits of co-existing with weeds. *Could the weed research juggernaut be turned around to focus on co-existing with weeds in the future?* To create a 'weed-literate' society, we must turn to topics on weeds relevant to broader societal needs. This is yet to happen except in a few utilization cases, such as lantana, cordgrass and water hyacinth.

Colonizing taxa have often been model organisms, featuring strongly in research on plant populations and communities. They will also feature in any research on ecological restoration, remediation of damaged landscapes, conservation farming, ethnobotany, and pharmacological botany.

If weed scientists think carefully about the existing knowledge base of our subject, they would realize that a great deal is already known about individual weed species and how they can be managed in different situations. As early as 1935, Walter Muencher's book on *Weeds* described 500 American weeds with notes on their biology, ecology, habitat preferences and control information. Muencher traced the origin of many American weeds to the transport and dissemination of contaminated grain from overseas that arrived in the USA in the 19th Century.

Muencher wrote his book before the discovery and commercialization of the first modern herbicide- 2,4-D, which occurred about a decade later. In revising the book in 1955, he added another 71 species to the original 500 and also made a particular reference to herbicides, acknowledging that they *'may offer the best, and for many weeds, the most economical method of control'*.

Le Roy Holm et al.'s famous treatise - '*The World's Worst Weeds'*, published in 1977 (Holm et al., 1977a), compiled the biological knowledge of 76 of the most significant global species. A companion volume: '*The World's Worst Weeds: Distribution & Biology*', followed (Holm et al., 1977b). Twenty years later, Holm and his colleagues produced a much larger book – '*World Weeds: Natural Histories and Distribution*', including 104 species as the most significant in the world (Holm et al., 1997).

Holm spent a great deal of time listing the world's worst weeds, basing his opinions on the global crop yield losses gleaned from FAO data and other sparse literature received from colleagues around the world. Unfortunately, Le Roy Holm also described weed species as villains! A comment about water hyacinth read as follows: "*I have seen it in some of the major rivers of the world, and I think it is the most massive, the most terrible and frightening weed problem ever known*" (Holm, 1969).

According to Holm et al., the ten worst weeds in the world in 1969 were: purple nutsedge (*Cyperus rotundus* L.), Bermuda grass [*Cynodon dactylon* (L.) Pers.], barnyard grass [*Echinochloa crus-galli* (L.) P. Beauv.], jungle rice [*Echinochloa colona* (L.) Link], goose grass (*Eleusine indica* L.), johnsongrass [Sorghum halepense (L.) Pers.], Guinea grass [*Megathyrsus maximus* (Jacq.) B. K. Simon & S. W. L. Jacobs], water hyacinth, cogon grass [*Imperata cylindrica* (L.) P. Beauv.] and lantana. This information, compiled 50 years ago, provides insights into the life cycles of individual species and their interactions with other species.

In addition to these compendia, the *Canadian Weed Science Society* published an impressive series on the biology, ecology and management of individual weeds under the theme '*The Biology of Canadian Weeds*' (Vanden Born and Alex, undated). This series commenced in 1973, and as of January 2003, it has covered 117 species.

There have also been several republishings and updates of this Canadian Weeds series. Hundreds of graduate students in *Weed Science*, in the 70s and 80s decades, benefitted greatly from these accounts. Since the early 1970s, numerous other books on weeds have been produced. Handbooks on weed management adorn the corpus of *Weed Science*, covering individual weed species in different cropping and non-crop situations.

The above foundational '*knowledge base*' on specific species was later extended in the late 1970s to quite impressive studies on the ecophysiology of weeds in major crops and other situations. The ecophysiology approaches to understanding and managing weeds brightened *Weed Science* in this period. Ecophysiology focuses on how the biophysical environment interacts with the growth and physiology of any organism.

These studies were firmly based on applying the principles of ecology to understand how biotic and abiotic factors influenced the growth of plants. Improved investigative methods allowed this research to accurately measure how ecological factors govern the interactions between weeds and crops. Ecophysiology also brought together scientists across different fields - agriculture, soil and nutrition, crop protection, entomology, and ecology - to assist in understanding how weeds behave in the fields (Leibman et al., 2001).

Ecological research and findings added to John Harper's calls (Harper, 1958; 1960) for integrating the knowledge of weed seed banks and population ecology to better manage weed populations. Harper (1958; 1960) also laid the foundation for ecological weed management, emphasizing the multiple factors in the environment that can be manipulated to favour one species over another. He also stressed the need to undertake weed control programmes in a 'site-specific' way, but only when their populations are above certain threshold levels and threaten crop yields, or otherwise become a nuisance.

Several books highlight ecological knowledge, forming the basis for applying ecological principles and approaches to managing weeds. Notable books, Robert Aldrich's *Weed-Crop Ecology: Principles in Weed Management* (Aldrich, 1984), Steven Radosevich and Jodie Holt's *Weed Ecology: Implications for Vegetation Management* (1984) and Miguel Altieri and Matt Leibman's (1988) two-volume treatise on *Weed Management in Agro-ecosystems: Ecological Approaches*. Radosevich et al. produced an update to their book in 1997.

A special symposium of the *WSSA*, held in 1996 in Virginia, also showed the need for knowledge of weed biology and ecology as essential for sensible weed management through integrated approaches. Scientists demonstrated how concepts of population biology, such as seed bank dynamics, root reserves, tuber dormancy, and longevity of vegetative parts of perennials, can be used to predict weed infestations (WSSA, 1996). In many ways, in 1996, WSSA was reiterating what the *British Ecological Society* had been doing for two decades!

Nevertheless, the WSSA symposium encouraged weed researchers to '*bridge the gap'* between theory and practice and apply the knowledge of weed biology and ecology to actual weed management. This required more focus on studies that would lead to integrating the knowledge of seed dormancy, germination ecology, competitive ability, and reproductive biology of individual species into sustainable weed management programmes (Bhowmik, 1997; WSSA, 1996).

In 1996, Douglas Buhler, a USDA Agriculturist, asked: *Is it time for weed scientists to reassess how they view their science and their interactions with society?* In the 1999 book, *Expanding the Context of Weed Management*, Buhler injected new ideas for broadening the perspectives of weed management (Buhler, 1996; 1999). Nevertheless, t*hirty years later, ecological studies on weeds are still not front and centre in weed discourses.*

Ecology reveals how crops and weeds try to outsmart each other and how even a few individuals of some weeds may cause yield losses. Such knowledge is the basis of IWM, which aims to improve on-field cultural practices that discourage weeds and favour crops (Lindquist and Kropff, 1996). The same principles of ecological management can be applied to colonizing taxa outside agriculture.

If there is indeed a *'knowledge gap*', it is the failure of weed researchers to translate the practical outcomes of their research into managing weeds. It is a '*knowledge translational gap*'. Weed scientists trained in ecology should be smart enough to interact with weeds more effectively, within the broader environmental and biodiversity management frameworks. They should also be at the forefront of educating the lay public of the need to approach weedy issues without exaggeration of potential harm.

Weed managers may also play a role in fostering a culture of understanding and trust through consistent communication and outreach that can pave the way for greater acceptance of 'living with weeds' as part of nature. The consistent message must be that *weeds are only a symptom of disturbances in land and water* and are not to be blamed for a wide variety of human-caused disturbances that lead to biodiversity losses. As several weed researchers, agronomists (Altieri and Liebman, 1988; Leibman et al., 2001) and thinkers (Sagoff, 2002; 2009; Davis and Thomson, 2000; 2001; Davis et al., 2011) have said, it is incorrect to brand all 'exotic' and weedy species as 'invaders'. Suffice to say that '*Not All Exotic Species Are Bad'*. Certainly not, all the time!

Colonizing species would feature as one of the most valuable bioresources available to meet the sustainable development goals across all developing nations. *Time will prove this prediction*. Re-framing the dialogue on weeds would help build a firmer foundation for a more balanced interaction with them. In the longer term, it would lead to better management of all weeds. Implementation of the CBD would also benefit from such a change in thinking.

The effects of global climate change are felt across the world, awakening people from their indifference towards Nature. A positive outcome is that the public is now tuned to environmental messages. Hence, the time appears to be suitable to provide the public with information that would increase their ecological awareness and a better understanding of weeds.

Avery Payton Hill and Elizabeth Hadly, in their 2018 paper "*Rethinking 'Native' in the Anthropocene",* pointed out the mistake people are making by the traditional conservation binary between "native" and "alien" species. The authors (Hill and Hadly, 2018) argued that as anthropogenic climate change rapidly shifts ecosystems, historical baselines become obsolete and species migrate, making the concept of a strictly "native" species fundamentally impractical.

The dialogue on colonizing taxa must change to discuss their positive values as environmental assets. Uncertainties about the negative ecological effects of colonizers may exist in specific situations. No one can or should deny that. Still, these should not deter future research from looking deeper into their ecological roles. *It just needs a different set of starting assumptions*. *The presumptions that weeds are responsible for what ails agriculture and the claims that they are the cause of irreversible declines in biodiversity are not supported by the evidence*.

Negative assumptions about weeds were first formed in modern agriculture. They became entrenched as agriculture expanded and urbanization took hold in the USA and other countries (Muencher, 1935; De Wet, 1966; Evans, 2002; Falck, 2010; Zimdahl, 2010). The problem is that an overemphasis on the adverse effects of colonizing taxa inhibits ecologically oriented weed research and related investigations, both within and outside agriculture. Such inhibitions need to be balanced by alternative views, backed by scientific evidence. Science, in the end, should be the basis of laying a foundation to change prevailing narratives and modify the negative perceptions that people have of weeds.

On the whole, there is ample scientific evidence to prove that many pioneering, colonizing taxa play crucial ecological roles in Nature and provide various ecological, societal, cultural and livelihood benefits. The evidence available is clear: *instead of being pushed aside, these biological resources must become an integral part of our lives. Fostering a better relationship should be based on a deeper understanding of the strengths of these organisms and what they offer to other plant relatives, as well as to human and animal societies*.

I conclude by recalling what George Santayana (1906) said: "*If we remember the past*, *we may not keep making the same mistakes*". Instead of creating fear about weeds, the options of utilizing them wherever possible need to be investigated more thoroughly for societal and livelihood benefits.

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With sincere gratitude, I acknowledge the '*weed-wisdom*' my mentors at the University of North Wales gave me. Geoff Sagar and John Harper often talked about how little we know of weeds and why certain species thrive in some habitats while others do not.

I still recall the *Harperian wit* when people asked John to 'define' weeds. With a twinkle in his eyes, he used to say: "*Weeds do not need a definition; they are just a nuisance to some people, but great models to study population biology*!"

Conversations with the late Peter Michael, an Australian weed scientist, inspired me to make the effort to argue for a balanced view of pioneer species in Australia. I also thank Robert Zimdahl for frank exchanges of views over the years, often challenging my opinions on the 'virtuous' side of weeds. Robert is also thanked for critically reviewing this essay and providing useful insights, which improved it.

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