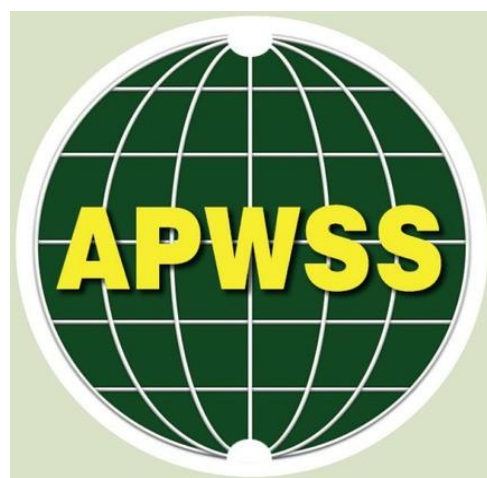


VOLUME 8, ISSUE 1, 2026



WEEDS

*JOURNAL OF THE ASIAN-PACIFIC WEED
SCIENCE SOCIETY*



Weeding

BETWEEN THE LINES
An anthology of essays
about our relationship
with nature

With a foreword by
Professor Tim Entwisle



The Paradox of Weeds

Nimal R. Chandrasena ¹

¹ Current Address: *Nature Consulting*, 17, Billings Way, Winthrop, WA 6150, Australia

E-mail: nimal.chandrasena@gmail.com

Published: 30 June 2026

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).

Keywords: utilization of weeds; virtuous weeds, Weed Science; weed literacy; eco-literacy; 'aliens'; 'invasive species'; invasions; weeds

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 fruticosus* 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 time and space, 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 CO₂ 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).

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. *Prosopis 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 management³.

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 alterniflora* (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,



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 Ajitharam 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).

land ownership and leadership). Lantana infestations in the forests of South India have become an important source of biochar⁴, which is widely used to improve soil fertility and reduce synthetic fertilizer use in plantation crops.

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 republics 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, *thirty 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.

Acknowledgements

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.

Literature Cited

- Ajitharam, A. et al. (2020). Water Hyacinth for Biocomposites—An Overview. In: Khan, A. et al (Eds). *Biofibers and Biopolymers for Biocomposites. Synthesis, Characterization and Properties*. Springer International. pp. 171-179.
- Aldrich, R. J. (1984). *Weed Crop Ecology: Principles in Weed Management*. Wadsworth Publ. Co., USA. p. 448.
- Altieri, M. A., et al. (2015). *Crops, Weeds and Pollinators: Understanding Ecological Interaction for Better Management*. FAO. p. 106 (<https://www.fao.org/family-farming/detail/en/c/1682752/>).
- Altieri, M. A. and Liebman, M. (Eds.) (1988). *Weed Management in Agro-ecosystems: Ecological Approaches*. Vol. 1. CRC Press, Boca Raton, USA, p. 354.
- Amigo, I. (2020). The Amazon's Fragile Future. *Nature*, 578: 505-507.
- APWSS (2015). Asian-Pacific Weed Science Society (APWSS) 25th Jubilee Conference. *Proceedings Volume 2*, Hyderabad, pp. 40-46 (<http://apwss.org.in/apwss-publications.htm>).
- 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. Academic Press. NY. 147-169.

- Barrett, S. C. H. (2001). The Baker and Stebbins Era comes to a Close. *Evolution*, 55 (11): 2371–2374.
- Bhagwat, S. A., et al. (2012). A Battle Lost? Report on Two Centuries of Invasion and Management of *Lantana camara* L. in Australia, India and South Africa. *PLoS ONE*, 7(3): e32407 (<https://journals.plos.org/plosone/journal.pone.0032407>).
- Bhowmik, P. C. (1997). Weed biology: importance to weed management. *Weed Science*, 45: 349-356.
- Binggeli P. (1994) The misuse of terminology and anthropomorphic concepts in the description of introduced species. *Bulletin of the British Ecological Society*, 25: 10-13.
- Buhler, D. D. (1996). Development of Alternative Weed Management Strategies. *Journal of Production Agriculture*, 9 (4): 501-505.
- Buhler, D. D. (Ed.) (1999). *Expanding the Context of Weed Management*. The Howarth Press, NY. p. 289.
- 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.
- Butler, R. A. (2014). 30% of Borneo's rainforests destroyed since 1973. Mongabay, 30 July (<https://news.mongabay.com/2014/07/30-of-borneos-rainforests-destroyed-since-1973/>).
- Chandrasena, N. R. (2007). Liabilities or Assets? Some Australian Perspectives on Weeds, In: K. U. Kim et al. (Eds.) *Utility of Weeds and Their Relatives as Resources*. Kyungpook National University, Daegu, Korea, 9-56.
- Chandrasena, N. R. (2019a). Editorial: Making a Difference- The New 'Weeds' Journal. *Weeds*, 1(1): 1-7 (http://apwss.org.in/Article.aspx?Article_id=1).
- Chandrasena, N. R. (2019b). Seeing 'Weeds' with New Eyes. *Weeds*, 1(2): 1-12 (http://apwss.org.in/Article.aspx?Article_id=7).
- Chandrasena, N. R. (2020). 'Alien' Species, 'Pertinacious Weeds' and the 'Ideal Weed' – Revisited. *Weeds*, 2(2): 1-15 (http://apwss.org.in/Article.aspx?Article_id=17).
- Chandrasena, N. R. (2021). 'Aliens', 'Natives' and 'Artificial Habitat'- Revisiting the Legacies of H.C. Watson and S.T. Dunn. *Weeds*, 3(1): 1-19 (http://apwss.org.in/Article.aspx?Article_id=23).
- Chandrasena, N. R. (2022). To Bee or Not to Be: Weeds for Bees. *Weeds*, 4 (1): 1-20 (http://apwss.org.in/Article.aspx?Article_id=32).
- Chandrasena, N. R. (2023a). Options for the Utilization of Water Hyacinth (*Pontederia crassipes* Mart.) – An Update. *Weeds*, 5(2): 1-20.
- Chandrasena, N. R. (2023b). *The Virtuous Weed*. Vivid Publishers, Fremantle, WA. p. 474.
- Chandrasena, N. R. and Rao, A. N. (2017). Asian-Pacific Weed Science Society: A Glimpse of the Past 50 Years and Perspectives. In: Chandrasena, N. R. and Rao, A. N. (Eds.) *50th Anniversary Celebratory Volume*. pp. 1-37 (<http://oar.icrisat.org/10344/>).
- CBD (1992). *United Nations Convention on Biological Diversity* (<https://www.cbd.int/convention/text/>).
- Chew, M. K. (2006). *Ending with Elton: Preludes to Invasion Biology*. Ph.D. Thesis, Arizona State University, Tempe, Arizona (Available at: https://www.academia.edu/4948103/Ending_with_Elton_Preludes_to_Invasion_Biology).
- Crosby, A. W. (1986). *Ecological imperialism: The Biological Expansion of Europe, 900-1900*. Cambridge University Press, NY, pp. 368.
- Darlington, W. (1847). *American Weeds and Useful Plants*. Orange Judd Company, NY. (George Thurber expanded Darlington's 1847 book, re-publishing it as a 2nd Edition in 1859).
- Darlington, W. (1859). *American Weeds and Useful Plants: Being a Second and Illustrated Edition of Agricultural Botany*. A.O. Moore Publisher. pp. 460. (Available at: <https://play.google.com/books/reader?id=YjBjAAAAIAAJ&hl=en&pg=GB.S.PR1>).
- Darwin, C. (1859). *On the Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life*. London: John Murray. p. 466 (http://darwin-online.org.uk/converted/pdf/1861_OriginNY_F38_2.pdf).
- Davis, M. A. and Thompson, K. (2000). Eight ways to be a colonizer; two ways to be an invader: a proposed nomenclature scheme for invasion ecology. *ESA Bulletin*, 81: 226–230.
- 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 (<https://www.researchgate.net/publication/51202855>).
- Denning, S. (2021). South-east Amazonia is no longer a carbon sink. *Nature*, 595: 354-355.
- Duns, G. J. (2020). Smooth Cordgrass (*Spartina alterniflora* Loisel.): The Case for Utilization of a Colonizing Plant Species. *Weeds*, 2(1): 17-29 (http://apwss.org.in/Article.aspx?Article_id=13).

- Dwyer, J. (2011). 'Weed Psychology and the War on Weeds'. *Plant Protection Quarterly*, 26: 82-86.
- Ens, E. et al. (2017). Aboriginal people and Australia's vegetation: Past and current interactions. Chapter 4, pp. 89-112. In: Keith, D. (Ed.). *Australian Vegetation*. 3rd Edition, Cambridge University Press, London.
- Evans, C. (2002). *War On Weeds in the Prairies West: An Environmental History*. University of Calgary Press, Calgary, Alberta, p. 309.
- Falck, Z. J. S. (2010). *Weeds: An Environmental History of Metropolitan America*. University of Pittsburgh Press. p. 256.
- Gibbens, S. (21 Aug, 2019). *National Geographic*: The Amazon is burning at record rates - and deforestation is to blame (<https://www.nationalgeographic.com/environment/article/wildfires-in-amazon-caused-by-deforestation>).
- Godwin, H. (1960). The History of Weeds in Britain. pp. 1-10. In: Harper, J. L. (Ed.) *The Biology of Weeds*. A Symposium of *The British Ecological Society*, 2-4 April 1959. Blackwell Scientific Publications, Oxford.
- Gopal, B. (1987). *Water Hyacinth. Aquatic Plant Studies 1*. Elsevier, Amsterdam. p. 471.
- Gaveau, D. L. A. et al. (2018). Rise and fall of forest loss and industrial plantations in Borneo (2000–2017). *Conservation Letters*, e12622 (<https://doi.org/10.1111/conl.12622>).
- Guiasu, R. C. and Tindale, C. W (2018). Logical fallacies and invasion biology. *Biology & Philosophy*, 33: 34 (Available at: 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.
- Harada, J. (2001). Research in the 21st Century for weed scientists in the Asia-Pacific region and roles of the new journal: a message from the President. *Weed Biology and Management*, 1: 1-4.
- 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. In: *Proceedings of the Third British Weed Control Conference*, 1: 179–188.
- Harper, J. L. (1958). 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. p. 256.
- Harper, J. L. (1977). *Population Biology of Plants*. Academic Press, London. p. 892.
- Hill, A. P. and Hadly, E. A. (2018). Rethinking “Native” in the Anthropocene. *Frontiers of Earth Science*, 6: Article 96.
- Holm, L. (1969). Weed problems in Developing Countries. *Weed Science*, 17: 113-118;
- Holm, L. G., et al. (1977a). *The World's Worst Weeds*. University of Hawaii Press, Honolulu. p. 609.
- Holm, L. G. et al. (1977b) *The World's Worst Weeds-Distribution & Biology*, University of Hawaii Press, Honolulu, p. 621.
- Holm, L. G. et al. (1997). *World Weeds: Natural Histories and Distribution*. John Wiley & Son, p. 1152.
- Ishizuka, K. (2001). The Role of a New Journal. *Weed Biology and Management*, 1: 15-19.
- IUCN (2018). *International Union for Conservation of Nature (IUCN) – Palm Oil and Biodiversity* (<https://iucn.org/resources/issues-brief/palm-oil-and-biodiversity>).
- Kannan, R., et al. (2016). Can local use assist in controlling invasive alien species in tropical forests? The case of *Lantana camara* in southern India. *Forest Ecology and Management*, 376: 166–173.
- Kim, K. U., Shin, D. H. and Lee, I. J. (Eds.) (2007). *Utility of Weeds and Their Relatives as Bioresources*. Kyungpook National University, Daegu, Korea. p. 222.
- King, L. J. (1966). *Weeds of the World Biology and Control*. Interscience Publishers, NY. p. 526.
- Laurance, W. F. et al. (2020). Tapanuli orangutan endangered by Sumatran hydropower scheme. *Nature Ecology & Evolution*, 4: 1438–1439.
- Leibman, M. et al. (2001) (Eds). *Ecological Management of Agricultural Weeds*. Cambridge University Press, U.K., p. 545.
- Lindquist, J. L. and Kropff, M. J. (1996). Applications of an Eco-physiological Model for Irrigated Rice (*Oryza sativa*)-*Echinochloa* Competition. *Weed Science*, 44 (1): 52-56.
- Marsh, G. P. (1864). *Man and Nature. Physical Geography As Modified by Human Action*. Charles Scribner Publishers, NY. p. 599 (<https://archive.org/details/man-and-nature-1864>).
- Marshall, E. J. P., et al. (2003). The role of weeds in supporting biological diversity within crop fields. *Weed Research*, 43: 77–89 (<https://www.researchgate.net/publication/229721733>).
- Mitchell, D. S. (Ed.) (1974). *Aquatic Vegetation and Its Use and Control*, UNESCO, Paris. p. 133.

- Muencher, W. C. (1935, 1955). *Weeds*. McMillan Ltd. NY [First published in 1935; revised in 1955; reprinted several times afterwards].
- Pascual, U. et al. (2017). The value of nature's contributions to people. *Current Opinion in Environmental Sustainability*, 26: 7–16 (<https://www.sciencedirect.com/science/article/pii/S1877343517300040?via%3Dihub>).
- Pieterse, A. H. and Murphy, K. J. (Eds) (1990). *Aquatic Weeds, the Ecology and Management of Nuisance Aquatic Vegetation*. Oxford University Press, p. 543;
- Phillips, D. and Camargos, D. (2020). *The Guardian*: How can we stop the Amazon burning? (<https://www.theguardian.com/environment/2020/may/05/a-deadly-cycle-of-destruction-how-greed-for-land-is-fuelling-amazon-fires>).
- Pirie, N. W. (1960). Water hyacinth: A cause or crop? *Nature*, 185: 116.
- Potts, S. G. et al. (2016). Safeguarding pollinators and their values to human well-being. *Nature*, 540: 220–229.
- Radosevich, S. and Holt, J. (1984). *Weed Ecology: Implications for Vegetation Management*. Wiley Interscience, NY. p. 265.
- Radosevich, S, et al. (1997). *Weed Ecology: Implications for Vegetation Management*. Wiley Interscience, NY, p. 589.
- Salisbury, E. (1961). *Weeds & Aliens*. The MacMillan Co., New York. p. 384.
- Sagoff, M. (2002). What's Wrong with Exotic Species? In: Galston, W. (Ed.) *Philosophical Dimensions of Public Policy*, Routledge, NY, p. 349 (Chapter 34).
- Sagoff, M. (2009). Who Is the Invader? Alien Species, Property Rights, and the Police Power. *Social Philosophy and Policy*, 26(2): 26-52.
- Santayana, G. (1906). *The Life of Reason; or The phases of human progress*. Chapter XII: *Flux and Constancy in Human Nature*. (p. 284). Archibald Constable & Co., London (Available at: <https://archive.org/details/thelifeofreason00santuoft/page/n5/mode/2up>).
- Sharma, V. and Pant, S. (2018). Weed as an underutilized bio-resource and management tool: a comprehensive review. *Waste and Biomass Valorization*, 10(7): 1795-1810. (<https://doi.org/10.1007/s12649-018-0212-2>).
- Siegfried, T. (2023). Pliny the Elder's Radical Idea to Catalog Knowledge. *Knowable Magazine*, 2 February (<https://knowablemagazine.org/content/article/society/2023/pliny-elder-first-encyclopedia>).
- Singh, A. K. and Singh, N. (2015). Application of *Lantana camara* L. in villagers of Sonebhadra, India: A possible management strategy to control invasion. *Ecology, Environment & Conservation*, 21(1): 257-259.
- Storkey, J. (2006). A functional group approach to the management of U.K. arable weeds to support biological diversity. *Weed Research*, 46: 513–522.
- Storkey, J and Neve, P. (2018). What good is weed diversity? *Weed Research*, 58: 239-243.
- Storkey, J. and Westbury, D. B. (2007). Managing arable weeds for biodiversity. *Pest Management Science*, 63: 517–523.
- Theophrastus (undated). *Enquiry into Plants and Minor Works on Odours and Weather Signs*. A 1916 translation (<https://ryanfb.github.io/loebolus-data/L070.pdf>).
- Transparency Market Research (2026). Herbicide Market Growth Update (<https://www.transparencymarketresearch.com/herbicides-market.html>).
- UN (2026). United Nations. Millennial Development Goal 15 of the 2030 Agenda for Sustainable Development. Biodiversity & Ecosystems (<https://sdgs.un.org/taxonomy/term/1166>).
- Uryu, Y. et al. (2008). Deforestation, Forest Degradation, Biodiversity Loss and CO2 Emissions in Riau, Sumatra, Indonesia. *World Wildlife Fund Indonesia*.
- US National Academy of Science (1977)- *Making Aquatic Weeds Useful: Some Perspectives for Developing Countries* (<https://www.nap.edu/download/19948>).
- Vanden Born, W. and Alex, J. F. (undated). History of the Canadian Weed Science Society (CWSS), 1929-2002.
- WSSA (1996). Weed Science Society of America. Proceedings of the Symposium: Importance of weed biology to weed management, Norfolk, Virginia.
- Zimdahl, R. L. (1980). Weed-Crop Competition: A Review. International Plant Protection Center, Oregon State University, Corvallis, Oregon, USA. p 197.
- Zimdahl, R. (1999). *Fundamentals of Weed Science*, 2nd Edition, Academic Press, New York, p. 556.
- Zimdahl, R. L. (2010). *A History of Weed Science in the United States*. Elsevier Inc., London, p. 224.

‘Weeding - Between The Lines’

John Dwyer ¹

¹ Independent Writer, Melbourne, Australia

E-mail: thedwyers@ozemail.com.au

Published: 30 June 2026

Editor’s Note:

This article is the introductory chapter of John Dwyer, QC’s recent book “Weeding – Between The Lines” 2023, published by the Australian Garden History Society. The book is an anthology of individual species - exotic and indigenous - and their historical and cultural associations with society, the reasons why they have been cultivated, and their weediness.

The introduction is re-published with John’s consent, given that the topic is highly relevant to WEEDS. John Dwyer has long been an advocate for a balanced view on weeds and a better botanical and ecological understanding. He has been a strong voice in Australia questioning the appropriateness of calling weedy colonizing species as ‘Aliens’ and ‘Invaders’, the lexicon upon which Invasion Biology has been built. Creating fear and apprehension in the public’s mind, John argues, does not help us manage weeds, where they can be problems (Dwyer, 2009; 2011, 2012; 2016).

The message in John Dwyer’s new book is extremely powerful, and the arguments made are compelling reading. It is the same message our Journal has been promoting since its inception in 2019. Weeds – shadows of humans - demand to be better understood before we attempt to control them!

Introduction

*What would the world be, once bereft
Of wet and wildness? Let them be left,
O let them be left, wildness and wet;
Long live the weeds and the wilderness yet.*
GERARD MANLEY HOPKINS, *INVERSNAID*

In 1999, I began, part-time, a Certificate Course in Horticulture at Burnley College. Some years previously, Joan and I had acquired a weekender with a large garden in the Dandenong Ranges near Melbourne. The property looked out over and formed part of a National Trust-classified landscape. I went to Burnley wanting to become a better gardener and found I enjoyed being a student very much. When I weighed up my enjoyment of life as a barrister with my time at Burnley, Burnley won hands down. I retired from the Bar after nearly 40 years to devote my time to learning about horticulture.

Of all the subjects in the course, I found weeds the most puzzling. There seemed to be no certainty about the criteria for designating a plant as a weed. When I had completed the Certificate course, Burnley had amalgamated with the University of Melbourne. I asked whether I could do a Ph.D. on weeds.

I already had, in addition to my Law degree, an M.A. in philosophy. My M.A. thesis, ‘Describing Acts’, used a legal setting to examine the idea that there could be many descriptions of a person’s act from different points of view. I argued that what a person was about and what their intention was should determine how their act was described.

My Ph.D. application was successful. Dr. Gregory Moore, the Principal, and Dr. Janet Schapper agreed to be my supervisors. Both my legal and my philosophical training guided my study of weeds. Dr Moore once remarked that I was cross-examining the authorities by asking whether there were established characteristics that made a plant a weed.

When considering whether the natural may not be good, I recalled John Stuart Mill’s essay on *Nature* (1874), in which he asked, ‘*If the artificial is not better than the natural, to what end are all the arts of life?*’ The title of my thesis, submitted in 2007, was ‘*Weeds in Victorian Landscapes*’.

The essays in this collection (see cover page, **Figure 1**) are connected to relationships through the ages between people, plants and landscapes. Some explore the fact that the same plant may be considered both a weed and a plant to be cultivated. Others consider aspects of the history of weeds in Victorian landscapes.

The way of life that has evolved from Roman times, through the age of Shakespeare, to colonial settlements at Port Jackson, Van Diemen's Land and the Port Phillip District includes crops, garden plants, medicinal plants and weeds. More general essays take this wider cultural and historical perspective on those plants: their roles in our civilisation and the natural historians who studied and cultivated them.

The last section of the anthology contains articles on individual exotic and indigenous plants and their historical and cultural associations, the reasons why they have been cultivated, and their weediness.

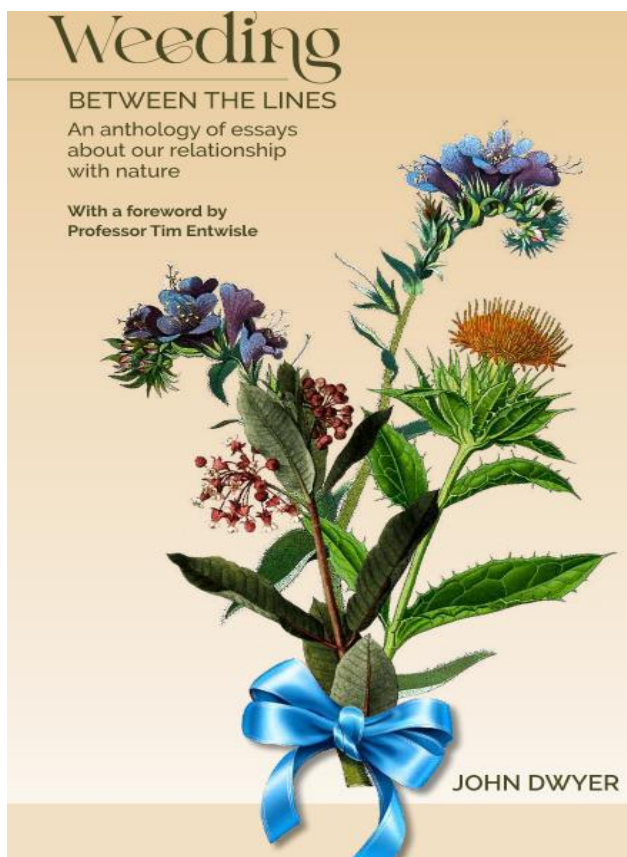


Figure 1. The Cover of John Dwyer's 'Weeding – Between The Lines' (2023)

Weeds – A Botanical Category?

Many people believe there exists a body of plants that are weeds. I expect that most, if not all, would

¹ As early as 1935, Walter Muencher's book on *Weeds* described 500 American weeds with notes on their biology, ecology, habitat preferences, sources, and control information. He 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. In revising the book, in 1955, Muencher added another 71 species to the original 500.

readily name plants you regard as weeds. But a little reflection suggests that 'weed' is a perplexing category. Some plants have been regarded as weeds in some times and places but not in others. Some plants that used to be weeds hardly count as such anymore. New plants are being added to weed lists all the time. As a category, 'weed' is inherently uncertain. Is it a feature of the plant or the human response to it that makes a plant a weed?

Despite many attempts over the past 60 years, weed scientists have not been able to agree on a set of necessary and sufficient conditions to establish which plants are weeds. Indeed, it has often been said that any plant may be a weed. If this is true, as a matter of logic, it must follow that whether a plant is a weed depends on something other than the plant. So in answer to the question posed in my topic, I would begin with the idea that 'weed' is not a botanical category. But there is a pronounced tendency, once a plant has been called a weed, to treat it as a bad plant regardless of the context.

If any plant can be a weed, perhaps it is our response to a plant that makes it a weed. What drives such responses? My thinking about the psychology of weeds began when I came across a perceptive review by Professor William Stearn (1956) of *Weeds* by W. C. Muenscher ¹. What struck me was Stearn's suggestion that the appropriate sphere of science for considering weeds was psychology rather than botany: '*Taken as a whole, weeds are not so much a botanical as a human psychological category within the plant kingdom, for a weed is simply a plant which in a particular place at a particular time arouses human dislike...*' ²

I will begin with an exploration of aspects of human psychology that seem to me to be relevant to an understanding of weeds, what I call weed psychology. I will then show how the category 'weed' with all its psychological overlay, has been widened to include many popular garden plants, and to make some suggestions about how we should respond.

Weed Psychology

What part do emotions play in our dealings with weeds? How did emotions such as fear and loathing become so widespread as the typical response to weeds? Weeds carry emotional impacts, which are

² "*Taken as a whole, weeds are not so much a botanical as a human psychological category within the plant kingdom, for a weed is simply a plant which in a particular place at a particular time arouses human dislike...*" — Prof. William T. Stearn (1956).

Stearn further categorized ancient weeds as **anthropophytes**—plants that have become highly dependent on human cultivation and disturbed soils, making their original wild habitats obscure.

sometimes very powerful. Weeds are often considered unsightly, as disfiguring the landscape, as a sign of disorder and neglect.

Weeds attract adjectives such as ‘ugly’, ‘pernicious’, ‘hateful’, ‘filthy’ and ‘noxious’; expressions of the emotions aroused by the threat to good order that they represent. Keith Thomas gave many examples in *Man and The Natural World* (1983). Weeds growing on waste land, roadsides, ruins, rubbish heaps, and other uncultivated areas, where they might merely be thought untidy, attract these epithets as readily as weeds on farms and in gardens. Feelings of guilt may also be involved in our response to weeds. We may feel that to permit weeds to take over a garden, or to allow thistles to grow unchecked in a paddock, is to fail to maintain proper standards, to be socially irresponsible, to set a bad example, to permit pollution.

Such feelings can operate when we are told that a particular plant is a weed. We may feel a strong compulsion to remove the plant even if it has not been troublesome in this location, without pausing to ask, ‘*Why do you say it’s a weed?*’

The depth of the feelings which may be involved is demonstrated by *Hamlet’s first soliloquy* (Shakespeare, 1599-1601) in which he contemplates suicide because of his disgust with the world after his mother’s unseemly marriage to his father’s brother just two months after his father’s death. *How did Shakespeare bring home to his audience the reality of Hamlet’s suffering?* By the following lines:

“...O fie! ‘tis an unweeded garden,
That grows to seed: things rank and gross
in nature Possess it merely...”.

HAMLET ACT 1 SCENE II

Shakespeare uses the emotions aroused by a garden possessed by weeds ‘rank and gross in nature’ to help us share in Hamlet’s emotions. The ‘unweeded garden’ around him is so unbearable that Hamlet wants to kill himself.

Why do weeds give rise to such feelings? A consideration of human psychology helps us to understand what humans think, say and do about weeds. Fear has been a key emotion in our response to weeds for a long time. *The Book of Isaiah* (c.742 BC) refers to ‘*the fear of briars and thorns*’ (Ch VII v.25). Many people are subject to a deep-seated fear that weeds will take over their patch, some even fear for the environment or even the planet as a whole.

The science fiction writer John Wyndham memorably exploited such fears in *The Day of The Triffids* (1951), his fable of feral carnivorous plants (**Figure 2**). The vital question is whether our fears

about weeds are grounded in reality or whether they should be seen as exaggerated and irrational. One explanation for the psychological basis of our fear of weeds lies in the association between weeds and contaminants.

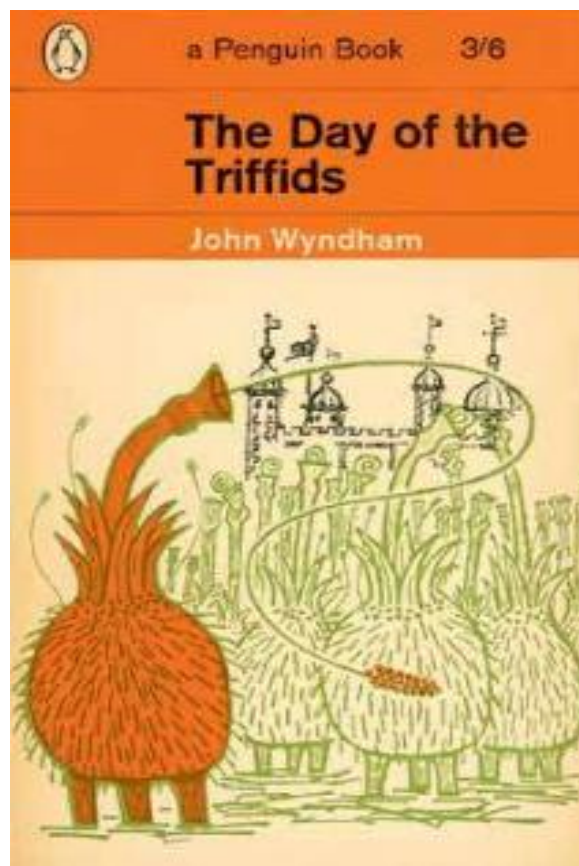


Figure 2. The Cover of John Wyndham’s ‘The Day of the Triffids’ (1951)

Weeds have sometimes been likened to dirt. For example, in 1909, Professor Alfred Ewart (1872–1937), Government Botanist and Professor of Botany in the University of Melbourne, applied what he said was Palmerston’s definition of dirt – ‘*matter out of its proper place*’ – to weeds:

‘*A weed is a plant out of its proper place, and a troublesome weed is one which makes itself objectionable by continually asserting itself in places where it is not desired*’ (Ewart and Tovey, 1909).

Humans reject the dirty as a contaminant, in contrast to the virtuous cleanliness. What is invoked here is a universal feature of human societies, the concept of pollution. Pollution ideas have been shown to be powerful influences on human behaviour. Neil Evernden, following the English social anthropologist Mary Douglas (1921–2007), pointed out that all societies identify contaminants, ‘something that is out of place and hostile to the environment, as a danger to the well-being of individuals or society.’³

³ **Editor’s Note:** The phrase ‘*dirt is matter out of place*’

was explained by an anthropologist – Mary Douglas,

It is, I think, apparent that conceptions of the environment in terms such as 'virgin' bush, 'pristine' native forest, and 'unspoiled' wilderness (matters of romantic imagination rather than something to be encountered in the real world) invite pollution ideas. Sometimes social groups have a need to specify some aspects of the world around them as polluting, and that need must be satisfied regardless of whether the specified threat is real.

Ideas about pollution have often been used as a means of social control. *'Danger beliefs are as much threats which one man uses to coerce another as dangers which he himself fears'* (Douglas, 1966). Mary Douglas (1966) also demonstrated that the human response to dirt is associated with our deep-seated need for order. Absence of order is something we tolerate with great difficulty. To identify something as a **pollutant** is to see it as threatening the appropriate order of things.

When plants are treated as weeds, they are seen as presenting a similar threat. What we are dealing with here is a social phenomenon. ***What makes us call a plant a weed is more about human needs than it is about the plant.***

Our need for order is also reflected in the unease, fear even, we feel about the absence of control. Out-of-control plants often attract the label 'weed'. As noted, Professor Ewart objected to weeds continually asserting themselves in places where they are not desired (Ewart and Tovey, 1909). Even a chosen plant may fall from favour if it becomes too hard to control; *'It is taking over'* says the gardener, and so yesterday's cultivated amenity plant has become today's (and perhaps tomorrow's) weed.

Weeds have sometimes been defined as *'plants that are not wanted'*. This gave rise to a widely quoted suggestion by Elmer Grant Campbell, in *Science* (1923), that it is a matter of human 'caprice' whether a plant is a weed. *I do not agree with Campbell.* Even if weeds are simply 'unwanted' plants, human wants and desires are not capricious. Wants are not wanton chance occurrences or arbitrary feelings. They are not able to be taken up or discarded at a whim.

As the philosopher Mary Midgley (1978) pointed out, *'Wants are not random impulses. They are articulated, recognisable aspects of life; they are the deepest structural constituents of our characters.'* This is a long way from caprice, which has been defined as: 'a sudden change of mind without apparent or adequate motive; whim'. But perhaps Campbell's real point was that calling a plant a weed

is often the expression of how we feel about this plant in these particular circumstances.

Which puts me in mind of the typical question asked by psychologists, 'How do you feel about that?' A more pertinent question, in some cases at least, might be, *'Why are you frightened of that plant?'*

To understand why weeds arouse anxiety, we must think more closely about their impact. There is nothing capricious about treating many plants as weeds. Nor is it simply that they are hard to control. The farmer has his reasons for treating plants as weeds. To begin, plants, which volunteer in a crop, compete with the crop for nourishment, light and water. Many weeds have had more serious bad effects.

The emotions of fear and dislike that such plants arouse are understandable. Do we reject such plants for the specific troubles they bring? Perhaps we are also governed by ancient responses and attitudes, which have become ingrained in our culture. Is a rationalisation available for every occasion when a plant is called a weed? The critical issue is the appropriate response in all circumstances. The emotions aroused and the actions they give rise to may be out of all proportion to the actual threat.

Whenever a plant is called a weed, some of the psychological overlay associated with the class is invoked. We may not always be conscious of the emotional and other forces at play, but we should recognise that they are likely to be present. For years, I was troubled by the fact that so many of the terms used in the vocabulary of weed science (words such as *alien, feral, invader, and infestation*) were emotive and judgmental.

The term *'invasion'* carries associations of an attack on our homeland by enemy forces and suggests we should automatically take action against the invader. Why do we speak of aliens, with overtones of enemy aliens or space invaders, instead of exotics, which carry a hint of excitement and romance? Why, when human aliens can become lawful citizens by naturalisation, do we fail to accept that naturalised plants have become part of the flora and continue to call them aliens? Why do we speak of feral plants instead of volunteers?

Why do we speak of plants as invading rather than simply spreading or increasing their range? ***Why do we speak of weeds infesting rather than simply being present?*** I now understand that the use of emotive language is closely related to the fact that emotions are involved, even if unconsciously. The

in her acclaimed book: *Purity and Danger* (1966). Since then, the phrase has been applied in a variety of contexts, drawing moral judgements, often about peoples' hygiene. Regrettably, it gave rise to the phrase: *'weeds are plants out of place'*, which is one

of the most unimaginative clichés widely used in news items, books, magazines and even research articles on weeds. Even at Weed Conferences, the phrase is commonly heard.

words used both reflect and compound emotions such as fear and anxiety, which distort our thinking about weeds. As James Brown of the University of New Mexico (1998) pointed out:

There is a kind of irrational xenophobia about invading animals and plants that resembles the inherent fear and intolerance of foreign races, cultures, and religions...This xenophobia needs to be replaced by a rational, scientifically justifiable view of the ecological roles of exotic species.

A civilised society should avoid xenophobia, whether against people or plants.

The American plant ecologist Mark Davis and others (Davis et al., 2011) have written of ‘a sort of simple-minded “**nativism**” paradigm, in which native species are embraced, and non-native species are vilified. Many people in Australia have such nativist attitudes towards plants. Conceptually, such attitudes have links to the nativist political movements that flourished in the USA, Canada, and Australia in the 19th and early 20th Centuries. The *Australian Natives Association* was the local manifestation, and the *White Australia Policy*, a long-standing outcome.

Nativist movements were not made up from Indigenous peoples; rather, they were established by native born persons, usually of British origin, who sought to keep out later arrivals on the basis that immigrants would distort or spoil cultural values. It is interesting that, as Zachary Falck (2010) has pointed out, nativists often referred to people they disapproved of as ‘human weeds’.

I contend that **nativism** should be as unacceptable for plants as for people. Sometimes xenophobia is expressed by statements such as ‘*introduced plants do not belong here*’, or ‘*are not at home here*.’ But belonging should not be determined by the geographic origin of species. *Exotic plants are part of our civilisation and belong here as much as we do. The fact that plants are exotics is never a sufficient reason to regard them as weeds or to seek to compel others to do so.*

Garden plants or ‘Invasive Alien Species’?

What do the following plants have in common: elms, daffodils, catmint and rosemary? The answer is that some people now call them ‘*Invasive Alien Species*’ (acronym, IAS). In recent years, the category ‘weed’ has been expanded. Hundreds of plants, which have been cultivated in gardens for many years, are said to have become environmental weeds or *invasive alien species*.

As examples, I will consider a number of plants included in *Weeds of the South-East* (Richardson et al., 2006). They are all introduced exotics, or ‘aliens’ if you do not like them. Most were introduced to Australia more than 150 years ago. Some have naturalised, that is, they have established themselves as part of the flora.

I should say at once that some plants introduced to cultivation in Australia have been very troublesome. We are all familiar with the prickly pear saga, with the curse of the blackberry and with gorse, to take but three examples. But the trouble is that the category ‘*invasive*’ tars with the same brush many plants that hardly seem troublesome at all. Some garden escapes have been much more serious than others.



Figure 3. Elms (*Ulmus* sp. L.), Daffodils (*Narcissus* sp. L.), Catmint (*Nepeta x faassenii* Bergmans ex Stearn) and Rosemary [*Salvia rosmarinus* Spenn.]

Weeds of the South-East (2006) is an indispensable reference work for Australia. It lists some 2,500 plant species. What is interesting for present purposes is the inclusion of many popular garden plants, often on the ground that they have become garden escapes or have the potential to do so. Most of the exotic trees commonly found in gardens and cultural landscapes are included: elms, oaks, poplars, maples, ash, and pepper trees.

Even Australian native trees, such as Cootamundra wattle, many other wattles, and sweet pittosporum, are included if they are outside their ‘natural range’ (a most problematic category which I have considered in detail elsewhere). Today I will concentrate on smaller garden plants, shrubs and herbs, to be found in many historic gardens.

Put to one side the half-welcome wildlings that occur in many of our gardens, such as English ivy,

forget-me-not, sweet violet and vinca. Let us look rather at a number of garden plants of long-standing use, to be found in many historic as well as contemporary gardens.

I grow them all, as many of you may. Many have been cultivated by humans for hundreds, if not thousands of years and are rich in cultural associations; they are truly part of our civilisation.

But some now call them weeds. We could also put to one side plants commonly grown in gardens, but which are often seen as ‘weedy’, such as agapanthus, cotoneaster and montbretia. Note, however, that what has aroused concern here is a tendency for these to persist around old gardens and settlements. The plants are thus already recognised as historic markers of old habitation, and as such of cultural heritage significance. This tendency has resulted in some surprising inclusions, such as daffodil, jonquil, belladonna lily, and acanthus.

Other occasional garden escapes listed as weeds include ajuga, catmint, foxglove, erigeron, French lavender, gazania, lamb’s ear, nasturtium, shasta daisy, rock rose, rosemary and Russel lupin. Some garden escapes are included because they are growing on roadsides and in wasteland.

As something will always grow on wasteland, I would have thought it was preferable to have a plant selected for its garden amenity growing there than less attractive possibilities like ‘*hateful docks, rough thistles, kecksies, burrs*’ (Shakespeare, 1591; *Henry V Act V Sc II*)⁴.

In *The Blue Field*, countryman John Moore (1948) tells us what *kecksies* are:

We have a word which schoolboys use for the crackly dry stems of the hemlock and the hedge-parsley: ‘kecksies’, a local word which is heard, I think, nowhere else in England; but Shakespeare puts it in the mouth of the Duke of Burgundy in Henry the Fifth...So, you see, he spoke our speech and thought our thoughts.

As for roadsides, it should be kept in mind that roads are manifestations of the culture that builds them, and that any landscape divided by a road becomes a cultural landscape. Roads and the land reserved next to them may have cultural significance in themselves and may contribute to the heritage significance of landscapes.

By making a road, we alter the ecology. The disturbance involved in building and maintaining a road often results in the growth of pioneer species in

the road reserve, although native vegetation has sometimes been preserved, whether by accident or design. Some may prefer to plant indigenous species in road reserves, but I cannot see that any harm is done if garden escapes establish themselves. The presence of attractive flowering plants seems to me to be a positive addition to roadsides rather than a reason to designate them as weeds.

It is disturbing that there have been few measured scientific studies of the behaviour of these plants. They have been included in weed lists based on anecdotes of field observation, and even the anecdotes have usually not been published in the weed science literature. If there is a concern that an exotic plant is becoming established in bushland, we need studies that measure how far and over what time, in what type(s) of bush, under what climatic conditions this has occurred, what is their ecological effect and so on. And we need to record the data, if we are to form a proper understanding of what nature is doing, and whether it is appropriate to intervene.

Instead of careful and exact observation of plants with attention to different circumstances and situations in which it might be necessary to describe them as weeds, we have ‘**an adjectival psychology**’ (Barthes, 1980). When writing about judging human actions, Roland Barthes used this term, which describes and condemns at one stroke, a psychology which ‘*is ignorant of everything about the actions themselves, save the guilty category into which they are forcibly made to fit*’.

Another name for this behaviour is **stereotyping**, where an individual is summed up and disposed of by a group description (often racially or gender-based) without regard to their actual qualities. Many are too ready to assign plants to the guilty categories ‘**Invasive Alien Species**’ or ‘**Weed**’, without giving proper consideration to the plant in the particular circumstances: its aesthetic or amenity value, its ecological function, its capacity to withstand drought, its medicinal or culinary uses, its cultural associations.

What, after all, is the point of listing these plants as weeds? Are we meant to reach for the ‘Round-up’ and spray these plants when they appear on roadsides and wasteland? How should we respond in our gardens? The listings do not seem to me to provide sufficient reason not to grow these plants. They do not seem to be ‘things rank and gross in nature’.

Because they have been popular garden plants for so long, many, if not all, are key components of historic gardens. It would, I think, be quite wrong to

⁴ **Editor’s Note:** The full Shakespearean quotation is: “*The freckled cowslip, burnet and green clover, wanting the scythe, all uncorrected, rank, conceives by idleness and nothing teems but hateful docks, rough thistles, kecksies, burs, losing both beauty and*

utility. And our vineyards, fallows and hedges...grow to wildness...”. (Duke of Burgundy to Henry) Henry V; Act 5. Kecksies are a type of wild carrot.

remove them. Some have even been suggested as 'groundcovers with weed-suppressing potential'. The reasons advanced for describing them as 'weeds' may be more a matter of ideology than science, and nativist ideas may well have been involved.

Conclusion

If we are to achieve a proper understanding of weeds, we should avoid the use of emotive and prejudicial language. To understand and describe the place of weeds in nature and in human society, we should aim to use expressions that are value-neutral and dispassionate. We should guard against the risk that our actions may be governed by our emotions; that we may treat plants as weeds in circumstances where to do so is not appropriate or justifiable.

We should seek to overcome emotions of fear and guilt in our responses to weeds. We should also recognise that we have choices about which plants are to be treated as weeds. Understanding that value judgments are involved, and that inappropriate social coercion may be present, we should look for the reasons why plants are called weeds and decide for ourselves whether the designation is compatible with our values.

Literature Cited

- Barthes, R. (1980). *Mythologies* (Hill and Wang, New York, 1980) p. 45.
- Brown, J. (1989). 'Patterns, modes and extents of invasions by vertebrates'. In: Drake, J. A. et al. (Eds.) *Biological Invasions: a Global Perspective*. Wiley, NY.
- Calder, W. (1975). *Peninsula Perspectives*. 2nd Edition, Jimaringle Publications, Melbourne, 1986), p. 117.
- Campbell, E. G. (1923). 'What Is A Weed?' *Science*, 58, Issue 1490, p. 50 (20 July 1923) (<https://www.science.org/doi/10.1126/science.58.1490.50.a>).
- Douglas, M. (1966). *Purity and Danger: An Analysis of the Concepts of Pollution and Taboo*. Routledge, London.
- Dwyer, J. (2006). 'Medicinal Herbs and Weeds in Colonial Victoria'. In: C. Preston et al. (Eds.) *Proceedings of the 15th Australian Weeds Conference*. Weed Management Society of South Australia.
- Dwyer, J. (2011). 'Weed Psychology and the War on Weeds'. *Plant Protection Quarterly*, 26: 82-86.
- Dwyer, J. (2012). Messages and metaphors: is it time to end the 'War on Weeds'? Keynote Address. *Proceedings 18th Australasian Weeds Conference*, Weed Society of Victoria Inc., 297-305.
- Dwyer, J. (2016). *Weeds, Plants and People*. PenFolk Publ., Victoria, p. 293.
- Davis, M. et al, (2011). Don't Judge Species on Their Origins. *Nature*, 474: 153-154.
- Ewart, A. J. and Tovey, J. R. (1909). *The Weeds, Poison Plants, and Naturalized Aliens of Victoria*. Government Printer, Melbourne. p. 110 (<https://www.biodiversitylibrary.org/item/114706>)
- Falck, Z. J. S. (2010). *Weeds: An Environmental History of Metropolitan America*. University of Pittsburgh Press. p. 256.
- Midgley, M. (1978). *Beast and Man: The Roots of Human Nature*. Ithaca, NY: Cornell University Press, p. 399.
- Mills, J. S. (1874). *Three Essays on Religion: Nature*: 3rd Edition. Longman and Green Publishers. pp. 3-65 (https://archive.org/details/threessays_onrel015875mbp/page/n9/mode/2up).
- Moore, J. (1948). *The Blue Field*. Collins, London, p. 222.
- Muencher, W. C. (1935, 1955). *Weeds*. McMillan Ltd. NY [First published in 1935; revised in 1955; reprinted several times afterwards].
- Richardson, F. J., Richardson, R. G. and Shepherd, R. C. H. (2006). *Weeds of the South East. – An Identification Guide For Australia*. F. J. and R. G. Richardson Publishers, p. 438.
- Shakespeare's Plays - *The Folger Collection* (Eds. B. A. Mowat & P. Werstine). Shakespeare, W. (1591). *The Life of King Henry the Fifth* (<https://shakespeare.folger.edu/shakespeares-works/henry-v/download/>).
- Shakespeare's Plays - *The Folger Collection* (Eds. B. A. Mowat & P. Werstine). Shakespeare, W. (1599-1601). *The Tragedy of Hamlet, Prince of Denmark*. (<https://www.folger.edu/explore/shakespeares-works/download/#hamlet>).
- Stearn, W. (1956). Review of *Weeds* by W. C. Muenschler, *Journal of The Royal Horticultural Society*, Vol. 81: 286-287.
- Thomas, K. (1983). *Man and the Natural World: Changing Attitudes in England, 1500-1800*. Penguin Books, London, U.K. p. 425 (<https://archive.org/details/mannaturalworldc0000thom/page/n7/mode/2up>).
- Wyndham, J. (1951). *The Day of the Triffids*. Penguin Books, p. 252.

Chronic Kidney Disease of Unknown Aetiology (CKDu) and Alleged Presence of Pesticides in Water Sources in Sri Lanka

M. W. C. Dharma-wardana¹

¹ Current Address: Department of Physics, Université de Montréal, Complexe des Sciences, Avenue Thérèse-Lavoie-Roux, Montréal, QC H2V 0B3 Canada.

e-mail: Chandre.dharma@yahoo.ca

Submitted: 10-June-2026

Accepted: 20 June 2026

Published: 30 June 2026

Abstract

Vlahos et al. (2021) have reported the presence of pesticide contamination above safe levels in well water in a region in Sri Lanka where Chronic Kidney Disease of Unknown Etiology (CKDu) is endemic and have drawn a linkage between the two. This claim goes against the generally accepted views on the composition of well water in these regions.

They conclude “*that agrochemical use in ... the Green Revolution ... may now be contributing to ill health, rapid progression of disease, and mortality*”. The authors propose “*reducing ... agrochemical contaminants in Sri Lanka and other tropical countries to reduce ... CKDu*”. These conclusions, tantamount to identifying the aetiology of CKDu, are unsupported by the evidence presented, even at the level of the simplest Bradford-Hill criteria of causation.

Keywords: Chronic Kidney Disease; CKDU, agrochemicals

Introduction

Chronic Kidney Disease of Uncertain etiology (CKDu) has been extensively studied for over two decades in Sri Lanka, and reported in Central America, India, and certain other locations around the world (Chandrajith et al., 2011; Dharma-wardana et al., 2015; Dharma-wardana, 2018).

In Sri Lanka, the incidence of CKDu has been as high as 15-23% in the North Central Province (NCP) (Wasana et al., 2026; Hettithanthri et al., 2021). These studies have led to the conclusion that those who contract CKDu are essentially those who use water from their own dugout wells; those who use water from springs, rivers, agriculture canals or from wells connected to the water table of the paddy lands do not contract the disease. This has been poignantly shown in comparing the incidence of CKDU in two adjacent villages, known as Badulupura and Sarabhoomi, in the Ginnoruwa area, located in the North Central

Province (NCP) of Sri Lanka. This area receives water from the Mahaweli River (Figure 1).

Studies of well water have implicated the presence of over threshold concentrations of fluoride ions (F⁻) occurring together with Ca⁺⁺ and Mg⁺⁺ ions (Dharma-wardana 2018, Balasooriya et al. 2020). Many of these studies review or add to the available data on pesticide levels, heavy-metal concentrations, fluoride levels and hardness of the well water used by the residents of the endemic areas.

Furthermore, in the case of those who use water purified via *Reverse Osmosis* (RO) of local water, the waste impurities obtained from RO have been analyzed for pesticide residues and heavy metal traces (Imbulana et al., 2020). All these studies have pointed to very low levels of pesticides or heavy metals, except for the early WHO study that suggested the possibility of higher levels of Cadmium in the water (Jayatilleke et al., 2013).

Several other later studies, including those of Levine et al. (2016), showed that Cd⁺⁺ levels in the water and soils of the CKDu endemic regions were way below danger thresholds. However, more recently, Vlahos et al. (2021) have reported the presence of pesticide contamination above safe levels in well water in a region in Sri Lanka where CKDu is endemic. They conclude, based on this single measurement, that:

“Agrochemical use in paddy and other agricultural practices that have characterized the last 70 years of the Green Revolution in Sri Lanka may now be contributing to ill health, rapid progression of disease, and mortality. Farming, traditionally a highly respected occupation and the well part of the “wealth” of the household, is now a source of danger and a risk”.

The authors propose “reducing agrochemical contaminants in Sri Lanka and other tropical countries to reduce CKDu”. These conclusions, tantamount to identifying the etiology of CKDu, are unsupported by the evidence presented, even at the level of the simplest Bradford Hill criteria of causation.

In particular, (i) similar non-persistent pesticide excesses have been detected sporadically in most parts of Sri Lanka, including where there is no CKDu; (ii) the pesticides reported in Vlahos et al. (2021) cause both hepatotoxicity and glomerular damage, while CKDu is associated with tubulo-interstitial damage where no hepatotoxic symptoms have been reported; (iii) the pesticides detected are known to be used episodically in farming and have short half-lives; hence the “single time-point” analysis is misleading; (iv) farming communities that use pesticides in the same way but remain essentially without CKDu are found to exist adjacent to those with CKDu; (v) the CKDu prevalence seems to correlate with local geomorphology rather than with farming.

The objective of our study, presented in this article, is to critically review the work of Vlahos et al. (2021) and establish that their results are better explained by a consideration of the geomorphology of the study region.

Methods

As this study is essentially a critical analysis of material available in published papers, the “materials” and data used here are entirely derived from the existing literature. The data for the geo-morphological analysis are obtained from Google Maps and such sources, as indicated. The “Methods” used involve the application of Bradford Hill criteria (Hill 1965) to determine if the data can be used to go from mere associations to aetiology.

The Vlahos et al. (2021) Study of CKDu in Sri Lanka

The study area in the Vlahos study is depicted in Figure 1. The area is part of the Accelerated Mahaweli River Irrigation Programme that was implemented in the late 1980s.

A major theme of the Vlahos’ study is the negative effects of the *Green Revolution*. It sharply increased food production, eliminated malnutrition, nearly doubled life expectancy, but also increased environmental pollution. Vlahos et al. (2021) have raised the important issue of the overuse of pesticides in agriculture and their possible role in CKDu.

When CKDu was detected in Sri Lanka, Mesoamerica, India, etc., an agrochemicals etiology was suspected. The favoured suspects were traces of heavy metals, such as arsenic (As) and cadmium (Cd), found in agrochemicals. However, already in 2012, it was evident that heavy metal concentrations in the water and soil in the affected regions were negligible (Nanayakkara et al., 2011), as re-confirmed by subsequent studies (Balasooriya et al., 2020; Jayasiri et al., 2022).

The presence of time-varying amounts of pesticides, such as diazinon (an organophosphorus insecticide) and propanil (a rice herbicide), in aquatic bodies has been reported in many studies. In the recent spatio-temporal study (Jayasiri et al., 2022), pesticides were detected linked to their application times. Given the short persistence lifetimes of about a day or less for diazinon and propanil at 30^o-36^o C temperatures, Vlahos et al. (2021) cannot use their “single-time point” data to construct a daily intake and a chronic toxicity assessment.

The time-averaged concentration of these pesticides would be insignificant and not likely to cause chronic toxicity. Furthermore, the well water is largely consumed as brewed tea or in cooking. Such processing removes steam-volatile substances like diazinon. The admissible daily intake (ADI) of, for example, diazinon for chronic toxicity for a 70 kg farmer is 0.14 mg/day, and the aggregate effect of episodic ingestion can be assessed only if urine and blood data are available.

Jayatilleke et al. (2013) detected pesticide residues in the urine of CKDu patients as well as in the controls. The proportions of CKDu subjects with above-reference values for different pesticide residues greater than 5% were: Chlorpyrifos (10.5%), Carbaryl (10.5%), Naphthalene (10.5%). Vlahos et al. (2021) have not reported any urine data or other biopsy data. The pesticides found in the Vlahos study are strongly hepatotoxic (Cakici et al., 2013); their nephrotoxicity manifests as glomerular damage.

In contrast, CKDu shows tubulo-interstitial damage (Nanayakkara et al., 2011) with no signs of hepatotoxicity or other effects typical of these pesticides. CKDu or its rate of progression cannot be correlated with a single-time pesticide measurement in the wells, and the geographic distribution of CKDu

evolution, unless we have time-dependent pesticide data in the blood and urine.



Figure 1. Note the Mahaweli River on the left, which drains northwards and the three adjacent farming villages - Badulupura (B), Dolahekaunawa (D) and Saramboomiya (S) in Ginnoruwa. CKDu is not endemic to farmers in S and D (Balasooriya et al., 2020). The wells in the low-lying S, D are connected to agricultural water, but the high-ground wells in B are fed by mineral-rich aquifers. (Adapted from Google Maps).

Shiple et al. (2020) have reported wells highly contaminated with diazinon, etc., in the upper Mahaweli area, where no CKDu exists. Hence, the proposed pesticide aetiology, focusing on diazinon as the most commonly detected pesticide that the authors have linked to CKDu, does not satisfy even simple Bradford Hill criteria for establishing such a linkage [i.e., a statistically valid observed association between a presumed cause (exposure) and an effect (aetiology)]. As discussed below. Hence, in sum, the Valhos et al. (2021) data provide no elucidation of the causes of CKDu or its prevention.

Bradford-Hill Criteria for establishing aetiology

The Bradford Hill criteria, first proposed in 1965 by Sir Austin Bradford Hill, are **nine** widely used viewpoints in epidemiology and medicine, which provide a framework to determine an association between a presumed cause of a disease (or sickness due to exposure) and an effect (aetiology). Its primary purpose is to assist in ascertaining a true **cause-and-effect relationship** (Hill, 1965). To evaluate whether the pesticide concentrations reported by Vlahos et al. 2021 can be causally linked to the aetiology of CKDu, the data must be scrutinized at least against some of the classic Bradford Hill criteria for causation.

1) **Specificity:** The causal claim fails the test of specificity on two fronts. First, the clinical manifestation of CKDu is strictly characterized by tubulo-interstitial nephritis without significant glomerular or hepatic involvement. In contrast, the primary nephrotoxic profile of the pesticides identified by Vlahos et al. (such as diazinon and propanil) induces acute glomerular damage and profound hepatotoxicity.

Second, the geographic distribution lacks specificity; high levels of these non-persistent pesticides have been documented in areas like the Upper Mahaweli region, where CKDu is virtually non-existent.

2) **Temporality and Biologic Gradient:** A "single time-point" sampling of highly labile, episodic agrochemicals cannot establish a chronic exposure timeline or a biological dose-response curve. Given the rapid environmental degradation half-lives of these compounds at tropical temperatures (30–36 °C), a single spike does not equate to the decades of sustained exposure required to induce chronic renal failure.

Consistency: The proposed agrochemical aetiology lacks consistency. Farming communities across Sri Lanka utilize identical Green Revolution agricultural inputs and pesticide regimens, yet the high prevalence of CKDu remains tightly confined to specific endemic

hydrogeological pockets within the North Central Province (NCP). Consequently, the association presented by Vlahos et al. (2021) reflects a transient environmental occurrence rather than a plausible causal mechanism for CKDu.

Implications for CKDu from the Geomorphology of the Ginnoruwa region

Vlahos et al. (2021) have largely ignored the fact that the wells they have studied are situated in terrain similar to that of Badulupura (which is close to Wilgamuwa, the region of the Vlahos study). The CKDu-affected residents of the Ginnoruwa region live on high ground where the geomorphology differs from that of the areas where there is no CKDu. It is this geo-morphological difference that ensures that there are higher levels of fluoride ions and hardness in the wells located in high ground, unlike the wells located in the lower elevations. The use of water from the latter is not associated with a CKDu risk.

CKDu prevalence may be correlated with the presence of fluoride and Mg, Ca ions in detailed studies. However, even an examination of the local geomorphology, as seen from the map of Ginnoruwa, 15-20 km South-East of Wilgamuwa, studied in Vlahos et al. (2021), is sufficient to bring out a difference between the two areas, of which only one is endemic to CKDu.

As shown in **Figure 1**, Ginnoruwa has three farming villages: Badulupura (B), Dolahekanuwa (D), and Sarabhoomiya (S). All three were settled in the 1980s. However, while most families in B have at least one CKDu patient, those in D and S have virtually no CKDu patients (Balasooriya et al., 2020).

Figure 1 also shows that Badulupura is in rocky high ground where the drinking-water wells are fed from regolith aquifers, while the wells in the CKDu-free low-lying D and S regions are connected with the water table of the paddy fields, as established using isotopic tracer studies (Edirisinghe et al., 2017). The well water in Badulupura (B) contains excessive concentrations of fluoride and magnesium ions (Balasooriya et al., 2020).

Similar excessive fluoride and magnesium concentrations have been found in reverse-osmosis filtration residues in other endemic regions (Imbulana et al., 2020), while no significant agrochemical residues were detected. Combinations of Mg⁺⁺ and F⁻ ions are suspected to synergistically cause CKDu (Dharma-wardana, 2018). So, it is natural to ask if the CKDu-associated wells of the Vlahos study have excess concentrations of Mg⁺⁺ and F⁻.

Results and Discussion

Our critical review indicates that the localized prevalence of CKDu cannot be explained by uniform agricultural pesticide application. On the other hand, there is strong evidence from multiple studies, conducted over many years by different research groups, that correlates the prevalence of CKDu with regional geomorphology and groundwater hydro-geochemistry.

Agrochemical inputs are distributed broadly across both endemic and non-endemic farming zones. However, the incidence of CKDu selectively tracks households relying exclusively on private, shallow dugout wells tapping a specific regolith aquifer matrix.

This geo-morphological dependency is sharply illustrated by the epidemiological divergence between the adjacent villages of Badulupura and Sarabhoomiya in Kebithigollawa. While both communities share identical socio-economic profiles, dietary habits, and agricultural pesticide practices, CKDu is highly endemic in Badulupura but nearly absent in Sarabhoomiya.

Geo-morphological mapping reveals that Sarabhoomiya is situated near natural springs and rapid-flushing drainage paths, whereas Badulupura sits on a low-gradient, high-evaporation terrain underlain by metamorphic bedrock. This setup promotes long groundwater residence times and deep mineral leaching.

The unique crystalline bedrock of the endemic NCP zones accelerates the subsurface weathering of minerals, enriching the dugout well water with elevated concentrations of fluoride (F⁻) ions alongside calcium (Ca²⁺) and magnesium (Mg²⁺) hardness. When ingested, these ions form stable chemical complexes that selectively damage the renal tubules over time. This dynamic directly aligns with the observed tubulo-interstitial pathology of CKDu.

Furthermore, the domestic processing of well water—primarily boiling it for brewed tea or cooking—volatilizes steam-volatile pesticide residues, such as diazinon, drastically reducing human ingestion well below the Admissible Daily Intake (ADI) thresholds.

The lack of corresponding pesticide biomarker data (in blood or urine) in the Vlahos et al. study further weakens the claim that these short-lived agrochemicals reach systemic, nephrotoxic concentrations in the local population. Thus, the spatial clustering of CKDu is fundamentally driven by the interaction between local geomorphology and drinking water hydro-geochemistry, rather than modern agrochemical runoff.

Conclusions

In conclusion, the Vlahos et al. (2021) study, a single-time measurement of pesticide concentrations, is totally inadequate to state anything useful regarding the incidence of CKDu in the North Central Province of Sri Lanka. Furthermore, Vlahos et al. (2021) have not measured in their study or taken into account the fluoride concentrations and hardness of the well water. Both factors are now accepted as being very likely to be linked to the incidence of CKDu in Sri Lanka. As discussed above, therefore, to draw a causal link between “Green Revolution” and its agricultural successes, presumably through the use of agrochemicals (fertilizers, herbicides and crop protection chemicals) and CKDu is unwarranted.

Acknowledgements

The author has no conflict of interest to report. This work was carried out at the National Research Council of Canada, but no specific funding was received for this study. I thank the Editor for improving the manuscript and especially the references section by providing URLs of articles that can be downloaded free of charge for the benefit of the readers.

Literature Cited

- Balasoorya, S., Munasinghe, H., Herath, A. T., et al. (2020). Possible links between groundwater geochemistry and chronic kidney disease of unknown etiology (CKDu): an investigation from the Ginnoruwa region in Sri Lanka. *Exposure and Health*. 12, 823-834 (<https://www.researchgate.net/publication/338000206>).
- Cakici, O. and Çömnden, E. A. (2013). Effects of oral exposure to diazinon on mice liver and kidney tissues: biometric analyses of histopathologic changes. *Analytical and Quantitative Cytopathology and Histopathology*. 35, 7 (<https://www.researchgate.net/publication/235884011>).
- Chandrajith, R., et al. (2011). Chronic kidney diseases of uncertain etiology (CKDue) in Sri Lanka: geographic distribution and environmental implications. *Environmental Geochemistry and Health* 33, 267–278 (<https://www.researchgate.net/publication/46307243>).
- Dharma-wardana, M. W. C., Amarasiri, S. L., Dharmawardene, N. and Panabokke, C. R. (2015). Chronic kidney disease of unknown aetiology and groundwater ionicity: Study based on Sri Lanka. *Environmental Geochemistry and Health*, 37(2): 221–231.

- (<https://www.researchgate.net/publication/264798276>).
- Dharma-wardana, M. W. C. (2018). Chronic kidney disease of unknown etiology and the effect of multiple-ion interactions. *Environmental Geochemistry and Health*, 40, 705–719 (<https://www.researchgate.net/publication/319432328>).
- Edirisinghe, E. A. N. V., Manthrilake, H., Pitawala, H. M. T. G. A., Dharmagunawardhane, H. A. and Wijayawardane, R. L. (2018). Geochemical and isotopic evidence from groundwater and surface water for understanding of natural contamination in chronic kidney disease of unknown etiology (CKDu) endemic zones in Sri Lanka. *Isotopes in Environment Health Studies*, 54(3): 244-261.
- Hettithanthri, O., et al. (2021). Risk factors for endemic chronic kidney disease of unknown etiology in Sri Lanka: retrospect of water security in the dry zone. *Science of The. Total Environment*. 795, 148839. (<https://doi.org/10.1016/j.scitotenv.2021.148839>).
- Hill, A. B. (1965). The environment and disease: association or causation? *Proceedings of the Royal Society of Medicine*, 58(5), 295-300.
- Imbulana, S. and Oguma, K. and Takizawa, S. (2020). Evaluation of groundwater quality and reverse osmosis water treatment plants in the endemic areas of Chronic Kidney Disease of Unknown Etiology (CKDu) in Sri Lanka. *Science of the Total Environment*. 745, 140716.
- Jayasiri, M. M. J. G. C. N., et al. (2022). Spatio-temporal analysis of water quality for pesticides and other agricultural pollutants in Deduru Oya river basin of Sri Lanka. *Journal of Cleaner Production* 330, 129897 (<https://pmc.ncbi.nlm.nih.gov/articles/PMC9306700/>).
- Jayatilake, N., Mendis, S., Maheepala, P., Mehta, F. and CKDU National Team (2013). Chronic kidney disease of uncertain aetiology, prevalence and causative factors in a developing country. *BMC Nephrology*, 14, 180. (<https://www.researchgate.net/publication/265602836>).
- Levine, K. E. et al. (2016). Quest to identify geochemical risk factors associated with chronic kidney disease of unknown etiology (CKDu) in an endemic region of Sri Lanka—a multimedia laboratory analysis. *Environmental Monitoring and Assessment* 188 (9): 548. (<https://www.researchgate.net/profile/Jennifer-Redmon/publication/307622923>).
- Nanayakkara, S. et al. (2011). Tubulo-interstitial damage as the major pathological lesion in endemic chronic kidney disease among farmers in North Central Province of Sri Lanka. *Environmental Health and Preventive Medicine*, 17, 213 (<https://pmc.ncbi.nlm.nih.gov/articles/PMC3348245/>).
- Shiple, E. R., Vlahos, P., Chandrajith, R. and Wijeratna, P. (2020). Agrochemical exposure in Sri Lankan inland water systems. *Environmental Advances*, 7 100150 (<https://www.researchgate.net/publication/356978573>).
- Vlahos, P., et al. (2021). Water sources and kidney function: investigating chronic kidney disease of unknown etiology in a prospective study. *NPJ Clean water*. 4, 50 (<https://www.researchgate.net/publication/356767619>).
- Wasana, H. M. S. et al (2026). Linking groundwater chemistry to bovine kidney damage: A one health perspective on fluoride-DOM-hard water interactions in CKDu-hotspots *Journal of Environmental Management* 404: 129580 (https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5611613).

Opportunities and Management of Water Hyacinth (*Pontederia crassipes* Mart.) in India – An Update

Nimal R. Chandrasena ¹

¹ Current Address: *Nature Consulting*, 17, Billings Way, Winthrop, WA 6150, Australia

Puja Ray ²

² Department of Life Sciences, Presidency University, 86/1 College Street, Kolkata-700073, India

Sushilkumar ³

³ Consultant, Opposite to Sports Club of Jabalpur, Tilhari, Mandla Road, Jabalpur- 482020, India

Nanjapur T. Yaduraju ⁴

⁴ Agricultural Consultant, Paramount Prime Apartments, Yadavagiri, Mysore- 570020, India

Adusumilli Narayan Rao ⁵

⁵ Consultant Scientist (Weed Science), Hyderabad-500033, India

Submitted: 6 June 2026

Accepted: 29 June 2026

Published: 30 June 2026

E-mail: nimal.chandrasena@gmail.com

Abstract

In this article, we provide an update on the status of water hyacinth (WH) infestations in India with a discussion of its history and the problems it causes. In reassessing how best to manage the species, within a sustainable economic framework, we also discuss the future of its local control, as well as its more holistic management, with utilization options clearly in mind. It appears to us that WH is almost *the perfect species* to demonstrate how the strengths of a colonising species can be put to beneficial, societal uses. Given that WH is deeply entrenched in India and never likely to be eradicated because of the vastness of its spread, we also see that India is almost the perfect country to benefit from WH.

Often, the reluctance to utilize WH is based on environmental concerns and the economics of harvesting, transport and processing, which are not trivial. Thankfully, in the last three decades, many technological solutions have been developed to make such processes efficient and economically viable. A vast amount of global literature highlights how WH biomass can be utilized for societal benefits. Therefore, the evidence for integration of WH management with utilization cannot be disputed. Some of the high-end utilization options discussed must move from proof-of-concept research to expedited adoption. Utilization options should balance the arguments about the conflicts aquatic weeds have with human interests. The high productivity, resilience and unique capabilities of WH simply cannot be ignored anymore. It is too valuable a resource not to be utilized further.

Keywords: Water hyacinth; *Pontederia crassipes*; *Eichhornia crassipes*; utilization, colonizing species

Introduction

Historically, water hyacinth [*Pontederia crassipes* Mart.; syn. *Eichhornia crassipes* (Mart.) Solms.] began to cause problems in the waterways of the USA in the 1940s (Penfound and Earle, 1948). The extent of problems caused by water hyacinth (abbreviated to WH from here on) in the USA was so vast that it led to the formation of the *Hyacinth Control Society* in 1961. In 1962, the Society launched the *Hyacinth*

Control Journal, which evolved to be the *Aquatic Plant Management Society* journal (APMS, 1964). In the treatise *The World's Worst Weeds*, Le Roy Holm and others (Holm et al., 1977) listed 76 of the most significant global weedy species. In Holm's list, WH (**Figure 1**) is No. 8 in the order of importance. Unfortunately, looking at species mainly from an agricultural viewpoint, Holm (1969) described many colonising taxa, including WH, as *'terrible villains'* (Chandrasena, 2023).



Figure 1 Water Hyacinth (*Pontederia crassipes* Mart.) of the Family Pontederiaceae ¹

A Conflicted Species

The 'Worst Weeds' listing by Holm et al. (1977) was based on yield losses in major crops that weeds cause. The listing of species, compiled more than 50 years ago, reflects the time when all weedy species were considered 'bad news'. Times have changed, along with concepts related to weed management.

In an early article for *Nature*, a British biochemist, Norman Pirie (Pirie, 1960), highlighted WH's incredible capacity to proliferate and cause economic damage. He was indeed the first to propose that people must learn to 'live with it' and put it to good use. As more and more species are recognized as 'beneficial' from both agro-ecological and societal perspectives, many in Holm's list of 'Worst Weeds' would not be considered particularly harmful in the way they were seen 50 years ago. The evolution of weed control technologies (i.e. herbicides, biocontrol agents and integrated systems) has also enabled managers to 'manage' most species well when they go awry or where their sheer abundance becomes problematic in waterways or in terrestrial situations.

One of the most important questions in *Weed Science* is the vexed issue of 'conflict species'. Many species, derided as 'Invasive Alien Species' (IAS), have undoubted beneficial values and can be bioresources for both humans and animals. This topic has ignited debate as *Invasion Biology* emerged in the late 1990s. Terms, such as 'alien', 'invader' and 'invasion' (*Invasion Biology* lexicon), impede the sensible management of weedy taxa. Instead of deriding species, managing weeds, where they are problematic, should be done with a greater understanding of their strengths and weaknesses and a balanced approach (Chandrasena, 2023).

This article explores the difficulties in managing WH, an undisputedly aggressive, aquatic coloniser, contrasted with the possibilities of putting it to beneficial uses. The issues associated with WH are similar to those of other aquatic species as well. Our focus in the article is India, which has been exposed to WH for more than a century since its deliberate introduction in 1896.

A Colonial Legacy in India

The botanical name of WH - *Eichhornia crassipes* - arose in Europe in the early 19th Century. The name honoured the Prussian Minister of Education, Culture and Medicine - **John Albert Friedrich Eichhorn** (Kitunda, 2018). The name was given by the German botanist, **Karl Friedrich Philipp von Martius** (1794–1868), who made an expedition to the Amazon basin during 1817-1820. On his return, Martius became the curator of the Munich Botanic Gardens.

WH, however, is a colonial legacy of the legendary German explorer, **Alexander Von Humboldt**, who first collected its seeds from the Orinoco River, a tributary of the Amazon, in the 1790s. The French Botanist **Alire Raffeneau-Delile** cultivated it in Egypt in the late 1790s under the auspices of Empress Josephine and Emperor Napoleon. Delile introduced WH to Africa via an expanding French network of Botanic gardens on the continent. Just over 100 years after the introduction in Africa, between 1880 and 1980, WH transformed from a much-admired flower to an economically damaging pest (Kitunda, 2018). Societies began to look at WH as a pernicious legacy of "the white man's burden" to beautify Africa.

The global spread of WH, due to human introductions, was expedited by hydrology changes (flow impediments) and pollution of the waterways.

¹ The Kew Plants Of the World Online: (<https://www.kew.org/plants/water-hyacinth>) accepts WH's name as *Pontederia crassipes* Mart., first collected in Brazil and named by the German botanist **Carl Friedrich Philipp von Martius** (1794-1868) (first published in *Nova Genera Et Species Plantarum per Brasiliam. 1: 9* (1823). In 1883, another German botanist **Hermann Solms-Laubach** (1842-1915) renamed the species as *Eichhornia crassipes* (Mart.) Solms, a name, now considered a synonym (Kew Plant List, 2023).

From an early date, European armies discovered that in addition to its aesthetic value, WH could be a military asset to enhance camouflage on battlefields, especially on waterways. As Kitunda (2018) explains, in the 1850s, a British Agricultural Officer cultivated WH in the Nile River in Egypt. Within 20 years, WH emerged as an ecological disaster affecting the Nile. It then caused a crisis across South Africa in the 1910s, Madagascar in the 1920s, Tanzania, Uganda and Kenya in the 1930s through to the 1970s. In the 1980s, WH bloomed heavily on Lake Victoria, the Nile, the Congo and almost all watercourses of Africa.

The known adverse effects in Africa did not stop the British from introducing WH to India. In India, WH was introduced in 1896, also as an ornamental, grown at the *Royal Botanical Garden, Kolkata*. Within the next 100 years, it spread across the sub-continent, infesting rivers, lakes, ponds, wetlands and irrigation canals, dramatically affecting livelihoods in pre-independent India. WH's impacts on the economy were so huge that by the 1950s, it was called '*The Terror of Bengal*' (Gopal, 1987).

In the USA, in 1975, Vietmeyer called WH the '*Beautiful Blue Devil*'. In an earlier review of WH utilization, Ray and Chandrasena (2015) suggested that WH could also be a '*Cinderella*' depending on one's viewpoint and is the perfect example of the paradox colonising taxa pose to humans. Jeremiah Kitunda (Kitunda, 2018) called it "*the flower of life and death*" and traced how the species spread in the 19th century from the Amazon Basin to the whole of the British Empire. Admiration for the '*enchanting beauty*' of the purplish flower was why it was introduced to various countries via Botanic gardens.

Growth Characteristics

Boyd (1974), Gopal (1987, 1990), Center et al. (1999; 2002), and Coetzee et al. (2017) have reviewed various socio-economic and ecological effects of WH. Other reviews describe WH's growth under varying conditions (Center and Spencer, 1981; Wilson et al., 2007; Gunnarsson and Peterson, 2007) and its reproductive biology (Zhang et al., 2010).

WH's exceptional success as a species is due to its capacity for clonal growth, producing ramets vegetatively, allowing populations to rapidly expand (Figure 2). Under high sunlight, temperatures around 28-32 °C and nutrient-rich water, WH populations can double in 8-10 days through clonal growth. In addition, WH can produce up to about 5000 seeds in one inflorescence, and usually, there are several such inflorescences per plant. Large root masses, bulbous petioles and stolons characterize a mother rosette, which has several ramets attached to it.

High rates of photosynthesis and growth under favourable conditions characterise WH. Its unique morphology (gas-filled air chambers in roots, leaves

and stolons) also allows for high gaseous transport of O₂ and CO₂. The factors limiting WH's growth in a waterbody are space, salinity, temperature, nutrients, disturbances and natural enemies (Wilson et al., 2007). Low levels of phosphorus (P) can also be a limitation for WH's expansive growth.

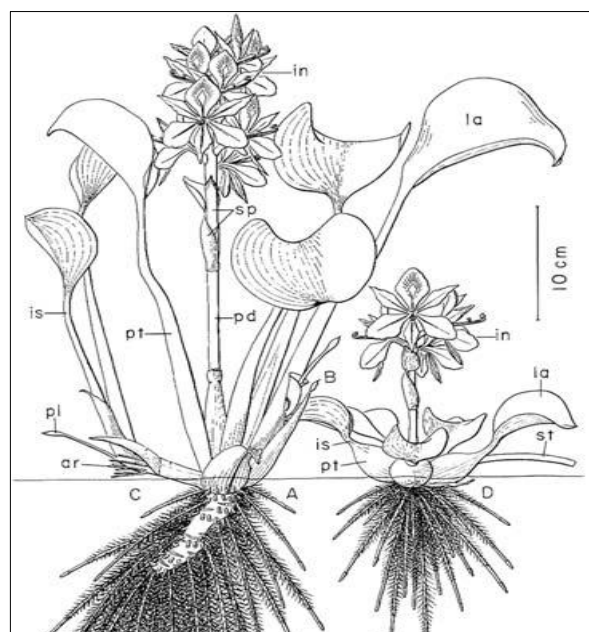


Figure 2. Morphology of *Pontederia crassipes* floating plants (From Center et al., 2002)

[A: the petiole-rosette form produced in crowded conditions; B: an expanding axillary bud; C: a developing ramet; D: bulbous-petiole rosette form produced as an offspring in open water conditions.

Abbreviations: ar—adventitious root; bb—bud bract; in—inflorescence; is—leaf isthmus; la—leaf blade; pl—primary leaf; pd—peduncle of flower spike; pt—petiole; rh—rhizome; st—stolon]

WH also shows high genetic diversity in its native range, although it is largely genetically uniform in much of the introduced range, resulting from genetic bottlenecks and the rarity of its sexual reproduction (Barrett, 1980; Zhang et al., 2010). Da Cunha et al. (2022) recently confirmed the high heterozygosity in the WH genome but low genetic diversity in its native range (Brazil). This finding, however, contrasts with the closely related 'anchored' WH (*Pontederia azurea* Sw.), which is also a floating aquatic with clonal growth. With extensive rhizomes and roots, *P. azurea* differs from *P. crassipes* by being attached to sediment, although it can also form large 'floating' colonies at the edges of water bodies.

Nonetheless, even without much genetic diversity, in the introduced regions, WH can tolerate a broad range of adverse conditions in water. The basis of its high tolerance of a range of pollutants in water is uptake and sequestration in roots or shoot tissues. The species can also resist pressure from herbivores, pests and diseases simply by the sheer biomass it produces, complemented by fragmentation.

Negative Effects

WH's globally recognised negative effects include blocking navigation and fishing, causing biodiversity losses, oxygen depletion in water, and fish kills when large infestations decay. Infestations also harbour mosquito breeding grounds, leading to an increase in vector-borne diseases, such as schistosomiasis and bilharzia in Africa. In addition, WH infestations also shelter rodents and other pests (Gopal, 1987; 1990; Nega et al., 2022). However, the scale of these effects depends on the size of the infestations and how the mats are distributed over water surfaces.

Villamagna and Murphy (2010) showed that the negative effects of WH are often non-linear to the infestation size. For instance, they found that the abundance and diversity of aquatic invertebrates generally increase in response to increased habitat heterogeneity and structural complexity provided by the large mats and root masses of WH but decline due to decreased phytoplankton (food) availability.

WH's adverse effects on fish depend on the fish community. Floating mats of WH usually harbour copious phytoplankton and invertebrate communities, which increase fish abundance. However, the opposite effect could also occur, especially with planktivorous fish. For instance, a decline in phytoplankton, due to the water surface being covered by WH mats, could have flow-on effects on higher trophic levels. With waterbirds, Villamagna and Murphy (2010) recorded an increased abundance likely related to the availability of fish and macroinvertebrates, particularly when WH infestations were at moderate levels.

Global Spread of WH

WH's native range extends from the Amazon Basin and rivers to Venezuela, Peru and even Jamaica (Kitunda, 2018). From its native range, it did not take much for this South American species to spread globally with the help of its human ally. The first record of WH outside South America was from a trade fair in New Orleans in 1884 (Penfound and Earle, 1948). Thereafter, WH spread around the USA and other countries. Introduced by the nursery trade, WH has now become deeply entrenched in Asia, South-East Asia, Papua New Guinea, Australia, almost all Pacific Islands (Oceania), almost the whole of Africa, several Mediterranean countries (Spain, Portugal, Italy), Central America, the Caribbean islands, and most tropical parts of the USA.

This global spread and pantropical distribution occurred within just over 200 years after it was 'moved' from its home base in Brazil to tropical regions. This distribution is primarily between 40° North and 45° South, including India. In addition, WH occurs as a 'casual' in several European countries

with quite cold temperate climates, e.g. Belgium, Germany, the Netherlands, the U.K., Hungary, Romania and the Czech Republic (Coetzee et al., 2017). The heaviest of WH infestations occur in tropical climates (between 28°C and 32°C).

In India, WH ceases growth when the temperature drops below 10°C. However, WH tolerates a range of temperatures, lighting conditions, pH, drought and salinity (Gopal, 1987). As an erect, stoloniferous, perennial, WH can grow up to 1 m in height. The buoyant leaves allow it to stand erect and form dense mats. This morphology, however, varies according to conditions. Genetic polymorphism has led to tristylism in WH (Barrett and Forno, 1982). Of the three style lengths, in the native Amazonian basin, the short style (S-morph) predominates. However, in introduced areas, including India, the long (L-morph) and middle-length style (M-morph) are found (Barret, 1992).

Water Hyacinth in India

Historical Knowledge

The historical overview of WH in Colonial Bengal (ca. 1910-1947), provided by Iqbal (2009), citing Chaudhuri (1936) and MacLean (1922), shows that in the 1920s and 1930s, WH covered an area of over 4000 square miles of the active Delta of East Bengal (an area of ca. 35,000). During this period, the annual damage attributed to WH in Bengal was estimated at more than six crore (60 million INR).

A direct link between food, clean water, diseases and human and animal health was also drawn with WH infested waterways in Bengal during and after *World War I* (Iqbal, 2009). During *World War II*, crop failures in Bengal were also attributed to the myriad problems caused by WH. It has been suggested that WH contributed to the great *Bengal Famine* (1943-44), which killed about three million people.

A second historical aspect of WH's rapid spread in India was the promotion of its growth by *Shaw Wallace*, a Company that provided a range of goods and services to the colonial rulers. After *World War I*, the Company wanted to produce ash from WH, which contained ca. 15% potash that could be used as fertilizer (MacLean, 1922). Global access to potash had been severely limited by the War. The Company offered the Bengali Government INR 84 to 112 per tonne of unadulterated WH ash. While the original scheme failed (Iqbal, 2009), this history shows that since 1918, it might have led to people deliberately cultivating WH in Bengal for harvesting.

The rapid spread of WH in India, and elsewhere, is due to its extraordinary capacity to reproduce fast by vegetative and sexual methods. The species is insect-pollinated. In India, a single plant can produce a few thousand to 5000 seeds, which can remain viable in mud for up to 20 years. Even without seeds, WH can

rapidly multiply. Gopal (1987) reported that two plants of WH could produce 30 offspring in 23 days and multiply to 120,000 in 120 days. Under ideal conditions, a doubling of WH infestations could occur in just 10 days. Severe infestations could reach up to 450 tonnes (wet weight) per ha.

Current Distribution in India

WH now occurs throughout India in small, medium or large freshwater lakes and reservoirs, lagoons, estuaries and wetlands, as well as streams, rivers, irrigation canals and paddy fields in most cities and villages (**Table 1**). The Table was constructed after a Questionnaire Survey of various weed research contacts in the different States and Union Territories through the ICAR-ARCIP-WM Network and the responses received. Information was also based on

various articles cited in Indian references (cited herein), abundant news media reports and on the authors' personal knowledge. Everywhere it has been found, especially on various large river systems, tributaries, lakes and wetland sites, some of which are protected by the RAMSAR convention, WH has been recorded as an aggressive coloniser.

In most Indian situations, there is sufficient water throughout the year to sustain WH populations. However, in drier situations, WH converts from an aquatic habit to a terrestrial one and survives. It has been estimated that in different States, ca. 20-25% of the total usable water surfaces are infested with WH, while in the States of Assam, West Bengal, Orissa and Bihar, the levels of infestation were much higher (Gopal, 1987; 1990; Sushilkumar, 2011a).

Table 1. Major Waterbodies, Rivers and Waterways Infested with Water Hyacinth in India *

State/Union Territory (UT)	Presence and extent	Responses on WH Occurrence and Locations
Andhra Pradesh	Widespread	Kolleru Lake, Sarvepalli Reservoir, Nellore Tank, Pynapuram Tank, Pennar Barrage and Nellore Water Supply Canal in Nellore District.
Andaman & Nicobar (UT)	Localised	Various freshwater ponds and streams on the islands.
Arunachal Pradesh	Widespread	Various small, medium, and large waterbodies.
Assam	Widespread	Bhadreti Lake, Deepor Beel Lake (Ramsar Site); widespread in most of the village ponds and Brahmaputra floodplains.
Bihar	Widespread	Ganga's tributaries, oxbow lakes (chauris), Moti and Kararai Lakes, Motihari and various small, medium and large waterbodies, Kusheshwar Sthan Lake (Darbhanga), Gogabill Lake (Kathihar).
Dadra & Nagar Haveli Daman & Diu (UT)	Widespread	Daman Ganga River network.
Chandigarh (UT)	Widespread	Various small, medium, and large waterbodies.
Chhattisgarh	Localised+	Arpa River, Dlapat Sagar Reservoir; Tandula River in Balod District.
Delhi (UT)	Widespread	Okhla Bird Sanctuary, Yamuna River.
Goa	Widespread	Mapusa River; Vast tracts of fields between Ambaji & Davondem, River Sal.
Gujarat	Widespread	Bilmora Lake; Sabarmati River, Bhadreti Lake; pond next to Bedi Marketing yard; Wier-Cum causeway – Surat; Tapi; widespread in city and village ponds.
Haryana	Widespread	Bhindawas Lake (Ramsar site, severe infestation); Ottu Lake (heavy infestation); widespread in city and village ponds.
Himachal Pradesh	Widespread	Widespread in all waterbodies; Nurpur Raja ka Talab reservoir.
Jharkhand	Widespread	Jamshedpur: in all rivers and tributaries, small and large water bodies.
Karnataka	Widespread	Bangalore: Doddabommasandra, Yelahanka, Jakkur, Rachenahalli, Nagavara and Hebbal, Bellandur Lake, Ulsoor Lake; Mysore: Karanji Tank; Kukkarahalli Lake; Dharwad: Unkal Lake; Uttara Kannada - Halyal Lake.
Jammu & Kashmir (UT)	Widespread	Dal Lake; various small, medium and large waterbodies (Azim, 2026; Srinagar, Dal Lake (personal communication – see later). Not present at higher altitudes.
Kerala	Widespread	Kuttanad, Alappuzha, Aleppy, Alappuzha-Changanassery canals, backwaters of Kumarakom, Vellayani Lake, Lake Vembanad (Ramsar site), Ashtamudi Wetland (Ramsar site); Sasthamkotta Lake, Thannermukkom Salt Water Barrier; all major rivers (Bharathapuzha, Periyar, Pamba).
Ladakh (UT)	Absent	No infestation reports due to cold, high-altitude desert climate.
Lakshadweep (UT)	Absent	No infestation reports as it does not have freshwater rivers or natural lakes — only small brackish ponds and groundwater lenses are present.

Table 1 (Continued). Major Waterbodies, Rivers and Waterways Infested with Water Hyacinth in India

State/Union Territory (UT)	Presence and extent	Responses and Comments on WH Occurrence and Locations *
Madhya Pradesh	Widespread	Kotwal and Piluwa dams, Bhind; Tikamghad; Ranital pond and Mahanadda pond, Jabalpur; Machan River in Betul district of MP; Sarni reservoir; city ponds in Khandwa, Bhoj Wetland (Ramsar site), Sakhya Sagar (Ramsar site), Sirpur Wetland (Ramsar site), widespread in village ponds and canals.
Maharashtra	Widespread	Mithi River, Mumbai; Panchaganga River, Kolhapur; Powai Lake, Bombay; Mula River at Holkar bridge in Pune; Salim Ali Lake, Ujani Dam.
Manipur	Widespread	Lamphelpat wetland in Imphal, Lkop lake, Loktak Lake (Ramsar site), Pumlane Lake.
Meghalaya	Widespread	Varioius wetlands, Betasing region of South Garo Hills.
Mizoram	Localised	Tam Dil Lake, Saitual Sub-division, Aizawl District, Palak Dil (Pala Tipo)
Nagaland	Widespread	Various small, medium and large waterbodies and canals.
Odisha	Widespread	Ansupa Lake, Bhitarkanika Mangroves, Bindo Sarovar in Bhubaneswar, Chilika Lake (Ramsar site), Hirakund Reservoir, Mahanadi River.
Puducherry (UT)	Widespread	Various small, medium, and large waterbodies and canals.
Punjab	Widespread	Sutlej River, Kanjhli Wetland (Ramsar site, 90% covered); Old Bikaner Canal; Harike Wetland (Ramsar site), Ropar Wetland, widespread in irrigation canals.
Rajasthan	Localised	Keoladeo National Park, Pichola Lake, Talkatora Lake.
Sikkim	Not reported	No published reports of WH infestation, possibly due to predominantly high-altitude, cold-temperature terrain, which limits establishment of WH.
Tamil Nadu	Widespread	Sembakkam Lake (a 100-acre water body completely choked with WH); Bhavani River, Kaveri River, Amaravati and Valgai reservoirs.
Telangana	Widespread	Hussainsagar and several large lakes and reservoirs; various small and large water bodies, and canals in Hyderabad.
Tripura	Widespread	Rudrasagar Lake (Ramsar site), Dumboor Lake.
Uttar Pradesh	Widespread	Gomati River, various water bodies in most cities, towns and villages.
Uttarakhand	Localised	Asan Barrage / Asan Conservation Reserve (Ramsar site), Giritaal lake, Niranjanpur pond, Naini lake, Bhimtal.
West Bengal	Widespread	River Panchaganga, Hooghly River system, East Calcutta Wetlands (Ramsar site), Kusheswar Asthan, Kursaila and Daini Wetlands, and in various waterbodies in most towns and villages.

*Table 1 was compiled through a structured review combining peer-reviewed literature on WH distribution in India, official wetland and Ramsar Site management reports, and contemporaneous news media coverage of infestation and control efforts across Indian States and Union Territories. Records are current as of June 2026. Where no documented record of infestation could be located for a given State/Union Territory, this is indicated as “Not reported” (absence of evidence, no confirmed absence); where ecological constraints (e.g., cold climate, lack of freshwater habitat) make establishment of WH highly improbable, the entry is instead recorded as “Absent”.

Losses Caused by WH in India

WH infestations can have major environmental and socio-economic effects in India, as was reported 100 years ago (Iqbal, 2009; Gopal, 1987). These include all the effects previously mentioned from the global literature (see *Negative Effects*). Other harmful effects include increased evapo-transpiration water losses, making fertile land near waterways unproductive, increased flooding risk due to blockages in canals, reducing water flows in water supplies to hydroelectric power stations, as well as blocking irrigation canals (Sushilkumar, 2011a, b; Ray and Chandrasena, 2015). Added to these are effects, such as reduced quality of drinking water and an increase in disease vectors (i.e., mosquitoes); increased health problems in infested regions (i.e.,

malaria, cholera and diarrhoea) and the decline in bird populations at wetland sites.

Where WH dominates and suppresses the available habitat and ecological niches of other aquatic life-forms, it disrupts critical plant-animal-environment interactions. The displacement of native plants adversely affects epiphytic, microbial, macroinvertebrate and phytoplankton communities. Fish kills have also been attributed to oxygen depletion, which occurs when large WH biomasses decompose in water (Ray and Chandrasena, 2015).

Reduced biodiversity in aquatic ecosystems, often claimed in literature as caused by WH infestations, could be due to obstruction to sunlight penetration. Decreased growth and productivity of phytoplankton could also occur under WH infestations, although there are no data available on direct measurements of these effects (Kato and Kato-Noguchi, 2026).

The rate of water loss from surfaces covered by WH, due to evapo-transpiration, is very high. In an early estimate, Van der Weert and Kamerling (1974) showed that water losses were 44-48% higher in a WH-covered lake in Surinam compared with open water. However, estimates vary greatly depending on waterway conditions and environmental factors (viz. humidity, sunlight, temperature and rainfall) (Lallana et al., 1987). Based on values in the literature (not fully discussed here), we contend that a WH-covered waterbody would lose water at a rate 3 to 6 times higher than that of open water. These are highly significant, especially in irrigation canals, some lakes and wetlands and drinking water supply reservoirs.

Our review finds that although the economic impacts of WH infestation are evident in India, they have not been comprehensively quantified at the national scale. Most Indian studies are limited by site-specific, subjective and qualitative assessment. Some studies are livelihood-focused, rather than providing monetary loss estimates attributable to WH.

In the State of Kerala (38,400 km²), where the WH problem is most intense, major sectors of the economy (transport, tourism, navigation, fisheries, agriculture, production and trade of other goods) are affected but not quite quantified in economic terms. Sasidharan et al. (2013) reported that high degrees of

nutrient pollution in water, viz. nitrates, nitrites and phosphates arising from agricultural runoff, sewage and industrial effluents, contribute to the prolific growth of WH across the State. More than 75% of waterbodies in Kerala are infested with WH, making large areas non-navigable and uncultivable.

As shown in a recent photo (**Figure 3**), a vast area of canals and waterbodies in the Central Kerala districts (Alappuzha, Ernakulam and Thrissur) is affected by WH infestations. WH infests rice fields, lakes, streams and canals, making large areas inaccessible, non-navigable and uncultivable. An estimated six lakh tonnes of cargo are moved every year using inland waterways in Kerala, which are seriously affected by WH, causing economic losses.

In Kerala backwaters, WH expands at the end of the rainy season when water bodies are less salty. Infestations disappear as rainfall decreases and water becomes saltier. However, during the time of its spread, WH disrupts navigation, bringing movement of both cargo and people to a halt (**Figure 3**), as boat engines are choked, especially during the opening months of the tourism season. The economic costs of these effects can only be surmised as substantial, although they have not been properly quantified.



Figure 3. Canals in Kerala, completely choked with WH, affecting tourism (Photo published on 16 March 2026) ²

One estimate, made more than 15 years ago, showed that of the 8 lakh ha of freshwater (8000 km²) available in India for aquaculture, ca. 40% has been rendered unsuitable for fish production, because of WH infestations. Most inland fishery reservoirs, in and around Bangalore and other major cities, have been badly invaded by WH. In West Bengal, WH created havoc in the State's fisheries, drinking water supplies, irrigation canals and rice fields. In Palta (West Bengal)

and Baranagar (Telangana) waterbodies, WH and *Lemna* spp., along with some mollusc species, blocked water pipes (Sushilkumar, 2011a).

Climate Change Effects on WH

An increase in CO₂ produces an increase in net photosynthetic rates of many plants, especially those with C₃ photosynthesis (Leakey et al., 2009). WH is a C₃ plant. Unlike the shade-tolerant, submerged

² Mathrubhumi E-Newspaper (<https://english.mathrubhumi.com/technology/science/water-hyacinth-impact-kerala-backwaters-video-euqguqjk>).

macrophytes, WH thrives on water surfaces with the capacity to utilise full sunlight for photosynthesis.

Studies conducted by Liu et al. (2010) using WH and two CO₂ concentrations (380 and 600 ppm) and four nutrient levels showed that in two months, growth was enhanced under nutrient-rich conditions. CO₂ enrichment increased the number of leaves per ramet and leaf area index of WH, but did not significantly increase leaf size or the number of ramets formed.

Root growth and assimilate allocation to leaves also greatly increased under high nutrient levels. The growth response proved that under elevated CO₂, the nutrients absorbed were mostly transferred to offspring ramets rather than maintained by the mother ramet. Such responses would benefit the plant's vegetative reproduction and the uptake of nutrients and other pollutants (Liu et al., 2010).

Water Hyacinth Management in India

A review of global literature, dating back to the 1940s, shows that for decades, the management of WH has been affected by local environmental and social conditions, as well as societal values and economic returns that are not always profitable (Mara, 1976). *In terms of adverse effects on the local environment and management costs, no other species is of greater concern globally.* Therefore, it is necessary to shift the emphasis from a simple, control-oriented mindset to a more holistic management. In such an approach, beneficial utilization of WH has to be a priority, although this requires a re-evaluation of the costs vs. benefits in terms of ecological and environmental costs, as well as the social services WH can provide.

Preventative measures

Prevention plays a key role in keeping WH from spreading. In India, as in other countries, wire mesh barricading at several locations of a water flow pathway is used to reduce WH entry into other waterways. Continuous removal of small pockets of WH from the edges of water courses is also crucial in the preventative approach, recommended in India (DWR, 2019). DWR's research has shown the success of prevention, as in the case of WH management in Tikamgarh in Madhya Pradesh and in the Kharkai River at Jamshedpur in Jharkhand.

One case study, documented from the Kharkai River, showed how effective prevention can be even in a large river. The Kharkai used to be infested up to several km every year during summer, resulting in increased cases of malaria, dengue fever and other problems. Responding to public complaints, the municipality took management action. The river water

usually stagnates in stretches after the monsoon rains in January. During the next few months, WH propagules germinate in such river reaches from buried seeds produced during previous years and clonal growth. The removal of the newly 'germinated' crop of WH offspring arrested its further proliferation (Sushilkumar – *personal observations*).

At many places, heavy iron mesh was installed to stop WH spreading from one part of the river to other parts. Teams of municipal labourers physically removed emerging WH colonies. This simple preventative approach arrested WH proliferation in the following summer. However, the case study showed how intensive the management effort required was. Nevertheless, the cost of implementation of the preventative programme was estimated at only 10% of the likely economic cost had WH covered the entire water surface of the river reach (Sushilkumar, 2011b).

Physical Removal

The main options for managing WH infestations at many locations include removal either by hand or by machinery. Both are most effective for small infestations, but are unsuitable for large infestations over large areas or in large canals. Medium- or large-sized aquatic weed harvesters have been available for more than six decades for the mechanical removal of WH. These machines were initially developed in the USA to tackle vast infestations in Florida. Newer designs of harvesters then came about and have been effectively deployed in India (**Figures 4-6**).



Figure 4. WH harvesting in Kerala (source: Matprop <https://matprop.in/water-resource-restoration-program/>)

However, with mechanical removal, disposal of large quantities of the biomass is a major obstacle, because of adverse effects on the banks of canals, dams and rivers and the costs involved.

In India, surveys indicate that manual removal of WH is the commonest form of control used in all States. However, labour is expensive, and the task is tedious. In small waterbodies, small-to-medium-sized excavators are used effectively, occasionally combined with a conveyor belt and locally modified

lifting equipment. Often, the disposal of manually or machine-removed WH biomass is a significant problem for authorities.



Figure 5. Water Hyacinth harvesting in a Kerala canal (source: Pendse and Deshmukh, 2023)



Figure 6. Large biomasses of harvested WH pose a problem unless used as a bioresource (source: Pendse and Deshmukh, 2023)

Water weed cutters and harvesters are also used in India, although their success for WH management depends on the frequency and intensity of use. It is also known that if not properly conducted, mechanical harvesting may even aggravate a local WH problem by fragmentation and spreading of propagules. If machines are not properly cleaned after operations,

contaminated mud could also spread WH from one location to another (Sushilkumar, 2011a).

Herbicides

Since the 1960s, herbicides, such as 2,4-D amine and ester, diquat, paraquat, glyphosate and metsulfuron, have been used in many countries to reduce WH infestations. While multiple and multi-year treatments are essential for long-term control, these herbicides do provide short-term relief. However, in India and many other developing countries, WH-infested sites are also used for drinking water, washing and fishing. This means that the use of herbicides at such sites may pose a public health risk (Center et al., 1999). It is also known that repeated treatments and the killing of large WH biomasses could adversely affect water quality, other vegetation and non-target organisms in aquatic environments.

In India, only three formulations of the auxin herbicide, 2,4-D (2,4-dichloro-phenoxy acetic acid; amine salt, sodium salt and ethyl ester) have been registered for use against WH (Choudhury, 2019). However, research trials have been done by different groups with paraquat dichloride, glyphosate and metsulfuron as potential candidates. Some of those formulations do not yet have aquatic registration in India and have only been used in trials.

Sushilkumar (2011b) reported that 2,4-D amine (2.0 kg ha^{-1}) was the best herbicide to control WH (98%), followed by glyphosate 2.5 kg ha^{-1} (96%) and paraquat 1.0 kg ha^{-1} (93%). Tank mixes of paraquat (0.3%) and 2,4-D amine (0.3%) were effective in managing WH at Dolon Village (Ludhiana). The studies (Table 2) noted that while these herbicides were effective on WH and economical to use, they may have potential undesirable effects on non-target organisms and water quality.

Table 2. Herbicides used for Water Hyacinth control in India

Herbicide	Rate	Comment	Source (Reference)
2, 4-D Amine salt (58% SL)	$1.0\text{-}2.0 \text{ kg ha}^{-1}$	• Provided ca, 75%-82% control at 25-30 DAT	Pradhan and Sushilkumar, 2019
2, 4-D Ethyl Ester (38% EC)	2.5 kg ha^{-1}	• Provided 88-93% control up to two months after application.	Yadav and Yadav, 2010
2,4-D Na salt (80% WP)	1.5 kg ha^{-1}	• Severe reduction in density after 21 days; Almost 100% kill at 35 DAT	Kathiresan and Deivasigaman, 2015
Paraquat	$1.0\text{-}2.0 \text{ kg ha}^{-1}$	• Severe reduction at 21 DAT, but WH showed regrowth after 3 months.	Sushilkumar, 2011b
		• 62-68% control of WH, but longer persistence limits its suitability	Pradhan and Sushilkumar, 2019
Glyphosate	2.5 kg ha^{-1}	• 90-100% control at 35 DAT	Kathiresan and Deivasigamani, 2015
	2.0 kg ha^{-1}	• 75% control at 21 DAT	Sushilkumar, 2011b
	$1.0\text{-}2.0 \text{ kg ha}^{-1}$	• 81-86% control at 25-30 DAT	Pradhan and Sushilkumar, 2019

Notes: Days after treatment (DAT); SL – Soluble Liquid; WP – Wettable Powder; EC – Emulsifiable Concentrate

Kathiresan and Deivasigamani (2015) concluded that 2,4-D sodium salt, glyphosate and paraquat offered efficient WH control, which was unaltered by the seasons (**Table 2**). However, their study noted undesirable effects, which included fish mortality and changes in water quality. Of the herbicides, glyphosate was the safest in terms of adverse effects, while also being the most effective in WH control. Pradhan and Sushilkumar (2019) also showed how 2,4-D, paraquat or glyphosate could be integrated with manual and mechanical control to control large infestations cost-effectively.

A recent study by the *Saguna Rural Foundation* (SRF), an NGO (SRT and SRF, 2021), reported that glyphosate was successfully applied by a drone to control large infestations of WH in the Ulhas River in the Thane District (Maharashtra) (**Figure 7**).

Analyses showed that glyphosate treatments did not leave any residues in the water, and the herbicide would be safe to use. WH in the treated areas collapsed over a short period, clearing the river reaches that were treated. **Figure 8** shows the use of a drone to treat a large lake in Telangana with a bioherbicide (not stated) and an anti-larval agent (Priya, 2019), which was claimed to be successful.



Figure 7. Drone spraying glyphosate in the Ulhas River control programme, 2021



Figure 8. A lake in Telangana, choked with WH and treated with a bio-herbicide and an anti-larval agent using drones. The project attempted to reduce the incidence of mosquito-borne diseases (Priya, 2019)

Despite the reported success with glyphosate, it is not approved for aquatic use in India. The *Central Insecticide Board & Registration Committee* (CIBRC) restricts glyphosate solely to terrestrial uses, such as in tea and weed control in non-crop situations. Also, several Indian States, including Kerala, have banned its use to protect water sources, which poses an obstacle for weed managers. Public opposition to glyphosate use is also very high in India, as shown by a spate of recent articles (Lele et al., 2025).

Biocontrol Agents

Biocontrol has long been the favoured method for WH control, with several agents released over the past 50 years. Biocontrol research began in the USA in 1961, and the first control agents were released in Florida in 1972. Of the agents, the most successful are the two Coleopteran weevils, *Neochetina eichhorniae* and *Neochetina bruchi* and the pyralid moth *Niphograpta albiguttalis* (Warren) [Lepidoptera]. These agents are well established in many countries where WH bio-control has been implemented (Wilson et al., 2007; Coetzee et al., 2017).

However, the insect agents do not wholly kill WH shoots, but cause varying degrees of leaf mortality. Adult weevils, feeding on leaves, and larvae tunnelling through petioles and meristematic tissue in the crown of the plant, can cause damage, preventing populations from expanding.

In addition to insects, several fungal pathogens have also shown promise against WH (Charudattan, 2001). Among the most promising fungal pathogens of WH are: *Uredo eichhorniae* Fragoso and Ciferri, *Acremonium zonatum* (Sawada) Gams, *Alternaria eichhorniae* Nag Raj & Ponnappa, *Cercospora piaropi* Tharp, *Cercospora rodmanii* Conway, *Myrothecium roridum* Tode and *Rhizoctonia solani* J. G. Kuhn. All of these pathogens are present in different continents and can be developed further against WH for use in the future (Ray and Hill, 2012).

In India, the available biocontrol agents of WH are summarised in **Table 3**. However, research shows that it takes a long time (20-36 months after the introduction of an agent) to control one cycle of WH. Nevertheless, the Coleopteran weevils, *Neochetina bruchi* and *N. eichhorniae*, have successfully cleared WH from many aquatic bodies (Jayanth, 1988; Ray et al., 2009; Sushilkumar, 2011a, b; 2022). The Indian experience is that after the release of bioagents in a water body, biocontrol of WH may occur in 4-5 cycles in a span of 5-7 years (Sushilkumar, 2022).

Once the infestation of WH becomes weak after 2 to 3 continuous cycles, the space and ecological niche vacated by the WH due to its suppression by the weevils could be taken up by other strongly colonizing species, such as alligator weed [*Alternanthera philoxeroides* (Mart.) Griesb.], water lettuce (*Pistia*

stratiotes L.) or salvinia (*Salvinia molesta* D. S. Mitchell). Such weed succession has been observed to occur in water bodies in India, unless those species are also managed at the early infestation stages.

Broadly, as in large African lakes (Opande et al., 2004), in many situations in India, especially in the extensive infestations, such as in Kerala, WH control by biocontrol agents is often inadequate and short-lived. In Kerala, even high numbers of weevils per

plant (5-7) were not able to kill WH completely, although weevil foraging reduced flower production drastically (Sushilkumar, 2011a;b). The bioagents are usually successful only in perennial waterbodies where water remains throughout the year. In contrast, they usually do not work in rivers and canals, where, during floods after the monsoon, all the WH gets washed away with the available weevil populations.

Table 3. Biocontrol agents in India used against Water Hyacinth

Biocontrol Agent	Comments	Source
Arthropod herbivores		
Mites - <i>Orthogalumna terebrantis</i> Wallwork (<i>Acarina: galumnidae</i>)	• Considered to be safe for field release in India.	Jayanth et al., 1988
	• Injurious effects involved leaf mining by the larvae (instars), leading to leaf wilting and reduced dry weight.	Haq and Sumangala, 2003
Weevil - <i>Neochetina bruchi</i> Hustache (Coleoptera: Curculionidae)	• Adults feed on leaves; larvae bore into petioles/rhizomes. Well established on WH in different parts of the country, achieving good control of WH along with <i>N. eichhorniae</i> .	Jayanth, 1988; Ray et al., 2009; Sushilkumar, 2011a, b, 2015
Weevil - <i>Neochetina eichhorniae</i> Warner (Coleoptera: Curculionidae)	• Adults feed on leaves; larvae tunnel into petioles and root crowns, disrupting vascular tissue. Well established throughout India. It is successful in stagnant ponds and lakes but not effective in running water, such as a river.	Ray et al., 2009; Sushilkumar, 2011a, b, 2015
Plant hopper - <i>Megamelus scutellaris</i> (Hemiptera: Delphacidae)	• Recently brought by DWR, Jabalpur, from South Africa for host-specificity testing against WH. The bioagent is under trial at the quarantine facility of ICAR-National Bureau of Agricultural Insect Resources (ICAR-NBAIR), Bengaluru	Archana Anokhe, 2026 (personal communication)
Fungal pathogens (Ascomycetes)		
<i>Fusarium oxysporum</i> Schlecht.	• Causes vascular wilt by colonizing xylem and producing fusaric acid and other phytotoxins. Showed good results within 10-15 days of application with good future prospects.	(Dutta et al., 2023), Pathak and Kannan, 2011
<i>Fusarium roseum</i> (Link) Snyder & Hansen		
<i>Alternaria japonica</i> Yoshii	• Causes leaf spot and blight in WH, which was the only species strongly susceptible to spore suspension (5×10^5 conidia/ml) of <i>A. japonica</i> . Needs further research.	Dutta et al., 2015
<i>Alternaria alternata</i> (Fr.) Keissler	• Causes leaf spot and blight, followed by dieback disease in water hyacinth	Aneja and Singh 1989, Ray et al. 2008, Dutta et al. 2015

Integrated Control

As reviewed recently by Su et al. (2018), Pin et al. (2021), Udume et al. (2021) and Nega et al. (2022), none of the physical, biological and chemical control methods, applied alone or in combination, have been successful in any country that has been affected by WH except at a very local level and small scale. This is indeed the primary reason why we should 'rethink' the WH control strategies and include WH utilization and product valorization as an integral part of future WH management (Karouach et al., 2022).

In India, limited attention has been paid towards studying the responses of herbivore insects on WH plants treated with sub-lethal doses of a herbicide. In one study (Sushilkumar, 2011b). The integration of herbicides with the bioagents resulted in control of two cycles of WH within a period of 21 months after the

initial release of weevils, whose application alone would have taken 2-3 years to control one cycle of WH. This integrated approach also drastically reduced the herbicide load in the waterbody.

Charudattan (2001) had already reported that the integration of the fungal pathogen *Cercospora rodmanii* with natural populations of *N. eichhorniae* and *N. bruchi* provided complete control of WH, while combinations of *C. rodmanii* with low rates of 2,4-D and diquat also showed compatibility.

However, a study in South Africa (Katembo et al., 2013) showed that a sub-lethal dose of glyphosate (8% of the lethal dose of Monsanto's 'Round-Up', 360 g a.i. L⁻¹) on WH resulted in a decrease in leaf N content of the treated infestation but had no effect on its C content. Thus, glyphosate sub-lethal treatments increased the leaf C: N ratio, but the reduced N content did not alter the weevil's feeding behaviour. The findings demonstrated the potential for

integrating control with the Coleopteran weevils and glyphosate, where the weevil population needs to be conserved. By taking out the centre of a WH infestation with a lethal dose of glyphosate, the borders are likely to receive spray drift at a sub-lethal dose, which will retard WH growth while providing a refuge for the weevils (Katembo et al., 2013).

The trials at DWR, Jabalpur, for the integration of *Nechoetina* spp. and the fungus *Alternaria alternata* showed that the fungus alone was not effective on WH. However, it enhanced the biocontrol efficacy of *Nechoetina* spp. In either a one-time treatment or several monthly treatments, the fungus was ineffective if applied alone. However, when the fungus was applied with the weevil, flower production in WH was considerably reduced due to their combined effect (DWR, Annual Report, 2019).

In other 'integrated control' studies, the manual-cum-mechanical removal of WH had a higher cost because of labour hire but gave the highest weed control efficiency (WCE) of 81-92%. Glyphosate (2.0 kg/ha) was the most cost-effective (84-86% control) with a cost of INR. 18,080 to 19,660 ha⁻¹. Applying the herbicide over the WH floating weed mat loosened it significantly, which led to its efficient removal, manually or mechanically, 25 to 30 days after treatment (DAT) (Pradhan and Sushilkumar, 2019).

Utilization Options

For a long time, WH has posed a dilemma for weed managers, although the spate of recent research in India and elsewhere appears to indicate a very strong change in that position. Discussing field-obtained evidence, Opande et al. (2004) said: "*There being both negative and positive socio-economic impacts, it is more correct to state that Water Hyacinth is not just an enemy but a friend of the lakeshore communities in the Winam Gulf*" (Kenya).

In a recent article on '*Living with floating aquatic invasions*', Kleinschroth (2021) argued the case for moving away from futile eradication efforts of species, such as WH, towards a pragmatic '*aquatic ecosystem management strategy*', *minimizing negative, local effects while integrating environmental and socio-economic benefits.*' We agree with this proposition.

In an early study on utilization, an economist, Michael Mara (1976), used a fee of US\$ 6.42 per wet ton of WH biomass in Florida to estimate that the by-products do not defray the harvesting and transport costs of the weed. His view was that the high costs of harvesting, transport and conversion to compost, animal feed or other products would lead farmers to 'dump' the material unless control programmes were subsidized or other '*economically feasible solutions*' were found for the harvested material.

In 1975, Vietmeyer reported how farmers in Bangladesh and Burma used large mats of WH to

create floating vegetable gardens. This was done by heaping lake sediments and organic muck on top of packed carpets of WH and other reeds, which grew prodigiously in the polluted river water. These practices have expanded in the last 50 years.

In the USA, early utilization focused on using WH to remove nutrients, metals and other pollutants from treated sewage (Boyd, 1974; Mitchell, 1974; Pieterse, 1978). These reviews also supported the use of WH as fish and livestock feed, compost and mulch. The reports also showed the potential for WH use in removing pollutants from industrial effluents and the commercial-scale uses of the biomass for paper and pulp, biogas and bioethanol production. Discussing the *paradox* presented by WH, the reports highlighted the need for *balancing the costs of WH control in different situations versus the benefits of its utilization.*

Recent Utilization Efforts

Chandrasena (2023) pointed out that the majority of articles on WH describe laboratory or pilot-scale studies and evidence of the utilization potential of WH that could be developed further. Many reviews emphasize how communities affected by WH can reduce environmental effects by putting WH to good use (Gunnarsson and Peterson, 2007; John, 2016; Feng et al., 2017; Kleinschroth et al., 2021; Karouach et al., 2022; Nandiyanto et al., 2023; Canning, 2025).

The use of WH for water purification remains doubtful as an application. However, Valipour et al. (2015) reported this possibility, assembling a continuous-flow wetland '*Bio-Hedge*' with WH and nutrient-consuming bacterial biofilms on WH roots and a mesh-matrix. In the 12-month study, WH grew slowly at a rate of 1.2% day⁻¹, but extracted N and P at 60% and 47% efficiency (influent vs. outflow).

One of the most valuable practical ways by which WH can be utilized is the use of its strengths to extract N and P nutrients and heavy metal contaminants from any effluent or treated wastewater. For such applications, WH could be utilized either alone or in combination with other pioneer species in treatment wetland designs. However, despite the compelling evidence, mostly from the USA, most other countries, including Australia, are hesitant about such systems for fear of causing further spread.

The effectiveness of WH in extracting other environmental pollutants in water depends on having sufficient colonies for uptake, the concentrations of the contaminants, the duration of exposure for uptake and favourable growing conditions. These are factors that can be manipulated in systems designed to optimize contaminant uptake while controlling the risks of the spread of WH. In a study conducted in South Africa, Newete et al. (2016) reported that WH stems and leaves bio-concentrated Cu, mercury (Hg), gold (Au) and Zn above the standard bio-

concentration factor (BCF) index of 1000 µg per g dry weight (equivalent to 1 g per kg dry weight).

Regular harvesting of the WH biomass assists in pollution reduction by allowing new growth to occur. The literature indicates that the harvested WH, following its use for wastewater or effluent treatment, can be valorized for various industrial applications with additional processing. To eliminate the risks of potential contamination (due to contact with human waste and other impurities), the harvested WH biomass should not be used for animal feed. Nevertheless, the material can be easily processed to become raw material for a wide range of industrial products, such as paper, construction materials and the production of biogas, bioethanol and biochar.

Utilization Experiences in India

India presents one of the most impressive and diverse national case studies on WH utilization, mainly because of the scale of the resource and the diversity of its applications (Pendse and Deshmukh, 2023; Abba and Sabarinath, 2025; Abba et al., 2025). Combined with attitude changes driven by 'green' technologies, as well as institutional and community engagement, India is witnessing a genuine paradigm shift in utilizing WH as a means of managing vast infestations. India harvests an estimated 200 metric tonnes of WH biomass ha⁻¹ year⁻¹, a figure that, if even partially valorised, would represent an enormous renewable feedstock resource for multiple industries.

The following sub-sections review the principal utilization pathways that have been investigated or implemented within India, with attention to both established findings and recent developments.

Wastewater Treatment and Phytoremediation

In India, Trivedy and Pattanshetty (2002) showed that WH growing in dairy waste significantly reduced Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids and Total Nitrogen in the effluent. Adding to this, Chaudhuri et al. (2008) also reported effective WH-based treatment of municipal wastewater in urban settings, reporting substantial reductions in N and P nutrient loads under optimal hydraulic retention times.

A relevant recent contribution is the comparative study by Pendse and Deshmukh (2023), which reviewed WH phytoremediation performances in India and found that the species consistently reduced BOD by 60–80% and COD by 55–75% in domestic wastewater. Most importantly, these results are on par with the effectiveness of WH for wastewater treatment in the USA (Wolverton and McDonald, 1979; Debusk et al., 1983; Reddy and DeBusk, 1987).

Heavy metal uptake is a particularly significant utilization capability of WH that can be applied in

reducing pollution caused by various industries. In India, as in other countries, the processes of textile dyeing, tanning of leather, electroplating, and pharmaceutical manufacture generate effluents contaminated with lead (Pb), chromium (Cr), zinc (Zn), cadmium (Cd), copper (Cu), silver (Ag) and arsenic (As). Ingole and Bhole (2003) provided early results of WH's high degree of tolerance and bioaccumulation of these metals in shoot tissues.

Galgali et al. (2023) reviewed and provided compelling proof that WH could be utilised as a key component of phytoremediation systems in future designs, especially in India, in constructed floating wetland configurations. A recent comparative study on the Nag River in Maharashtra found removal efficiencies of 79–83% for iron, 74–76% for zinc, 70–73% for copper, and 62–74% for lead using WH under field conditions (Bramhankar et al., 2026). There is clearly great potential for utilizing WH for phytoremediation of industrial effluents to extract inorganic ions (Pb, Cr, Zn, Mn, Cu, As, etc.) by designing small systems. Similar applications could be used to reduce phenols, dyes and other organic pollutants discharged in untreated effluents. What the literature shows is that WH is quite simply the best aquatic species that can be used for this task.

Biogas Production

Indian research on biogas production from WH biomass spans from bench-scale studies to community-scale pilot studies. Early studies of Singhal and Rai (2003) established a benchmark: 100 kg of semi-dried WH yielding ca. 400 Litres of biogas per day. The relatively low lignin content of WH, compared to terrestrial biomass feedstocks, accelerates digestion kinetics, although the high water content of WH (ca. 94%) necessitates pre-treatment or co-digestion with denser substrates.

Community-level biogas enterprise models have also emerged in India, most notably the initiative '*Payal Jwala*' launched in Kerala in 2021 by social entrepreneur Anuroop G., working with the *Centre for Research on Aquatic Resources* (CRAR). The initiative converts WH from the backwaters and canals of Thanneermukkom into biogas distributed to households as a cooking fuel alternative to LPG, simultaneously addressing WH infestation, energy poverty, and indoor air pollution (Krishnan, 2022). Such models demonstrate that the technology is both feasible and socially scalable under Indian conditions, but require government support for replication.

Bioethanol and Biofuel Production

As India successfully reaches its 20% ethanol blending target in 2025, five years ahead of the original 2030 schedule, WH has a huge scope as a second-generation feedstock for bioethanol production under the *National Biofuel Policy* (Awasthi

et al., 2013). Researchers at IIT Kharagpur and other institutes like ICRISAT established a method utilizing pore-scale phenomena to extract a high percentage of fermentable sugars and bioethanol from the hemicellulose in WH, achieving significant yield increases (Cherwoo et al., 2025). Thus helping in aquatic ecosystem cleanup without competing with food crops and avoiding the "food vs. fuel" debate.

Recent reviews (Abba and Sabarinath, 2025; Abba et al., 2025) found that WH biofuels can reduce the levelized cost of energy (LCOE) by up to 25%, increase ethanol yields by 40%, and improve sugar release by 50% through optimised pretreatment. Such metrics place WH within reach of commercial viability for bioethanol production under Indian conditions.

In an important study, Mannivannan and Narendhirakannan (2014) reported that cellulose, hemicelluloses and lignin contents of WH ranged from 23-50%, 18-22% and 3-28%, respectively. The study showed how the dried WH biomass could be first hydrolysed with dilute H₂SO₄ to a delignified substrate, further degraded by fungi (*Trichoderma reesei*) and then fermented aerobically by yeasts (*Pachysolen tannophilus*, *Candida intermedia*, *Pichia stipitis* and *Saccharomyces cerevisiae*) to yield bioethanol. This bio-conversion yielded bioethanol in the range of 0.021-0.043 g g⁻¹ of WH biomass. Given that such a biofuel yield is competitive with other common low-cost sources, this utilization needs to be further developed and optimised for adoption by industries.

Composting, Vermicomposting, Green Manure and Soil Amendment

WH's utility as a green manure for crop production has been studied in India by incorporating freshly chopped WH into rice fields to improve soil organic carbon. However, direct field application of fresh WH carries the risk of re-establishment from viable plant fragments and potential allelopathic effects from residual chemicals in WH tissue. Composting or vermicomposting effectively eliminates such risks (Sushilkumar and Bhan, 2000).

Composting is the most widely practised WH utilization method in India, requiring no specialised infrastructure and yielding a product (compost or vermicompost) that farmers can readily use. In India, composting of WH requires about 50–60 days, with decomposition accelerated by adding urea (2–5%), lime (2–5%), or cow manure (10%) to the chopped WH biomass (Gajalakshmi and Abbasi 2002). One tonne of WH compost contains ca. 20 kg of N, 11 kg of P, and 25 kg of K (equivalent to 105 kg of ammonium sulphate, 69 kg of phosphate and 50 kg of

potash), making it a nutrient-rich organic fertilizer that can partially replace synthetic fertilizer inputs.

Co-vermicomposting of WH with fly ash using the earthworm *Eisenia fetida* improved the water holding capacity, cation exchange capacity and available nutrient fractions relative to conventional organic waste vermicompost, a particularly relevant finding given the co-location of coal fly ash generation and WH infestations in India (Mishra et al., 2025).

Compost and vermicompost making from WH has great potential in India. This utilization option does not require any specific machinery or skills. However, in spite of the huge WH biomass available, composting and vermicomposting are not sufficiently prevalent in India owing to misconceptions. Even the vast biomasses removed mechanically by municipalities are left unattended to decompose and decay unused. Nevertheless, some smart farmers in several States have been observed to collect the decaying WH biomass and use the material in their farms.

One Indian company, "CEF Srinagar Biofuel Private Limited", established in 2021, has recently commercialized enriched compost made from WH and other aquatic weeds, harvested from the Dal Lake in Srinagar (Jammu & Kashmir). In this project, about 200 tonnes of WH-dominated aquatic weed biomass were harvested per day. In the recent de-weeding, up to June 2026, the company processed about 37,000 metric tonnes of WH and other aquatic weeds to produce ca. 5600 metric tonnes of compost. The product has been sold to farmers in Kashmir, Uttar Pradesh and Punjab with success, showing promise that it can be replicated elsewhere in the world (Azim, 2026, *pers. comm.* - Sushilkumar)³.

WH fibre products – 'Eco-Friendly Livelihoods

WH stems yield cellulose fibre suitable for paper pulp, grease-proof paper, yarn, ropes, cordage and fibre-board production. The WH biomass provides raw materials for various other handicraft industries and the world-famous WH furniture (Olal et al., 2001; Nega et al., 2022). As in Africa (Ayanda et al., 2020) and many South-East Asian countries, NGOs across India produce WH paper diaries, cards, and stationery — products that command premium pricing in the eco-friendly and sustainable goods markets.

In recent years, global funding has focused on a renewed interest in such value-added uses of WH to create a wide variety of products and employment opportunities for communities. WH-based products include attractive and colourful mats, hats, handicrafts, bags, baskets, laundry bins, necklaces, head caps, diaries, greeting cards, lampshades and

³ Project Coordinator – Mohd. Tariq Azim; CEF House, B-II/58, Mohan Cooperative Industrial Estate, Mathura

Road, New Delhi – 1100.

footwear (Montoya et al., 2013; Pin et al., 2021; Udume et al., 2021; Kleinschroth et al., 2021).

In India, women's groups and others (such as handicapped groups) have come together to form "Community-Based Organizations" to harvest and process WH to manufacture a similar range of products, which have a market among resident local populations, as well as tourists from overseas and visitors at large. Reports from Africa also indicate that along the Nile, WH biomass has been turned into ropes for makeshift bridges across the river.

There are many case studies of WH fibre providing an eco-sensitive livelihood for rural communities in India, explored by non-government organisations (NGOs). Apart from coarse yarn and rope, the use of treated and refined WH fibre for high-value textiles and sanitary napkins (Vijayakumar et al., 2026) is particularly praiseworthy in India. Such uses have also been reported from Africa and other South-East Asian countries (Chandrasena, 2023).

While still in early commercial stages, many of these applications show the diversity of value-added products that can be generated from WH. These programmes, under the banner of transforming 'waste-to-wealth', are expanding across many States of India. The projects work closely with *Self Help Groups* (SHGs), "training women to convert WH into eco-friendly products, fostering both environmental preservation and economic empowerment in their communities" (*The Better India*, 2026)

It is also noted that these increasingly popular WH-based products (**Figure 9**) minimize the local impacts of WH on choked waterways. They are also low-technology, cottage industry products from which communities benefit. The production requires only simple inborn skills and can readily be components of nationwide livelihood improvement programmes.



Figure 9. A sample of WH-based fibre products

Complementing the cottage industries are the large-scale uses of dried WH as compost and biogas for rural households. Olal et al. (2001) and John (2016) reported that such means of practical utilization have led to a perception prevalent in African villages that WH is really a 'blessing' that empowers

both women and men and is 'not always a menace'. India is not far behind in this attitude change.

Other Utilization Options with Potential in India

The following utilization options have the potential for further development in India. However, as far as we are aware, some are only under laboratory or pilot-scale investigation in collaborative projects, especially between researchers in India, China, Japan and Korea. Nevertheless, these options reinforce our belief in the value of WH biomass valorisation for societal benefits and industrial applications.

Biochar

Pyrolysis of dried WH biomass yields biochar, which can be used for soil amendment, for improved water retention and enhanced cation exchange capacity. Biochar also provides pH buffering, nutrient retention and carbon stabilising in soil (Canning, 2025). Biochar production also provides a safe disposal pathway for metal-contaminated WH biomass from phytoremediation systems, with metals stabilised in the char matrix rather than released to the environment. Practical applications are likely to be developed with further research and cost evaluations.

Biobriquettes

Briquetting is the densification of biomass to increase the energy density of biomass residues. In several African countries, WH is converted into Biobriquettes with dried algae as a binder. The briquettes are a low-cost fuel, comparable with wood-based charcoal. WH briquettes have heat energy (calorific value of 18 MJ kg⁻¹). Carbonized WH (charcoal) can be converted into briquettes with algae, gum arabic or cassava starch used as binders. The briquettes are low-cost fuel, comparable with charcoal in energy density (Davies and Davies, 2013; Rodrigues et al., 2014; Carnaje et al., 2018). However, surprisingly, we find that Indian research has not yet explored this highly desirable option.

Animal fodder

WH dried biomass is a source of crude protein (ca. 20% of dry matter) and carbohydrates and has been used as cattle and fish fodder in many Asian-Pacific countries (Nega et al., 2022). The presence of calcium oxalate crystals in stems requires the biomass to be chopped and mixed with other fodder, such as legumes and grasses. In India, there is evidence that dried WH has been incorporated successfully into mixed rations without adverse animal health effects. Nevertheless, the practice is not common, although stray animals have been observed to feed on WH.

Source of Chemicals, Biopolymers, Bio-absorbents and Bio-Plastics

Global research reveals that WH biomass could be extracted for a variety of invaluable chemicals (Lalita et al., 2012; Bakrim et al., 2022). These remain much under-exploited in India. However, cellulose extracted from WH is widely used in high-value biopolymers, bioplastics and bio-absorbents in several countries (Schneider et al., 1995; Mahamadi, 2011; Saratale et al., 2020; Ramirez-Rodrigues et al., 2021).

Biopolymers and bio-plastics derived from WH cellulose are already used in high-end car manufacturing for internal trims, dashboards and panels (Prasanth et al., 2021), replacing materials that are otherwise made from fossil fuel-driven processes. Such applications appear to have commenced in materials research in India. Given that global literature points to spectacular achievements that are already in commercial use, cellulose fibre extraction needs to be considered as one of the most useful future applications of WH biomasses.

Supercapacitors and nanomaterials

An emerging and technically sophisticated application in India is the use of WH-derived activated carbon in supercapacitor electrodes (Prasanth et al., 2021; Mahata et al., 2025). Activated carbon derived from WH biomass has specific capacitance values suitable for lithium-iron batteries - a finding that positions WH as a precursor feedstock for advanced materials manufacturing and sustainable industries. The process involves carbonizing the cleaned and dried stems, followed by chemical activation using KOH. Mahata et al.'s research (2025) revealed that the activated carbon derived from WH has a useful high surface area of 1600–2450 m² g⁻¹.

Integrated utilization concept

An estimated 200 tonnes ha⁻¹ year⁻¹ of WH biomass is available across 8 million ha of water bodies in the country. The ability to fully utilize this resource requires not just technology but infrastructure, harvesting machinery, drying facilities, rural supply chains, and market linkage mechanisms.

A few decades ago, India saw the disposal of WH biomass with accumulated heavy metals and other pollutants as a major constraint to its management. This position has changed nowadays with a clearer understanding that such risks can be easily managed.

The proposition that WH biomass, contaminated with metal ions or organic molecules, contaminated WH biomass generated during phytoremediation, could be used to produce biogas, bioethanol and plaster board is valid in India. Clearly, the harvest of WH biomass, if handled appropriately, generates multiple co-products across energy, agriculture, and

materials sectors, offering a compelling economic case for commercial-scale utilization. The financial viability of any single product stream (for example, biogas alone or compost alone) is often marginal. Hence, the integrated utilization of WH as a resource requires planning the manufacture of a combination of co-products that would substantially change the economics of dealing with WH in a positive direction.

Two of the most socially embedded utilization models in India are the *Assam Pani Meteka Craft Industry* (ASRLM, 2024) and the *Kerala Kudumbashree WH Weaving Networks* (The Secretariat, Kerala, 2025). They are success stories today because they integrate livelihood creation with sustainable resource extraction and community ownership in continued WH harvesting and utilization. Scaling up such models through *State Rural Livelihood Missions*, NABARD-linked microfinance, and export promotion under the GI framework offers a replicable template for other WH-infested States.

Obstacles to Utilization

As with any technology, there are barriers to WH utilization that need to be overcome. Some obstacles require technological solutions, while others need community support and political will for implementation. Some developing countries are slow to utilize WH because the systems to deal with its spread from an existing, infested area are not well developed. This means that education is a key component in the integration of WH utilization with its management, where required, in different settings.

In some countries, there are challenges related to efficiently harvesting and dehydrating WH biomass without making adverse local impacts. The deliberate cultivation of WH for utilization will also be challenging in some situations without adequate safeguards to manage the undesirable effects of WH on aquatic ecosystems to which it can spread. In addition, developing high-efficiency facilities for harvesting, processing and dehydration are needed, as well as further improvements in product valorization (Su et al., 2018; Pin et al., 2021; Nega et al., 2022).

Despite the published successes, we find that the WH-based wastewater pollution removal technologies are yet to be adopted widely by many States of India where possibilities exist. Among the main obstacles to adoption are concerns about increased risks of spread and costs involved in transferring the technologies from pilot-scale to field applications.

In Australia, the zero-tolerance attitude towards WH prevents people from exploring its utilization. The entrenched view is that the costs of managing outbreaks far outweigh any beneficial uses. In most advanced economies, labour is expensive and also not readily available for laborious tasks. Furthermore, the costs of mechanical harvesting, transport of any

'green' material and processing are also usually prohibitive. Consequently, efforts for the practical utilization of WH as an inexpensive plant biomass will most likely be made only in developing countries.

Other obstacles to WH utilization are related to the optimization of effective technologies, which require investment. Local solutions for product valorization should ensure an effective supply chain and market opportunities for WH by-products (Pin et al., 2018). Such challenges need to be overcome in different countries with knowledge exchange and technology transfer, especially in industrial-scale applications.

Well-trained people with aquatic weed management and ecological expertise, as well as ecological literacy, are required to monitor and manage any spread risks. The literature on WH also indicates the important role non-governmental actors and civil society can play in taking the lead in utilizing the power of this incredible colonizing species.

Managing Water Hyacinth – Looking Ahead

Specifically for India, our review finds that reliable data and information are lacking in the country for a proper assessment of WH, either as a problem to solve or as a resource for exploitation. As shown in the first-ever *Water Bodies Census 2018-19*, India has 15.98 million ha of freshwater bodies (ca. 4.86% of India's total landmass). The largest freshwater areas are ponds and tanks (18.22 lakh ha), followed by reservoirs (31.5 lakh ha), lakes (1.44 lakh ha) and wetlands (5.64 lakh ha) (Government of India, 2018).

While this national statistic is important, an estimate of how much of these inland water resources are affected by WH and to what degree is yet to be established. A comprehensive assessment would be desirable, given the issues discussed herein. It would require a GIS analysis that would give an estimate of the total areas of canals and small waterways, as well as rice paddies. These relatively easy steps should be followed by an estimation of major river reaches, tributaries and areas affected by WH. As shown in **Table 1**, the ICAR-AICRP-WM Network respondents could then be requested to provide a reasonable estimate of the total infestation area.

Brij Gopal, in 1987, cautioned against the utilization of WH, saying that: '*Developing countries should not encourage the propagation of this weed for utilization. The interests of humanity can only be safeguarded by seeking effective long-term control of WH, rather than by its utilization*' (Gopal, 1987).

Interestingly, utilization of WH was well underway in the USA by the time Gopal made those comments. Perhaps Gopal's extreme caution was based on the Indian historical experiences of people cultivating WH in Bengal for making potash (as discussed by Iqbal,

2009). We contend that Gopal was handicapped without the scientific evidence we now have of utilization options. Multiple projects across India are a testament to the success of community-based approaches to managing WH, integrated with utilization (*The Better India*, 2026). We suggest that utilization can be implemented without necessarily causing further spread, but as part of a long-term, locally adopted WH management strategy.

Recent reviews of 'value-added products', derived from WH biomass, discuss the constraints as well as the compelling opportunities in WH product valorization for the benefit of communities (Pin et al., 2018; Su et al., 2018; Bakrim et al., 2022; Nega et al., 2022; Chandrasena, 2023; Abba and Sabarinath, 2025; Abba et al., 2025). Given the vast amounts of WH available as a major bioresource, we also believe that this *virtuous side* of WH cannot be ignored anymore and should be put to practical uses.

WH arrived in India not of its own accord. Humans were responsible not just for its introduction but also for facilitating its spread and deep entrenchment. Given that WH will never be eradicated from India or from the Asian-Pacific region, the time is upon societies to *benefit from the species by putting it to good use through appropriate technology and socially responsible, community-driven programmes*.

The socio-economic effects of WH are dependent on the size of infestations, the uses of the waterbody, and the success of control methods used. While effective strategies to control WH are known, control programmes often suffer from a lack of funding to have lasting impacts. Weed managers in most countries, including those in advanced economies (i.e. the USA and Australia), acknowledge that it is impossible now to eradicate WH where it has more than a foothold. Therefore, while efforts are made to contain it where its local impacts are unacceptable, it is pragmatic to explore how utilization can be part of an integrated solution to controlling WH and plan to overcome the obstacles to doing so.

As we have discussed, the corpus of literature on WH problems, management and opportunities is vast. Encouragingly, the subject does not appear to lack interest, as shown in so many recent reviews, even in the last few years. Our experiences show that each management strategy (i.e., physical, chemical, biological, or any combination as 'integrated control') has its own set of advantages and disadvantages and could be modified and applied in different situations. The success of each method, on its own or in various combinations, cannot be disputed. They do work, but only in small or very localized infestations.

We agree with the broad generalisation in the literature that effective long-term control strategies for WH have not yet been developed in any country. However, given the limitations of the biocontrol

agents, our view is that an effective long-term control strategy should be much more 'location-specific', based on the conditions of each site. This requires taking into account the size of the infestation and its spatial distribution over the waterbody, the designated use of the water, its size, and its spatial configuration. Weather patterns affecting WH are not critical in India.

This vast literature on WH available from across the continents provides a comprehensive *knowledge base* of its biology and ecology, as a monoculture or in mixed populations. The factors that make WH resist control efforts are also well documented (Britto et al., 2026). With this knowledge, we believe that the highly successful coloniser is *much too strong for humans to manage in the long run without causing further unnecessary disturbances and damage to already fragile aquatic ecosystems*. Perhaps we should be prudent and *learn to live with it*.

We also contend that 'control' will not work alone at any infested site, even over a medium-term scenario, unless the primary factors that contribute to WH's proliferation are mitigated. The critical external factors that authorities can influence include reducing, via legislation or otherwise, nutrient pollution of waterways, which is rampant in Indian cities, burdened with heavy populations. India is no exception here. Severe infestations of WH are a manifestation in many other densely populated cities, especially in tropical and sub-tropical countries.

Waterways in most cities in India, large and small, as well as peri-urban townships and rural areas, suffer from being unclean and spoiled by direct discharges of untreated or partially treated sewage, industrial and domestic effluents. Away from the densely populated areas, in rural India, excessive runoff of fertiliser used in agriculture is the main cause of WH dominance in many lakes, swamps and smaller tributaries of major rivers. Unless action is taken to mitigate these human-related habitat 'disturbances', WH management will continue to be an almost impossible goal to achieve.

Research across India has shown that in any State that has waterways seriously affected by WH, action on the ground needs a 'location-specific', integrated plan that includes all possible management options. Implementation also requires a citizen's participatory approach that combines the efforts of the non-governmental sector, comprising small or large environmental groups, along with government departments and University researchers.

We strongly recommend that authorities and civic bodies, particularly in urban areas, engage the services of professional vendors to remove WH using

heavy machinery for managing WH at different locations in India. The utilization of WH, '*turning waste into wealth*', as raw material for a wide variety of industries or for other uses, must also be done under scientific and administrative supervision and accountability to mitigate any risk of spread. There is abundant literature and many examples, from Africa in particular, cited herein, that should be used to facilitate such WH management discourses.

There is also an urgent need to monitor the existing infestation and map its spread using modern GIS tools, remote sensing, drones and artificial intelligence. Departments in National, State and Local Governments, including municipalities, must step up to keep their data and information updated, as has been done in the USA and Australia.

Conclusions

Way back in the 1960s, aquatic weeds were seen as "*the symptoms of human failure to manage our resources*" (Pirie, 1960; Holm, 1969; May, 1981). In those days, the utilization of aquatic weeds, mainly as biofertilizers and animal feed, was an incidental 'spin-off' from which farmers could recover some costs of control (Mara, 1976). However, purposeful utilization of WH for sewage and industrial wastewater treatment then evolved in the 1970s, proving the value of the species (Wolverton and McDonald, 1979).

The factors that contribute to the spread of WH across regions and containment are now well known. Despite this knowledge, there are justifiable concerns in some countries about the further spread and the environmental risks WH poses, given that its unmanaged populations have created havoc over more than a century in most countries (Kriticos and Brunel, 2016). This dominant narrative continues to be the main obstacle to utilization.

In a recent globally focused bibliometric analysis of WH literature, Brito et al. (2026) analysed 3,845 articles that have been published in five continents (ca. 30 countries)⁴. Their objective was to identify the patterns, trends, and impact of WH in those affected countries and societies. One conclusion they drew was that there is an urgent need for international cooperation in both research and management of WH. For instance, Brito et al. (2026) argued for comparative studies between temperate and tropical regions to generate insights into the ecological and socio-environmental factors that shape the 'invasive dynamics' of the species.

⁴ Brito et al. (2026) retrieved In total, 6,496 articles, covering a period from 1927 to December 2024. Of these, their study used 3845 peer-reviewed articles in 1422 journals that were relevant to the research questions they asked: i.e. (1) what makes WH so

aggressive ("invasive") in different situations and (2) what functional traits best explain WH's success beyond its native range.,

We agree that progress toward effective WH management requires interdisciplinary and multi-scalar approaches capable of integrating ecological, social, and economic dimensions and adapting strategies to the specific conditions of each region.

Relevant to our assessment and discussion on WH is the fact that Brito et al. (2026) found Indian research publications accounting for 21% of all research on WH, followed by China. Together, India and China, the two most populous nations in the world, were responsible for one-third (32%) of all WH publications. In India, the largest number of articles fall within the phytoremediation research landscape area (ca. 2.5% of total publications). This, in our view, is research in the right direction, prompted by the crucially important realisation of a bioresource, freely available, that has been much under-utilized.

In managing WH infestations, science-based aquatic weed management tactics and strategies are needed. Country-by-country approaches with utilization are needed in developing countries, which are affected by vast populations of WH. Biogas, bioethanol, compost, and use in pollution removal all appear as viable options, despite the absence of comprehensive cost-benefit analyses or life-cycle assessment studies. Such studies have been done elsewhere and can be adopted in India.

As discussed in this essay, the utilization of WH as part of management is a well-proven approach. It all comes down to society's preparedness, backed by science, to accept the potential of a colonizer to provide immense benefits in an uncertain future and '*learning to live*' with it (Kleinschroth et al., 2021). The ideal solution should be the utilization of WH, which would not encourage its further spread, but help control its vast growth potential to manageable and acceptable levels in different situations.

WH is one of the best examples for use in educational and public discourses related to creating a 'weed-literate' society. The wide variety of practical utilization options of WH, highlighted herein, should be sufficient to demonstrate how its abundant growth and biomass can be an asset for boosting economic development among needy populations, especially in developing countries. The undesirable effects of vast populations of WH on waterways are predictable in most aquatic systems. How to manage those effects with 'integrated control' is also known, despite under-achieving on the control objectives in most settings.

Although aggressive colonizing species, such as WH, '*affect people's livelihoods and human well-being*', Shackleton et al (2019) argued that '*They provide both benefits and costs in different contexts, leading to complexity. A better understanding of this is therefore needed, to aid decision making*'.

This review of WH in India shows that the species could be an exemplar to help humanity deal with a

changing globe and create an '*environmentally literate*' society that enacts decisions based on both sound science and the needs of humanity. A change in attitude towards colonizing taxa, epitomized by WH, appears crucial as we face an uncertain future, complicated by climate change.

Humans are the most potent agency that must take responsibility for actions with a deeper appreciation of past mistakes. A relic of colonialism, WH is now so deeply entrenched in India and may never ever be fully eradicated. More than 100 years of control efforts to remove WH in infested regions have failed because the species is just too successful as a pioneer species in new environments. Seeing the species with 'new eyes', along with utilization options, appears to be the only prudent way forward, while maintaining the health of critical ecosystem services and managing the plant communities best adapted to the human-disturbed environments.

Science helps us approach the '*world of weeds*' with both wonder and humility. Science may also help to remove the unconscious bias some people have against weedy colonizers. Scientific ethics call for us to have an honest dialogue with *Nature* and what we find in life. Science will also help us fight misinformation, navigate the troubled waters and find a more reasonable position concerning weeds. What we must all strive for is to '*rethink Nature*' (Hill and Hadly, 2018) and find the '*middle ground*' in the weed discourses. Instead of continuing to blame WH and other colonizing taxa for human follies, the role of such species in shaping local livelihoods and human well-being should become a central theme for discussion (Shackleton et al., 2019).

Cultivating an attitude of '*living with weeds*', even with those, such as WH, that may, from time to time, cause some environmental concerns, is pragmatic. Such a tolerant attitude will help us reduce the environmental and social costs of taking unsustainable actions against specific taxa and navigate a precarious future unfolding around us.

Hill and Hadly (2018) recently wrote: '*As the world stumbles deeper into the Anthropocene, the novel biogeographic dynamics (globalization, mass disturbance, and climate change) will progressively warp habitats*'. Under such disturbances, WH and other colonizing taxa will not just thrive but also change the habitats they occupy. Learning from Nature, it is also important to realise that with or without humans on the planet, WH and other colonizing taxa will play vital roles in stabilizing the earth's disturbed and damaged ecosystems. *They will also survive catastrophes on Earth. We may not.*

Acknowledgements

We thank those Indian colleagues, especially of the ICAR- AICRP-WM Network, who provided information concerning the occurrence and abundance of WH across Indian States.

Literature Cited

- Abba, A. and Sabarinath, S. (2025). Sustainable management of water hyacinth (*Eichhornia crassipes*): community-led strategies for livelihood enhancement in rural India. *Results in Engineering*, 26: 105033 (<https://www.science-direct.com/science/article/pii/S2590123025011089>).
- Abba, A., Sabarinath, S. and Mustapha, R. (2025). Advancing Circular Bioeconomy through Systematic Review of Multi-product Biorefinery approaches for Water Hyacinth based Renewable Energy. *iScience*, 28 (7): 112807 ([https://www.cell.com/iscience/fulltext/S2589-0042\(25\)01068-5?](https://www.cell.com/iscience/fulltext/S2589-0042(25)01068-5?)).
- Abdelhamid, A. M. and Gabr, A. A. (1991). Evaluation of water hyacinth as a feed for ruminants. *Archives of Animal Nutrition*, 41:745-756.
- Aneja, K. R. and Singh, K. (1989). *Alternaria alternata* (fr.) Keissler, a pathogen of water hyacinth with biocontrol potential. *Tropical Pest Management*, 35(4): 354–356.
- Aquarius Systems (2023). Aquatic Plant Harvester to Remove Water Hyacinth (<https://aquarius-systems.com/aquatic-plant-harvester-to-remove-water-hyacinth/>).
- ASRLM (2024). Assam State Rural Livelihoods Mission. 'Pani Meteka Craft Programme: Scaling water hyacinth artisan livelihoods across the Brahmaputra Valley'. Government of Assam Annual Report, 2023–24 (<https://asrlms.assam.gov.in/frontimpotentdata/water-hyacinth>).
- Awashti, M., Kaur, J. and Rana, S. (2013). Bioethanol production through Water hyacinth via optimization of pretreatment conditions, *International Journal of Emerging Technology and Advanced Engineering*, 3 (03) (2013) 42–46.
- Ayanda, O. I., et al. (2020). *Eichhornia crassipes* (Mart.) Solms: Uses, Challenges, Threats, and Prospects. *The Scientific World Journal*, Article 3452172.
- Bakrim, W. B., et al. (2022). *Eichhornia crassipes* (Mart.) Solms: A Comprehensive Review of Its Chemical Composition, Traditional Use, and Value-Added Products. *Frontiers of Pharmacology*, 13: 842511.
- Barrett, S. C. H. (1980). Sexual reproduction in *Eichhornia crassipes* (Water Hyacinth). I. Fertility of clones from diverse regions. *Journal of Applied Ecology*, 17(1), 101-112.
- Barrett, S. C. H. (1992). Genetics of Weed Invasions. In: S. K. Jain and L. W. Botsford (Eds.) *Applied Population Biology*, pp. 91-119. Kluwer Academic Publishers, Netherlands.
- Barrett, S. C. H. and Forno, I. W. (1982). Style Morph Distribution in New World Populations of *Eichhornia crassipes* (Mart.) Solms. (Water hyacinth). *Aquatic Botany*, 13: 299–306.
- Boyd, C. E. (1974). Utilization of Aquatic Plants. In: Mitchell, D. S. (Ed.) *Aquatic Vegetation and Its Use and Control*, Chapter 7 (pp. 107-115), UNESCO, Paris.
- Bramankar, D., Bhattacharya, D., Jha, A. K. and Halder, S. (2026). A comparative study of phytoremediation potential of water lettuce (*Pistia stratiotes* L.) and water hyacinth (*Eichhornia crassipes* [Mart.] Solms) for mitigating contaminants in the Nag River, Maharashtra, India. *Cleaner Water*, 6: 100252.
- Brito, L. d. S., Lillebø, A. I. and Teixeira, H. (2026) Global distribution of *Pontederia crassipes*: a systematic and bibliometric review of biomass variations and environmental correlations. *Frontiers of Environmental Science*, 14: 1703625 (<https://doi.org/10.3389/fenvs.2026.1703625>).
- Canning, A. A. (2025). Review on Harnessing the Invasive Water Hyacinth (*Eichhornia crassipes*) for Use as an Agricultural Soil Amendment. *Land*, 14: 1116 (<https://doi.org/10.3390/land14051116>).
- Carnaje, N. P., Talagon, R. B., Peralta, J. P., Shah, K. and Paz-Ferreiro, J. (2018). Development and characterization of charcoal briquettes from water hyacinth (*Eichhornia crassipes*)-molasses blend. *PLoS ONE* 13(11): e0207135.
- Center T. D. et al., (1999). Biological control of water hyacinth under conditions of maintenance management: Can herbicides and insects be integrated? *Environmental Management*, 23: 241–256.
- Center, T. D., Hill, M. P., Cordo, H. and Julien, M. H. (2002). Water hyacinth. In: Van Driesche, R. et al. (Eds.) *Biological Control of Invasive Plants in the Eastern United States*. USDA Forest Service Publication FHTET-2002-04, 41-64.
- Chandrasena, N. R. (2023). Options for the Utilization of Water Hyacinth (*Pontederia crassipes* Mart.) – An Update. *Weeds*, 5(2): 1-20.
- Charudattan, R. (2001). Biocontrol of Water Hyacinth by Using Pathogens: Opportunities, Challenges, and Recent Developments. In: Julien, M. H. et al. (Eds.) *Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes*. ACIAR Proceedings, Canberra, p. 102.

- Chaudhuri, J. (1936). 'Agrarian Problems Of Bengal-1'. *The Bengal Cooperative Journal*, 117.
- Chaudhuri, S. R., Salodkar, S., Sudarshan, M., Mukherjee, I. and Thakur, A. R. (2008). Role of water hyacinth-mediated phytoremediation in wastewater purification at East Calcutta wetland. *Environmental Sciences*, 5(1), 53–62 (<https://doi.org/10.1080/15693430701833427>).
- Cherwoo, L. et al. (2025). Transforming aquatic weeds into resources: *Pontederia crassipes*, water hyacinth mining for a circular bioeconomy. *Environmental Management*, 75: 2458–2478.
- Choudhury, P. P., Singh, R., Ghosh, D. and Sharma, A. R. (2019). *Herbicide Use in Indian Agriculture*. ICAR - Directorate of Weed Research, Jabalpur, Madhya Pradesh, p. 110.
- Coetzee, J. A. et al (2017). Monographs on invasive plants in Europe No. 2: *Eichhornia crassipes* (Mart.) Solms *Botany Letters*, 164 (4): 303–326.
- Da Cunha, N. L., Xue, H., Wright, S. I. and Barrett, S. C. H. (2022). Genetic variation and clonal diversity in floating aquatic plants: Comparative genomic analysis of water hyacinth species in their native range. *Molecular Ecology*, 31(20): 5307-5325.
- Davies, R. M. and Davies, O.A. (2013). Physical and Combustion Characteristics of Briquettes Made from Water Hyacinth and Phytoplankton Scum as Binder. *Journal of Combustion*, Article: 549894.
- Debusk, T. A., et al. (1983). Removal of Nitrogen and Phosphorus from wastewater in a Water Hyacinth-based treatment system. *Journal of Environmental Quality*, 12(12): 257–262.
- Dutta, W., Ray, D. and Ray, P. (2015). Molecular characterization and host range studies of indigenous fungus as prospective mycoherbicidal agent of water hyacinth. *Indian Journal of Weed Sciences*, 47(1): 68–74.
- Dutta, W. et al. (2023). The mycobiota associated with the weed water hyacinth, *Pontederia crassipes*, in Kolkata, India, with emphasis on biological control of the macrophyte. *Biocontrol Science and Technology* (<https://www.researchgate.net/profile/Wri-Dutta/publication/369551398>).
- DWR (2019). Annual Report (Bilingual). 2018-19. ICAR-Directorate of Weed Research, Jabalpur. p. 178.
- Ebel, M., et al. (2007). Cyanide phytoremediation by water hyacinths (*Eichhornia crassipes*). *Chemosphere*, 66: 816–823.
- Feng, W., et al. (2017). Analysis of utilization technologies for *Eichhornia crassipes* biomass harvested after restoration of wastewater. *Bioresource Technology*, 223: 287–295.
- Galgali, P, Palimkar, S, Adhikari, A., Patel, R. and Routh, J. (2023). Remediation of potentially toxic elements -containing wastewaters using water hyacinth - a review. *International Journal of Phytoremediation*, 25(2):172-186.
- Gajalakshmi, S. and Abbasi, S. A. (2002). Effect of application of water hyacinth compost/vermicompost on the growth and flowering of *Crossandra undulaefolia* and on several vegetables. *Bioresource Technology*, 85(2): 197-199.
- Ghabbour, E. A., et al. (2004). Metal binding by humic acids isolated from water hyacinth plants [*Eichhornia crassipes* (Mart.) Solm-Laubach: Pontederiaceae] in the Nile Delta, Egypt. *Environmental Pollution*, 131(3): 445–451.
- Gopal, B. (1987). *Water Hyacinth. Aquatic Plant Studies 1*. Elsevier, Amsterdam. p. 471.
- Gopal, B. (1990). Aquatic weed problems and management in Asia. Chapter 18 (pp. 318-340). In: Pieterse, A.H. and Murphy, K (Eds.). *Aquatic Weeds: The Ecology and Management of Nuisance Aquatic Vegetation*. Oxford University Press, Oxford.
- Government of India (2018). Water Bodies – First Census Report. Ministry of Jal Shakti (<https://www.pib.gov.in/PressReleaseFramePage.aspx?PRID=1919482®=48&lang=2>).
- Gunnarsson, C. C. and Peterson, C. M. (2007). Water hyacinths as a resource in agriculture and energy production: A literature review. *Waste Management*, 27: 117–129.
- Haq, M. and Sumangala, K. (2003). Acarine regulators of water hyacinth in Kerala (India). *Experimental & Applied Acarology*, 29: 27–33 (2003)
- Hasan, S. D., Ranjan, D. and Talat, M. (2010). Water Hyacinth Biomass for Biosorption of Hexavalent Chromium: Optimization of Process Parameters. *BioResources*, 5(2): 563-575.
- Hill, A. P. and Hadly, E. A. (2018). Rethinking “Native” in the Anthropocene. *Frontiers of Earth Science*, 6: Article 96.
- Holm, L. G., et al. (1977). *The World's Worst Weeds*. University of Hawaii Press, Honolulu. p. 609.
- Ingole, N. W. and Bhole, A. G. (2003). Removal of Heavy Metals from Aqueous Solution by Water Hyacinth (*Eichhornia crassipes*). *Journal of Water Supply Research and Technology, AQUA*, 52 (2): 119–128.
- Iqbal, I. (2009). Fighting With a Weed: Water Hyacinth and the State in Colonial Bengal, c. 1910–1947. *Environment and History*, 15 (1): 35–59 (<http://www.environmentandsociety.org/node/3365>).

- Jayanth, K. P. (1988). Successful biological control of water hyacinth (*Eichhornia crassipes*) by *Neochetina eichhorniae* (Coleoptera: Curculionidae) in Bangalore, India. *Tropical Pest Management*, 34:263–266.
- John, M. (2016). Production of organic compost from water hyacinth [*Eichhornia crassipes* (Mart.) Solms] in the Lake Victoria Basin, *Journal of Agriculture & Allied Sciences*, 5: 55–62.
- Karouach, F. et al. (2022). A Comprehensive Evaluation of the Existing Approaches for Controlling and Managing the Proliferation of Water Hyacinth (*Eichhornia crassipes*): Review. *Frontiers of Environmental Science*. Article 9:767871.
- Katembo, N., Hill, M. P. and Byrne, M. J. (2013). Impacts of a sub-lethal dose of glyphosate on water hyacinth nutrients and its indirect effects on *Neochetina* weevils. *Biocontrol Science and Technology*, 23:12, 1412-1426.
- Kathiresan, R. M. and Deivasigamani, S. (2015). Herbicidal control of water hyacinth (*Eichhornia crassipes*) and its impact on aquatic environment. *Indian Journal of Agronomy*, 60 (4): 606-609.
- Kato, M. and Kato-Noguchi, H. (2026). The Impact of Water Hyacinth (*Pontederia crassipes*) on Freshwater Ecosystems: Ecological and Socio-ecological Significance. *Sustainability*, 18, 5390.
- Kitunda, J. M. (2018). *A History of the Water Hyacinth in Africa: The Flower of Life and Death from 1800 to the Present*. Boulder, CO: Lexington Books, p. 334.
- Kleinschroth, F. et al. (2021). Living with floating vegetation invasions. *Ambio*, 50: 125–137.
- Kobayashi, J. T., Thomaz, S. M. and Pelicice, F. M. (2008). Phosphorus as a limiting factor for *Eichhornia crassipes* growth in the upper Paraná River floodplain. *Wetlands*, 28: 905–913.
- Krishnan, A. (2022). Kerala Man Helps Households Make Biogas From Weed That Chokes Lakes; Here's How. *The Better India* (<https://thebetterindia.com/275841/kerala-entrepreneur-helps-convert-water-hyacinth-into-biogas-lpg-save-money/>).
- Kriticos, D. J. and Brunel, S. (2016). Assessing and Managing the Current and Future Pest Risk from Water Hyacinth (*Eichhornia crassipes*), an Invasive Aquatic Plant Threatening the Environment and Water Security. *PLoS ONE*, 11(8), e0120054 (<https://journals.plos.org/plosone/article?id=10.1371>).
- Lalita, P., et al. (2012). Secondary Metabolites of *Eichhornia crassipes* (Water hyacinth): A Review (1949 to 2011). *Natural Product Communications*, 7(9): 1249-1256.
- Lallana, V. H.; Sabatini, R. A. and Lallana, M. D. C. (1987). Evapotranspiration from *Eichhornia crassipes*, *Pistia stratiotes*, *Salvinia herzogii* and *Azolla caroliniana* during summer in Argentina. *Journal of Aquatic Plant Management*, 25: 48–50.
- Leakey, A. D. B., et al. (2009). Elevated CO₂ effects on plant carbon, nitrogen, and water relations: Six important lessons from FACE. *Journal of Experimental Botany*, 60(10): 2859–2876.
- Lele, A., Nulkar, G. and Joshi, R. (2025). Glyphosate is not a solution to get rid of invasive water hyacinth — it's an ecological hazard. *Down To Earth*, 17 Feb. (<https://www.downtoearth.org.in/water/glyphosate-is-not-a-solution-to-get-rid-of-invasive-water-hyacinth-its-an-ecological-hazard>).
- Liu, J-Z, Ge, Y-M, Zhou, Y-F and Tian, G-M (2010). Effects of Elevated CO₂ on Growth and Nutrient Uptake of *Eichhornia crassipes* Under Four Different Nutrient Levels. *Water Air Soil Pollution*, 212: 387–394.
- Liao, S. W. and Chang, W. L. (2004). Heavy metal phytoremediation by water hyacinth at constructed wetlands in Taiwan. *Journal of Aquatic Plant Management*, 42: 60–68.
- MacLean, K. (1922). 'Water Hyacinth. A Serious Problem in Bengal.' *Agricultural Journal of India*, XVII.
- Mahamadi, C. (2011). Water hyacinth as a biosorbent: A review. *African Journal of Environmental Science and Technology*, 5(13): 1137-1145.
- Mahata, et al. (2025). Transforming Aquatic Weed (Water Hyacinth) into High-Performance Flake-like Activated Carbon for Application in Lithium-Ion Batteries. *ACS Sustainable Resour. Manage.* 2025, 2, 11, 2235–2248.
- Mannivannan, A. and Narendhirakannan, R. T. (2014). Bioethanol Production from Aquatic Weed Water Hyacinth (*Eichhornia crassipes*) by Yeast Fermentation. *Waste and Biomass Valorization*, 6: 209-216.
- Mara, M. J. (1976). Estimated Values for Selected Water Hyacinth By-Products. *Economic Botany*, 30: 383-387.
- Mishra, S. S., Dash, M. R., Dung Dung, M. S. and Baitharu, I. (2025). Bioconversion of water hyacinth by vermicomposting with fly ash using an exotic earthworm species, *Eisenia foetida*. *Ecology, Environment and Conservation*, 31 (February Suppl.), S123-S135.
- Mitchell, D. S. (Ed.) (1974). *Aquatic Vegetation and Its Use and Control*, UNESCO, Paris. p. 133.

- Montoya, J. E., et al. (2013). Large-scale composting as a means of managing water hyacinth (*Eichhornia crassipes*). *Invasive Plant Science and Management*, 6 (2): 243–249.
- Nandiyanto, A. B. D., et al. (2023). Progress in the utilization of water hyacinth as an effective biomass material. *Environment, Development and Sustainability* (<https://link.springer.com/article/10.1007/s10668-023-03655-6#citeas>).
- Nega, D. T., Venkata Ramayya, A. Million, M. A. and Manenti, F. (2022). Invasive Water Hyacinth Challenges, Opportunities, Mitigation, and Policy Implications. Chapter 9 (175-203) In: Shukla, G. et al. (Eds) *Floristic Diversity - Biology and Conservation. Sustainable Development. IntechOpen* (<http://dx.doi.org/10.5772/intechopen.106779>).
- Newete, S. W., et al. (2016). Sequestration of precious and pollutant metals in biomass of cultured water hyacinth (*Eichhornia crassipes*). *Environmental Science and Pollution Research*, 23: 20805–20818.
- Olal, M. A., et al. (2001). Water hyacinth utilization and the use of waste material for handicraft production in Kenya. In: Nightingale D. L. M. (Ed.) *Micro and Small Enterprises and Natural Resource Use. Micro-Enterprises Support Programme*, UNRP, Nairobi. pp. 119-127;
- Opande, G. O., Onyango, J. C. and Wagai, S. O. (2004). Lake Victoria: The water hyacinth (*Eichhornia crassipes* [Mart.] Solms), its socio-economic effects, control measures and resurgence in the Winam Gulf. *Limnologica*, 34:105-109.
- Pathak, A. and Kannan, C. (2011). Isolation and pathogenicity of some native fungal pathogens for the biological management of water hyacinth. *Indian Journal of Weed Science*, 43: 178-180.
- Pendse, D. S. and Deshmukh, M. P. (2023). A comprehensive study on an integrated approach for water hyacinth management to conserve natural water resources in India. *Materials Today: Proceedings*, Vol. 124: 10-19.
- Penfound, W. T. and Earle, T. T. (1948). The biology of the Hyacinth. *Ecological Monographs*, 18: 448-472.
- Pin, L. A., Pennink, B. J. W., Balsters, H. and Sianipar, C. P. M. (2021). Technological appropriateness of biomass production in rural settings: Addressing water hyacinth (*E. crassipes*) problem in Lake Tondano, Indonesia. *Technology in Society*, 66: Article ID. 101658.
- Pieterse, A. H. (1978). The water hyacinth (*Eichhornia crassipes*) – a review. Abstracts. *Tropical Agriculture*, 4(2), 9-42.
- Pirie, N. W. (1960). Water hyacinth: A cause or crop? *Nature*, 185: 116.
- Pradhan, A. and Sushilkumar (2019). Aquatic weeds management through chemical and manual integration to reduce cost by manual removal alone and its effect on water quality. *Indian Journal of Weed Science*, 51(2): 183–187.
- Prasanth S. M. et al. (2021). Application of biomass-derived products in mid-size automotive industries: A review. *Chemosphere*, 280: 130723.
- Priya, L. (2019). 'Free From Mosquitoes & Water Hyacinth: How Drones With Bio-Enzymes Are Saving Hyderabad's Lakes'. *The Better India*, 4 May 2019 (<https://thebetterindia.com/180933/hyderabad-lake-ghmc-mosquito-dengue-drone-innovation-india/>).
- Ramirez-Rodrigues, A. E., Morales-Barrera, L. and Cristiani-Urbina, E. (2021). Continuous biosorption of Acid Red 27 Azo dye by *Eichhornia crassipes* leaves in a packed-bed column. *Nature Scientific Reports*, 11: 18413.
- Ray, P and Chandrasena, N. (2015). Beautiful Blue Devil or Cinderella? Perspectives on opportunities with Water Hyacinth [*Eichhornia crassipes* (Mart.) Solms]. *Proceedings 25th APWSS Conference*, Vol. 2 (p. 45), Hyderabad, India. 13-16, October, 2015.
- Ray, P and Hill, M. P. (2012). Fungi associated with *Eichhornia crassipes* in South Africa and their pathogenicity under controlled conditions. *African Journal of Aquatic Science*, 37: 323-331.
- Ray, P., Sushilkumar and Pandey, A. K. (2008). Deleterious effect of herbicides on water hyacinth biocontrol agents *Neochetina bruchi* and *Alternaria alternata*. *Biocontrol Science and Technology*, 18(5): 517–526.
- Ray, P., Sushilkumar and Pandey, A. K. (2009). Impact Evaluation of *Neochetina* spp. on different growth stages of Water Hyacinth. *Journal of Plant Protection Research*, 49 (1), 2009
- Reddy, K. R. and Debusk, T. A. (1987). State-Of-The-Art Utilization of Aquatic Plants in Water Pollution Control. *Water Science and Technology*, 19(10): 61-79.
- Rodrigues, A. J., et al. (2014). Converting Water Hyacinth to Briquettes: A Beach Community-Based Approach. *International Journal of Sciences: Basic and Applied Research*, 15(1): 358-378.
- Saguna Rice Technique (SRT) Saguna Rural Foundation (SRF) (2021). YouTube Video (https://www.youtube.com/watch?v=k3GOZTGic-I&list=PLlen8rAzy71B_zsZ-Mj3V7nUcfrYSLFpw).

- Saratale, R. G., et al. (2020). Utilization of noxious weed water hyacinth biomass as a potential feedstock for biopolymer production: A novel approach. *Polymers*, 12(8): 1704.
- Sasidharan, N. K., Azim, T., Ambika Devi, D. and Samuel Mathew, S. (2013). Water hyacinth for heavy metal scavenging and utilization as organic manure. *Indian Journal of Weed Science*, 45(3): 204–209.
- Schneider, I. A. H., Rubio, J., Mishra, M. and Smith, R. W. (1995). *Eichhornia crassipes* as biosorbent for heavy metal ions. *Minerals Engineering*, 8: 979–988.
- Shackleton, R. T., Shackleton, C. M., Kull, C. A. (2019). The role of invasive alien species in shaping local livelihoods and human well-being: a review. *Journal of Environmental Management*, 229: 142-157.
- Singhal, V. and Rai, J. P. (2003). Biogas production from water hyacinth and channel grass used for the phytoremediation of industrial effluents. *Bioresource Technology*, 86(3): 221-225.
- Su, W., et al. (2018). The Resource Utilization of Water Hyacinth (*Eichhornia crassipes* [Mart.] Solms) and Its Challenges. *Resources*, 7: 46 (9 p), Article: 7030046.
- Sushilkumar, and Bhan, V. M. (2000). *Technical Bulletin: Management of Water Hyacinth through Composting and Biological Control*. National Research Centre for Weed Science (ICAR), Jabalpur, India.
- Sushilkumar (2011a). Aquatic weeds problems and management in India. *Indian Journal of Weed Science*, 43 (3&4): 118-138.
- Sushilkumar (2011b). Biological based chemical integration for early control of water hyacinth. *Indian Journal of Weed Science*, 43: 211–214.
- Sushilkumar (2015). Weed Utilization: Wealth from Waste. *Indian Farming*: 65 (7): 73-75.
- Sushilkumar (2022). Biological control of Parthenium, water hyacinth and water fern: A few success stories. In: Mishra et al.. (Eds.) '*Technological Glimpses on Weeds and their Management*'. p. 81. Indian Society of Weed Science, India.
- The Better India* (2026). The Better India Website (<https://thebetterindia.com/141776/water-hyacinth-organic-manure/>).
- The Secretariat, Kerala (2025). Kudumbashree water hyacinth weaving initiative: Kottapuram Integrated Development Society model. Government of Kerala (<https://thesecretariat.in/article/water-hyacinth-handicrafts-face-a-climate-test>).
- Tiwari, S., Dixit, S. and Verma, N. (2007). An Effective Means of Biofiltration of Heavy Metal Contaminated Water Bodies Using Aquatic Weed *Eichhornia crassipes*. *Environmental Monitoring & Assessment*. 129: 253–256.
- Trivedy, R. K. and Pattanshetty, S. M. (2002). Treatment of dairy waste by using water hyacinth. *Water Science and Technology*, 45 (12): 329–334.
- Udume, O. A., Abu, G. O. and Stanley, H. O. (2021). Composting: A Low-cost Biotechnological Approach to ameliorating macrophyte nuisance in fresh waters. *Journal of Agriculture and Ecology Research International*, 22(3): 47-71.
- Valipour, A., Kalyan Raman, V. and Ahn, Y-H (2015). Effectiveness of Domestic Wastewater Treatment Using a Bio-Hedge Water Hyacinth Wetland System. *Water*, 7: 329-347.
- Van der Weert, R. and Kamerling, G. E. (1974). Evapotranspiration of water hyacinth (*Eichhornia crassipes*). *Journal of Hydrology*, 22, 201–212.
- Vietmeyer, N. D. (1975). The Beautiful Blue Devil. *Natural History Magazine*, Issue 9 (Nov) p. 64. *The American Museum of Natural History*.
- Vijayakumar, G.; Baskar, S.; Raghupathy, S. and Rangarajulu, S. K. (2026). Biodegradable Menstrual Pads from Hydrophytic Weeds: Sustainability Assessment, Absorption Performance and Microbial Safety. *Processes*, 14, 918 (<https://doi.org/10.3390/pr14060918>).
- Villamagna, A. M. and Murphy, B. R. (2010). Ecological and socio-economic impacts of invasive water hyacinth (*Eichhornia crassipes*): a review. *Freshwater Biology*, 55: 282-298.
- Wilson J. R. U., et al. (2007). The decline of water hyacinth on Lake Victoria was due to biological control by *Neochetina* spp. *Aquatic Botany*, 87: 90-93.
- Wolverton, B. C. and McDonald, R. C. (1979). The water hyacinth: from prolific pest to potential provider. *Ambio*, 8:1-12.
- Yadav, D. B. and Yadav, A. (2010). Chemical Control of Water Hyacinth (*Eichhornia crassipes*) in Natural Water Bodies. *Indian Journal of Weed Science*, 42 (3 & 4): 246-248.
- Yan, S-H., et al. (2017). Advances in management and utilization of invasive water hyacinth (*Eichhornia crassipes*) in aquatic ecosystems – a review. *Critical Reviews of Biotechnology*, 37(2): 218–228.
- Zhang, Y-Y, Zhang, D-Y and Barrett, S. C. H. (2010). Genetic uniformity characterizes the invasive spread of water hyacinth (*Eichhornia crassipes*), a clonal aquatic plant. *Molecular Ecology*, 19(9): 1774-1786.

Professor Kozo Ishizuka – An Appreciation from the Asian-Pacific Weed Science Society (APWSS)

By Dr. Nimal Chandrasena, Editor-In-Chief, APWSS



The APWSS has lost another one of its stalwarts, a former President, Professor Kozo Ishizuka, who passed away in April 2026. He was cremated on 8 April.

In the following tribute, I am noting down some personal memories, because he was a friend whom I deeply respected. I am also well aware that he was a friend and mentor to many other weed scientists as well, before he retired from the *Department of Applied Biochemistry* at the *University of Tsukuba* around 2000.

As a professor, he led his Department's research, leaving behind a significant corpus of work. Kozo was one of the most important researchers in Japan who worked on uptake, translocation and mode of action and metabolism of herbicides.

His well-published research portfolio shows that he was indeed an early pioneer in Japan who worked with the cutting-edge plant physiology and biochemistry research tools and techniques that emerged in the late-1970s through to the 1990s. He was also very keen on the differential responses of weedy 'biotypes' or 'ecotypes' to herbicides, which was an important area of study in those days.

Most important to APWSS was the leadership he gave to Japan and the Society three decades ago. Kozo Ishizuka was APWSS President from 1993 to 1995 and organized the 15th APWSS Conference in Japan, at Tsukuba, which was held from 24 to 28 July. As our readers know, the APWSS, formed in 1967, is currently in its 59th year of existence.

Professor Ishizuka was a very private person. We were unable to visit him in subsequent visits to Japan, despite making frequent enquiries. His obituary, from the family, received via the *Weed Science Society of Japan* (WSSJ), reads as follows:

[Obituary] We are deeply saddened to announce that Professor Ishizuka passed away on April 6th, 2026. We offer our heartfelt condolences. He was 93 years old.

In accordance with Professor Ishizuka's will, there will be no funeral service, and all offerings such as condolence money, flowers, and incense are declined. Therefore, respecting Professor Ishizuka's wishes, his family did not hold a funeral service, and he was cremated on April 8th by only his eldest daughter and eldest son. Furthermore, his family requested that we convey to everyone that Professor Ishizuka deeply appreciated the kindness shown to us during his lifetime, but they have firmly declined any memorial services. Therefore, we will not be holding a formal farewell ceremony. However, we understand that Professor Ishizuka would be pleased if you could each find an opportunity to offer a toast or other tribute.

Kozo was a generous host who encouraged international exchanges across the Asian-Pacific region. When I was at the University of Colombo, I visited his Department at Tsukuba University twice, in 1989 and 1992. On both occasions, we spent hours discussing matters related to weeds and their management, especially the uptake, translocation and mode of action of herbicides, among other matters related to Weed Societies.

Herbicides were my speciality, too, in the early days, and there was much to discuss, I recall, especially the use of cell lines to study herbicide metabolism. As shown by Ishizuka's research (see later), he was extremely active in many areas of herbicide biochemistry and was happy to share that knowledge with other scientists.

In 1989, I informed him of the imminent plans in Sri Lanka to found the Weed Science Society of Sri Lanka (WSSSL), which occurred a year later, in 1990. I invited Kozo to visit Sri Lanka as our Chief Guest at the founding event of the Sri Lankan Society. However, his commitments at home did not allow him to travel at that time. Instead, Dr. Jiro Harada, another eminent Japanese weed scientist, from *Akita Prefectural University*, came to Sri Lanka and did the honours.



Kozo Ishizuka – a generous host. With the Editor, in 1992



The photo shows Dr. Hiroshi Matsumoto, the Editor (Dr. Nimal Chandrasena) and Professor Kozo Ishizuka in front of his Department at Tsukuba University in 1989.

Where Kozo Ishizuka's heart was is clear in the lead article of the first issue of the Japanese *Journal of Weed Biology and Management* (WBM), 2001; 1: 15–19, in which he explained the value and function of a learned Society and the Journal of such a Society. These views resonate with the much older APWSS and our Journal, which commenced in 2019.

THE FUNCTION OF THE LEARNED SOCIETY AND THE SOCIETY JOURNAL

The society journal is generally understood as one of the most important activities of a learned society. A learned society has firstly to provide opportunities for the exchange of information on research and investigation in relevant fields of science, resulting in the establishment of a new, independent speciality.

Moreover, a society has a function also to promote and encourage the development of new areas of approach by the introduction of technologies and ways of thinking gathered from other fields of science.

Another function of a learned society would be to take responsibility for evaluating priority and protecting the originality of the members' research and investigation from other claims. The Society journal should guarantee this evaluation and protection.

In his article, Kozo Ishizuka recognized that the fast-emerging economies and agricultural research in Asian-Pacific countries could benefit greatly from technology exchange and transfer from developed countries.

Having had close connections with several developing countries, he was keen to promote knowledge-sharing, particularly on rice weed management and other areas of research between Japan and those countries, for mutual benefit. For this to occur, he advocated for increased international cooperation and information exchanges throughout the region, as follows.

TECHNOLOGY EXCHANGE AND TRANSFER IN ASIA-PACIFIC REGION

It could be said that weed science in Japan, for instance, seems very advanced and well-developed. But as agriculture in Japan actually faces many changes ahead and is much influenced by international economics and domestic urbanization, weed management in arable, as well as non-arable, land is expected to further develop in various directions. Even in rice paddy agriculture, there are still many difficulties to be overcome.

There is a host of experiences and technologies, new or traditional, in agriculture in the Asia-Pacific region, which the Japanese themselves should learn more about, and the Japanese should promote exchanges and transfers among countries and areas in the region. In the region, there are many common issues in agriculture, and it may be profitable to compare examples.

As with information on weed propagation, the impacts of herbicides on human environments, such as the fate of herbicides in soils and water, the contamination of the surroundings and toxic effects on fisheries should also be compared among local areas. At present, there are accumulations of excellent research, investigations and technical information, which deserve to be valued highly.

Researchers, working on weed management or weed science in the region, have their own criteria for the evaluation of research and investigations.

*In addition, there is unfortunately no internationally authored academic journal with a pre-review system, covering the Asia-Pacific region, whereas **Weed Science** and **Weed Technology** are issued by the Weed Science Society of America and **Weed Research** by the European Weed Research Society, respectively, and each of them takes responsibility for the development of weed science and technology in each region.*

The WBM was born in 2000, and it is likely that Kozo Ishizuka may have been one of the strongest voices within the WSSJ at that time. In our case, it took another 19 years before the APWSS launched our own Journal **Weeds**. However, clearly, Professor Ishizuka should be remembered as a significant figure within our APWSS community and by the Japanese Weed Science Society. His vision, generosity and leadership gave direction and assistance to the development of the careers of many younger scientists, including mine.

We should gratefully remember his contributions and thank him for being a pillar of strength for the APWSS over a long period.

Some of Kozo Ishizuka's early research articles include the following:

- Matsumoto, H. and Ishizuka, I. (1984). Effect of Temperature on Metabolism of Simetryn in Rice Cultivars. *Weed Research (Japan)*, Vol. 29: 159-163.
- Hisajima, S., Ishizuka, K., Yoeup Paek, K., Namwongprom, K. and Subhadrabandhu, S. (1989). "Multiple Shoot Induction from Seeds of Japanese Chestnut (*Castanea crenata* Sieb. et Zucc) and Successive Shoot Multiplication In Vitro". *Agriculture and Natural Resources* 23 (3)::267-272.
- Matsumoto, H., Nishi, S., Ishizuka, K. (1991). Action of Thiocarbamate Herbicide Dimepiperate on Plant Metabolism. *Journal of Weed Science and Technology*, 36 (3): 257-265.
- Lee, J. J., Matsumoto, H. and Ishizuka, K. (1992). Light involvement in oxyfluorfen-induced protoporphyrin IX accumulation in several species of intact plants. *Pesticide Biochemistry and Physiology*, 44 (2): 119-125.
- Sakoda, M., Usui, K., Ishizuka, K., Harada, N., Ono, H., Uda, H. and Hasegawa, K. (1993). Structure-activity relationships of raphanusanins and their analogues. *Phytochemistry*, 32 (6): 1371-1373.
- Pornprom, T., Matsumoto H., Usui, K. and Ishizuka, K. (1994). Characterization on Oxyfluorfen Tolerance in Selected Soybean Cell Lines. *Pesticides Biochemistry & Physiology*, 52(2): 107-114.
- Seo, Shigemi, Ishizuka, Kozo and Ohashi, Yuko. (1995). Induction of Salicylic Acid β -Glucosidase in Tobacco Leaves by Exogenous Salicylic Acid. *Plant and Cell Physiology*. 36. 447-453.
- Sunohara Y., Matsumoto H., Usui K. and Ishizuka K. (1996). Ethylene Action Inhibitors Suppressed Clomeprop Metabolite [2-(2,4-Dichloro-m-tolyloxy)Propionic Acid]-Induced Electrolyte Leakage from Radish Roots. *Weed Research (Japan)*, 41(3): 234-240.
- Pornprom T., Usui K., Matsumoto, H. and Ishizuka, K. (1994). Absorption and Metabolism of Oxyfluorfen in Tolerant Soybean Cells *Weed Research (Japan)*, 39(3): 180-182.
- Rho, Y.-D.; Matsumoto., H., Usui, K. and Ishizuka K. (1996). Involvement of Foliar Absorption and Translocation in Differential Response between *Bidens tripartita* and *B. frondosa* to Bensulfuron Methyl. *Weed Research (Japan)*, 41::211-215.
- Deng, Fan, Usui, Kenji, Shim, Ie, Kobayashi, Katsuichiro and Ishizuka, Kozo. (1997). Difference in glutathione content, glutathione S-transferase activity and GS-pretilachlor content between rice and early watergrass seedlings. *Journal of Weed Science and Technology*. 41. 295-301.
- Ishizuka, K. (2001), Roles of the new journal. *Weed Biology and Management*, 1: 15-19.