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APWSS

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Asian-Pacific Weed Science Society: A Glimpse of the Past 50 Years and Perspectives

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Abstract

Since the mid-1940s, exciting discoveries of new herbicides led to noticeable improvements in weed control in many crops over the following two decades, leading to yield increases. However, the optimism of achieving weed control through herbicides alone was short-lived. The harmful effects caused by an overuse of chemicals were felt through the 1950s, igniting the need for ecological thinking to understand weeds *prior* to their control. This is why Weed Science took an important change in direction in the late-1950s to encompass studies of weed biology and, ecology - to anchor the evolving discipline in a broader agro-ecological context. As the World's population increased dramatically in the 1960s, in the Asian-Pacific region, there was a deeply-felt need to improve weed control to increase food production. In 1967, the Asian-Pacific Weed Science Society (APWSS) was born to *promote an exchange of ideas on weed control* across the region, including the use of herbicides.

The period of *ecological enlightenment* (1960 to 1975) led to weeds being understood as 'colonizing species'. Colonizing species opportunistically capture resources created by habitat disturbances caused naturally, or by human activities. The placement of weed studies within this ecological framework broadened the discipline to include sustainable weed control practices promoted through the vehicle of Integrated Weed Management (IWM). As a result, discourses in Weed Science, including those at the APWSS, from around the late-1980s, expanded to cover biological and ecological aspects of weeds, as well as mechanisms of crop-weed interactions (i.e. competition, allelopathy, and critical weed-free periods). This trend has continued in recent decades, causing a paradigm shift - *from herbicide dominated weed control to Weed Science*.

In more recent times, research in the Asian-Pacific region has focused on reducing a dependence on herbicides, in favour of integrated weed management (IWM). Management of herbicide resistance in weeds; understanding the potential impacts of climate change and genetically-modified organisms (GMOs) in agriculture; and special weed problems, such as weedy rice, dominate the APWSS research agenda. Reducing conflicts between weeds and men, through a recognition of the redeeming value of weeds and utilization of weeds as bio-resources are also emerging as topics of interest. In our time, when the need to increase the output of food for the rising population of the world is acutely felt, and interlinked human impacts on the globe are accelerating, the scope of Weed Science cannot but expand. The major challenges humans face in this second decade of the 21st Century will encourage us to deeply reflect on our relationship with weeds. We hope that Weed Science will help us learn from weeds that 'co-existence' and austerity are virtues for the future survival of our species.

Keywords: Herbicides; Asian-Pacific Weed Science Society; weed control; Weed Science.

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Introduction

Agricultural production losses due to pests, diseases, and weeds can be substantial, although estimates of such losses are difficult to obtain, and vary much across countries of the Asian-Pacific region. The adverse effects of pests, diseases, and weeds are greatly influenced by local agronomic and climatic factors in different countries, and by the local, socio-economic factors, operating within their production systems. While many factors cause losses in agricultural production, there is little doubt that weeds are a major concern. However, because weeds are so common and widespread in the Asian-Pacific 'tropical' region[16], together with a few temperate countries, their significance in terms of causing production losses is not well appreciated. The economic costs of weeds in most of the Asian-Pacific countries are also not well known, although estimates exist for specific crops in some countries. For example, the well-known Australian study (Sinden *et al*., 2004) estimated total losses in Australia, due to weeds to be about Aus $4 billion/year. In India, even with conservative estimates of average 10% losses in any crop, Yaduraju (2012) suggested that loss of food grain yield, attributable to weeds would far exceed US $ 13 billion/ year.

However, in many situations, the negative impacts of weeds are not perceived to be as dramatic, as those caused by pests and plant diseases. Some of the pioneers of Weed Science considered weeds only as 'nuisances', and that too, only when they are 'very abundant' (see Harper, 1960). In a similar vein, we could excuse farmers, particularly in our region, for considering weeds as just another annoyance, without much consideration for economic losses they may cause. In fact, many societies and cultures of our region consider weeds to be useful allies recognizing their redeeming values (see Chandrasena, 2007).

In our view, most chemical weed control methods evolved, through the past 50 years or more, without the full knowledge of the weed related losses that can be prevented. There is not much understanding of what weeds really are, or their role in nature. However, weed scientists, with an ecological-bent, have been long aware that weeds are only '*colonizing species*' (defined as *plants or animals that find themselves in a new locality, confronted by challenges of a new environment; and therefore, pioneers in that environment*) and weed problems persist because of favourable environments created for their proliferation by modern agricultural practices and other disturbances[17].

The Asian-Pacific region and countries cover a wide geographical area, with diverse landscapes, climates, cultures, economies, and agriculture systems. They include countries of South Asia, East Asia, South-East Asia, West Asia, and Oceania, including New Zealand, Australia, Fiji, and the United States. In 1967, the Asian-Pacific region's population was 3.461 billion; in 2017, it is now 4.478 billion. The region, therefore, accounts for about 60% of the current world population of 7.511 billion[18], while occupying just 37% of the Earth's land mass and 48% of the global arable land. Seven of the 10 most populous nations in the

[16] The founding fathers of APWSS deliberately targeted stimulating Weed Science and weed control in the 'tropics', through the Society, giving major attention to rice, coconuts and other crops, because weeds were roughly estimated to 'stifle' as much as 40% of production in the tropics (APWSS, 1977; APWSS 1988).

[17] Ecologically speaking, Bunting [1960] referred to weeds as '*pioneers of secondary succession*'. Baker [1965] defined a weed as '*a plant …if, in any specified geographical area, its populations grow entirely or predominantly in situations markedly disturbed by man, (without, of course, being a deliberately cultivated plant)*'.

[18] http://www.worldometers.info/world-population/population-by-country/ (Accessed 19th June 2017).

world are in this region (i.e. China, India, USA, Indonesia, Pakistan, Bangladesh and Japan), accounting for more than half of the global population. This region includes some of the oldest civilizations and culturally rich countries in the world. It also accounts for four of the top 10 global economies (USA, China, Japan and India), and 58% of world's GDP, which can also be regarded as the 'powerhouse' of global science and technology and human ingenuity.

The Asian-Pacific Weed Science Society (APWSS) came into being following an "*Asian-Pacific Weed Control Interchange*", held during 12-22 June 1967 at the East-West Center, University of Hawaii, in Hawaii. A group of 87 individuals, from 22 countries, participated at the inception meeting under the theme: "*Weed Control - Basic to Agriculture Development*". On the last day, a Workshop recommended the formation of an organization: "…*to facilitate the interchange of current weed control information and promote research in Weed Science...*" The primary motivations for founding the APWSS become clearer in the words of one of our founding fathers - William Furtick (1969):

> *"…Weed Science suffers because weeds have been an integral part of agriculture from the beginning and their damage is less dramatic than that caused by insects and diseases. However, it is apparent that weed control is a pre-requisite for the development of modern agriculture, which is based on developing high yielding, high quality varieties that can produce their potential only under optimum fertility, water and freedom from pests.*
>
> *This means that without weed control, modern agriculture will end up under a canopy of weeds. It is the duty of the weed societies to get this story across to others in agriculture. It has often been possible for the representatives of industry to convince the farmer whose income is affected, while professional agriculturist is oblivious to this basic importance of weed control. This cannot continue, but can only be changed by a planned effort…"*

Scientific societies serve many purposes. They are conduits for information and provide networking opportunities for their members. Societies are often important lobbying organizations that make sure that governments regularly hear scientists' perspectives on various scientific issues. Regional societies, such as the APWSS, made up of a number of affiliated, national societies of individual countries provide opportunities for wider exchanges and interactions, across those countries. As our founding fathers imagined, the Society provides the foundation for the '*planned effort*' (Furtick, 1969) and coordination on which the platform can be built, making weed scientists of the region feel that they '*belong*' to a worthwhile community, through knowledge sharing. They also play a critical, peer evaluation role of scientific claims being made.

Over the years, the discipline of Weed Science has also developed in many countries of the Asian-Pacific region, but the pace of that development has varied widely. Professional scientific societies dealing with weeds and weed control have been widely established for mutual exchange and sharing of knowledge. Besides organizing conferences, symposia and other activities at the national level, these societies have also provided important settings for sharing of international experiences on emerging issues in Weed Science.

Given the importance of the region on a global scale, in this 50th Anniversary year of the APWSS, in this paper, we cast our eyes on the *World of Weed Science*, prior to the 1967 founding of the Society to understand the social milieu in which our founding fathers operated, and the platform on which the

Society was built. We also review prior events, the evolving state of knowledge about Weed Science, which form the foundation upon which the APWSS has been built, for the benefit of the region.

We are aware that our interpretations of history are shaped by our own background and experiences, which may be different to the perceptions of others. Nevertheless, we regard this as an opportune moment for deeper reflection. Understanding the historical context in which APWSS was born is critical to planning the directions for its future. Understanding some of the challenges we face within the discipline of Weed Science will assist APWSS to move its scientific enquiries and endeavours in directions that may better suit our region, its growing population and food production needs, whilst protecting limited natural resources and the fragile environment. To this end, as we celebrate 50 years of APWSS existence, we also offer a summary of major highlights, an analysis of significant events, and a broad overview of the Society's contribution to Weed Science in the region.

In capturing the essence of APWSS's impact on matters related to weeds and their control, we hope its value in the region is better understood. Notwithstanding the challenges ahead, we hope that our interpretations and perspectives will assist further developments in Weed Science in the region, as well as stimulate the Society to grow further, over the next 50 years!

Development of 'Weed Science' – through the Lens of History

Although weeds have interfered with human activities since recorded time, as a discipline, Weed Science was slow to develop. The first humans, our hunter-gatherer ancestors, hunted animals and searched for edible plants. When some humans accidentally discovered that they could deliberately grow food crops, they settled in one place, beginning the journey of agriculture, around 10,000 to 12,000 years ago.

Within a few millennia, humans also realized that the production of the crop of their choice, mostly, coarse-grain cereals, was greatest when that crop grew in the absence of competing, inedible species, which grew in the same habitat, around their dwellings. Our ancestors would have manually removed such species, releasing their crops from weed competition. "Slash and burn" agriculture, still used widely in developing countries, was also an early attempt at reducing weeds in areas of habitation that were converted to cultivation. After several millennia of settled agriculture, Bronze Age humans (approximately, 3,500-1,000 BC) appeared to have understood the concepts of growing crops as monocultures to obtain higher yields; expanding cultivated areas along the river deltas to capitalise on seasonal flooding and reduce yield losses due to weed competition.

However, in those early millennia, humans managed weeds with bare hands, or sharp sticks, long-handled tools with a flat blade made up of rudimentary iron or bronze (hoes, mamoty). Human labour was cheap and readily available, including slave labour, right up to modern times. Use of metal tools for weed control, occurred first in the Bronze Age, and expanded later, in the Iron Ages (approximately, 1,000 BC to about 1,000 AD). Historical records, such as Egyptian art and hieroglyphics, preserved in the pyramids, show that ancient civilizations, up to at least 3,500 BC used animals (bulls, buffaloes, and horses), to pull ploughs for tillage, and concurrently, achieve weed control. Animal power supplemented human labour as an essential part of ploughing and weed control for millennia, and continue even today in many Asian-Pacific countries.

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[19] A history of Weed Control in the United States and Canada by F. L. Timmons was originally published in *Weed Science*, 1970. 18 (2): 294–307). It has been republished in 2005 - *Weed Science*, 53: 748-761.

In tracing the history of Weed Science in the USA and Canada, Timmons (2005)[19] concluded that relatively few agricultural leaders and farmers became interested in weeds as a problem before 1,200 A.D. or even 1,500 A.D. For several millennia, weed control was incidental to tillage for land preparation, growing and cutting, or pasturing of thickly planted crops. An English farmer, Jethro Tull (1762)[20], then invented row cropping, permitting 'horse-drawn hoeing' whilst controlling weeds through cultivation. The steam-driven tractor, invented in the mid-19th Century, then replaced the horse. During the early part of the 20th Century, fuel-driven tractors were built in both Europe and USA, making large-scale ploughing and land preparation possible, simultaneously achieving weed control.

However, as traced by historians – Clinton Evans (2002) and Zachary Falck (2010) until the mid-20th Century, crop losses, due to weeds, were considered '*manageable*' with some effort, and mostly ignored, while research efforts in agriculture focused mostly on the control of plant pathogens and insect pests that caused spectacular, and large-scale damage to crops.

A review of literature indicates that Entomology and Plant Pathology had been disciplines for nearly a century before Weed Science became an important subject. In our view, early farmers *accepted* a relatively constant, predictable, crop yield loss from omnipresent weeds. In contrast, as Burnside (1993) pointed out, '*Weed Science developed as a Step-child*' and impacts of plant pathogens and insect pests were conceived as more devastating and unpredictable, although losses caused by those organisms varied greatly from year to year.

It appears, historically, that farmers were most concerned by the *unpredictable* losses from pests, other than weeds. Perhaps a relatively benign attitude towards weeds prevailed at least within some sections of the society in North America, as evident in the following stanza, written by a famous American Poet – James Russell Lowell (1848):

> *"…One longs for a weed, here and there, for variety; though a weed is no more than a flower in disguise, which is seen through at once, if love give a man eyes..." A Fable for Critics (1848)*

Ralph Waldo Emerson's famous quote, made in a speech in 1863: "…*What is a weed? A weed is a plant whose virtues have not yet been discovered…*" also shows that sections of the American society had no qualms about boldly expressing the positive aspects of weeds (Emerson, 1863; also see Chandrasena, 2015).

We would add that most Asian-Pacific societies evolved with similar, but more than a relatively benign attitude towards weeds. Many cultures in our region have valued weeds for millennia for a variety of uses. Until herbicides were introduced in the 1960s, 70s and 80s as the panacea for obtaining higher crop yields, many societies did not consider weeds as enemies, and were willing to accept some losses due to weeds as inevitable. In making this point, we emphasize the fact that much of the great strides in improving food production in those decades, pre- and post- "Green Revolution", was largely due to a combination of improved cultivars, fertilizer use, more holistic crop protection and other agronomic practices, and not just herbicide use.

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[20] Tull, Jethro (1762). Horse-Hoeing Husbandry or An Essay on the Principles of Vegetation and Tillage. Of Weeds, Chapter VII, p. 73. (http://www.archive.org/details/horsehoeinghusba00tull).

The *human-weed conflict*, which has been concocted and marketed as a '*War with Weeds*', is unfortunate, and its effect has been pervasive, much to the detriment of proper scientific inquiry within Weed Science. The needless '*us-and-them*' narrative began very much in the last two decades of the 19^{th} Century, and the blame must be attributed to attitudes at that time, prevalent in North America, invaded, and settled largely by people of European descent (see Evans, 2002; and Falck, 2010).

Weed Science, as a discipline in agriculture, first received significant national recognition in USA only in the mid-1940s (Burnside, 1993). Bolley in the USA, Bonnett in France, and Schultz in Germany, around 1900, independently, found that solutions of copper salts, used for controlling plant diseases, would selectively control broadleaf weeds in cereals (see Timmons, 2015). This led to the use of copper sulphate and other chemicals (sodium borate and sodium arsenate), for selective weed control in the first decade of the 20^{th} Century, ushering a new beginning for weed control, which was not possible until that time.

Following on, the almost simultaneous discovery of herbicides: 2, 4-D (2, 4-dichloro-phenoxy acetic acid) in the USA, and MCPA [(4-chloro-2-methyl-phenoxy) acetic acid] in England, during 1941-42 revolutionized the field of weed control. For the first time in history, around 1944, the selective activity of these auxin-like herbicides in controlling broad-leaved weeds in grass turf was demonstrated in the USA and UK, leading to much excitement and the release of the first commercial herbicides (see Duke, 2005).

The post-World War II period saw a great deal of interest in the possibilities of applying chemical solutions - organic compounds, that could selectively destroy weeds across large landscapes, thereby saving labour, which would otherwise be spent on weed control. The fact that herbicides could be economically synthesized in bulk, on an industrial scale, galvanized industry, adding to the excitement of discovery and development. The period of 25 to 30 years after the end of World War II is regarded as the *'Golden Age of Herbicides'*, and as Duke (2005) pointed out, the cost of discovery and registration was not prohibitive at that time, so even small companies made profit from new discoveries and got involved in weed research.

However, the demonstration of efficacy with which herbicides could control weeds also narrowed the focus of enquiry, leading to the skewing of Weed research in favour of herbicides, and the somewhat glamorous research on 'Mode of Action' of herbicides. On the positive side, the mode of action research led to strong interactions between weed scientists, plant physiologists, and biochemists, both within industry and outside, perhaps working so closely for the first time. The joint research between the industry scientists and academics led to major findings on the mechanisms of uptake, translocation, biochemical pathways, and metabolism of chemicals within plants. Some of this weed research, such as those on photosynthetic inhibitors, revolutionized the field of Botany and our understanding of how plants function.

A Glimpse of the Past – Pre APWSS Influences

In the APWSS 40^{th} Anniversary publication, Baltazar (2007) referred to several significant events (see below), which may have influenced the developments of Weed Science in the Asian-Pacific region:

- **Before 1960-Start of Chemical Control** Herbicides were introduced into the region; auxin-herbicides (2, 4-D, MCPA), amides (butachlor), carbamates (thiobencarb), dinitroanilines (trifluralin), etc.

- **1960-Green Revolution:** The development of "Miracle Rice" and "Mexican Wheat"; high-yielding varieties (HYVs) of rice and wheat, largely, short-statured cultivars, replacing tall, traditional cultivars, signalled the start of the 'Green Revolution' and the doubling of crop yields. The introduction of HYVs emphasized the critical role of weed control.

- **1970-Shift from Transplanting to Direct-seeding:** Rice cropping increased from one crop per year with transplanted rice, to 2-3 crops with direct-seeded rice (DSR) cultivation, again increasing yields. The water regimes changes in DSR favoured moisture-loving grasses, shifting the major weed problems in rice from broad-leaf weeds to more difficult to control grasses.

- **Changes in Pest (Weed) Control Paradigms:** The change in the crop protection paradigm to more holistic integrated weed management (IWM) in cropping systems, incorporating cultural, biological, and chemical control strategies for major weed problems.

We essentially agree with those sentiments. Our review of APWSS literature also finds that herbicide-based weed control was a key component, and perhaps even *the driving force* for establishing the APWSS as a Society 'promoting linkages' across industry, farmers and academics. However, a nuanced understanding of history would indicate *it was not the only factor*. We believe our predecessors would have been influenced by various events and initiatives, which preceded the founding of the Society. Other motivations, such as which weed species were making the biggest impact across the region; obtaining a good understanding of weeds through studies of weed biology and ecology, and establishing the platform for training, education, and extension through a coordinated approach, were at play, as reviewed below.

Ecological Perspectives to Understand *What Weeds Are*

Looking back at the history of Biological Science and Weed Science, we see the '*period of ecological enlightenment*' somewhere between 1960 and 1975, when Herbert Baker initially formulated thoughts on what might be '*an ideal weed*' (Baker, 1965). Contributions from other giants in Ecology, Charles Elton (Elton, 1959), Jack Harlan (Harlan, 1965), Ledyard Stebbins (Stebbins, 1965), John Harper (Harper, 1957b; 1960; 1965) and Hugh Bunting (Bunting, 1960), to name a few, also led to our current understanding of *what weeds really are*. Ideas and views espoused by these pioneers shaped and moulded weed research, setting in motion directions for Weed Science to evolve, and indeed the careers of a large number of weed scientists.

The potential of 'globe-trotting', invasive species, both plants and animals, had already been mooted in 1958 by Charles Elton in his landmark thesis (Elton, 1958). Evidence of many weeds in cultivated fields being 'wild relatives of crops' had been also compellingly compiled and presented (see Harlan and De Wet, 1965). Not to miss the point, Jack Harlan also pointed out the remarkable similarities between the greatest weed of them all - humans - and other '*colonizing species*'(see discussion in Chandrasena, 2015).

It would be fair to say that the scientific enquiries and ecological perspectives referred to above, continue to be seminal ideas in our attempts to explain *what weeds are* and *why they behave in the way they do*. This understanding should underpin everything weed scientists do, although, we lament that *understanding lags a long way behind practice* when it comes to weeds. '*Know Your Enemy*' is a catch cry we do not subscribe to, because we do not consider weeds as enemies. Many weeds have redeeming values, and are useful biological resources to various cultures and societies. However, war metaphors have been, and are still often used in slogans associated with weed control. Instead of understanding the true nature of the organisms we are dealing with, we find critical aspects of their ecology and biology are often overlooked by a good proportion of both weed researchers and weed control practitioners, leading to poorly executed research and weed control.

By late 1950s and early-1960s, as university departments and faculties expanded all over the world, the gap between 'basic science' (covering topics like Plant taxonomy, genetics, physiology, biochemistry, evolution, and ecology) and 'applied science' (such as agronomy, soil science and crop protection) opened up widely in academia. This created a strong disconnection between the understanding of the biology and ecology of weeds, leading to poorly executed weed control research and interpretation of results.

For several decades in the past 50 years, we find weed control research reported essentially as part of cropping, without much thought on why and how, and a tendency to shunt ecology and biology away as unimportant. A large amount of weed research, reported at APWSS Conferences and other forums, therefore, suffer from inadequate demonstration of an understanding of basic Botany and Plant Ecology, subjects that underpin the 'science' of weeds. Many scientists think that a basic understanding of 'Science' is necessary before a practical application is developed; therefore, 'Applied Science' relies on the results generated through basic science. Others favour a move away from basic science to find solutions to actual problems. Both approaches are valid in our view. Whilst it is true that some weed problems demand immediate attention, few effective and sustainable, weed control solutions would be found without the help of the knowledge foundation generated through basic Weed Science. Perhaps, our APWSS founders were also concerned 50 years ago of the inadequacy of application of scientific methods in the region?

Impacts of Excessive Dependence on Pesticides and Herbicides

During the 1950s and 1960s, rumblings of trouble were beginning to be heard (see Duke, 2005). The discipline of Weed Science came under criticism by some as being nothing more than 'herbicide science' and a conduit for herbicide companies to market their products, which were in an expansion mode. Although the focus quickly changed to capture studies in weed biology and ecology, as well as non-herbicidal weed control methods, the perception that Weed Science was a discipline, largely focused on herbicides, continued for many years, perhaps with some negative consequences. Introducing an influential symposium, organized by the *British Ecological Society*, held at Oxford, U.K., during 2-4 April 1959, John Harper (1960) wrote:

> *"…this Symposium has been concerned with the biology of weeds, which has been interpreted to exclude chemical control. This has been a deliberate policy, because symposia and conferences in weed control have been held in abundance. Herbicides are, however, so widespread in use that they are beginning to form part of the 'normal' environment of weed populations. Already weed strains have been selected, which are resistant to some of the chemical herbicides. It will be a tragedy if the botanist does not take opportunities now offered to follow the influences of this most potent force on the distribution, frequency, evolution, and dynamics of weed populations…"* (Harper, 1960)

This 1959 meeting highlighted the need to focus on the taxonomy, biology and ecology, including reproduction systems, and the evolution of weeds. It impressed the scientific community to commence studies of weeds from an individual perspective (autecology), and as part of populations and communities (synecology).

Keeping herbicides out of the Symposium, John Harper steered the directions Weed research should take, which were pivotal in the development of our discipline. Three years earlier, he had already prophetically sounded the early warnings on the dangers of overuse of herbicides and the likely development of herbicide resistance in weeds (Harper, 1956; 1957b).

Looking back at history, a much more influential symposium – the *First International Union of Biological Sciences Symposia on General Biology* – was subsequently held in California, during 12-16 February 1964. The proceedings – *Genetics of Colonizing Species* - Edited by Baker and Stebbins (1965) are regarded by many ecologists as a seminal landmark in the evolution of Weed Science, because several evolutionary biologists made remarkable contributions at the Conference to the field of biological science, offering a glimpse of how Darwin's theory of evolution might actually be operating in Nature. As the Editors stated:

> *"...the Symposium had as its object, the bringing together of geneticists, ecologists, taxonomists and scientists working in some of the more applied phases of ecology –such as wildlife conservation, weed control, and biological control of insect pests..."* Baker and Stebbins (1965)

The explanation of possible genetic systems operating within 'colonizing species' brought the discourse of weeds to a higher plateau than before. With a focus squarely on *Plant Science*, it stimulated research over the next few decades on using weeds as model, experimental organisms to understand how plant populations behave. This, combined with studies on the biology, ecology and eco-physiology of individual weed species changed the direction of Weed Science forever, which, up to that time, had an inordinately unbalanced focus on herbicides. Concurrently, during this period of *ecological enlightenment*, the heightened awareness obtained on plant and animal population biology and ecological perspectives on weeds (i.e. related to succession, vacant niches, see Baker, 1965), brought in more 'science' to the Weed Science discipline.

By the early 1960s, other societies of biologists and ecologists influenced the directions of weed research across the globe. This brought about a change of focus of Weed Science on to studies of weeds, as biological organisms, and not just the examination of herbicides, to kill them. Stimulating the discourse on converting ecological theory into practical management of plant and animal populations, the *British Ecological Society* launched the *Journal of Applied Ecology*, in the heady days of the early 1960s.

Launching the Journal, its first editors Hugh Bunting and Vero Copner Wynne-Edwards optimistically wrote (Ormerod and Watkinson, 2000):

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

Reviewing the literature, we find that the turnaround of focus to *understand weeds*, as purely a group of plants with special attributes for colonizing vacant niches created by disturbances, was achieved at least about 10 years prior to the formation of APWSS. Perhaps the amplified awareness on the need to *understand weeds, as a basis for their control* may have influenced the thinking of our founders at that time. It is also probable that they were concerned about the potential for any technology, particularly, herbicide technology, to go wrong when it is used without an appreciation of unintended consequences and collateral damage.

Apart from the *Genetics of Colonizing Spe*cies, we may also add Rachel Carson's major contribution, *Silent Spring*, published in 1962 (Carson, 1962) as a landmark, which influenced the development of Weed Science. The book sounded an ominous warning to the scientific community on the adverse impacts of excessive pesticide use across USA, including the large-scale use of herbicides. *Silent Spring* was inaccurately criticized within the Weed Science community (Robert Zimdahl, *pers. comm*., July 2017). However, the impact of *Silent Spring* was a vastly increased regulatory control of all pesticides, and the mandatory requirement for comprehensive research data on modes of action, efficacy, toxicology, and environmental fate of xenobiotics.

The stringent approval requirements increased research efforts on all pesticide applications. The additional costs for herbicide/pesticide evaluations slowed down new discoveries considerably. The mandatory requirements for registration resulted in increased funding, which promoted closer working relationships between researchers, the pesticide/herbicide industry, independent reviews, and efficacy evaluations. Both these influences, it could be argued, would have had positive and negative consequences.

The mandatory studies in the environmental fate and toxicology of pesticides, particularly on aquatic and soil biota, strongly increased the environmental awareness of the potential and real effects of overuse of chemicals, and public perceptions of those risks. Closer working relationships between researchers and the industry, some would argue, effectively stifled dissent, and objective assessment of such impacts, so that the required improvements with regard to responsible use of chemicals could be made.

Due to the strong marketing campaigns by herbicide manufacturers in the 1970s through to 1990s, in the early days, *Weed Science might have been properly called Herbicide Science* (Thill *et al.*, 1991). Lamenting on this negative perception, Donald Wyse stated twenty-five years ago (1992):

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

With the recognition of the need to anchor Weed Science in its basic sciences – *Botany* and *Ecology*, over the next two decades, the emphasis shifted from herbicides to a more holistic, integrated weed management (IWM) approach (Thill *et al.*, 1991; Wyse, 1992; Zimdahl, 2012). Public concerns on the potential impacts of widespread pesticide use had driven the science of managing insect pests towards integrated pest management (IPM) at that time. Following in the same direction, IWM was an effort to, in Zimdahl's words (2012): *"…overcome the paralysis of the pesticide paradigm and conceive a Weed Science research program that addresses both society's perceptions of safety and the scientific community's perceptions of risks…"*

The discourses at that time responded to public pressure, and included scientific ideas on population and community ecology, the genetic basis of evolution, carrying capacity of ecosystems, limiting resources and limits of growth. Arguments for reducing the large loads of herbicide and other pesticides used in agriculture swirled around in the 1960s and 1970s. A primary motivation was to achieve acceptable levels of environmental safety, while mitigating the negative economic impacts of weeds and pests with chemicals.

Whilst herbicide-based research continued on aspects, such as reducing herbicide contamination of surface and ground water resources, and modifying application technology to increase weed control efficiency, IWM stimulated research and practical applications, incorporating all of the available weed control methods, based on ecological principles, weed thresholds, as well as economic goals of weed control.

IWM also shifted the emphasis from 'weed control' to 'weed management', with the incorporation of knowledge of population biology (e.g., weed seed population dynamics; soil seed bank; species shifts over time) into control programmes. Other vital elements in IWM included weed hygiene (preventative weed control); cultural practices (i.e. crop rotations, multiple cropping, minimum tillage, crop residue uses, and manipulations of water and nutrients) and biological control. The primary intentions were sustainable weed management, and large-scale reductions in herbicides used for weed control, in the advanced economies, at that time.

Other Historical Events

Strong linkages began forming in the 1950s among herbicide industry scientists, weed researchers in Universities, professional weed managers and extension staff in the public sector, across the developed regions in North America and Europe. The early networks also included farming lobby groups, and environmentalists. With regard to historical perspectives on the formation of Weed Science Societies and landmark events, which preceded the formation of the APWSS, we highlight the following:

- As public interest grew, among farmers, scientists and industry, the first dedicated weed journal in the USA (called, *Weeds*) was launched in 1951 as the journal of the Association of Regional Weed Control Conferences. This was followed by the formation of the Weed Science Society of America (WSSA) in 1956, which took over the publication of *Weeds*; and re-named it *Weed Science* in 1968.

- The European Weed research Council (EWRC), which later became the European Weed research Society (EWRS)[21] was formed in 1958, and launched its official journal Weed research in 1961.

- As previously indicated, the British Ecological Society launched its influential journal - the Journal of Applied Ecology in 1964 - to *promote the application of ecological theory to improve policy and management decisions on biodiversity, ecosystems, natural systems, environment and natural landscapes*.

- In Australia, the First *Australian Weed Conference* was held in 1954, under the auspices of the Australian Agricultural Council, although the first Weed Science Society in Australia - the *Weed Society of New South Wales*, was formed in 1966, a year before APWSS was formed.

- The Hyacinth Control Society was formed in 1961 primarily for weed managers to share information on their efforts to control water hyacinth [*Eichhornia crassipes* (Mart.) Solms] in Florida's lakes, rivers and canals (Schardt, 2010). The *Hyacinth Control Journal* began in August 1962, to provide information about water hyacinth control to aquatic plant managers. The Society then broadened its scope in the 1970s to address plant management issues across the USA, re-incorporating as *The Aquatic Plant Management Society* (APMS). The Hyacinth Control Journal was expanded and re-named the *Journal of Aquatic Plant Management* to address all invasive aquatic plants.

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[21] In May 1958, a meeting of Weed scientists in Ghent (Belgium) set up an international working group to accelerate progress in solving weed problems. The first outcome was to a conference at Stuttgart-Hohenheim where Project Groups on bracken, wild oats, and methods of herbicide evaluation were organized. The EWRC was established at a second meeting at Oxford in 1960. The Council became a fully-fledged Society in 1975 with 24 member country representatives. The 1960 meeting also started the journal Weed Research.

- In 1966, the US Agency for International Development (USAID) launched a major effort to develop weed control in the USAID aided nations. The program was carried out through a contract with the International Plant Protection Center (IPPC) of the Oregon State University (see Furtick, 1969).
- The British Crop Protection Council (BCPC)[22] was established in 1968. Renowned for the '*Brighton Weed Conference*', BCPC celebrates its 50th Anniversary in 2017. Its 'Weeds Working Group' was established initially in 1968, almost coinciding with the founding of the APWSS.
- The *Canada Weed Committee* – the precursor to *The Canadian Weed Science Society* – with 15 government-appointed members, was formed in 1968[23].
- The *Indian Society for Weed Science* (ISWS) was established in 1968. Publishing of its journal 'Indian Journal of Weed Science' began in 1969.

In spite of the universal importance of weeds as a limiting factor in food production and the vast amount of herbicides being used for vegetation control in various situations, throughout the 1950s and 1960s, government support for Weed Science and weed research in almost all countries was lukewarm. A viewpoint that prevailed at that time was that weed research should be largely left to the agrochemical industry, which had proven to be outstandingly successful in developing and marketing herbicides, across the globe, making huge profits. Perhaps, an important difference was lost in that discourse: marketing of herbicides and/or other pesticides and deep scientific enquiry in to weeds and their control are quite different activities.

A second viewpoint was that fundamental aspects of weed research should be left to the university sector, which, in theory, was well set up to undertake the required research. In practice, however, the agrochemical industry, like any other industry, faced ever-increasing commercial pressures, which limited what they could achieve in terms of herbicide development, leaving many gaps to be filled. In addition, university research was restricted by individual interests and expertise of incumbent staff, finance, the need to select projects suitable for completion of post-graduate student thesis within 3-4 years. Whilst universities were acknowledged as the doyens of conceptualization, scientific theory, and sometimes, applied research, they were handicapped by weak linkages with industry and real-life on-farm agriculture. They were also unable to operate as commercial enterprises, doing 'science' and commercialization of findings simultaneously, in the industrial context, perhaps until recent decades[24] Essentially, this left the more practical side of weed control and testing of herbicides in the hands of enthusiastic, but often, inadequately-resourced agronomists, and ill-equipped organizations, who had little hope of solving major weed problems with in depth understanding of weeds.

It is interesting to note an overt criticism in Furtick's words, made in 1969: "…*professional agriculturists in the region are oblivious of the basic importance of weed control*…" He was referring to the apparent deficiencies in weed control across the major crops in the Asian-Pacific region, which had not quite caught up with the 'winds of change' blowing across North America and Europe, in particular.

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[22] The BCPC was founded in 1968 when the British Weed Control Council (set up in 1953) and the British Insecticide & Fungicide Council (set up in 1962) merged to form a single body.

[23] The Canada Weed Committee was renamed in 1978 as the '*Expert Committee on Weeds*', a name that endured the ensuing 25 years. The Canadian Weed Science Society was finally formed in 2002 by amalgamating various precursor groups (such as the Wild Oat Action Committee and Quack grass Action Committee).

Given this, we believe that APWSS was conceived because of the need for 'collective bodies' to help plan and take action, and co-ordinate the implementation of weed control programs through interactions, and collaborations among 'like-minded' people in the Asian-Pacific region.

APWSS – From Weed Control to Weed Science

The Founding Years (1967-79)

Our review of the founding event and the first ten years of APWSS activities indicates a great deal of passion, enthusiasm, and unmitigated goodwill to collaborate on Weed research and to find practical solutions for weed problems that plagued many of the developing countries of the region. 'Food security' for developing nations was a central theme in the deliberations. Excerpts of a released communiqué, from the East-West Center, announcing the formation of the APWSS, reveals it (APWSS, 1967):

> *"…Representatives of 21 Countries meeting in Hawaii have formed an International Body to attack the mounting food shortage in tropical areas through weed control. The organization is the Asian-Pacific Weed Science Society; and it was organized by a recent weed control conference sponsored jointly by the University of Hawaii's College of Tropical Agriculture and the East-West Center's Institute for Technical Interchange.*
>
> *The Society will seek to stimulate research into how extensively weeds limit food production in the tropics, giving major attention to rice in Asia and to coconuts in the Pacific. Also, the Society will promote the design and application of weed control programs, including training programs, best suited to the agriculture, economics, cultures, and traditions of emerging countries…*
>
> *To date, most research in weed control and the use of herbicides and equipment has been confirmed to the temperate zone. The recent weed control conference brought out that there are 3000 to 5000 trained workers in the temperate zone, compared with fewer than 100 in the tropics. So scanty has been research in the tropics that it is not even known how much food production is lost to weeds, and, conversely, how greatly production might be expanded through proper controls. But, although firm data are lacking, it is surmised that weeds stifle as much as 40% of production in the tropics…"*

Table 1 presents summary details of papers presented at the APWSS Conferences in the early years. Topics discussed at the founding conference clearly reveal the intents. They include new herbicides, and herbicides for weed control in rice and other agronomic crops, pastures, horticultural crops and brushlands. Some attention was paid to herbicide physiology and degradation, while general topics included the importance of conducting weeds surveys in different countries and the role of education, training, and extension.

None of the papers at the founding Conference could be classed as studies in Weed Biology or Ecology. However, reflecting the mood at that time, the case for herbicide use to better control weeds and achieve increased crop yields was strongly argued. The founding Conference also strongly advocated for weed surveys in individual countries to address the dearth of weed information. It also highlighted the importance of training of weed workers, and 'taking the message to the farmers' through extension.

[24] An example of a high-impact, academic product, related to Weed Science, that has been commercialized on a global scale is genetically modified organisms (GMOs).

Table 1: Major categories of papers and presentations at APWSS Conferences, 1967-79*

Topic	1967	1969	1971	1973	1975	1977	1979
New Herbicides	5	3	3	5	13	8	8
Rice Weed Control, including herbicides	11	12	17	6	12	3	9
Weed Control in agronomic crops, including herbicides	9	8	14	17	14	18	36
Weed Control in horticulture, forestry, plantation crops, including herbicides	6	3	3	10	15	16	24
Herbicide mode of action, soil residues, metabolism, physiology, biochemistry	6	6	3	12	21	11	8
Non-herbicide methods, including biological/cultural control	0	0	1	0	4	5	13
Weed biology, ecology	0	5	5	16	13	23	24
General, perspectives, weed surveys	10	6	5	4	6	3	6
Legislation, education, training, extension	5	2	1	8	0	4	6
Total	**52**	**45**	**52**	**78**	**98**	**91**	**134**
Total related to Herbicides	71%	71%	77%	64%	77%	62%	63%

* We followed a general sense, obvious in the paper titles and sometimes, indicated by the themes in the published Proceedings to attribute the APWSS Conference papers to different themes, in this Table and those to follow. There may be some errors in attribution, although these are likely to be minor.

In those early years, herbicide-related presentations dominated the Conferences - up about 60-70% of the papers presented (Table 1). The herbicide research would have excited the region's weed scientists. It initially revolved around introducing new herbicides, demonstrating their efficacy in controlling weeds in a variety of crops, cost-benefits, and potential economic gains. In later years, herbicide efficacy trials were complemented by studies of modes of action, selectivity and the environmental fate of those chemicals.

As Zimdahl (2012) pointed out, many Weed Science textbooks and journal papers published in the 1960s, 1970s and 1980s devoted more than 50% of their contents to characterizing herbicides, herbicide modes of action and herbicide-environment interactions, showing a *collective commitment to herbicides as the best solution to weed problems*. As evident in the data (Table 1), APWSS proceedings were not much different those days. The founding years also set the pattern for the next decade (see APWSS, 1988), introducing the previously mentioned themes under which papers were presented. Enthusiasm to educate and train people in not just in weed control, but also in scientific enquiry, was also evident in the early inter-changes.

In the early days, not much attention was paid to aspects, such as surveys to identify major weed problems; new species and their taxonomy; ecology and biology of major species; and various non-herbicide based methods that might be effectively deployed against weeds. Weed impacts in the environment hardly got a mention in the early days, except for perhaps, aquatic weeds. At the second Conference, in 1969, Le Roy Holm and James Herberger described the task of compiling an inventory of "*The World's Worst Weeds*" with a global focus. Up to that time, there was no compendium of weeds, which had the greatest impact on agriculture and other human endeavours. Holm and Herberger (1969) expressed concern for the dearth of real data and information on priority weeds, as well as trained personnel in the Asian-Pacific region at that time:

> *"…there are about 200,000 species of angiosperms recorded. Some estimates suggest that 30, 000 of these may behave as weeds. We have looked at about 3000; and were very soon able to reduce the list of weed species to 100. It appears now that about 50 of these maybe worth serious consideration on a world basis. On a world basis, surely, one of the characteristics of a troublesome species is that it has established itself over all or most of the agricultural regions of the earth. Cyperus rotundus* L.*, a native of Asia, may be the world's worst weed. It is in all of the major crops and most of the important agricultural regions of the world…*
>
> *We are short of weed workers for most countries. The world always seems short of funds for weed research. Yet, the use of herbicides is increasing very rapidly and we need good and wise men to guide and counsel us during this rapid change in the use of a pesticide. We need more training centers. The biology and life histories of most of our serious weeds have never been studied. With so much to do, and with meagre resources, we need to act wisely and not run off in the wrong direction with our time and effort. We need to know what the World's Worst Weeds' are, so that we can do first things first…"* (Holm and Herberger, 1969)

Table 2 provides the list of species Holm and Herberger named '*The World's Worst Weeds*'. The information on the distribution, biology, habitat, agricultural importance and other aspects of these weeds, compiled in the treatise (Holm *et al*., 1977; 1979), and the rankings provided, with the basis explained, were pivotal in drawing the attention of the Weed Science community to the importance of addressing specific species, as a matter of priority. These efforts, led by Le Roy Holm, jointly with other senior weed researchers, are considered by many as landmarks in the global Weed Science corpus of knowledge.

We believe that 'taking stock' of which weeds should be focused on and how, whilst tolerating those minor species that really had no impact on crop yields, changed the way weed scientists thought about weeds. A new focus on weed biology and ecology occurred, evident from the marked increase in such papers at the fourth APWSS Conference. This increased focus was also influenced by the host country – New Zealand. As an 'island' nation, with borders protected by the oceans, New Zealand, by this time, had begun to query the correlation between human-mediated introduction of essentially, European weeds to the country, and spread of those species due to land-use practices, such as pasture establishment and forestry.

The early Conferences focused heavily on rice, the most important crop in the Asian-Pacific region, with barnyard grass (*Echinochloa* spp.), sedges (mostly, *Cyperus* spp.) and broad-leaf, rice weeds receiving the most attention. Following the adoption of high-yielding varieties (HYVs), herbicide-based control strategies for weeds affecting all other major cereals (wheat, maize, and sorghum) also received attention, followed by upland crops (pulses, vegetables, sugar cane, pineapple, etc.) and plantation crops. The papers reveal considerable concerns about lack of information on impacts of weeds on those crops.

Table 2: The World's Worst Weeds Top 18 as Listed by Holm and Herberger (1969)*

Family	Botanical Name	Common Name	Ranking
Cyperaceae	*Cyperus rotundus* L.	Purple Nutsedge	1
Poaceae	*Cynodon dactylon* (L.) Pers.	Bermuda grass; Couch grass	2
Poaceae	*Echinochloa crus-galli* (L.) Beauv.	Barnyard grass	3
Poaceae	*Echinochloa colonum* (L.) Link	Jungle Rice	4
Poaceae	*Eleusine indica* (L.) Gaertn.	Goose grass	5
Poaceae	*Sorghum halepense* (L.) Pers.	Johnson grass; Aleppo grass	6
Poaceae	*Imperata cylindrical* (L.) Beauv.	Cogon grass; Alang-alang	7
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	Water Hyacinth	8
Portulacaceae	*Portulaca oleracea* L.	Purslane	9
Chenopodiaceae	*Chenopodium album* L.	Fat Hen; Lambs Quarters	10
Poaceae	*Digitalia sanguinalis* (L.) Scop.	Large Crabgrass	11
Convolvulaceae	*Convolvulus arvensis* L.	Field Bindweed	12
Poaceae	*Avena fatua* L.	Wild Oats	13
Amaranthaceae	*Amaranthus hybridus* L.	Slim Amaranth; Smooth Amaranth	14
Amaranthaceae	*Amaranthus spinosus* L.	Prickly Amaranth; Spiny Amaranth	15
Cyperaceae	*Cyperus esculentus* L.	Yellow Nutsedge; Nutgrass	16
Poaceae	*Paspalum conjugatum* Berg.	Paspalum; Sour grass	17
Poaceae	*Rottboellia exaltata* L. f.	Kokoma grass; Guineafowl grass	18

*Listed in Group 1, are the 18 most serious weeds, in the approximate order in which the species are reported as 'troublesome' by the World's agriculturists. The top 10 in the above list stand apart from all other weed species as they are the most often cited troublemakers in the largest number of field crops in the largest number of countries.

For rice, the selective herbicides – MCPA and 2, 4-D (for broad-leaf weed control) and propanil (for the control of barnyard grass and sedges) - had already been in use for about 20 years in USA. However, adoption had been slow in the Asian-Pacific region. There was inadequate information on cost-benefit advantages, even though the early deliberations advocated the use of these herbicides more widely. The herbicide industry also used APWSS Conferences to introduce major rice herbicides, such as butachlor, thiobencarb, nitrofen, oxyfluorfen, and bifenox in the region. Efficacy demonstrations stimulated wide-scale adoption.

Ending the first decade, at the 5th Conference, held in Japan, there was a heavy focus on the integrated management of rice and other weeds with a special symposium. Overall, the first decade of APWSS Conferences and deliberations ended with a great deal of optimism, and recommendations for the adoption of herbicides as a primary tool for improving weed control in the region. Whilst the focus was squarely on the use of herbicides, the decade also embraced the importance of ecological studies on weeds; integrated weed management, as well as the need for the collection of economic data on yield losses of rice and other crops that can be attributed to weeds.

The Middle Years (1981-1989) - Changing Weed Research Needs

There is no doubt that herbicides began to be adopted readily for weed control during the 1970s, with Japan, Korea, and Taiwan (ROC) leading the way. This trend continued in the 1980s, transforming the way weeds in the Asian-Pacific region were managed in major crops, particularly rice. New discoveries excited Weed researchers; and aggressive marketing by industry led to adoption of various herbicides and their combinations, as well as split-applications and sequential treatments into weed control programs.

The literature reveals a large number of papers in the 1980s (see Table 3), dedicated to practical applications of existing herbicides (2, 4-D, paraquat, asulam, atrazine, glyphosate, etc.) in various agricultural settings, including 'minimum tillage' cultivation. The promotion of numerous combinations of established rice herbicides (such as propanil, molinate, butachlor, oxyfluorfen, thiobencarb, etc.), integrated with improved cultivars, water level management, nutrient management, and cultural weed control, contributed to marked increases in rice yields across the region.

Of particular importance during this period was the development of glyphosate for non-selective, broad-spectrum weed control in 'minimum tillage', and its application using 'wiping' techniques. Reflecting these shifts, herbicide-related discussions accounted for an average of 60% of papers presented.

Table 3: Major categories of papers and presentations at APWSS Conferences, 1981-1989

Topic	1981	1983	1985	1987	1989
New Herbicides	8	13	13	25	20
Rice Weed Control, including herbicides	5	16	4	5	18
Weed Control in agronomic crops, including herbicides	26	4	16	23	9
Weed Control in horticulture, forestry, plantation crops, including herbicides	30	6	4	30	5
Herbicide mode of action, soil residues, metabolism, physiology, biochemistry	6	6	22	19	14
Non-herbicide control, including biological and cultural control	14	8	8	8	12
Weed biology, ecology	18	17	33	26	29
General, perspectives, weed surveys	9	7	7	5	12
Legislation, education, training, extension	4	3	3	3	2
Total	**120**	**80**	**110**	**144**	**121**
Total related to Herbicides	63%	56%	54%	71%	55%

In addition to the expanded use of existing herbicides, the 1980s also saw the introduction of new classes of herbicides, in particular, sulfonylureas (bensulfuron, metsulfuron, and others)and 'graminicides', including fluazifop-butyl and haloxyfop-methyl to the region. Effective at much lower rates than the older herbicides, sulfonylureas gave the opportunity to reduce herbicide loads in the environment. The highly selective activity of the graminicides enhanced the prospects of controlling troublesome, tropical grasses in the region, such as cogon grass (*Imperata cylindrica*) and torpedograss (*Panicum repens* L.).

Some highlights and landmarks of these 'Middle Years' APWSS Conferences are presented below:

- A literature review will detect influence of host countries on the APWSS deliberations. For instance, the 8th Conference in 1981 (India), attracted a large number of papers on weeds in upland crops, biological control, weed ecology and allelopathy. The 8th Conference introduced fluazifop-butyl (Fusilade®) for grass weed control; and a new rice herbicide - anilofos (HOE 30374™) to the region.
- Common weeds in upland crops were highlighted at this Conference, which also focused on emerging problems in the South-Asian region. The first paper on parthenium weed (*Parthenium hysterophorus* L.) emerging as a major problem in the region was at the 1981 Conference.
- At the 9th Conference, in 1983, hosted by the Philippines, a similar trend continued with a heightened emphasis on eco-physiological aspects of major weeds of the region and their integrated management. Discussions on novel biological control agents and allelopathy broadened the scope of weed research.
- Whilst championing the benefits of fluazifop-butyl, haloxyfop, and fenoxaprop-ethyl for grass weed control, the Manila Conference introduced Pretilachlor (Sofit®), mefenacet® and the pyrazole herbicide - benzofenap (NC-310™; Taipan®) as highly effective, pre-emergence, broad-spectrum herbicides for transplanted or direct-seeded rice. For broad-spectrum weed control in upland crops, the non-selective herbicide - glufosinate ammonium (Basta®) and the imidazoline herbicide - imazypyr (Arsenal®) were also first introduced at this 9th APWSS Conference.
- At the 10th Conference (Thailand), the effectiveness of bio-control insects- weevils: *Cyrtobagus salvinniae* Caulder & Sands, against salvinia (*Salvinia molesta* D. S. Mitchell) and *Neochetina eichhorniae* Warner, against water hyacinth - was demonstrated. The problem of giant mimosa (*Mimosa pigra* L.) in the region, including Northern Australia, was also first highlighted in 1985.
- Both the 11th Conference (1987) at Taipei, Taiwan (ROC) and the 12th Conference (1989) at Seoul, Korea were dominated by rice, reflecting major transformations occurring at that time in Asian rice cultivation. As Japan, Korea, and Taiwan headed towards achieving self-sufficiency in rice production, the research demonstrated heavy dependence on herbicides for achieving higher yields.
- A new herbicide class - sulfonylureas (bensulfuron; metsulfuron, pyrazosulfuron and cinosulfuron) was introduced for both transplanted and direct-seeded rice, with biological activity in the range of 10-40 g a.i. ha^{-1} transforming weed management in rice. Other rice herbicides introduced included dithiopyr (Mon 7200™) and cinmethylin®. Imazethapyr (Pursuit®) with broad-spectrum activity on grasses and other weeds were also introduced at the 1989 Conference in Korea.
- Both the 1987 and 1989 Conferences strongly advocated integrating allelopathy into weed management with comprehensive reviews of information available. Nevertheless, the introduction of so many new herbicides to the region, and discussions of other herbicides (such as fluroxypyr and imazapyr) indicates that the 1980s was really the 'herbicide decade' in the Asian-Pacific region.

The Maturing Years, 1991-1999

Increased herbicide use thus became an indispensable part of agriculture in most countries of the region in the 1990s. An average of 54% of papers presented at APWSS Conferences during this decade covered this aspect. However, concerns on the environmental safety, and the emergence of herbicide resistant weeds, attributed to overuse of chemicals, began to be voiced at the APWSS Conferences. The word 'sustainable agriculture' and 'sustainable weed management' appeared several times in the Conferences' main themes, during this period, indicating the concerns of the community.

Table 4: Major categories of papers and presentations at APWSS Conferences, 1991-1999

Topic	1991	1993	1995	1997	1999
New Herbicides	3	13	13	8	16
Rice Weed Control, including herbicides	4	6	12	8	15
Weed Control in agronomic crops, including herbicides	7	18	23	8	30
Weed Control in horticulture, forestry, plantation crops, including herbicides	5	3	13	12	12
Herbicide mode of action, soil residues, metabolism, physiology, biochemistry	3	11	43	15	20
Herbicide Resistance – mechanisms and management	0	3	3	9	2
Non-herbicide control, including biological/cultural control	3	17	16	6	13
Weed biology, ecology	10	24	25	25	46
General, perspectives, weed surveys	3	15	17	5	7
Legislation, education, training, extension	2	5	6	3	0
Total	40	115	171	99	161
Total related to Herbicides	55%	44%	63%	52%	58%

The following is a brief summary of highlights in this decade:

- Additional, new chemicals were introduced, with prospects for more effective broad-spectrum weed control in rice. Apart from sulfonylureas, the research demonstrated how quinclorac, pretilachlor and other herbicides could be integrated with cultural control and water level management.
- New rice herbicides included the following: cyclosulfamuron (introduced in 1993 at the 14th Conference), pyribenzoxim, tralkoxydim (EK 2612) in 1997. The 'One Shot' herbicide (Riceguard®), which combined anilofos and ethoxysulfuron, was first introduced in 1997 for both transplanted and DSR. Bispyribac-sodium (Nominee®) from Kumiai Chemicals Japan, was also released for use as a post-emergence herbicide in DSR, and for broader weed control on rice levees and rights-of-way in 1997.
- At the 15th Conference (1995), at least three new herbicides for upland crops were introduced: cyhalofop-butyl (Clincher®); sulfosulfuron, to control grasses and broadleaf weeds in wheat; and halosulfuron for the control of purple nutsedge in upland crops. At the 16th Conference (1997), under new herbicides, pyraflufen-ethyl and imazapic were introduced for broadleaf weed control in wheat and other crops.
- The 1990s also saw a large volume of research on environmental impacts and mobility of herbicides in soil and water. The Conferences devoted significant time discussing how to optimize herbicide delivery, to mitigate the non-target effects, while questioning the over-reliance on herbicides. During this period, various weed problems in the region were highlighted, including the first occurrence of 'weedy rice' in Japan, which had originated from inter-breeding of wilder strains with modern cultivars (Watanabe, 1995). Similar 'weedy rice' problems in Malaysia and Korea were also highlighted.

- Weed ecology and biology, allelopathy, biological control and other tools for weed management were well covered. Under non-herbicide control, various countries reported on the successes of releasing the water hyacinth weevils - *Neochetina eichhorniae*, and *Neochetina bruchi* Hustache in the region, along with the moth - *Sameodes albugattalis* Warren. Research also focussed on the possibility of developing fungal pathogens as bio-control agents (mycoherbicides) for major weeds, including barnyard grass.

- Herbicide resistance became a new theme for discussion within the Asian-Pacific region in the early 1980s. An early example was canary grass (*Phalarisminor* Retz.), a major weed in wheat, in the north-western regions of India, which had become resistant to isopropturon, due to continuous use of this single herbicide, for 10-15 years. The research led in the withdrawal of isopropturon and substitution by four alternate herbicides (clodinafop, fenoxaprop, sulfosulfuron, and tralkoxydim) to manage canary grass resistance in India (Kirkwood *et al*., 1997). From Australia, Taylor (1996) reported on the development of resistance to bensulfuron in barnyard grass and other major rice weeds. This herbicide had been used in 90% of Australian rice fields for at least 10 consecutive years, since 1985. Resistance management involved combining sequential applications of alternate mode of action herbicides (molinate, thiobencarb, bensulfuron, and MCPA) at lower rates than label recommendations, combined with cultural control.

- Other presentations in the decade highlighted a much more concerning development, that of cross-resistance to herbicides. For example, Tiw *et al*. (1997) described the development of simultaneous resistance in goose grass [*Eleusine indica* (L.) Gaertn.] to herbicides from both classes 'fops' (aryloxyphenoxy-propionates) and 'dims' (cyclohexanediones). Although they are quite different classes of herbicides, their mode of action is common, i.e. both inhibit the enzyme ACCase (acetyl co-enzyme A carboxylase), which catalyzes the first step in fatty acid synthesis in plants.

The New Millennium Years, 2001-2015

The new millennium years ushered in a reduced focus on herbicides and less time devoted to chemicals (see Table 5). Persistent reports on negative environmental impacts, concerns about human safety, and the ever-increasing number of herbicide resistant weeds (see Heap, 2015) appeared to shift emphasis from herbicides to more sustainable, integrated approaches.

The re-invigoration of preventative control (i.e. weed hygiene, border protection), with an emphasis on weed seed banks, vehicles of weed spread and 'invasion pathways', was a new era that moved the discipline from weed control to weed management, and also from reactive, tactical weed control to a more pre-emptive and strategic frame of mind.

An increase in the number of papers presented on such topics attest to the fact that the APWSS community, in the New Millennium, had begun to appreciate the benefits of approaching weed problems more holistically and connecting with broader issues of land, water, and environmental management, as well as climate change. Conference themes of '*Ecologically-based Weed Management for Sustainable Agriculture*' in 2001; '*Sustainable Development*' in 2003, 2005, and 2015; '*Food Security*' in 2013 demonstrate somewhat of an 'awakening' within the APWSS community and a re-focussing of attention to those aspects.

Table 5: Major categories of papers and presentations at APWSS Conferences, 2001-2015

Topic	2001	2003	2005	2007	2010*	2011	2013	2015
New Herbicides	12	8	6	5	0	3	0	5
Rice Weed Control, including herbicides	14	12	32	8	10	3	7	15
Weed Control in agronomic crops, including herbicides	9	5	18	5	9	6	13	14
Weed Control in horticulture, forestry, plantation crops, including herbicides	8	2	16	12	7	11	7	23
Herbicide mode of action, soil residues, metabolism, physiology, biochemistry	8	5	6	25	2	12	6	11
Herbicide Resistance – mechanisms, management	13	14	3	2	2	10	10	13
Non-herbicide control, including biological/ cultural control and allelopathy	15	28	8	29	22	11	29	26
Weed biology, ecology	52	29	9	38	45	41	17	32
General, perspectives, weed surveys	8	10	10	6	7	11	8	
Legislation, education, training, extension	3	5	3	2	1	2	5	
Total	142	118	111	132	105	110	102	139
Total related to Herbicides	45%	39%	73%	43%	29%	41%	42%	58%

* The APWSS 2009 Conference was delayed until 2010, because of security concerns in Pakistan

Adding to the above themes, the 23rd Conference (2011), in Australia, mooted the subject of managing weeds in a '*Changing World*', acknowledging the various changes occurring, not just in the weed floras, but also how we approach weed management. Issues discussed broadened to highlight the full integration of the benefits of herbicides, biological control, and other tactical tools with catchment-scale management tools (such as GIS-based mapping and climate change modelling).

The strategic approach to weed management explained the importance of closing the door on the introduction of risky species by influencing the nursery industry, weed scouting, and surveillance, across large areas, such as watershed catchments, as well as rapid responses to new weed infestations, all of which are areas of weed management well developed in Australia and New Zealand. Nevertheless, reflecting the growing concerns, developing herbicide resistance development and its management were common topics in 2011.

Presentations in the New Millennium also broadened the scope of Weed Science in the region from agricultural weeds to include environmental weeds. Weeds in non-agricultural areas had not been a priority topic at APWSS Conferences in previous decades, perhaps because the initial focus had long been on controlling agricultural weeds. Other highlights during this period are as follows:

- Global agrochemical companies continued introducing new herbicides to the region, although the pace of new discoveries was slow. The 18th Conference in China (2001) promoted several new herbicides: cyclosulfamuron; flumioxazin; ethametsulfuron; The Beijing Conference also had a strong 'ecological' bent, as suggested by the theme, including allelopathy and biological weed control, with

63% of papers presented promoting the integration of ecological knowledge into practical control. The 19th Conference in Manila (2003) continued the ecologically based weed management theme (more than 60% of papers). Among new herbicides, carfentrazone was introduced to region in 2003.

- Herbicides again dominated the 20th Conference in Vietnam (2005) with about 73% papers presented discussing various aspects of chemical control, under the central theme - 'Six decades of Weed Science since the discovery of 2, 4-D'. The host-country, with heavy reliance on herbicides for maintaining agricultural productivity, may have also influenced the focus. Penoxulam and flucetosulfuron were introduced as new herbicides to the region in 2005, and 'utilization of weeds' emerged as a new category.
- As with the 2001 Conference, the 21st Conference in Sri Lanka (2007) had somewhat of an ecological focus with more than 50% of papers covering weed surveys, environmental weeds, the biology and ecology of known species, and integration of some weed control practices, including allelopathy. Herbicides, particularly, for upland crops, remained a constant theme. Strongly reflecting the host country's interests, the 22nd Conference in Pakistan (2010) focused on managing weeds in various upland crops, particularly through the integration of cultural methods and allelopathy.
- As shown in Table 5, since 2001, there has been a decline in the total number of papers on herbicides (average of 46% for eight Conferences, the least being 29% in 2010). However, on average about 20-25% of those herbicide papers were on resistance development and management.

APWSS –Perspectives for the Next 50 Years

Our review finds that the region was slow to appreciate that most weeds can only be managed, not fully eliminated, and this requires a strategic approach. IWM had been in practice in the advanced economies since around late-1980s. Although cultural weed control and biological control have long been favourite themes at APWSS, demonstrations of the full integration of IWM applications were relatively few in the APWSS proceedings, until the New Millennium. This shows slow adoption, possibly due to lack of engagement from governments. We would also say that most Asian-Pacific countries had been largely focused on 'tactical' weed control, as opposed to 'strategic' control, until this fourth decade.

The strategic approach, including the full integration of all available techniques – knowledge of weed biology and ecology, prevention of spread, eradication, containment, and asset protection activities – at times and places that make them most effective and efficient, took time to develop. Despite studies on the biology of individual weeds, most research in the region tended to avoid asking critical questions, such as: *Why are these weeds here? What factors are at play?* Perhaps, the focus on herbicides for at least three decades, and their undoubted short-term success, has had a negative effect of stultifying the development of the 'science' in Weed Science, in the region. Perhaps, herbicides also gave the erroneous impression that weeds can all be eradicated, rather than managed, as the situation requires.

We believe that managing weeds, reducing their negative impacts, and even attempting to eliminate them from farmers' fields, as required, have been consistent goals in Weed Science. This, we believe, is critically important to the economic prosperity of the region, through increased production of food and fibre, as well for managing the unique biological diversity and somewhat fragile environment of heavily populated, individual countries. The number of herbicides–the major driving force of modern weed management–which stood around 70 in 1967 has risen to more than 300. Yet, weed problems have continued to increase in the region, as attested by APWSS Conferences. Our approach to weed control has evolved from relying only on herbicides to more integrated and holistic weed management.

However, it needs little emphasis to realize that weed management is only one aspect of securing food for future generations, within a sustainable future environment. An often-heard comment (excuse?) at APWSS Conferences is that Weed Science gets very little attention from governments, and is poorly funded because the contribution of agriculture to the economies of our region (percentage Gross Domestic Product, GDP) is relatively small. For middle-income countries of our region, and emerging economies, the range is a low 8% (Sri Lanka) to a high of 25% (Pakistan). The higher value is comparable with the average for all 'Least Developed Countries' in the world (as per United Nations), which is 26%[25].

Whilst instantaneous measures of agriculture's contribution to a country's GDP may be useful to economists, it has little relevance to ecological sustainability. The market has a tendency to dramatically revalue essential resources when they are in short supply. For example, freshwater – a finite and vulnerable resource, essential to sustain life, development and the environment – is usually undervalued until supply is disrupted. Food will follow closely on its heels. It also needs to be emphasized that in many developing countries, although the contribution of agriculture to GDP of a country may be low, more than 50% of the population still depend on agriculture and related activities, and most of this population is poor.

Nevertheless, the comparison with advanced economies (Japan, Korea, Australia, and New Zealand) is stark. For example, only New Zealand has an agriculture output within the above range. As a percentage of GDP, New Zealand's agricultural output was 9.38% in 2010, and this decreased to 6.38% by 2014 (latest available figures) showing an economy moving away from agriculture. Australia and Korea are somewhat similar (around 2.5%, even with a population difference of 2:1 in favour of Korea); while Japan's agricultural, output is only 1.1% of GDP, which is lower than even North America (Canada 1.8% in 2013; and USA, 1.25% in 2014). These facts reveal about functioning of those national economies.

Our view is then, broadly, a general decline in agriculture as an income-generating endeavour, as part of the national economy is evident for both developed and developing countries. With regard to managing weeds, encumbered by declining budgets in all countries, not much has changed in the approaches to management of agriculture and environment in the last two decades, apart from the rapidly growing community interest in the impacts of climate change. Communities in many Asian-Pacific countries have also been stirred by the introduction of genetically modified organisms (GMOs), particularly, herbicide-tolerant crops, and their potential effects on traditional production systems. Whilst efforts continue to reduce the amounts of pesticides and herbicides used in agriculture, as a safeguard against residues in food and the environment, the development of herbicide resistance in weeds is already a major concern in the region. These and other challenges will influence Weed Science in the region, as well as other related disciplines.

In the following sections, we highlight some pressing issues that would surely influence the future of Weed Science, as a discipline, and the region, as a whole.

[25] Agriculture (with value-adding) as % of GDP in 2016 – Australia (2.61%); Bangladesh (14.77%); Cambodia (26.66%); China (8.56%); India (17.35%); Indonesia (13.45%); Japan (1.1%); South Korea (2.2%); Laos (19.48%); Thailand (8.34%); Vietnam (18.14%); Malaysia (8.65%); Myanmar (28.2%); Pakistan (25.23%); Philippine (9.65%); Sri Lanka (8.21%); New Zealand (6.8% in 2014); Source: World Bank Data; accessible at: http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations

The Population Challenge

By 2025 AD the global population (currently, 7.514 billion) is expected to reach 8.5 billion. Of this, 83% will be in developing countries (Presently, there are 1.403 billion people in China; and 1.284 billion in India). Although the population growth rate has declined from a peak in 1963 (2.1%) to the current 1.13%, there will be more than 9 billion humans on the Earth by 2038. While the rate of growth has steadily declined, population growth will continue beyond 2038. Most would agree that one of the greatest future challenges is to increase food production for this humanity, in geographical areas, where productivity has already declined.

The challenge is actually to increase food and fibre production in a sustainable manner, while maintaining life-sustaining ecosystems. Therefore, particularly in developing countries, a negative attitude towards any group of plants, including weeds, is a mistake that we cannot afford to make. In order to alleviate socio-economic hardships, and to conserve biological and cultural diversities, it is necessary to build on existing links between people and biological resources. The success of this depends on accommodating local knowledge and priorities of communities, with some trade-offs between development and conservation. The ultimate goal must be for the present generation to be 'custodians of landscapes' instead of being relentless exploiters and this requires positive appreciation of all plant resources.

Weeds and Biodiversity

Given the increasing recognition of biodiversity values of weeds in farming landscapes, the issue of *which weeds to control and which ones to live with*, is looming as an important aspect in our region as well. From European perspectives, Clarke (2000) noted that in the new millennium, there will have be more demand for weed management practices that control damaging levels of weeds, whilst maintaining beneficial species. Presently, weeds remain a production constraint in agriculture, and a threat to profitability, and hence, considered as having very low or no value.

Sagoff (2005) explained that the term 'biodiversity' was coined in USA, to bring political attention to the goal of protecting species. It is now widely used in ecology to convey the message that nature is a complex matrix of species-interactions between all living forms. However, the tendency of some authors to exclude non-native or introduced species in a given area, including cultivated or engineered ones, from 'biodiversity', has led to confusion (Sagoff, 2005), leading to question: *Are weeds not part of the same biodiversity?*

Biotic interactions between weeds and their environment, particularly, the dependence of animals, such as insects, pollinators, and birds on weeds has been of interest for several decades. Fifty years ago, John Harper (Harper, 1958; Harper *et al*., 1957) used the example of tansy ragwort (*Senecio jacobaea* L.) to illustrate the extensive biotic relationships a weed has in food chains, expressing the view that Ragwort control in agricultural fields '*might affect all the organisms in the food chain*'.

Of late, in Britain and other European countries, interest in weeds as important components of the biodiversity of farmlands and the landscape has been heightened. This is due to the recognition that by reducing weeds in arable farms, irreparable damage is being done to the biological diversity in vast areas of agricultural and semi-rural landscapes. An ecological rule is – in diversity, there is strength. Robinson and Sutherland (2002) reported that most arable weeds in British farms have declined since the 19th century, and losses have accelerated towards the end of the 20th Century with intensification of agriculture. A number of farmland birds have declined (Krebs *et al*., 1999), and invertebrate animals have also shown similar declines. Changes in agriculture, including the intensity of farming, changes in drainage, introduction of new crops, changes in sowing season, and increased use of agrochemicals (fertilizers, herbicides) have all been implicated. The development of more ecologically sustainable farming systems, maintaining some weed species within crops is a new challenge for Weed Science (Marshall, 2002; Marshall *et al.*, 2003; Storkey, 2006; Storkey and Westbury, 2007).

In this discourse, weeds are recognized as not just bystanders in the biological diversity of nature, but as critical components. Managing weeds within the crop to support biodiversity inevitably involves the risk of reducing crop yields and the long-term build-up of problem weed communities. However, a pragmatic approach to reconciling biodiversity with crop production is to manage low populations of 'beneficial' weed species. As opposed to 'invasive' weeds, beneficial weeds are defined as species that provide low levels of competition with an arable crop and has potential value as a resource for higher trophic consumer groups.

Marshall *et al*. (2003) recently identified a range of tolerable weeds on three basic attributes: (a) the number of insect species associated with them; (b) the number of and the importance of weed seeds in the diet of farmland birds; and (c) a competitive ability index. Their evaluation resulted in some species, such as annual meadow grass (*Poa annua* L.) and prostrate knotweed (*Polygonum aviculare* L.), as being more important for biodiversity in arable systems than others like black grass (*Alopecurus myosuroides* Huds.) and speedwell (*Veronica persica* Poiret). The challenge in the Asian-Pacific region also will be to apply such methods to select species that may be tolerated to achieve a sustainable ecological balance.

Storkey (2006) extended this approach to identify groups of weeds that are similar in terms of the balance between their competitive ability and biodiversity value. This 'trait-based' analyses, based on attributes, such as seed weight, flowering time and maximum height, identified two beneficial groups that could potentially be managed to reconcile biodiversity with crop production. To illustrate, these were: (a) spring germinating species, including fathen (*Chenopodium album* L.), lady's thumb (*Persicaria maculosa* Gray) and *Polygonum aviculare*, and (b) autumn germinating species, including *Poa annua*, groundsel (*Senecio vulgaris* L.) and chickweed (*Stellaria media* (L.) Vill.). Species in this latter group have a growth form that is complementary to the crop. That is, they generally grow below the crop canopy, forming an understory, and maturing early, avoiding crop competition late in the season. As a result, they utilize, in part, resources that the crop is unable to capture, and the total productivity of the system is increased.

Storkey suggested this example as a possible 'win–win' situation, where a certain amount of weed biomass is maintained, and is associated with minimal loss of crop yields. Reconciling crop production and biodiversity conservation will be a key aspect of Weed Science for habitat management in future farming landscapes in both developed and developing countries.

Climate Change Impacts on Weed Distribution

In the coming decades, the trend of increasing concentrations of greenhouse gases and enhanced greenhouse effect presents serious threats to both agriculture and natural ecosystems. Climate change is therefore likely to be the biggest challenge faced by the human society. The Inter-governmental Panel on Climate Change (IPCC, 2014) Report states that, on a global scale, the number of cold days and nights has decreased, with a concomitant increase in the number of warm days and nights. Reporting that the frequency of heat waves has increased in large parts of Europe, Asia, and Australia, IPCC's conclusion is that human influence has contributed significantly to the observed global-scale changes in the frequency and intensity of daily temperature extremes, since the mid - 20th Century. Although there are still skeptics, our position is that we appreciate the indisputable scientific evidence, gathered, analyzed and interpreted by scientists, which point to anthropogenic contributions.

The responses of crops, weeds, or natural vegetation communities are inexorably linked to the climate modifications that humans have exacerbated. The impact of climate change upon weeds includes changes in landscape features, and creation of abiotic, suitable habitat 'hotspots', which will allow some species to spread more widely. To illustrate, in Australia, climate change modelling shows increased vulnerability of south-west and south-east Australia to invasion by several tropical weeds, broadly indicating a southern (poleward) movement of those species from the wet (warm) tropics (Duursma *et al*., 2013). Learning from Australia and other countries, the subject needs attention in the developing Asian-Pacific countries.

Herbicide Resistance in Weeds

Whilst modern herbicides have revolutionized weed control over the last 70 or so years, herbicide use has led to high selection pressure for herbicide resistance in many weeds. It is a normal and predictable outcome, as part of natural selection, first predicted by John Harper in 1956 (see quote below).

> *"…This discussion on weed ecology emphasizes that the weed flora of a region may undergo striking changes over long periods. Nevertheless, weed populations possess important properties of stability, which make it unlikely that the use of herbicides will lead to major weed problems from previously minor, but herbicide-resistant, weeds. Susceptible species may develop resistant strains, and action must be taken to meet this danger..."* (Harper, 1956)

Herbicide resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a wild type individual of the same species. Reviewing the subject, Ian Heap (2015) suggested that herbicide resistance is a particularly challenging problem, exacerbated recently by the decline in herbicide discovery, reduction of available herbicides, due to the banning of many, based on safety to humans and the environment. According to the International Survey of Herbicide Resistant Weeds, as of 10 July 2017[26], there are currently 480 unique cases (species x site of action) of herbicide resistant weeds globally, with 251 species (146 dicotyledons and 105 monocotyledons).

Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 163 different herbicides. Herbicide resistant weeds have been reported in 91 crops in 69 countries. North America remains the 'hotspot', followed by Europe, Australia, Asia, and South America. Not surprisingly, regions that do not use herbicides intensively, such as Africa, have few problems of herbicide resistance (Heap, 2015).

Of the 16 sites of action, so far determined, resistance to ACCase (acetyl co-enzyme A carboxylase), ALS (acetolactate synthase), and EPSP (5-enol-pyruvyl-shikimate-3-phosphate) synthase inhibitors are among the most common resistance mechanisms (Heap, 2015). These are not surprising to the enlightened weed scientist, as our pioneers pointed out six decades ago (Harper, 1957; Baker, 1965; Stebbins, 1965) that many weeds have an innate capacity to evolve resistance to any weed control strategy used continuously for long periods. The best weapon against this capacity of weeds to evolve under selection pressure is to change its direction, as often as possible, and utilize a diversity of weed control strategies to destabilize evolution (Heap, 2015).

[26] The international survey of herbicide resistance weeds. Online at http://weedscience.org/

Genetically-modified Crops

A genetically modified organism (GMO) is one that has been modified by gene technology; or an organism that has inherited particular traits from another organism (the initial organism), being traits that occurred in the initial organism because of gene technology. Genetically modified (GM) crops have resulted in a major shift towards less emphasis on new herbicide research. Therefore, investments in research to discover herbicides with new modes of action have decreased dramatically.

For the major crop of our region, *viz*. rice, recent commercial developments have taken place for three herbicide resistant varieties: Clearfield® (imidazolinone resistant), Roundup Ready® (glyphosate resistant) and Liberty Link® (glufosinate resistant), with genes for resistance derived from different sources. The adoption of herbicide-resistant transgenic biotech crops over the past two decades has added a new dimension to the field of Weed Science. Some Asian-Pacific countries have enthusiastically accepted these, which others are considering benefits against losses. Even with well-developed guidance resources around the use of GM herbicide-tolerant crops, including the management of any resistant weeds and volunteer plants, the public is not entirely convinced of the long-term safety of the GM technology. This presents a significant future challenge to the Asian-Pacific countries, because of the aggressive push towards wider adoption in the region, based on the potential to increase food production, and food security.

Weed Research

Weed research aims to answer essentially the following questions: *which weeds are the most significant in terms of adverse impacts on agriculture or the environment, and why (in terms of biology and ecology); and how to successfully manage them and reduce their adverse impacts*. As we have discussed in our paper, weeds in agriculture are a consequence of how we grow food; those that are problematic in other situations, do so because they are adapted to capturing vacant niches created by disturbances (such as land clearing). Added to this would be colonizing species, previously denied access to an occupied ecological niche by geographical isolation, or climatic conditions.

We firmly believe that studying both the ecological and human components of agroecosystems should allow weed scientists to construct management strategies that more fully address agricultural production, environmental consequences, and social implications of weeds and weed control. However, as we look back at the past 50 years, it is evident that *our understanding of weeds lags a long way behind practices of weed control*. Nevertheless, we appreciate that, in many situations, one cannot wait until all factors related to an individual, potentially problematic species are understood, before taking action.

Literature indicates that most of serious species are exotics that were introduced into our region. Many have come into the Asian-Pacific region from elsewhere in the world, arriving first as desirable plants introduced by humans (i.e. new crops, pasture species, cover crops, ornamentals), or just as hitch-hikers, as goods and commodities get moved around. Our region has been greatly affected by such exotic species. The region's weed floras are also complemented by locally important species, which can tolerate and thrive in disturbed situations, mostly caused by humans (such as cultivation, land clearing, and deforestation).

We understand the biological attributes of weeds more clearly now than ever before – thanks largely to Herbert Baker, Ledyard Stebbins, Jack Harlan, John Harper, and other pioneers of our discipline. However, part of our all-important weed research agenda must aim at understanding the key factors that are driving the proliferation of weed species, so that we can take action to mitigate them, firstly, at a local level, and then in the region. We are aware that this is easier said than done!

Intensive research into the biology of major weeds will surely lead to their long-term effective management. There are many examples from the Asian-Pacific region of detailed studies forming the foundation for optimizing control options. Unfortunately, this enlightened attitude is not widespread in both developed and less-developed economies. The common practice in most countries has been to deploy whatever means at hand, and reactively overcome a weed problem. When successful approaches (i.e. integration of the primary methods of weed management - weed hygiene, cultural, physical, biological, and chemical-based methods) are not utilized, failure is guaranteed. We also find much of the academic-sounding weed research in the region has little practical value, because of flaws in articulating the initial research question.

As we have discussed, much has happened in Weed Science research within the Asian-Pacific region since the Society held its first Conference in 1967. The world now has an impressive armoury of new herbicide chemistries, herbicide safeners, and application technologies. We also have current problems, related to over reliance on herbicides for weed control, which should not continue. In the years to come, new challenges may arise. From our point of view, the priority for weed research in the Asian-Pacific region should be to support research that aims to understand the mechanisms of weed impacts that will then lead to better approaches to weed management, which can be adopted readily in our region.

Broadly, the priorities should include the following:

- Understanding the impacts of weeds on ecosystems, and specifically, factors governing invasions across large landscapes by multiple weed species, as well as individual species;
- Increasing the research capacity in biological control, as this appears to be the best control option for many widespread and abundant weed types;
- Assessing opportunities for the integration of both ‘weed-led’ and ‘site-led’ weed management with broader natural resource management (NRM) objectives; this includes management of biodiversity, fire, pest animals and livestock and protective native ecosystems;
- Increasing the understanding of interactions between invasive plant species and their invaded habitat, including synergistic effect son natural ecosystems and biota.

Having come through the early decades where the focus of most weed research was on herbicide efficacy testing, we have now moved well beyond herbicides. Weed research now has to focus on policy solutions, stakeholder engagement and large-scale vegetation and landscape management, as well as ‘site-led’ and ‘weed-led’ approaches, encompassing integrated weed management. Since around 2000, weed research in developed economies has focused on understanding invasion biology; invasion pathways and the invasion process (see Williamson, 1995). This is commendable, as an increased understanding of these aspects will lead to weed researchers better appreciation of the ecological consequences of plant invasions, including the impacts of weeds on broader biodiversity of both agricultural and non-agricultural situations, and climate change. A move of Weed Science in this direction is inevitable and desirable.

The reality of many pest/weed management problems in the field is that the level of complexity requires multidisciplinary teams to develop effective solutions. Consequently, we suggest that the success in securing funding for future weed research lies in weed scientists in our region developing strong collaborations across disciplines (as opposed to addressing weeds from a weed control perspective only, with nominal references to other disciplines). Collaboration, we hasten to add, has been not easy across the Asian-Pacific countries, because our ‘Science’ does not exist alone, but is strongly influenced by the sensitive geo-politics of our era.

Prospects for Weeds as Bio-resources or Utilization as a Management Tool

Much has been written about negative impacts of weeds in many countries. However, this view is not universal, and there is increasing interest in the values of weeds as an essential component of the human-modified landscapes. The use of weeds as bio-resources and/or their utilization as a management tool has not been fully realized in the Asian-Pacific region, despite the extensive use of weeds as biological resources (as food, medicines and raw material for various uses) by the region's populations (see Chandrasena, 2007).

Developing a healthier attitude towards weeds and *Nature* appear critical for our region. These are most reflected in the Permaculture movement[27], which originated out of the Land care movements in Australia in the 1970s. Coined by the founder - Bill Mollison, a biologist, the term permaculture is a portmanteau of 'permanent agriculture' and 'permanent culture'. Its primary strategy, accepts a greater role for trees, perennial plants and fast growing species to stabilize degraded, human-modified landscapes. The movement involves a life-style change as well, where people are assisted to become more self-reliant through the design and development of productive and sustainable gardens and farms.

However, our view is that a foray into permaculture goes way beyond what Weed Science colleagues, such as Miguel Altieri, Matt Liebermann, and others of that ilk, envisioned and promoted as 'agro-ecology' (see Altieri, 1995; 1999 and Altieri and Liebman, 1988). We need to absorb from the philosophies of the permaculture movement, only what is directly relevant to our Weed Science community. Instead of creating 'gardens of Eden', the pragmatic approach would be to reflect on our relationships with Nature. From the Weed Science viewpoint, permaculture is not far removed from a large-scale revegetation strategy, its foundation being the use of plant species consonant with a particular area; and *mimicking what nature does*. Notwithstanding other sustainable elements (i.e. producing food locally with minimal outside inputs, creating healthy ecosystems, building soil, constructing housing using local, renewable resources, ending pollution, erosion and degradation of landscapes) colonising plants get a 'fair go' in this framework.

Weeds are not condemned even implicitly; instead, the permaculturist's view is that every plant has its uses, and weeds are no exception. An often-used slogan in the movement is '*one person's weed is another's medicine or building material*'. Although the number of people committed to the permaculture lifestyle is still minuscule, its attitudes, favouring sustainable land use, resonate with the view that plant resources should not be devalued. To many Asian-Pacific societies, it is a practically reality to have austere life styles!

Agro-ecological or permaculture designs are intended to reach noble goals, namely, improved living systems, which are both economically and ecological sustainable, and are *'in tune'* with the locally available biodiversity. However, to be sustainable in any country, these approaches need primarily to meet the aspirations of landholders and farmers and, secondly, to contribute to meeting the broader environmental and socio-economic and political agendas of governments.

We are aware of other interests growing in the region, such as '*Chemical-Free Weed Control*' in Australia[28], which is essentially a part of the growing popularity of the pesticide-free farming systems. Pesticide free farming is an area that requires the attention of weed scientists, because managing weeds in these

[27] https://permaculturenews.org/what-is-permaculture/

systems depends on depleting the existing weed seed banks with non-chemical methods, and preventing any harmful build-up of weeds that do not serve much of an ecological function near the crops being grown. The justification for more scientific investigations into appropriate weed management methods and promoting the development of chemical free farming is the Asian-Pacific region lies in its market potential. For example, in USA alone, the total U.S. organic product sales in 2016 reached nearly $50 billion. Organic farming has averaged double-digitgrowth over the last five years[29].

In a strategic approach to managing weeds, we wish to promote a greater recognition of the utility of these plant resources. The summary condemnation of plant taxa that we may not like to have in a particular situation, or enterprise, is not a sensible way to approach a somewhat complex problem, largely created by man. A much broader appreciation of the useful attributes of weeds will allow us to develop applications that could improving the human condition. Weeds are clearly highly successful plants, largely due to superior colonising ability and competitiveness. These attributes can be very useful, not just in repairing damaged ecosystems, but also in providing food and fibre for all animals, including humans in the future.

Linking Weed Science Knowledge to Practical Action

A responsibility for our Society, as well as professional weed scientists and land managers is to adopt innovative approaches to managing weeds. Weeds are ubiquitous, in that they do not respect artificial boundaries, such as fence lines, which demarcate a cropping field from adjacent weed-infested areas. Weed management programmes in the future will have to be re-aligned to meet the needs of maintaining the balance between economic, social, and environmental concerns. This requires a holistic, risk management approach, and an analysis of the ecological, biological factors, and physical factors, within farming or non-farming landscapes, along with interrelated components. Weeds are only one constraint for agricultural production, but we need to be mindful of other interactions as well.

Published literature and the vast collection of APWSS Proceedings themselves indicate that, broadly, there is a good baseline of knowledge on weed issues and weed management frameworks available in the Asian-Pacific region. Yet, there are still wide differences in how weeds are managed in each country. These differences reflect not just economic disparities, and possibly, levels of education, but also government funding and social priorities. For instance, poverty alleviation and food security are the highest priority in developing countries of the region, whereas, the developed economies are struggling with other social issues (i.e. ageing populations and labour shortages in Korea and Japan). Land clearing, and soil erosion, due to over development are common problems, as are other environmental concerns (e.g. pollution of waterways).

In all countries alike, we find deficiencies in funding for on-ground weed management programmes and weed research. Australia and New Zealand are classic examples in this regard, where this funding has been in sharp decline over the past two decades, except perhaps for managing herbicide resistant weeds. The decline in funding has necessitated community involvement for implementing community-led weed

[28] A series of 'Chem-Free Weeding Workshops' were held in Australia, in 2014-15, organized by Dr. David Low (E-mail: david.low7@bigpond.com), promoting a public discourse on non-chemical weed control. Several government agencies supported the workshops, valuing the insights they provided into current public perceptions of herbicide pollution and health issues (Source: https://www.eventbee.com/v/chemfreeweedingsydney2015)

[29] Source: Organic Traders Association, OTA (https://www.ota.com/about-ota)

management programmes, with governmental institutions often taking only a 'backroom' administrative role. In this environment, recognition of the importance of human culpability in creating environmental problems is often lost. The public also has limited power to change the way environmental management is practised.

The fact that we have made errors in introducing exotic plants for perceived benefits to countries, where they did not exist before, is evident. In taking action to reduce this risk, Asian-Pacific countries can certainly benefit from the experiences of Australia and New Zealand. These 'islands' have developed excellent 'border protection' policies and Weed Risk Assessment (WRA) frameworks, which have been globally adopted (see FAO, 2011). Key long-term strategies that are likely to minimize the negative impacts of weeds in the Asian-Pacific region include preventing the introduction of species that can become new weeds in the region, through risk assessments and strict regulations of plant imports, bio-security, and other prevention methods.

Education, Extension and Information Services

Extension is one of the most important processes in Weed Science, since it serves to inform the end user – usually, the farmer – about which weed control methods may benefit production, while safeguarding the farming environment. However, farmers are not the only ones who need to be informed. Decision makers, such as politicians, administrators and the public also need to be accurately informed of the importance of managing weeds and the methods appropriate for the task. As John Swarbrick (1991), an APWSS stalwart suggested, successful extension requires the receiver to have confidence in the giver of that information. Whatever the topic, the extension officers need to have the right attitude, background, and culture to enable a comfortable transfer of information to farmers or others. In this regard, training in Weed Science, at the level required, is crucial. Several APWSS countries have been active in promoting such training of extension officers, as evident in the activities of our affiliated societies.

There are now a several weed control technologies available in the Asian-Pacific region. As an example, in the case of direct-seeded rice, available technologies include cultivar selection; the use of low rates of herbicides; timing of flooding of fields and growth stages of crops; herbicide rotation to prevent resistance development; crop residue management for weed control; stubble burning to reduce weed seeds (see Rao *et al*., 2007). The Australian '*Rice Check'* package is a good example of how farmers may be introduced to a prescribed series of actions to follow, in order to maximize crop yields (see Lacy *et al*., 2000).

'Ricecheck' is a rice production prescriptive package with simple and objective recommendations. Its adoption was partly responsible for Australia's consistent highest rice yield per hectare (ha), through the 1970s and 1980s. The package shows how farmers should take into account water availability and local weather patterns, when they take certain actions at certain times in the growing season, and continually monitor and check their crop. The benefits of observing, checking, and recording crop data is that crop growth and management actions can be directly related to the yields and grain quality benchmarks.

We believe that successful Weed Science extension needs to adapt such crop and/or cultivar-specific, technology packages to local conditions and practices. Integrated weed management packages are not likely to be adopted by farming communities, unless weed scientists and extension workers ensure that their recommendations are practicable 'on the ground', within the environmental, socio-cultural and economic conditions and constraints of farmers and non-farming communities in our region.

The importance of local research and demonstration trials cannot be overstated to achieve longer-term success. In many situations, adoption of a good weed control method will require innovation, which could be some modifications and or integration of the available approaches.

Reviewing the APWSS literature, it is evident that agriculture in our region varies from highly industrialised systems to peasant systems; from agriculture with large areas of monoculture cropping to small areas of shifting cultivation and mixed cropping. Some of the sophisticated, more productive systems require high-energy inputs (mechanical or chemical energy), while other systems continue to rely on human and animal power and low inputs with modest or low productivity. Production methods, based on highly mechanized, high-technology-based methods (*viz*. 'western' agricultural methods) may not be appropriate for agriculture of a good proportion of the Asian-Pacific region. Our proceedings have often highlighted that farmers of the Asian-Pacific region rely on governmental and non-governmental sources for information, advice, credit and support, because they cannot afford complex support systems (such as environmental monitoring systems; GIS-linked, web-based, information systems for predictions of likely local weather, or water availability).

As highlighted by Swarbrick (1991), failure to realize the wide gulfs between existing production systems, will lead to waste and frustrations in all aspects of Weed research, education and extension. The wide diversity of people and cultures in the Asian-Pacific region means that '*one-size fits all*' solutions will not work. As a Society that has already made a mark in Weed Science and weed control research, APWSS also has a responsibility to deliver research, which may not be of our own choosing, but which are 'appropriate'. The process to do this successfully is consultation, discussion and information exchange through existing and future networks. Evolving technologies allow scientists to connect with each other much more freely and quickly. Casting an eye on the future, as an over-arching regional Society, APWSS must continue to energize the member countries and their local, affiliated Societies to engage with all stakeholders in this regard.

As previously stated, it is also important to recognize that weeds are not the only constraint to agricultural production and *Weed Science does not stand alone*. Securing food, within a safer environment for future generations will come only through the application of scientific knowledge across various disciplines. Therefore, weed scientists must keep in constant touch not only with each other, but also with other applied scientists, who provide research, information, education, and extension in other disciplines, such as plant breeding, agronomy, entomology, plant pathology, modelling, water science, and climate science.

International Collaboration

Looking back at the past 50 years, it is evident that APWSS has been important for international collaboration, and for connecting people in our region with each other, and providing a forum for exchange of Weed Science information. The biennial APWSS Conference is now internationally recognized as an important forum for both cultural exchange and for sharing of practical experiences in weed control. Additional symposia, workshops and networks, such as the *Parthenium weed Network*, have assisted in linking young weed scientists in the region with industry, internationally recognised institutions, and senior scientists. Several books and monographs, sponsored by APWSS, and written by members have strengthened international exposure of our Society, and made weed scientist of the region known more widely.

A Final Word

As a final word, we ask again - *what have we learnt from Weed Science in the past 50 years? Do we really know why we have weeds? Do we know why they behave in the way they do? Are all weeds evil – as they have been generally regarded to be? Do we know, with any degree of certainty, how much of crop yield losses and other losses can be attributed to weeds?* As significant as the accomplishments have been, we are of the view that the full potential of Weed Science is yet to be realized in the Asian-Pacific region. While we re-iterate that *Weed Science is not just about weed control*, we hope the maturity of the discipline would help show the way in shaping and improving our management of all natural resources, and not just agriculture.

Our review found that developments of weed control practices over the past 50 years have indeed, resulted in major improvements in how we deal with weeds in nearly all of the Asian-Pacific region's countries. As weeds are an important component of agricultural systems, increased crop yields, obtained in recent times, can be partly credited to improved management of weeds. In addition, all over the region, there appears to be a higher degree of confidence in addressing weed-related issues in 2017 than in 1967. We attribute this, at least partly to the efforts of the APWSS, and membership, who have diligently strived to uphold the primary objective stated in 1967: "…*To promote Weed Science, in particular in the Asian and Pacific regions, by pooling and exchanging information on all aspects of Weed Science*…" Yet, we are acutely aware that Weed Science is the most poorly funded discipline within the broader field of crop protection.

Full integration of the gamut of tactics and techniques that can be used to reduce the negative impacts of weeds should be our primary goal in weed management. Perhaps, a qualifier may be added – *Only when and where there is a problem with weed abundance*. Only then will the potential benefits of weed control be sustainably realized. To achieve this goal, we need a complete understanding of weed ecology; the relationship weeds have with crops (in the agricultural fields), their interactions with other plants (natural communities) and the environment Although much is known about these relationships, this knowledge is often incomplete for major species, particularly, under changing circumstances imposed by increased disturbances and climate change. In this regard, the Asian-Pacific Region is no exception to other regions.

Radosewich and Holt (1997) pointed out that: "…*any plant can be a weed and no plant is always a weed…"Understanding weeds* still lags a long way behind our inadequate attempts to control them. We believe that at least our region must lead in recognizing the special attributes of these species, as important components of the earth's biological resources and their role in ecological succession. Although weed abundance brings them *occasionally* into conflicts with humans, our review of the literature from the Asian-Pacific Region supports the viewpoint that *not all weeds are bad all the time*.

Given this, we believe that human populations and societies in the Asian-Pacific Region will benefit by focusing on a more holistic weed management paradigm, which includes resolving conflicts with weeds amicably, and perhaps even co-existing with them (See Chandrasena, 2014; 2015). Instead of continuing an unsustainable war against weeds, perhaps a better approach for the region as a whole would be to train the next generation of weed scientists to develop a healthier attitude towards weeds, treat them as biological resources, rather than enemies, and manage them, as appropriate to the situation. We acknowledge that weed occurrence is inevitable, where human habitation and disturbances continue, and there is no simple remedy for the problem of weed persistence in its many manifestations. However, we re-iterate that *weeds are a symptom of inappropriate land-use*; for instance, over-development of land for agriculture, including vegetation clearing, conversion of grassland ecosystems for pasture, clearing of lands for human settlements and linear infrastructure, such as rail and road, and similar human-caused disturbances. The more we understand this, the better we will be at planning how to manage plants that thrive under such disturbances. This, we believe, should be a primary message of APWSS, going forward.

When seen through a broader lens, *Weed Science can be a powerful tool to understand Nature and connect with it*. If the weed scientists of our region look closely about what they are engaged in, they are likely to understand the critical inter-dependency between organisms (including all plants and all animals, including humans) and the environment. We now live in a world, separated so much from Nature, due to our busy lives and aspirations, and confusion through the pace of technology change.

Perhaps, enjoying a moment with weeds, which do not ask for much, other than to be understood, but know how to thrive in inhospitable environments, will open our eyes to the benefits and potential of weeds. Perhaps, this understanding will also lead us to respond more effectively to some of the major challenges humans face today: a burgeoning population, poverty, inadequate energy and food, negative impacts of unmitigated resource exploitation, urban developments and disturbances, environmental pollution and other forms of degradation and relentless growth. In conclusion, we re-iterate, w*eeds are certainly not the culprits if we cannot produce enough food; reduce poverty, or prevent the degradation of our environment*. Rather, it is our lack of understanding of how to live with weeds and manage weeds, that is limiting us.

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References

Altieri, M. A. (1995). Agroecology – The Science of Sustainable Agriculture. 2nd Edition, Westview Press, Colorado, USA, 433 pp.

Altieri, M. A. (1999). The ecological role of biodiversity in agro-ecosystems. *Agriculture Ecosystems and Environment,* 74: 19–31.

Altieri, M. A. and Liebman, M. (Eds.) (1988). *Weed Management in Agroecosystems: Ecological Approaches*, Volumes 1 and II. CRC Press, Inc., Boca Raton, Florida, U.S.

APWSS (1977). Commemorating 10 Years, 1967-1977. Asian-Pacific Weed Science Society. APWSS Commemorative Book, compiled by International Plant Protection Center. Oregon State University, Corvallis, Oregon, USA. July 1977. pp. 46.

APWSS (1988). A Trail of Activity 1967-1985. List of Papers presented at the 1st – 10th Conference of the Asian-Pacific Weed Science Society. Committee for the 10th Conference Anniversary Memento. Department of Agriculture and Thai Pesticides Association, 24 June 1988. pp 84.

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

Baker, H. G. and Stebbins, G. L. (Eds.) (1965). The *Genetics of Colonizing Sp*ecies, Academic Press, New York.

Baltazar, A. (2007). Asian-Pacific Weed Science Society (APWSS). Commemorating 40 Years (1967-2007). Asian-Pacific Weed Science Society, Los Banos, Laguna, Philippines. pp. 52.

BCPC (2017). British Crop Protection Council. Expert Group on Weeds. http://www.bcpc.org/expert-groups/weeds (Accessed on-line: 10 June 2017).

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.

Burnside, O. C. (1993). Weed Science – The Step Child. *Weed Technology*, 7: 515-518.

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

Chandrasena, N. (2007). Liabilities or Assets? Some Australian Perspectives on Weeds. *In*: K. U. Kim, et al. (Eds.) *Utility of Weeds and their Relatives as Resources*, pp. 9-56. Kyungpook National University, Daegu, Korea.

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

Chandrasena, N. (2015). Of Weeds and Men: Some Perspectives. *In*: Rao, A. N. and Yaduraju, N. T. (Eds.) *Weed Science for Sustainable Agriculture, Environment and Biodiversity*. pp. 1-20. Vol. 1. Proceedings of Plenary & Lead Papers. 25th APWSS Conference, 13-16 Oct. 2015, Hyderabad, India.

Clarke, J. H. (2000). Weed management for the new millennium. *Aspects of Applied Biology*, 62: 221-230.

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

Duursma, D. E., Gallagher, R. V., Rogers, E., Hughes, L., Downey, P. O., *et al*. (2013). Next-generation invaders? Hotpsots for naturalized sleeper weeds in Australia under future climates. *PLoS ONE*, 8(12): e84222. doi:10.1371/journal.pone.0084222.

Elton, C. S. (1958). *The Ecology of Invasions by Animals and Plants*. London: Methuen & Co. Ltd., 181 pp.

Emerson, Ralph Waldo (1863). Quote in 'Fortune of the Republic' a Lecture first given in December 1863. https://archive.org/details/fortunerepublic00emergoog.

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

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

FAO (2011). Food & Agriculture Organisation of the United Nations. Procedure for Post-Border Weed Risk Management, 2nd Edition. Online at: http://www.fao.org/fileadmin/templates/agphome/documents/Biodiversity-pollination/Weeds/Docs/ProceduresPostBorderWeedRiskManagement.pdf.

Furtick, W. (1969). Progress Report on Weed Control Activities in Developing Countries. Proceedings of the 2nd APWSS Conference, 16-20 June 1969, Laguna, Philippines. 18: 20.

Harlan, J. R. (1965). The possible role of weed races in the Evolution of Cultivated Plants. *Euphytica*, 14: 173-176.

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 the resistance to herbicides. Proceedings 3rd British Weed Control Conference. 1: 179-188.

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

Harper, J. L. (1958). The ecology of ragwort (*Senecio jacobaea* L) with especial reference to control. *Herbage Abstracts*, 28: 151-157.

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

Harper, J. L. (1965). Establishment, Aggression, and Cohabitation in Weedy Species. *In*: H. G. Baker & G. L. Stebbins (Eds.) *Genetics of Colonizing Species*. pp. 245-266, Academic Press, New York.

Harper, J. L. and Wood, W. A. (1957). *Senecio jacobaea* L. in Biological flora of the British Isles. Journal of Ecology 45: 617-637.

Heap, I. (2015). Herbicide Resistance – A Global Perspective. *In*: Rao, A. N. and Yaduraju, N. T. (Eds.) *Weed Science for Sustainable Agriculture, Environment and Biodiversity*. pp. 127-135. Vol. 1. Proceedings of Plenary and Lead Papers. 25th APWSS Conference, 13-16 October 2015, Hyderabad, India.

Holm, L. and Herberger, J. (1969). The World's Worst Weeds. Proceedings of the 2nd Asian-Pacific Weed Science Society Conference, 16-20 June 1969, Laguna, Philippines. 1-14.

Holm, L., Pancho, J., Herberger, J. and Plucknett, D. (1979). *A Geographical Atlas of World Weeds*. John Wiley and Sons, New York. pp. 391.

Holm, L., Plucknett, D., Pancho, J. and Herberger, J. (1977). *The World's Worst Weeds: Distribution and Biology*. University of Hawaii Press, Honolulu. pp. 609.

IPCC (2014). Climate Change 2014. Synthesis report summary for policy makers. Inter-governmental Panel on Climate Change. http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full.pdf.

Kirkwood, R., Singh, S. and Marshall, G. (1997). Resistance of *Phalaris minor* to Isopropturon: Mechanism and Management Implications. Proceedings of 16th APWSS Conference, 8-12 September 1997, Kuala Lampur, Malaysia. 204-207.

Krebs, J. R., Wilson, J. D., Bradbury, R. B. and Siriwardena, G. M. (1999). The Second Silent Spring? *Nature*, 400: 611-612.

Lacy, J., Clampett, W. and Nagy, J. (2000). Bridging the Rice Yield Gap in Australia. *In*: Papandimetriou, M. K., Dent, F. J. and Herath, E. M. (Eds.) *Bridging the Rice Yield Gap in the Asia-Pacific Region*. pp. 47-56, FAO Regional Office, Bangkok, RAP Publication 2000/16.

Lowell, J. R. (1848). *A Fable for Critics* (Page 23). G. P. Putnam, Broadway, NY, pp. 80.http://quod.lib.umich.edu/m/moa/aax1065.0001.001/25?q1=weed&view=image&size=100

Marshall, E. J. P. (2002). Weeds and Biodiversity. *In:* Robert E. L. Naylor (Ed.), *Weed Management Handbook*, 9th Edition British Crop Protection Council. pp. 75-93. Blackwell Science, Oxford, U.K.

Marshall, E. J. P., Brown, V. K., Boatman, N. D., Lutman, P. J.W., Squire, G. R. *et al*. (2003). The role of weeds in supporting biological diversity within crop fields. *Weed Research*, 43:77–89.

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

Radosewich, S. and Holt, J. (1997). Weed Ecology, 2nd edition. Wiley Publishers, New York.

Rao, A. N., Johnson, D. E., Sivaprasad, B., Ladha, J. K. and Mortimer, M. (2007). Weed management in direct-seeded rice. *Advances in Agronomy*, 93: 153-255.

Robinson, R. A. and Sutherland, W. J. (2002). Post-war changes in arable farming and biodiversity in Great Britain. *Journal of Applied Ecology*, 39: 157–176.

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

Schardt, J. D. (2010). APMS by the Decade. Available online: http://www.apms.org/wp/wp-content/uploads/2012/10/APMS-by-the-Decade-by-Jeff-Schardt-APMS-50th-Anniversary-2010-FINAL.pdf. Accessed July 14, 2017. (Also: see link in http://www.apms.org/society/about/)

Sinden, J., Jones, R., Hester, S., Odom, D., Kalisch, C., *et al*. (2004). The economic impact of weeds in Australia. Technical Series, No. 8. CRC for Australian Weed Management, Adelaide. 55 pp.

Stebbins, G. L. (1965). Colonizing Species of the Native California Flora. *In*: H. G. Baker & G. L. Stebbins (Eds.) *Genetics of Colonizing Species*. pp. 173-192, Academic Press, New York.

Storkey, J. (2006). A functional group approach to the management of UK arable weeds to support biological diversity. *Weed research*, 46:513–522.

Storkey, J. and Westbury, D. B. (2007). Managing arable weeds for biodiversity. *Pest Management Science,* 63: 517–523.

Swarbrick, J. T. (1991). Research, Information, Education and Extension. Plenary Lecture. Proceedings of 13th APWSS Conference, Jakarta, Indonesia, 15-18 October 1991. Volume 1: 27-35.

Taylor, M. (1996). Sequential Programs of Molinate, Thiobencarb, Bensulfuron and MCPA for Weed Control in Water-Seeded Rice in New South Wales. Proceedings of the 11th Australian Weeds Conference. Melbourne (Ed. R. C. H. Shepherd). 150-152.

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

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

Tiw, K. P., Kon, K. F., Lim, F. W. and Cornes, D. (1997). A Biotype of Goosegrass Cross-resistant to the 'Fops' and 'Dims' and its Management. Proceedings of 16th APWSS Conference, 8-12 September 1997, Kuala Lampur, Malaysia. 225-228.

Watanabe, H. (1995) Weedy Rice Problem in South-East Asia and Control Strategy. Proceedings of 15th APWSS Conference, 24-28 July 1995, Tsukuba, Japan. 93-103. 68-80.

Wyse, D. L. (1992). Future of weed science research. *Weed Technology*, 6: 162-165.

Yaduraju, N. T. (2012) Weed management perspectives for India in the changing agricultural scenario in the country. *Pakistan Journal of Weed Science Research,* 18 (Special Issue), 703-710 [Proceedings of 23rd Asian-Pacific Weed Science Society Conference, Cairns, 26-29 Sep, 2011, pp. 597-603].

Zimdahl, R. L. (2012). *Weed Science: A Plea for Thought - Revisited*. SpringerBriefs in Agriculture. Springer. pp. 73 (DOI: 10.1007/978-94-007-2088-6_5).

Commemorating 50 Years (1967 - 2017)

50th Anniversary Celebratory Volume Asian-Pacific Weed Science Society

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