REVIEW PAPER

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Invasive Weed Species in Malaysian Agro-Ecosystems : Species, Impacts and Management

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ABSTRACT Theoretical considerations on the paths of invasion of weeds are described with special mention of the invasive traits and spread of weedy species in terrestrial and aquatic agro-ecosystems in Malaysia. A sizeable number of introduced, naturalized, and native plant species in Malaysia have established and spread as invasive weed species, and some are classified as scheduled pests under the Plant Quarantine Act 1976 and Plant Quarantine Regulations 1981. Population increase, intensive agricultural and forestry practices, urbanization, and degradation and fragmentation of natural habitats are some of the driving anthropogenic and non-anthropogenic forces that increase the movement of weed species and new invasions. Today there are more than 100 weed species in our agro-ecosystems, many of which are invasive. The paths of invasion of weeds in our agro-ecosystems are largely unknown. Management of invasive weed species in Malaysian agro-ecosystems are very much herbicide-based, integrated with other control measures including cultural practices, prescribed burning, animal grazing, and to certain extent, followed by manual and mechanical roughing. Successful management of noxious invasives in our ecosystems will require the development of a long-term strategy incorporating prevention programmes, extension and educational activities, and sustainable and educational multi-year integrated approaches that prevent reinvasion or encroachment by other noxious invasive weed species. Invasive weed species impact on public awareness, legislation, conservation biology, agriculture, forestry, soil and water resources, and recreational and other related activities in the Malaysian agriculture and waterways management. One can easily visualize the extent of measurable economic impact of these invasives by the amount of herbicides sold per year in Malaysia to combat this menace. During1991-1999, herbicides accounted for RM220–230 millions/year or 76-79% of the total pesticide sales in Malaysia. If the costs of weed management operations yield and quality losses of crops, disease and pest occurrences (weeds being the alternative hosts of many diseases and pests) are taken into account, the figures can be quite monumental. Other social impacts are discussed.

ABSTRAK Huraian terhadap jalanan-jalanan penaklukan rumpai telah dibuat dengan pengambilkiraan teoretikal besertakan sebutan khas ke atas ciri-ciri invasif serta penyebaran spesies rumpai yang bersifat invasive di dalam ekosistem-ekosistem daratan dan aquatik di Malaysia. Terdapat sebilangan kecil tumbuh-tumbuhan yang diperkenalkan, disemulajadikan serta tumbuhan asal telah bertapak dan menjadi spesies penakluk di Malaysia, dan sesetengah dari nya adalah species pendatang, dan ada yang tersenarai selaku perosak-perosak berjadual di bawah Akta Kuarantin Tumbuhan 1976 dan Peraturan Kuarantin Tumbuhan 1981. Peningkatan populasi penduduk, amalan-amalan pertanian dan perhutanan yang intensif, perbandaran, serta perluluhan dan pemencilan habitat semulajadi merupakan beberapa tekanan antropogenik dan bukan antropogenik yang meningkatkan perpindahan spesies rumpai serta kejayaan penaklukan-penaklukan baru. Dewasa ini terdapat lebih dari 100 spesies rumpai di dalam ekosistem-ekosistem kita, dan ada yang bersifat penakluk. Jalanan penaklukan rumpai di dalam ekosistem-ekosistem pertanian kita, secara am tidak diketahui. Pengurusan rumpai-rumpai penakluk di dalam ekosistem-ekosistem pertanian adalah berdasarkan penggunaan racun herba, yang disepadukan dengan lain-lain tindakan kawalan kultura, pembakaran terancang, ragutan haiwan, dan kadangkala diikuti oleh perumpaian secara manual atau mekanikal. Kejayaan pengurusan rumpai-rumpai bermasalah di dalam ekosistem-ekosistem pertanian kita memerlukan pembangunan strategik jangka panjang melibatkan program-program penghalangan, aktiviti-aktiviti pengembangan dan pendidikan, serta pendekatan pendekatan multi-tahunan mapan yang boleh menghalang atau kemasukan baru oleh lain-lain spesies penakluk rumpai. Spesies penakluk rumpai mengimpakkan kesedaran awam, perundangan, biologi konservasi, pertaninan, perhutanan, pengurangan sumber-sumber tanah dan air, riadah dan lain-

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lain aktiviti yang bersangkutan dengan pengurusan pertanian serta saliran di Malaysia. Seseorang itu boleh menilai impak ekonomi penakluk-penakluk ini berdasarkan amaun racun herba yang dijual setiap tahun di Malaysia untuk mengatasi musuh ini. Pada tahun-tahun 1991-1999, sebanyak RM220–230 juta/tahun atau 76-79% daripada jumlah jualan racun perosak di Malaysia. Jika lain-lain kos seperti operasi pengurusan rumpai, kehilangan hasil dan mutu tanaman, kejadian-kejadian penyakit dan kehadiran perosak-perosak (rumpai menjadi perumah alternatif bagi banyak penyakit dan perosak) diambil kira, nilai sebenar akan menjulang tinggi. Lain-lain impak social juga dibincangkan.

Key words: Agro-ecosystems, invasive weeds, socio-economic impact, control measures.

> *"One can wonder at the diversity and beauty of nature, but also its specificity and ruthlessness. We are primarily interested in the welfare of one species,* Homo sapiens, *and other animal and plant species that interact with us humans. There are probably less than a hundred other species making up most of these interactions, both beneficial and detrimental, accompanying anthropogenic activities. Thus there are both assets and liabilities in species invasion"* (D. Scott, 1997)

INTRODUCTION

Nature abhors vacuum. This is precisely the underpinning principle that leads to colonisation and consequential establishment of open spaces by invasive plant species. Plant invasions are worldwide phenomena, arising from intentional and unintentional transport of plants, quite often aided by anthropogenic activities [1, 2], and augmented by natural factors [3, 4], have profound effects on the biodiversity and altered the structure and functions of many ecosystems [5]. Such activities have allowed introduced, naturalised plant species and some endemics to increase their geographic range and become land management problems [6]. Invariably, differences between environments in their degree of resistance or susceptibility to invasions are aligned to differences in base-rate probability of an introduced species becoming naturalised, subsequently becoming an invasive pest in the new environments. These are some of the key elements in the risk assessment systems for exotic introductions. With the apparent breakdown of biogeographical borders due to increasing international trade and globalisation, the magnitude and complexity of invasive plants (weeds!) in the agro-ecosystems require that future management be based on sound ecological principles and concepts. It is a truism when [7] lamenting that ecological management of invasive weeds require substantial increases in the application of ecological knowledge and its integration with other forms of knowledge. After decades of weed control, invasive plants continue to infest all agro-ecosystems worldwide, and Malaysia is no exception. While many of these invasive weed species are not true indigenes of Malaysia or Malesia, nevertheless they have colonized, and adapted to local habitats, thereby causing socio-economic impacts on the farming and non-farming communities alike. As we move into the future, a clear and far-sighted view of invasive plant ecology and holistic management approach is necessary. Management must focus on addressing the cause of invasions rather than treating the symptoms of weeds [8]. Management of invasive weeds is knowledge-driven. Knowledge of mechanisms and processes driving plant invasion and ecological factors directing plant community dynamics is central to developing ecologically based invasive plant management programmes in our effort to reach out to farmers, land managers, extension agents, and policy- makers alike.

This paper describes some of the introduced, naturalised, and endemic plant species in the Malaysian agro-ecosystems, which have established and spread as invasive weed species. Theoretical considerations on the paths of invasion of weeds are described with special mention of the invasive traits, and spread of the invasive weedy species in the terrestrial and aquatic agro-ecosystems in Malaysia. The socio-economic impacts of infestation of invasive weed species on agro-ecosystems, and management of these invasives are also discussed briefly.

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Some Theoretical Considerations

Invasion Process in Plants: Introductions, Colonization, and Naturalization

The path of a biological invasion or synanthropisation (*sensu* Fallinski [9]) by weeds is influenced by several factors, namely, the attributes and mode of transportation of the invading species, the characteristics of the invaded ecosystems, and their interactions, often facilitated by anthropogenic activities. The basis of this invasion is substitution whereby the stenotypic species are replaced by eurytropics, the endemics by cosmopolitan counterparts, and the autochthonous ones by allochthonous species. Invariably, the approaches to investigate the causes and mechanisms of synanthropisation of an invading species, indeed quite often exemplified by weeds, are multi-faceted. Probably, the most common one is the search for certain traits of the invasive species [10, 11, and 12] in synchrony with the hypothesis that species traits have a strong influence on the invasion process. Another approach is the search for the special characteristics of an invaded weed community to assess whether there are certain weed communities resistant or especially prone to invasions [13]. The abiotic traits of the invaded site may also be emphasized [14].

Heger [15] lamented as many case studies show, that there is an intrinsic problem for all these approaches: every single process of invasion seems unique, and for every rule an exception seems to prevail; a situation identified as "lack of rules" by Roy [16]. In such a situation, there is a need for a holistic approach taking into consideration weed community dynamics, and diversity, weed species composition, and migration of propagules, the latter not only dependent on biotic interactions within the community but also strongly limited by recruitment [17]. This corresponds to the hypothesis of crucial role of transportation in the process of weed invasion [18, 19], a contemporary opinion widely accepted for a synthetic viewpoint of invasions [20, 21, 4 and 22].

Groves [23] distinguishes between introduction, colonization and naturalization. Plant introduction occurs when at least one viable propagule arrives at the new site beyond its previous geographic range, and subsequently establish populations of adult reproductive plants. Following removal of environmental barriers, transport of propagules is possible, allowing consequential success of migration of alien plants into a new region, ecosystem or habitat [24, 25]. The failure or success of immigrant-emigrant species following introduction into a new environment is an intriguing ecological consequence, an issue worth exploring in the development of techniques to prevent or control introductions and their eventual spread. Cousens and Mortimer [26] and Williamson [4] cited several examples of establishment failure of plant species following introduction.

Successful introduction of individuals in a new location or habitat is mediated through recruitment. Recruitment itself is a function of the number of dispersed seeds, viability rates, and the probability of juvenile survival establishing into adulthood, ensuring the perpetuity of populations into subsequent generations. Recruitment-mediated founding populations following successful introduction in turn are affected by the availability of safe-sites (*sensu* Harper, [27]); propagule pressure (*sensu* Williamson [4] arriving at those locations; and the survival rate of arriving propagules [28, 29] (Figure 1). The resultant populations after successful introduction comprise the founding or 'source' population (patch) of progeny that advances as a front, and 'satellite' populations originating from isolated individual progeny, and migrating from this source, subsequently forming new patches.

Colonization occurs when plants in a founding population reproduce and increase in sufficient numbers to become self-perpetuating [6]. Cousens and Mortimer [26] envisaged colonization as the rate of proportional increase of self-perpetuating patches advancing on all fronts, represented by an equation:

$$(dA/dt)/A = 2\pi r^2 t \qquad (1)$$

where A equals the area occupied, r is the radius of the population, and t is the time in years or generations. Ideally, this model of range expansion is intuitively possible, but it does not take into account the dispersibility status of a founding source population, giving rise to new satellite populations of the species.

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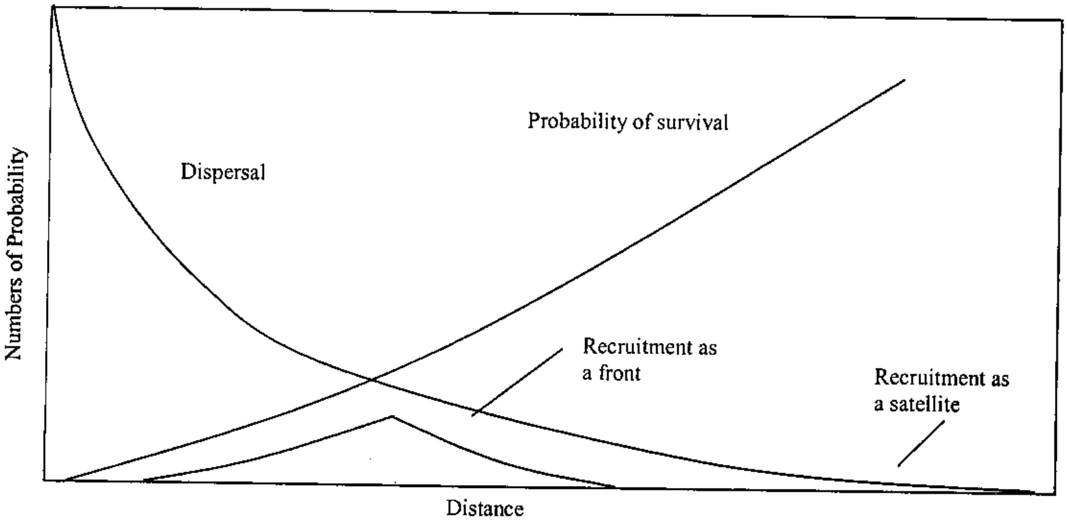

Figure 1. Recruitment of new genotype as a function of the number of dispersed seeds and the probability of juvenile survival (modified from Radosevich *et al.*[6])

Holmes *et al.* [30] advocated the use of reaction-diffusion models, combining a parameter of diffusion with deterministic population growth to study movement and spread of dispersing invasive species in a plant community. Accordingly,

$$dA/dt = \pi 4rD \qquad (2)$$

where A, t, and r represent area, time, and radius, respectively, and D is a diffusion parameter somewhat like environmental porosity or spread. Evidently, predictions of plant colonization based on this model underestimated the area being invaded by orders of magnitude.

A farmer or land manager facing invasive plant species in his area would pose a relevant practical management question emerging from such analyses. Should containment of an invading species be made at the founding source or among satellite populations following successful introduction? Moody and Mack [31], Cousens and Mortimer [26] and Ghersa *et al.* [32] advocated that for successful containment, the strategy would be to remove satellite populations as they occur through time, and over space as these populations have potentials for rapid spread and coverage *vis-à-vis* the front of a source population.

Successful naturalization of a species in its new environment prevailed with the establishment of new self-perpetuating populations dispersing widely throughout the region, incorporating into the resident flora. In the absence of a threshold constraining the establishment of a metapopulation of the new species, and the prevalence of outlier satellite populations, the range of an invading species may be pushed more rapidly [33]. The dynamics of a metapopulation in which a plant species requires a particular type of site for establishment, and such sites are scattered can be described by an equation [34]:

$$P_{t+1} = P_t + cP_tV_t - xP_t \qquad (3)$$

where t equals time, P is the number of populated sites, and V is the number of vacant sites, cP_t is the number of new sites colonised, and xP_t is the number of sites where existing population become extinct. More often, the success of invading species depends on very rare recruitment events, and human-mediated activities and perturbations - namely, soil disturbance and fire provide greater opportunity to spread.

The rates of successful introduction, colonization, and subsequent naturalization of an invading species, and becoming weedy and invasive in a new habitat are incredibly low [35]. Environmental sieves and dispersal constraints, natural disasters and human interventions, and internal dynamics are some of the causal factors determining, and to a certain extent, limiting the success of weed species becoming part of the extant community. Environmental filters act by removing species lacking specific traits [36]. In Britain studies showed that only 0.53% of 220,000 imported species introduced to Britain became naturalised and not all of them were invasive [37]. Such low incidences of successful naturalizations are attributed to low base-rates probability of invasions [4]. In Australia, estimates of base-rate probability of an imported plant becoming a weed ranged from 0.007% [37] to as much as 17% [74] with a central tendency of 2% [38, 35]. Williamson and Fitter [39] estimated from a range of case studies that only 0.1%, and between of 0.01 and 1.6% of introduced plant species became naturalized species, subsequently becoming weeds.

Biological Invasion Pathway: Model of Steps and Stages, Crucial Situations, and Favourable Characteristics

As explained by Heger [15] crucial situations favouring special characteristics of invasive weed species must prevail for successful invasions of a habitat. A chronological dissection of an idealized weed invasion process is given in (Figure 2). There is a sequence of stages, and each stage can be reached by overcoming a specific step. Initially, the presence of a weed species in the new habitat corresponds to the dormant period of the propagule, assisted by immigration. At the stage of spontaneous establishment, at least one new generation of a weed species or an aggregation of sympatric weed species have been produced in the new habitat without any anthropogenic influence. A weed plant reaching the permanent establishment stage is an indication that at least one population has the minimum viable number in the new habitat ensuring a good chance for persistence and survivorship. The completion of spread in a new habitat represents the fourth stage of invasion whereby the weed plant in question has occupied all suitable sites in the new habitat inferring new barriers to dispersal are reached. In order to progress from one stage to another the invasive weed species must achieve the steps of immigration, independent growth and reproduction, population growth until the minimum viable number is reached, and acquisition of new localities. These four steps comprise the main problems encountered that a weed "has to deal with" in the course of invasion, posing as a sequence of barriers [2] (Mooney and Drake]. Cronk and Fuller [40], Kowarik [41], Hastings [42], and Wade [43] advocated a systematic analysis of subdivisions distinguishing different phases (or stages) of an invasion process, but none of them differentiates between a stage which can be reached, and the process of reaching it. Williamson and Fitter [39] presented cases examining when the probability for a plant becomes a weed. If the mechanisms of biological invasions are investigated from an ecological viewpoint, it makes no difference whether or not a plant is a weed or otherwise.

Ideally, the most effective way to limit plant invasions is to prevent them from happening. However, preventive strategies to curtail invasions are difficult to achieve due to the paucity of descriptions of biological and environmental characteristics of invasive species in part [6] and truly predictive models of invasion biology have been proven to be elusive [44]. Invariably, it is difficult to determine which plant species are most likely to be invasive and to prevent introduction, unless adequate descriptions of a species' biology and its habitat requirements are understood.

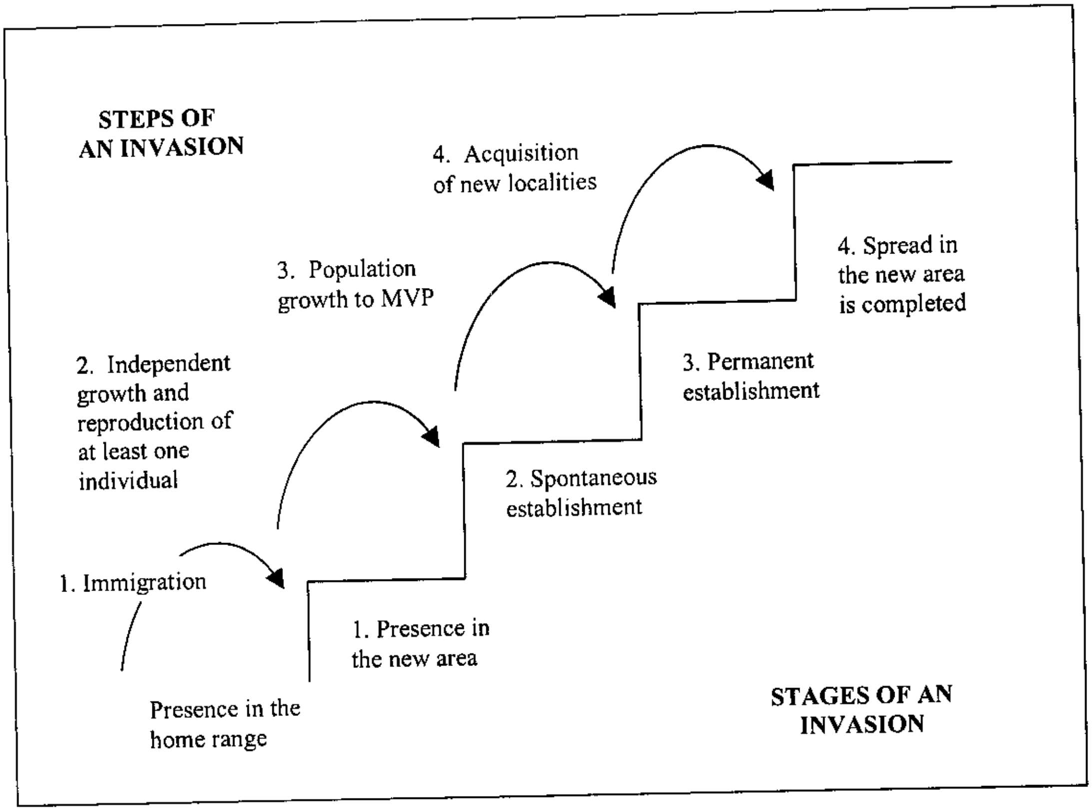

Figure 2. Chronological dissection of an idealized weed invasion process. MVP- Minimum viable populations (adapted from Heger [15]).

Invasive Weed Species in Malaysian Agro-Ecosystems

The warm tropical climate of Malaysia with adequate rainfall and available nutrients permits the luxuriant growth of crops and weeds alike almost all year round. This, coupled with mass transport of goods and the populace, continuous opening and exploitation of new farming areas, intensive agricultural and forestry activities, urbanization, abandoned and derelict farmlands, and fragmentation of natural habitats and agro-pastoral sites, among others, are some of the driving forces that increase the movement of weed species across natural boundaries within the country, thereby influencing the success of new invasions. While many of these invasive weed species are not true indigenes of Malaysia or Malesia, nevertheless they have colonized, and adapted to the local habitats, with socio-economic impacts on the farming and non-farming communities alike. (Table 1) illustrates some of the invasive weed species in Malaysia.

Some of these species are classified as scheduled pests under the Plant Quarantine Act 1976 and Plant Quarantine Regulation 1981. The terrestrial invasives include the wide spread of *Imperata cylindrica*, *Ischaemum rugosum*, the *Echinochloa* species aggregates, *Pennisetum polystachion*, *Fimbristylis milicea*, *Cyperus rotundus*, *Scleria sumatrensis*, *Scirpus grossus*, *Eleusine indica*, *Leptochloa chinensis*, *Melastoma malabathricum*, *Mikania micrantha*, *Pueraria phaseoloides*, *Calopogonium cereleum*, *Chromolaena odorata*, *Mimosa pudica*, *Mimosa invisa*, *M. pigra*, *M. quadrivalvis*, and *Asystasia gangetica* in many agricultural areas, along roadsides, railway tracks, and in derelict and abandoned sites. In the reservoirs, waterways, drainage and irrigation canals, aquatics such as *Eichhornia crassipes*, *Salvinia molesta*, *S. cucculata*, *Pistia stratiotes*, *Hymenachne acutigluma*, *Hydrilla verticillata*, *Ipomoea aquatica*, *Utricularia speciosa*, *Cyperus malaccensis*, and *Rhynchospora corymbosa* are quite prevalent. One can easily visualise the extent of measurable economic impact of these invasives by the amount of herbicides sold in Malaysia to combat this menace yearly. In 1991-1999, herbicides accounted for RM 220-230 million/year or 76-79% of the total pesticide sales in Malaysia. If the costs of weed management operations yield and quality losses of crops, disease and pest occurrences (weeds being the alternative hosts of many disease and pests) are taken into account, the figures can be quite monumental.

Except for a few species, most of the invasive weed species in Malaysia are of foreign origin. Unfortunately, we do not have a complete record of when these non-indigenes were first recorded in Malaysia. More often than not, human activities, such as farming and importation of farm produce, and rearing of ornamental fishes, led to deliberate and sometimes unwarranted introduction of exotic plant species into Malaysia. Based on the definition of a naturalised plant [45], these invasives have escaped from cultivated lands or gardens, ponds or aquaria, and established as weeds. The *Pennisetum* aggregates, namely *P. polystachion, P. purpureum*, and *P. setosum* are good examples of where their introduction into the country for animal fodders [46], precipitated their becoming serious weeds, invading roadsides, abandoned farms, and open spaces throughout the country. Importation of animal fodder and seeds brought in as impurities with leguminous covers are a source of weeds while enforcement of the Plant Quarantine Act 1976 is in place, stringent monitoring of these consignments is difficult if not impractical. In the case of the aquatic weed species such as *Eichhornia crassipes, Salvinia molesta, S. cucculata, Pistia stratiotes, Hymenachne acutigluma, Hydrilla verticillata*, many were brought in through the importation of exotic fishes, mainly for aquarium display and maintenance. The consort of King Chulalongkorn of Thailand was enchanted by the beautiful flowers of the waterhyacinth, and brought in the weed from Bogor in 1853. In Malaysia, Chinese pig farmers brought in the water hyacinth as food supplements for the hogs. These transactions have led to unwarranted release into ponds, lakes or reservoirs, while some escaped into rivers, drainage and irrigation canals in the country. There is a paucity of information on the up-to-date status of distribution and infestation of invasive weeds in Malaysia. The data bank on the invasion pathway of weed species is severely lacking. Baki *et al.* [47], among others, recorded wide- spread distribution of *Pennisetum polystachion* and *P. setosum*, in Peninsular Malaysia. The work of Baki *et al.* [48], Pane [49], Azmi [50], highlighted the extent of infestation of *S. molesta, Leptochloa chinensis, Echinochloa* aggregates, respectively, in Peninsular Malaysia. The wide-spread presence of *Hydrilla verticillata, Eichhornia crassipes* and *S. molesta*, in water reservoirs, ex-mining pools, drainage and irrigation canals in 1996 - 2002 in Kedah, Perlis, Perak, and Penang was recorded by Mashhor *(pers. comms.)*, while Azmi *(unpublished data)* reported measurable presence of *P. stratiotes* and *Hymenachne acutigluma* in drainage and irrigation canals of MADA, Seberang Prai, Tanjung Karang, and Krian-Sungai Manik granaries. In KADA, *Nymphoides indica* was very prevalent. Interestingly, no measurable changes were observed on the extent of infestation of the waterhyacinth in Peninsular Malaysia since early 1980's. Baki (unpublished data) in his surveys of aquatic weeds in Peninsular Malaysia in 2000-2001 noted similar patterns of infestation in major rivers, ex-mining pools, and drainage and irrigation canals, despite routine clearing work by the authorities.

Baki [51] described the invasion dynamics and population spread of *S. cucculata* (hitherto unrecorded in Malaysia), *Typha augustifolia, Phragmites australis, P. repens, Rhyncospora corymbosa, L. repens*, and *Leersia hexandria* of Timah Tasuh Water Reservoir in Perlis from 1996 to 1999 (Table 2). These weeds covered *ca.* 13, 27, and 43% of the reservoir's water surface in 1996, 1997, and 1998, respectively, with the dominant presence of S. *cucculata. Hydrilla verticillata*, which were mostly within the shallow edges of the reservoir, registered *ca.* 45, 67, 76, and 76% of the reservoir water body in 1996, 1997, 1998, and 1999, respectively. By 1999 the weeds have invaded no less than 50% of the water surface of the reservoir.

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Table 1. Some invasive weed species in Malaysian agro-ecosystems.

Weed species	Code[A]	Mode of spread and propagation[B]	Origin	Reference
Ageratum conyzoides L.	AGECO	S	Tropical America	[52]
Alternanthera philoxiroides (Mart.) Griseb[# a]	ALRPH	C/S	Tropical America	[53]
Amaranthus lividus L.	AMALI	S	East Asia	[53]
A. spinosus L.	AMASP	S	Unknown	-
Azolla pinnata R.Br.	AZOPI	C/S	Tropical Asia	[53]
Asystasia intrusa Blume.	ASYIN	C/S	India	[54]
Borreria alata (Aubl.) DC	-	S	Tropical America	[53]
Brachiaria mutica (Forsk.) Stapf.	-	C/S	Tropical Africa	[53]
Chromolaena odorata (L.) King and Robins	EUPOD	C/S	Africa	[54]
Cleome rutidesperma DC	CLERT	S	West Tropical Africa	[53]
Clidermia hirta (L.) D.Don.	CXAHI	S	Tropical America	[52]
Cordia curassavica (Jacq.) Roem. and Schult	CRHCY	S	Tropical America	[55]
Crassocephalum crepidiodes (Benth.) S. Moore ***	CRSCR	S	Tropical Africa	[52]
Croton hirtus L'Herit	CVNHI	S	Tropical America	[53]
Cynodon dactylon (L.) Pers.	CYNDA	C/S	Asia/Africa	[53]
Cyperus digitatus Roxb.	CYPDG	S	Tropical Asia?	[53]
C. difformis L.	CYPDI	S	Old World Tropics	[53]
C. esculentus L.	CYPES	C/S	India?	[52]
C. iria L.	CYPIR	C/S	Asia	[52, 53]
C. kyllingia Endl.	CYPKY	S	Asia	[52, 53]
C. malaccencis LAM	CYPMA	C/S	South East Asia	[52]
C. pilosus Vahl.	CYPPI	C/S	Asia	[52, 53]
C. rotundus L.	CYPRO	C/S	India	[53]
Digitaria ciliaris(Retz.) Koel.	-	C/S	Taiwan	[53]
D. setigera R. and S.	-	C/S	Tropical Asia	[52]
D. ternata (A.Rich.) Stapf.	DIGTE	C/S	Tropical Asia	[54]
D. violescens Link.	DIGVI	C/S	Tropical Asia	[42, 53]
Echinochloa crus-galli ssp. *crus-galli* (L.) P. Beauv.	ECHCX	S	Europe, India	[53]
E. crus-galli ssp. *formosensis* P.Beauv. Ohwi	ECHCS	S	Asia, Taiwan	[56]
E. colona (L.) Link.	ECHCO	S	India	[53]
E. glabrescens Munro ex. Hook.f./Kossenko	ECHGL	S	Old Tropics, India?	[57]
E. oryzicola Vasing	ECHCR	S	Old Tropics	[56]
E. stagnina (Retz.) P. Beauv.	ECHST	C	Africa	[56]
Eclipta prostrata L.	ECLAL	S	Unknown?	-
Eichhornia crassipes (Mart.) Solms.	EICCR	C/S	South America	[54]
Eleocharis acicularis (L.) Roem. and Schult.[# a]	ELEOC	S	Northern Hemisphere	[53]

Table 1 *(Continued)*

Weed species	Code[A]	Mode of spread and propagation[B]	Origin	Reference
Eleusine indica,(L.) Gaertn.**	ELEIN	S	South America	[54]
Eragrostis pilosa (L.) P. Beauv.	ERAPI	S	Old World Tropics	[52]
Erechtites valerianaefolia DC.	EREVA	C/S	Tropical America	[52]
Erigeron sumatrensis (Retz.) Walker	-	S	Tropical America	[54]
Eriochloa polystacya H.B.K.	-	C/S	Tropical America, West Indies	[53]
Euphrobia heterophylla L.	EPHHL	S	Tropical America	[52]
Fimbristylis dichotoma (L.) Vahl.	FIMDI	C/S	Southeast Asia	[53]
F. globulosa (Retz.) Kunth.	FIMGL	C/S	Southeast Asia	[52]
F. miliacea (L.) Vahl.*	FIMMI	C/S	South America	[53]
Fuirena umbellata syn. *F. quinquangularis* Roxb.	FUICI	S	Unknown	-
Gleichenia linearis syn. *G. dichotoma* Hook.	GLCDI	C/S	Tropical Asia	[52]
Hydrilla verticillata,(L.F.) Casp./Royle	HYLLI	C/S	Asia	[53]
Hymenachne acutigluma,(Stued.) Gilliland	-	C/S	India	[53]
Hyptis capitata Jacq.	HYPCA	S	Tropical America	[52, 53]
Imperata cylindrica (L.) P. Beauv./Raeusch.	IMPCY	C/S	Tropical Asia	[53]
Ipomoea aquatica Forssk.	IPOAQ	C/S	Southeastern Asia	[52]
Isachne globosa	-	C/S	Tropical Asia	[52]
Ischaemum rugosum Salisb.	ISCRU	C/S	South East Asia	[53]
Lantana camara L.	LANCA	S	Tropical America	[52]
Leersia hexandra Sw.	-	C/S	Tropical America	[53]
Lemna purpusilla syn. *L. minor*	LEMMI	C	Unknown	-
Leptochloa chinensis (L.) Nees.	LEFCH	S	Tropical Asia	[53]
Limnocharis flava (L.) Buchenau*	-	C/S	Tropical America	[53]
Lindernia crustacea (l.) F. Muell.	LICR	C/S	Tropical Asia	[52]
Ludwigia adscendens (l.) Hara	LUDAC	C/S	Tropical Asia	[53]
L. hyssoppifolia syn. *L. linifolia*	LUDLI	S	Tropical America	[53]
Lygodium flxuosum (L.) Sw.	LYFFL	S	Old world Tropics	[52]
Marsilea minuta L.	MASMI	C/S	Unknown	-
M. crenata Presl.	MASCR	C/S	Unknown	-
Melastoma malabathricum auct. non L.	MESMA	S	Asia	[53]
Melochia corchorifolia L.	MEOCO	S	Malesia	[53]
Mikania micrantha H.B.K.	MIKMI	C/S	South America	[53]
Mimosa invisa Mart. ex. Colla	MIMIN	S	Brazil	[52]
M. pigra Jusl./L.[#]	MIMPI	S	Tropical America	[57]
M. pudica L.	MIMPU	S	Tropical America	[40]
Monochoria vaginalis (Burm. f.) Presl.*	MOOVA	C/S	Asia	[53]

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]**Table 1** *(Continued)*

Weed species	Code[A]	Mode of spread and propagation[B]	Origin	Reference
Murdannia nudiflora (L.) Drennan.	MUDNU	C/S	Unknown	-
Myriophyllum aquaticum (Vell.) Verc. [#] [α]	MYPBR	C/S	Tropical America	[53]
Nephrolepis biserrata (Sw.) Scott.	NEHBI	C/S	Old Wrolde Tropics	[52]
Nymphoides indica (L.) O.K.	NYPIN	C/S	South America	[53]
Oldenlandia corymbosa L.	OLDCO	S	Unknown	-
Oryza sativa L. (weedy rice)	ORYSA	S	Asia (Malaysia, Vietnam)	[58]
Ottochla nodosa (Kunth) Dandy	-	C/S	Southeast Asia	[57]
Panicum repens L.	PANRE	C/S	Asia	[53]
Paspalum conjugatum Berg.	PASCO	C/S	Tropical America	[53]
P. distichum L.	PASDS	C/S	Unknown	-
P. vaginatum syn. *P. virginatum* L.	PANVI	C/S	Unknown	-
Pennisetum polystachion (L.) Schult. [#]	PESPO	C/S	Tropical Africa	[53]
P. setosum (Sw.) L. Rich. [#]	PESSE	C/S	Tropical Africa	[53]
Pistia stratiotes L.	PIIST	C/S	Unknown	-
Rotala indica (Willd.) Koehne	ROTIN	C/S	Tropical America	[53]
Rhyncospora corymbosa L. Britt.	RHCAUS C/S		Unknown	-
Rottboellia cochinensis (Lour.) W.D. Clayton [#]	-	C/S	India	[53]
Sagittaria guyanensis H.B.K.	SAGGU	C/S	Tropical Africa/Southeast Asia	[53]
Salvinia cucculata Aubl.	SAVMO	C	South America	[53]
S. molesta D.S.Mitchell	-	C	South America	[53]
S. natans (L.) All.[#] [α]	SAVNA	C	Old World	[53]
Scirpus grossus L.	SCPGR	C/S	South East Asia	[53]
S. juncoides Roxb.	SCPJU	C/S	Asia	[52, 53]
S. mucronatus L.	SCPMU	C/S	Asia	[52, 53]
Scleria sumatrensis Retz.	SCLSU	C/S	South East Asia	[52]
Sphenoclea zeylanica Gaertn.*	SPDZE	S	Tropical Africa	[52, 53]
Stenochlaena palustris Bedd	-	C/S	Asia	[52]
Utricularia speciosa Vahl.	-	C/S	Asia	[53]

* Resistance to 2,4-D; ** Resistance to glyphosate; *** Resistance to paraquat; [A] Bayer code, [B] C - Clonal growth; S – Seeds/spores; [#] Scheduled pests under Plant Quarantine Act 1976 and Plant Quarantine Regulation 1981); [α] Detected but has not attained invasive status.

Preliminary seed bank studies indicated that soil samples retrieved from the reservoir soil bed contained weed seeds with not less than 23% viability. It was uncertain whether those seeds were those from the present weed vegetation in and around the reservoir or those left imbedded from the farms inundated in 1992 or earlier. Invariably, the floating islands of decomposed mats of old *S. cucculata* plants acted as fertile seed beds for other weed species, allowing *C. platystylis, L. hexandra, P. repens, L. repens* and *Isachne globosa* to germinate, proliferate and establish, hence the perennial infestation of these weeds both on the edges and as floating islands in the reservoir Baki *et al* [51].

The man-made water reservoir was devoid of weeds upon its completion in 1992, until 1994 when unsuspecting anglers, and fishermen, practicing fresh-water aquaculture in the reservoir, brought in the scourge. Since then the weeds contribute a perennial maintenance problems for the authorities, incurring US$500,000 annually to alleviate the menace through mechanical and manual means. Rich nutrients from feeding rivers and streams, fish feed, and agricultural activities, in the vicinity of the reservoir, are thought to be responsible for the luxuriant growth of aquatics in the reservoir.

Mimosa quadrivalvis var. *leptocarpa* syn. *M. longihirsuta,* only recently recorded in Malaysia and Malesia, is another potentially invasive weed species within the *Mimosa* aggregates [59]. It was a new species record for Malaysia and Malaesia. Subsequent field surveys conducted in 1996 – 1998 recorded increased infestation of the weed from small and localised pockets in Penang to areas hitherto uncolonised in Perlis, Kedah, and Penang states in northern Peninsular Malaysia [60]. The weed has since colonized new areas in northern Perak, especially on derelict, abandoned farms, and ex-tin mining spoils (Baki, unpublished data). The weed populations were highly clustered with *Ip* (Lloyd's patchiness index) values ranging from 13.67 to 68.94 (Table 3).

Field populations displayed erratic oscillations and this apparently was due to high mortality of seedlings. Each plant produced *ca.* 11,550 seeds/year with 97.1% – 98.3% viability. Only about 5.75% of the seeds produced emerged as seedlings out of which only 24.85% became successful colonisers of open space (Table 4). There is a slight increase in fruit-bearing adult populations of 2.54%/year over the 1996 -1998 period. This translates to an increase of seed bank populations in soils (5.95%/year) over the same period. The plant exhibited robust clonal growth producing many primary and higher-order stolons, which in turn acted as fruit- and seed-bearing entities, and resource-capture. Arguably, high seed-production capacity, coupled with robust and aggressive clonal growth identifies *M. quadrivalvis* as an invasive weed to monitor in Peninsular Malaysia.

In rice granaries, weedy rices claimed territorial success as new invasives outclassed the earlier successful infestation by the *Echinochloa* aggregates, sedges, and broadleaved weeds in rice granaries since the late 1980's. Since their first detection in the Tanjung Karang granary in 1987, the scourges have invaded, albeit in slow rates, to other granaries. The possible paths of invasion of weedy rices to other rice granaries, and some of the dominant weedy rice accessions, are shown in (Figure 3). The scourge spread to MADA in 1990, Besut in 1995, Sungai Manik/Kerian in 1996, Seberang Prai in 1997, Seberang Perak and Kemubu in 2001 (Azmi *et al.*, unpublished data). Regrettably, there is a paucity of information on season-mediated infestation of weedy rices in the granaries of Peninsular Malaysia since its first detection in 1987. Initial work by Azmi (unpublished data) indicated that by Season II of 1993 about 700 ha of the farm blocks of Sungai Nipah, Sungai Burong, Sungai Leman, and Sekinchan in the Tanjung granary was infested with weedy rices, with some farms recording 50% invasion. Thereafter, the degree of infestation of weedy rices in Tanjung Karang was on a downward trend,

Table 2. Percentage cover of noxious aquatic weeds in Tasik Timah Tasuh (1996 –1999) (Adapted from [58]).

Species	Percentage Cover			
	1996	1997	1998	1999
Leersia hexandra Sw.	27.2	29.1	33.7	34.4
Panicum repens L.	2.1	2.3	3.8	4.2
Hymenachne pseudointerrupta (Steud.) Gilliland	7.8	7.7	7.9	8.4
Isachne globosa (Thunb.) O.K.	+	++	++	+++
Phragmites australis (Cav.) Trin. Ex. Steud	1.4	1.4	1.8	2.2
Imperata cylindrica (L.) Beauv./Raeusch.	+	+	+	+
Cyperus compactus Retz.	+	+	+	+
C. platystylis R. Br.	4.5	4.7	4.8	5.0
C. iria L.	+	+	+	+
Scirpus grossus L.	+	+	+	+
Typha augustifolia L.	1.8	2.3	2.5	2.4
Ipomoea aquatica Forsst.	+	+	++	+++
Ludwigia adscandens (L.) Hara	+	+	++	++
L. octovalvis (Jacq.) Raven	+	+	++	++
Polygonum barbatum L.	+	+	++	++
P. pulcrum L.	1.5	1.6	1.5	1.7
Eclipta alba (L.) Hassk.)	+	+	+	+
Mikania micrantha H.B.K.	+	+	+	+
Alternanthera sessilis B.Br. ex DC	+	+	+	+
Asytasia coromandeliana Wright ex. Nees	+	+	+	+
Hydrilla verticillata (L. F.) Casp./Royle[@]	45.2	48.8	56.7	75.3
Salvinia molesta Mitch.	+	+	+	+
S. cucculata L.	28.2	34.3	34.0	32.5
Eichhornia crassipes (Mart.) Solms	+	+	+	+

* Mean of 2 surveys in June and December from 5 sampling sites with 10 replicates each; + - < 0. 5%; ++ - < 1.0; +++ - < 2.0%; @ - submergent/ non-floating weed, not taken into the computation of % cover; figures represent infestation volume of water bodies.

Table 3. Average values of Lloyd's patchiness index *(Ip)* of *M. quadrivalvis* fruit-bearing populations sampled in 1996 - 1998 in Perlis, Kedah and Penang (after Baki 60) #

Locations/State	1996		1997	1998
	(S1)*	(S2)	(S3)	(S4)
Perlis	22.34Aa	23.45Aa	13.67Ab	46.98Ac
Kedah	33.87Cb	37.67Cb	23.19Ba	68.94Cc
Penang	27.45Bb	29.92Bb	16.52Aa	52.32Bc

* Data were collated and analysed for each 6-monthly sampling; # Values followed by a common upper case within a column or lower case letter within a row are not significantly from each other (HSD)*(p>0.01).*

Table 4. Seed, seedling and established immature and fruit-bearing mature plant populations of *M. quadrivalvis* raised in an insect-proof house and under natural conditions in Peninsular Malaysia (1996 – 1998) (after Baki [59]) * +

Year	No. seeds/plant	% Viability	% seedlings	% established plants
1996	12133 a (12383)A	97.7 a (97.1)A	7.03 a (5.15) A	1.81 a (1.12) A
1997	12089 a (7899)C	96.9 a (97.4)A	6.81 a (3.87) B	1.83 a (0.79) B
1998	12111 a (11662) B	100.0 a (98.3) A	7.46 a (5.74) A	1.73 a (1.15) A
Mean	12451 (10648)	98.2 (97.6)	7.10 (4.92)	1.79 (1.02)

* Values in the parentheses are from natural population census; + Values followed by a common upper or lower case letter within a column are not significantly different from each other (HSD) *($p>0.01$)*

possibly due to effective control measures by farmers and aggressive campaigns and advisory activities by the extension agents to root out the scourge in the area, as shown by low incidences of weedy rices based on acreages of infestation in Season I, 2000, up to Season II, 2002 (Table 4). However, in Season I, 2000 up to Season II, 2002, a marginal increase in terms of acreages of farm blocks recording weedy rice infestations prevailed. In MADA these infestations were rather erratic, accounting for about 0.17%, 1.39%, and 2.41% of the granary in 1993, 2001 and 2002, respectively. Farm blocks recording >50% infestations with weedy rices increased substantially from *ca.* 2% in Season 1, 2001 to *ca.* 5.9% in Season 1, 2002. The parallel figures for Seberang Prai (Penang), and Perak were 3.09% and 3.71% of the granaries, respectively. Pockets of infestation were also observed in Negeri Sembilan, and the Endau-Rompin farm blocks of Pahang and Johore, accounting for about 13.69 and 22.09% of the rice-growing areas in both states, respectively In Krian-Sungai Manik, *ca.* 2.57%, 3.56%, and 3.71% of the granary were infested with weedy rices in 2000, 2001, and 2002, respectively. Interestingly, the granary of Ketara Irrigation Schemes, Besut, Trengganu recorded a high degree of infestations of weedy rices from 750 ha in 2000 to 3122 ha in 2002, or 5.21% - 21.67% of the granary. The KADA granary in Kelantan also recorded weedy rice infestations.

Being sympatric and in niche commonality with each other, weedy and commercial rices co-exist, competing for space and common pools of nutrients for growth, survivorship, and establishment. One cannot rule out the possibility of *in-situ* evolutionary forces operating among weedy rice populations in individual rice granaries in Malaysia [61], thereby generating distinct weedy rice populations, although studies by Mislamah *et al.* [62] showed no such occurrence of distinct populations of weedy rices in different rice granaries. Albeit management pressures to alienate and suppress the former through tillage, water management, herbicide treatments and occasional roughing, weedy rices continue to prevail. Such continued prevalence was possible as weedy rices have very apparent ecological advantage over the commercial rice varieties. Weedy rices have a short maturation period of less than 90 days *vis-à-vis* 115 –120 days for commercial rices, taller plant height, faster growth rate, and (most importantly) shatters ripened seeds earlier than commercial varieties [63, 64]. These special traits enable weedy rices to pre-empt resource capture earlier than their commercial counterparts. Within the short growth period of <3 months, weedy rices are able to establish themselves in open spaces, devoid of commercial rice plants, and shed seeds, augmenting seed reservoirs in the seed bank.

Following the reasoning of Heger [15], crucial situations favouring special characteristics of invasive weed rices must prevail for successful invasion through a sequence of stages, in rice ecosystems in Peninsular Malaysia. From the initial presence, when a reservoir of seeds in the new habitat occupies an adequate number of safe sites (*sensu* Harper [27]), to the sequential stages of spontaneous and permanent establishment with the minimum viable number, a good chance for persistence and survivorship is ensured. Weedy rice seeds, being non-dormant, would emerge spontaneously given adequate moisture and other germination prerequisites, and establish quickly. The extent of such emergence and establishment reflects the size of the seed bank and density- and non-density- mediated seedling dynamics occurring prior to maturity and seed set.

Invariably, these weed species display some, if not all, of the characteristics of an ideal weed [9], allowing them to grow and colonise any open spaces available, competing aggressively for resources and other needs. By definition, an invasive plant species is aggressive, and can persist in most ecosystems [26]. In the context of invasive weeds, the prevailing intrinsic life-history traits, such as the ability to escape native predators, small seed size, short juvenile period, persistent seed bank, and young reproductive age, are associated with aggressive traits, and with the displacement of native plants [65]. These traits and the extrinsic nature of the agro-ecosystems are equally important in determining the success of introduction, colonization and subsequent establishment and expansion of invasive weed species. I believe that the invasive non-indigene weed species in Malaysia have undergone active naturalisation processes impinging on resource and space capture. Based on the arguments of Simberloff and Von Holle [66], we also believe that these introduced non- indigenes frequently interact with one another and that facilitative interactions are common and prevailing. The fact that weed species depicted in (Table 1) have invaded open spaces and established themselves in Malaysian agro-ecosystems fortify the arguments that time-mediated weakening of environmental resistance (*sensu* Chapman [67]) or biotic resistance (*sensu* Simberloff and Von Holle [66]) by native species prevail, and synergistic interactions among invaders may well lead to accelerated impacts on native ecosystems – an invasional 'meltdown' process (*sensu* Simberloff and Von Holle [66]). On this accord, we can safely argue that the successful invasion and dominance of these non-indigenes, and notwithstanding the specific inherent traits of the weed species themselves, and were attributable to habitat disturbances – many were due to human activities. Furthermore, the dominance of these non-indigene weed species in our agro-ecosystems indicated that the prevalence of crucial situations favouring special characteristics of invasive species. This argument parallels the successful overcoming of the theoretical four steps and four stages of an invasion process of a new and disturbed habitat by invasive weed species based on the model of Heger [15]. In the same vein, the introduction-, colonization-, and naturalization-mediated success of invasive weed species through environmental sieves [6], overcoming environmental and dispersal constraints [36], herald their establishment and incorporation as new resident flora in the new habitat or agro-ecosystems. The ability of some of these invasive weed species to pre-empt, and subsequently compromise on resource and space capture *vis-à-vis* their sympatric counterparts, irrespective of whether they are crop or weed species, is an intriguing ecological question to ponder. A central issue is the dual ability of these weeds to reproduce clonally (*sensu* Harper [27]) through extensive stolons or subterranean rhizomes, simultaneously producing persistent seed bank. While the clonal modules ensure better resource capture especially through a guerrilla growth strategy (*sensu* Harper [27]), abundant seed production by some invasive weed species guarantees better chances of survivorship in future generations, despite environmental and dispersal constraints prevailing in the habitat Booth and Swanton [36]. Invasive weed species such as *Scirpus grossus, Cyperus malaccensis, C. rotundus, I. cylindrica, L. chinensis, Panicum repens, I. rugosum, P. polystachion, R. cochinensis, C. odorata, M. micrantha, Asystasia gangetica,* and *Mimosa* aggregates, are all capable of producing extensive clonal modules in addition to ability to produce large seed banks. The aquatics such as *E. crassipes, S. molesta, S. cucculata, H. verticillata,* or *N. indica,* denoted by very efficient, opportunistic and fast clonal growth, enable them to capture territorial space and resources faster than the less competitive counterparts. Many invasive weed species in Malaysian agro-ecosystems, besides having persistent seed bank, and small seed size and added features enabling efficient dispersal, possess inherent life history traits such as short juvenile period and young reproductive age, closely associated with aggressiveness. The terrestrials such as *C. rotundus, I. cylindrica, L. chinensis, P. repens, I. rugosum, P. polystachion, R. cochinensis, C. odorata, M. micrantha, A. gangetica,* and *Mimosa* aggregates, the *Echinochloa* aggregates, *L. chinensis* or weedy rices are characterized by these life history traits, many reaching maturity and producing seeds within three months after seedling establishment. Further, these aggressives possess wide ecological ranges with plastic growth habits, capable of surviving in a variety of ecosystems. In the case of the *Echinochloa* aggregates, *L. chinensis* or weedy rices their short life-cycle yet capable of shattering seeds earlier than the rice crops ensure better chances of space capture by the weeds. Total absence of seed dormancy among weed rice or in *L. chinenis* [49], the later having deeper rooting habits, thus capable of exploiting more nutrients from deeper soil profiles than rice, while displaying more efficient photosynthetic ability than rice. Seeds of *I. rugosum* germinate even under 15 – 20 cm inundation [68], the habitat not suitable for seed germination for many terrestrial weed species.

One measure of the invasiveness of a weed species is its aggressivity index. This index is density-mediated, and is affected by the duration of crop-weed competition. Others employed path analysis to generate path coefficient values to delineate the direct and indirect effects of crop-weed competition on growth and yield components [69, 70]. Suzana *et al.* [71] and Nabi [68] employing linear model analysis to assess the differential competitive ability of *E. crus-galli* ssp. *crus-galli* and *I. rugosum* against rice either in monocultures or in mixtures registered density- and time-mediated differences in the number of tillers plant^{-1} produced as the results of crop-weed competition. When subjected to intense competition with *I. rugosum*, rice produced 100% unfilled grains. Under intense inter-specific competition from *E. crus-galli* or *I. rugosum*, rice at densities lower than 217 plants m^{-2} spent only a marginal amount of its resources for reproductive components thereby registering only *ca.* 0.01 in reproductive effort values. The respective mean values of aggressivity index of barnyardgrass and wrinklegrass in competition with rice was *ca.* –0.96 and –0.42.

PREDICTIONS AND IMPACTS

It is indeed a truism when D. Scott [72] lamented our pre-occupation with the welfare of mankind in the context of liabilities and assets of species invasion. In the same vein and with respect to the status of Malaysia as a mega-biodiversity entity, and the apparent breakdown of biogeographical borders due to increasing international trade and globalisation, how effective and useful is the prediction, risk assessment, and impact of species invasion or invasiveness of an exotic weed species to safeguarding of our exclusive biogeography and the distinctness of our native flora and fauna? With widespread infestations of *P. setosum, P. polystachion, R. cochinensis* and *M. pigra*, and clandestine introductions of *Cyperus papyrus, Alternanthera philoxeroides*, and *S. natans*, listed as scheduled pests under the Plant Quarantine Act 1976 and Plant Quarantine Regulations 1981, along with a host of other terrestrial and aquatic weeds, we may tend to "ignore" advice, predictions and decision theory of invasions [35]. On the other hand, should we consider new stringent legislations to arrest new waves of invasion of exotic plant species? Likewise should we institute risk assessment, prediction and impact studies on future plant importations that might become weeds and potentially invasive [73, 74 and 75]? The risk that a plant species will become an invader is a function of the properties of the species, the environment it is released in, and the way it is introduced to the new environment (cf. the generalised ecological risk assessment framework of Brown and Reinert [76]). The literature on predicting weediness seems to focus on the plant traits, somewhat less on the importance of the environment, and less still on introduction methods. Perrins *et al.* [18], among others, found some fairly high accuracy rates in retrospective identifications of known weed species. Others claimed to have developed successful weed prediction systems (e.g. Reichard and Hamilton [77]).

Essentially, there are two fundamental issues in the prediction of the impact of invasive weed species in an agro-ecosystem. Firstly, the issue of precision in invasion predictions of plant species introduced intentionally or otherwise into an agro-ecosystem must be considered. These introduced plant species become naturalised as casuals or converted to become invasive weeds, elegantly discussed, by Lonsdale [74], Panetta [75]; Panetta *et al.* [38], Rejmanek and Richardson [65]; and Smith *et al.* [35]. This is a cornerstone in the assessment of consequential impacts of such invasives on the environment. Such impact assessment requires empirical data, and represents the second issue pertaining to invasives.

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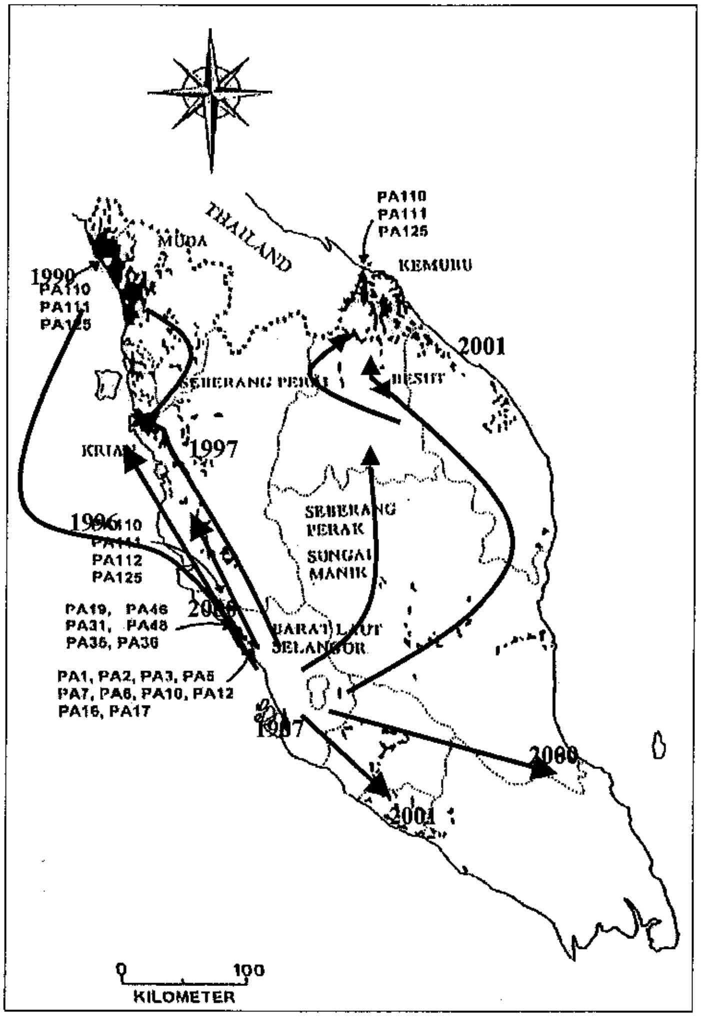

Figure 3. Possible paths of invasion (indicated by arrows) by weedy rices in the Malaysian rice granaries. The dates refer to year of detection. PA1, PA2, PA3...PA125 denote weedy rices accessions (adapted from Baki [78]).

The impact of invading weed species, especially by the non-indigenes among a native flora and its environment, has ecological and socio-economic consequences. The intriguing issues remain: what are the traits that confer invasiveness? How are these impacts measured? Can impacts of invasive plant species be predicted? Parker *et al.* [79], based on some empirical examples, argued that the total impact of an invader comprised three fundamental dimensions: range, abundance, and the per-capita or per-biomass effect of the invader, measured at the individual, species, community and ecosystem levels, although Williamson [22] contended that propagule pressure is the only consistent predictor of impact in an ecosystem.

The overall rate of exotic plant species introduction to Malaysia is unknown, so are the rates of introduced species that are converted to successful invaders (*sensu* Williamson [4]. The overall base rate of probability for species to become pests is a product of three other probabilities (see Williamson and Fitter [39]), and the probability of a species becoming an invader is generally quite small. Williamson and

Fitter [39] estimate that *ca.* 10% (between 5% and 20%) of organisms introduced into a new environment become casuals, 10% become naturalised, and 10% of these naturalised species go on to become pests. Thus only 0.1% of the species originally introduced, because of low 'base-rate effect', are expected to become pests. Crawley *et al.* [37] found that the rate of conversion of naturalised plants to weeds was *ca.* 1.3%, giving the overall transition rate from importation to weediness as 0.007%. On this consideration and based on the acreage of rice granaries invaded by weedy rices to date since 1987, including the slow rates of human intervention in terms of control measures taken against the scourge, these weedy rices are successful invader after all, infesting 3.89% of rice granaries in 2002. Despite quarantine screening procedures under the Plant Quarantine Act 1976 and Plant Quarantine Regulations 1981, we are not in a position to predict reliably the weed status of exotic or naturalised, or endemic species in the country. Perhaps this is due to missing links in the ecological data of weeds, or naturalised plant species, notably the base-rate effect, becoming weeds. The apparent lack of a Weed Risk Assessment System to be placed within the context of the Plant Quarantine Act 1976 and Plant Quarantine Regulations 1981 makes it difficult to monitor weeds as potential and serious pests in the country. Nevertheless, the recommendations of such a system are worth heeding if one assumes that the losses due to allowing in a weed are at least 8 times those due to excluding a harmless organism screening systems will generate invaluable information on the invasiveness of a particular introduced or naturalised weed species. Smith *et al.* [35] in a detailed assessment of the relationship between a base-rate probability of 2% with which imported plant species become weed pests, and the the accuracy of a weed risk assessment (WRA) system, showed that only 0.7% of plants assessed and allowed into Australia will become weeds (Figure 4). However, the interactions between base-rate probability and accuracy of screening for weediness, somewhat reduced the reliability of WRA (Figure 4a). The base-rate effect also means lower probability of an accepted plant actually being weedy than the accuracy of WRA alone would imply (Figure 4b). There is a fallacy in such a method predicting an introduced plant species becoming weedy, as weediness does not necessarily equate with invasiveness. Recognisant of the species [35]. Using the decision theory developed by Mathhews [80], assessments of the validity of and time-mediated and location-specific variations in base-rates, as well as data on the socio-economic and ecological losses due to weeds, and gains due to useful species. I am in the opinion that under certain circumstances, the government may be better advised to focus on assessing the risk posed by casuals and naturalised species, and eradicating them where feasible, than trying to predict weed status at the importation stage. In most situations, naturalization of invasive weed species may be irreversible, and it is arguable whether any intentional introductions are acceptable.

Table 5. Estimates of weedy rice infestations in Peninsular Malaysia (after Baki et. al [58] and Baki [81]).

Granary	Area (ha)	Degree of infestation (ha)*								
		1993	1995	1996	1997	1998	1999	2000	2001	2002
MADA**	96,459	168	?	300	225	<50	992	1104	1,340	2,321
Pulau Pinang	14,846	-	-	-	40	87	95	91	390	458
Perak[a]	42,966	-	-	n**	n**	n	550	1,107	1,530	1,593
Selangor **	18,320	n	n	9,660	36,664	11,256	399	113	200	210
Negeri Sembilan	1,095	-	-	-	-	-	-	-	950	150
Johore/Pahang[b]	1,267	-	-	-	-	-	-	100	250	280
Trengganu	14,405	-	-	10,000	12,000	?	?	750	1,687	3,122
Kelantan[c]	38,740	-	-	-	-	-	-	-	10	10

*Average/season; ** First detected: MADA 1990; Selangor 1987; [a]Krian-Sungai Manik -1996; Seberang Perak -1997; [b]Endau Rompin, [c]Inside and outside KADA; n – Negligible acreage; - Not detectable; ? Unknown.

There is the issue of quantifying the impact of invasive weed species from a policy or management perspective, aligned with the opinion of farmers, extension agents, weed scientists, and land managers alike, that the introduction of these invasives does or is likely to cause societal, economic and environmental harm. Indeed, calculating the economic costs in terms of damages or eradication/control is one useful approach to measuring impact of an invader [82]. In the case of public utilities such as water reservoirs like Timah Tasuh in Perlis, or the hydroelectric power dam of Sultan Yusuf in the Cameron Highlands, or maintenance of drainage and irrigation canals in MADA, KADA, or Besut, calculation of such impacts of invasion by *S. cucculata, Eichhornia crassipes, N. indica,* and other weeds would be made easily. Policy makers and maintenance managers have the choice of either going for total eradication of the prevailing invasive weed species, or control their populations below the economic thresholds, taking into account the feasibility of removal or restoration, and the present and potential future impacts of the scourge on the ecosystem under their charge.

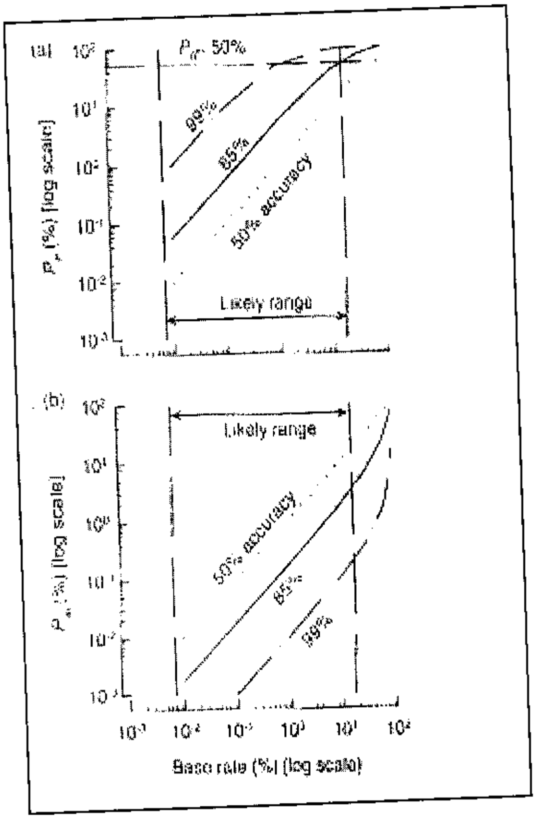

Figure 4. The theoretical relationship between the base-rate probability with which imported plant species become weeds, (a) the proportion P_{ri} of weeds among species rejected by WRA system, and (b) the proportion P_{ai} of weeds among species permitted entry by the system. These terms are defined as: $P_{ri} = I_r/(N_r + I_r)$, where I_r is the number of invaders and N_r the number of non-invaders rejected by the screen; and $P_{ai} = = I_a/(N_a + I_a)$, where I_a is the number of invaders, and N_a non-invaders allowed in by the screen. Also shown are the likely range of base–rates curves on different accuracy levels, and in the case of Fig. 4a, 50% of rejected plant species are pests. P_{ri} = proportion of weed forecasts correct; P_{ai} = proportion of non-weed forecasts incorrect (modified from Smith *et al.* [35]).

Malaysian agriculture is very much plantation-based with great economic emphasis on cash crops, namely oil palm, rubber, and cocoa. Sizeable acreages of the arable lands are planted with food crops like rice, pepper, fruit orchards, and vegetables. These monoculture pursuits have led to high incidences of difficult-to-control invasive weed species. One can easily visualize the extent of measurable economic impact of these invasives by the amount of herbicides sold per year in Malaysia to combat this menace. Also there are many unwarranted environmental and social problems, increased incidences of herbicide resistance, loss of beneficial organisms and almost total disappearance of fresh water fish in the rice granaries [78]. The highly invasive *I. cylindrica, P. polystachion, R. cochinenis, Mikania micrantha, A. gangetica, E. indica, and I. rogosum* are common sights in many young oil palm, rubber, cocoa, and sugar cane plantations, exposed areas along road sides, railway tracks, and other areas within the fringes of plantations.

The special deciduousness trait of weedy rices, allowing early shattering of seeds *vis-à-vis* commercial rice varieties, and the absence of dormancy enable the scourge to establish early in rice fields. This coupled with the sharing of common tillage and harvesting machines among farmers (invariably, farm machines whether they are self-owned or hired, are contaminated with seeds of weeds and weedy rices) has aggravated the weedy rice problem in rice granaries. For example, a 35% field infestation of weedy rices contributed a density-mediated yield loss of 50 - 60%, or 3.20 – 3.84 tons/ha/season valued at MYR 2,816 – 3,379/ha/season. In extreme cases, yield losses of about 74 –100% have been recorded (Azmi *et al.*, unpublished data). In such cases, lodging occurs, resulting in total yield loss. Such risks may prevail if our granaries are poorly managed allowing consequential severe infestations of the scourge. If this happens, then our national target of the current 65% self-sufficiency in rice supply to our consumers will be severely affected.

On average, harvesting with combined harvesters may lead to about 10% loss in rice yields. Of this, 5% loss is due to spillage and another 5% is due to weedy rice seeds. These estimates are on the low end of the scale compared with cases where a more severe infestation of weedy rices occurring. If the national average yield is 5 tons/ha, yield loss of about 0.5 ton/ha can be envisaged. In such a situation, and with the rice growing area of *ca.* 209,300 ha in Peninsular Malaysia, and based on the current government-guaranteed price of MYR 850/ton, a monumental loss of 104,650 tons of rice yields valued at MYR 88,952,500.00/season or MYR 222,381,350.00/year may occur due to spillage and weedy rice infestations. The average seeding rate practised by most rice farmers is *ca.* 150 kg/ha. If weedy rice seedlings emerging from the average spillage of 0.5 ton/ha are not destroyed prior to seeding, a reservoir of 0.65 ton/ha of seeds will grow for potential harvest. Such harvest will be of consequential lower yields and quality, laden with weedy rice impurities, thereby fetching lower prices at the mills.

Weedy rice infestation incurs further costs to farmers. Farmers need to practise thorough land preparation, water management, and herbicide-based weed management to ensure total control of weedy rices and other weeds prior to seeding. In-crop care augmented with roughing and spot sprays of those weeds and weedy rices escaping earlier control measures must be carried out to ensure good crops. These proper agronomic practices and crop care will inevitably lead to more hours spent in the fields. For some farmers these valuable hours should be spent elsewhere to generate better income or better-paid jobs. In the same vein, inculcation of the zero-tolerance concept of weed infestation and practice of weed control by farmers is difficult and expensive, especially among aging rice farmers in the country. In the other extreme, inexperienced farmers tend to overlook weedy rice infestations until after the post-tillering stage. At that time, some form of growth damage has occurred among the commercial rices.

Management Strategy for Invasive Weeds in the Malaysian Agro-Ecosystem

Rationale, Concepts and Ecological Considerations

The story of agriculture is indeed the story of weed interference [83]. The classical concept and practice of weed management is managing weed interference to minimize the effects of weed competition on the crops. Today the modern neoclassical, functional and economic approaches of weed management go beyond arresting the damage of weed competition on the crop in question. Such approaches are knowledge-based, requiring knowledge-intensive management skills and inputs of crop-weed ecology, weed community dynamics, economic thresholds, production costs (including risk and ethical analysis, and costs to the environment following successive applications of herbicides), innovative ecologically based management practices, competitive crop cultivars, and transgenic crops engineered for herbicide resistance and improved herbicide application methods.

Many agro-ecosystems consist of contrived monocultures undergoing high level of disturbance in the course of crop production. Because of this they are vulnerable to weed, pest and disease invasions, needing appropriate amelioration through management. Yield losses incurred are the ultimate aggregate consequence of interference between heterogeneous weed phenotypes and a homogeneous crop phenotype. Agrestal weeds have evolved in response to cropping practices by adapting and occupying niches left available in agro-ecosystems.

The needs for innovative new technologies include ecologically based management practices, competitive cultivars, and transgenic crops engineered for herbicide resistance. Improved application methods in combination with highly knowledge-intensive management skills to maintain and improve weed control in crops are very apparent and pressing.

Elton [84] argued that crop monocultures, being frequently subjected to disturbances, are unstable and consequently vulnerable to invasions. In the annual crop ecosystem like cereals, or vegetables, cyclical habitat disturbance with cropping cycles is the principal determinant of community dynamics and stability. The long-term persistence of guilds of weeds points to mechanisms conferring resilience to management and stability in weed communities [85, 86]. Weed management practices are therefore seen as modifiers of the intensity and form of crop-weed competitive interactions.

Understanding the underlying factors governing the dynamics of crop-weed communities and their potential stability is of prime importance if individual control tactics are to be critically evaluated as part of a strategy of weed management in crops. The perennial issue of ranking noxious weed species in the priority listing for control is equally important [87]. This is especially useful in the biological weed control programme [57, 88]. The task in setting priorities for weed control is not easy or straightforward, and requires cooperation among the regulating government agencies, weed scientists and farm operators and extension agents. The development of complete weed database is the first prerequisite. In many developing countries, there may not be enough weed scientists and relevant personnel to undertake the tasks of developing the complete weed database, and prioritizing weed species for control. Regional cooperation among weed scientists and working groups may offer a solution to this apparent impasse.

Historically, weed management has been aimed at controlling weeds, through herbicide treatments, tillage and water management regimes, primarily to reduce yield losses through competition. Consequently, weed control decision-making frameworks with strong herbicide-based focus, such as the economic threshold has been developed. Jones and Medd [89] pointed out some theoretical concerns and reservations on the application of the static approach of economic threshold in weed management decision-making. They advanced a case for long-term approaches to population management of weeds, principally through an optimal level of intervention rather than minimizing the yield effect of weeds in a single season or year. Such interventions are explicitly targeted at reducing the weed seed bank through time.

Management of invasive weed species is knowledge-driven, and must focus on addressing the cause of invasions rather than treating the symptoms of weeds. Knowledge on mechanisms and processes driving plant community dynamics is central to developing ecologically based invasive plant management programmes. A multi-pronged approach involving farmers, extension agents, land managers, and quarantine personnel is required for successful containment of invasive weed species from further spread.

In most cases, weed management is the concern and goal of farmers, extension agents, and land managers. Simberloff [87] argues that it may be possible to eradicate undesirable plant populations (weeds!), particularly if eradication campaigns are augmented with a monitoring system to detect early invasions. From a societal aspect, an inspirational eradication campaign also may enlist citizen support for managing other introduced species.

Prevention of weed invasion from front populations into peripheral satellite populations, or both, is an important prerequisite for successful containment of invasive weeds against further spread. Such pursuits require empirical data to explore ways to predict plant invasion and spread in the effort to develop ecologically based management programmes. Approaches helping to characterise invasion by generating information on species demography, and GIS construction are useful. Sheley and Krueger-Mangold [90] proposed a sustainable method of weed control through successional management approach that considers and manipulates disturbance, colonisation, and species performance.

Two crucial factors need to be considered to manage invasive weeds in Malaysia. Of primary importance is that a considerable number of invasive weeds in Malaysia are non-indigenes, and many are endemics, which have escaped into disturbed areas and involved with weedy traits. Secondary to this is the fact that weed management in the country has evolved into an herbicide-based pursuit, augmented by other control operations. These factors influence, to a certain extent, the weed communities prevailing, and their dynamics, with spatial dominance of a particularly invasive species or group of species in a particular agro-ecosystem or habitat.

No single weed management component or control method can effectively control weeds in any crop or agro-ecosystem. Farmers normally employ a battery of control methods to achieve satisfactory results. These include, principally, the agro-technical and preventive methods comprising land preparation and tillage, water management and manual weeding; crop manipulation through seeding rates, planting density allelopathy and a choice of competitive cultivars; and chemical weed control. In certain cases, biological control using bio-control agents and bioherbicides is instituted.

Preventive measures, eradication, and control options

Prevention

Preventing the introduction of invasive weeds is the most effective method for their management and is an essential component of a noxious weed management strategy. However, this is difficult to enforce. The major elements of a prevention programme are to stop the introduction of noxious weed seeds or vegetative propagules, reduce the susceptibility of the ecosystem to invasive weed establishment, develop effective education and extension materials and activities, and establish a programme for early detection and monitoring. Encroachment by weeds happens through establishment of small populations in close proximity to a larger infestation [91]. To prevent this kind of encroachment, effective containment of neighbouring weed infestations through herbicide sprays on the borders of infested areas should be made. Strict quarantine enforcement preventing free movement of animals, vehicles and farm machines from infested lands should also be carried out. In the case of weedy rices, only certified weed free rice seeds should be planted by farmers. Similar enforcement should be made in the planting of legume cover crops in oil palm, rubber, and cocoa estates.

Educational and extension materials in the forms of brochures, pamphlets, posters, calendars, scientific papers, internet websites, and other electronic media can be made available to the public, farmers, landowners, farm managers to educate them on invasive weeds. The government and non-governmental organisations, and general public should be involved in the overall campaign of awareness – this will increase the potential of early and rapid response to new infestations.

Essentially the best management of invasive weeds in Malaysia is to recognise potential weed problems early, control weeds before they reproduce and spread, and monitoring sites regularly to maintain adequate sequential control measures. Effective early detection efforts are knowledge-driven, and farmers, extension agents, landowners, and all stakeholders are well trained. One successful method for preventing invasion of weeds is through regular field surveys and aerial photography, and where weeds are moved before they become established [91].

Eradication is an expensive undertaking and is often a stepchild in the field of introduced species management [92, 87]. Rather, maintenance management is usually seen as the appropriate response – controlling an invader at a density sufficiently low that we can tolerate it.

Simberloff [87], in his treatise on the economics of eradication, lamented that although the success of permanent eradication of an invader from a site is alluring, society cannot undertake to eradicate every pestiferous invader, given the costs of successful eradication may entail. Eradication becomes the best management option when the benefits derived are clearly overwhelming [93]. However, cost-benefit analyses on invasion economics are especially problematic, and perhaps have been adequately conducted [18]. Primarily, it is very hard to predict the trajectory of invasions, and predictions on the effects of various management measures are equally difficult. Others consider eradication of introduced invasive plant species (weeds!) are doomed to fail, given the growing movement of cargo and people through the forces of globalisation and those causing invasion leading to global homogenisation (e.g. the "planet of weeds" (*sensu* Quammen [94]).

The success of any eradication campaign is very much dependent on the extent of infestation of a particular invasive weed. Eradication is not complete until all viable propagules of the weed are depleted from the soil [95]. Because one or a few individuals can subvert eradication effort, a government agency or interagency entity must be able to compel cooperation [96]. In this context, the Quarantine Section of the Department of Agriculture, Sabah with the cooperation of the Malaysian Plant Protection Society was able to galvanise efforts in their successful eradication of the invasive *M. pigra* in the state in the 1980's. It is uncertain whether cost-benefit analyses have been conducted on the successful eradication of giant mimosa in Sabah.

Mechanical Control

Mechanical weed control includes burning, handpulling, hoeing, shovelling, tilling, mowing and mechanical hand weeding. Removing weeds with bare hands, weeding tools like the rotary weeder or hand-pushed rotary cultivators is a principal direct control method used in many parts of Afro-Asian and Latin American countries, either alone or augmented by chemical control. These methods are effective in loose and moist soils with shallow rooted weeds that are killed with complete crown removal [91], but are laborious, time-consuming and inefficient for bringing about effective control, especially in large farms. These techniques are also effective for the control of small infestations or weeds at the fringe of a major infestation. Not all weeds can be properly controlled by hand weeding, especially the perennials such as *Commelina* spp., *Cynodon dactylon*, *Imperata cylindrica*, *Echinochloa stagnina*, *Oryza picta* or *O. longistamina* [97], or weeds with special survival mechanisms such as rice crop mimicry (e.g. *I. rugosum*) [98, 99]. Handweeding is merely a supplement to chemical to control perennial weeds, namely *P. distichum* and *A. sessilis* not destroyed by tillage and herbicide. Handweeding is not effective in dry soil, where weed seedlings break and re-sprout easily. This method is suitable for small farms [100].

In rice, cereal row crops, or vegetables weeding using hand tools such as the crescent-shaped machete or *sabit*, hoe, narrow spade, Swiss hoe, or pointed sticks can be used to remove weeds between rows. Weeding by machine is possible in irrigated transplanted rice. However, augmented manual removal of weeds close to rice hills and those within transplanting rows of rice is required to achieve clean weeding. In Malaysia, sequential handweedings in rice is effective but expensive with a labour requirement of 20-man days/ha (US$360 – 387 ha^{-1}) [50].

In water reservoirs, drainage and irrigation canals, mechanical weeding is employed to remove aquatics such as the *Eichhornia crassipes*, *Monochoria hastate*, *Salvinia cucculata*, *S. molesta*, *Pistia stratoites*, *Hymenachne acutigluma*, *Nymphea indica*, *Hydrilla verticillata*, *Rhynchospora corymbosa* or *Scirpus grossus*. These were done with JCV machines attached to cranes, or with special floating harvesting machines [101, 51]. These operations are usually augmented with manual removal of those weeds escaping mechanical clearing.

In the case of Timah Tasuh Water Reservoir in Perlis, it was very apparent that both the mechanical and manual control measures taken were inadequate to alleviate the weed menace [51]. I believed that the apparent failure of the present control measures taken were due to

(a) inadequate intensity and frequency of cleaning operations,
(b) control measures were confined or close to the spillways and saddle dam areas,
(c) periodic control measures taken on floating weeds did not take into account the possibility of preventive containment using

floating embankments thereby preventing break-up and wind-drifts of these "weed islands" to other areas, hitherto uncolonised by the weeds,

(d) very few or no control operations were taken in the northern half of the reservoir especially the secluded "bays", - non-accessable to boats or cranes, serving as the sources for further or perennial infestations of noxious species, *viz: Typha augustifolia, Pistia australis, Hymenachne interrupta, Salvinia cucculata, Cyperus platystylis, C. pilosus, Leersia hexandra, Panicum repens, Ludwigia repens and Isachne globosa,*

(e) free access by local villages, fishermen, etc. to the reservoir perhaps allowing other sources of weed infestation,

(f) free drainage of water (perhaps weeds as well?) into the reservoir especially from the northern half from rivers and streams, and

(g) drainage of fertilizers into the reservoir from farming and related activities in surrounding areas. This may help to enrich the nutrient status of the reservoir, thereby encouraging the proliferation of the weeds.

We believe that a more concerted and holistic approach is needed to reduce (if not totally annihilate) the weed populations in Tasik Timah Tasuh to a manageable level. Proper scheduling of cleaning operations aligned to the construction of floating embankments to "keep the floating weeds at bay" from invading other areas are needed. The use of proper cleaning machines like aquatic weed harvesters, widely used in Florida, may help to speed up the cleaning operations. In fact, the employment of such machines may be a cheaper option in the long run to manage the weed menace, despite higher initial input costs. More importantly, no access by outsiders, other than the management authorities of Tasik Timah Tasuh, should be allowed. In this way, unwarranted loadings of aquatic weeds (viewed by some for their aesthetic value to help "beautify" the reservoir) into the reservoir can be prevented.

Mowing is also commonly used to control both annual and perennial invasives along highways, roadsides, railway tracks, and banks of drainage and irrigation canals. The effectiveness of mowing often depends on timing and the type of weeds prevailing. Invasive perennials such as *I. cylindrica, P. repens, S. grossus,* with extensive sub-terranean stolons or rhizomes, where profuse basal regrowth occurs (in the case of many grasses like *I. rugosum, I. timorense, I. muticum,* or *C. dactylon*), or those with stolon or stem fragments where re-sprouting may occur (in the case of *A. gangetica, C. odorata*) are not effectively controlled by mowing. In contrast, the optimum time of mowing for most invasive annuals is before flowering or seed set.

For invasive shrubs, or trees, mechanical methods can include chaining, bulldozing, roller chopping, root ploughing (power grubbing), and shredding. These options are fairly commonly used in replanting schemes of rubber and oil palm, or cocoa estates where old trees and some woody invasives are discarded to make way for new ones (Ahmad Faiz, *pers. comms.*). Common woody invasives include *Acacia mangium, Melastoma malabathricum, or Eugeissona tristis.* Wild bananas (*Musa* spp.), a true indigene of Malaysia are another perennial invasive weed species in rubber and oil palm estates, especially on hilly terrains in Malaysia where mechanical or manual slashing have proven ineffective due to basal regrowths (Chung, G.F. *pers. comms.*).

Cultural Control

Tillage practices can control invasive annuals, but in the case of perennials rarely provide control. In rice, land preparation, especially puddling and harrowing, provides weed-free environment at planting, often aids in good crop establishment while minimizing weed growth and proliferation in the established crop. Soil should be harrowed after first ploughing, when weeds have reached the seedling stage. This will kill the majority of invasive weeds of rice, namely, *E. colona, E. crus-galli, L. chinensis, I. rugosum,* or weedy rice seeds [56, 49]. Adequate land levelling is critical to eliminate inadequately flooded areas that are ideal for the growth and development of difficult-to-kill semiaquatic weeds. Tillage only serves as a transient measure of weed control because soils contain many dormant weed seeds. Invariably, the site-specific influence of tillage in suppressing weed populations for the incoming rice crop varies according to the soil moisture, soil type, herbicide regimes and the inherent seed bank and propagules. Aldrich [102], *inter-alia,* recorded increased density of selected weeds when a cultural practice is imposed continuously on a weed community a response termed "weed association". Utomo and Susanto [103] in a series of experiments to assess the influence of tillage on weed community, recorded indicator species of *Euphorbia geniculata* and *Richardia brasiliensis* in the no-tillage fields; *E. geniculata* and *I. cylindrica* in minimum tillage equivalents; and *E. geniculata* and *R. brasiliensis* in fields subjected to intensive tillage regimes.

Tillage itself influences seed burial; the latter subsequently affects seedling emergence. Tillage moves some seeds to sites that are unfavourable for germination in the following year, thus building the seedbank over time [104] while reducing tillage or using shallower tillage results in a rapid depletion of the seed bank [105]. In the case of *Panicum repens,* burying of rhizomes through tillage deeper than 30cm greatly reduced culm emergence [106].

Sheep, goats, and cattle grazing have been employed to control successfully aggressive weeds such as *Pennisetum polystachion, P. setosum, Mikania micrantha, Asystasia gangetica, A coromandeliana, Eleusine indica, E. colona, Digitaria spp., Ischemum* spp. aggregates but not *Mimosa pudica, M. invisa, M. pigra,* and *Melastoma malabathricum, or Clidemia hirta* in young oil palm, rubber, or cocoa estates, as well as in their fringes [107]. The stocking rates vary according to the age of the crops, the prevailing weed species cover, and the paddock system being employed in placing these animals for grazing. In rice fields, ducks and chickens, released in netting enclosures after harvests, have been proven effective in reducing the infestations of *Echinochloa* spp., *Leptochloa chinensis, Ischaemum rugosum,* and weedy rices – the dominant invasives among weeds of rice fields (Mislamah, *unpublished data*).

Leguminous cover crops are a common feature in young oil palm, rubber, and cocoa plantations in Malaysia. Commonly used legumes species from the genera *Calopogonium, Stylothanthes, Mucuna,* and *Pueraria,* although *M. pruriens* was later abandoned due its strangling effects on the young oil palm, rubber, and cocoa crops (Ahmad Faiz, *pers. comms.).* Beside the ability to enrich soils by fixing nitrogen with their symbionts, the rhizobacters legumes prevent invasive weed species from encroaching into open spaces in between rows in these young plantations. At one time, *M. micrantha* was brought in as a cover crop in the estates, not realising its invasive potential as a weed.

Biological control

Baki [60] reviewed some of the Malaysian initiatives on biological control of weeds. The success in these efforts to control these invasives was patchy and transient in nature. For example, Syed [108] liberated lepidopteran *Pareuchaetes pseudoinsulata* and the coleopteran *Apion brunneeonigrum* onto *Chromolaena odorata* populations in Sabah in 1970-1973. Only the former insect species established, but failed to provide adequate control [109]. Likewise, in the case of *Acalitus odoratus* Keifer (Acaridoptera: Eriophyidae), arriving fortuitously in Malaysia and neighbouring countries, inflicted insignificant damage on the weed [109].

Ung and Yunus [110] argued that the pest status of major exotic weeds was attributed to the lack of effective biological control agents and suggested the introduction of proven bio-control agents to achieve some form of control. This strategy worked following the introduction of bio-control agents *Metrogaleruca obscura* syn. *Schematiza cordiae* and *Eurytoma attiva* in controlling the weed *Cordia curassavica* [112]. The weed colonized > 2000 ha of coconut plantation in Kuala Selangor district in 1977. Introduced in December 1977, the bio-control agents denuded 1380 ha of *C. curassavica*-infested areas by October 1978 [110]. Today, *C. curassavica* no longer constitutes a problem.

At the implementation stage of the programme, *M. obscura* was affected by local predators, the ants, *viz. Oecophylla* sp. and *Crematogaster* sp., and the bugs, *Cantheconidia* spp. and *Metrogaleruca obscura* displayed compensatory build-up of populations for the numbers devoured by these predators [111]. Ung and Yunus [110] reported the complementary action of *E. attiva* in subjugating *C. curassavica* into weak seedless shrubs. This bio-control agent also suffered initial and transient setbacks when attacked by the parasites *Eupelmus* spp. and *Neanastatus* spp. *Eurytoma attiva* populations recovered despite the predation.

Calycomyza lantanae and *Ophiomyia lantanae* released onto *Lantana camara* populations, a noxious weed of the plantations failed to register measurable damage. Although the former bio-control agent caused severe localized defoliation, it was insufficient to arrest the weed infestation effectively [112].

Another important and invasive weed species where biological control attempts were made, albeit unsuccessful, is *Mikania micrantha*. Following the encouraging results from Cock [113], a programme to control *M. micrantha* was initiated with the introduction of *Liothrips mikaniae* Priesner from Trinidad. Despite the initial problems with rearing the insect coupled with the presence of predatory thrips, *Xyloplothrips* sp., field releases of the bio-control agent were made in April 1990 – June 1991 and May- June 1992. The liothrips failed to arrest the luxuriant growth of the weed [114].

The recent interest in the biological control of *M. pigra* in Malaysia was the result of increasing infestation by the weed in agricultural land and open places. After a battery of host-specificity tests, Malaysian scientists in collaboration with fellow scientists in CSIRO, Australia liberated several insect bio-control agents onto populations of the giant mimosa. These agents include the seed feeding bruchid beetles, *Acanthoscelides quadridentatus* and *A. puniceus*, the stem-boring moths, *Nuerostrota gunniella* and *Carmenta mimosa* and the stem-feeding beetle, *Chlamisus mimosae*. The bruchids, although establishing readily, did not inflict significant damage on the weed (A. Sivapragasam, *pers. comms.* 2001). Work by Mislamah (*pers. comms.* 2003) indicated that the bio-control agent spread up to 300 m from the points of release in the *M. pigra*-infested areas of Kedah, Kelantan, Malacca, Penang and Selangor. *Chlamisus mimosae, N. gunniella* and *C. mimosa* established good population counts at and within the vicinity of the sites of release in Peninsular Malaysia. Incidentally, populations of *A. quadridentatus* and *A. puniceus* have become established in Kota Bharu and other sites in Kelantan, adjacent to the region where they are established in Thailand [57]. Both *C. mimosae* and *N. gunniella* caused severe damage to the stems of giant mimosa, reducing seed numbers by *ca.* 56%. *Carmenta mimosa* was quite damaging to the young plants of *M. pigra*.

Another success story in the biological control of weeds in Malaysia was that of *S. molesta* using curculid beetles, *Cyrtobagous salviniae*. Baki *et al.* [115, 48] reported good control of the weed at the sites of release in Selangor and Malacca. The contamination of the Macap Water Reservoir in Malacca, one of the release sites, has led to the disappearance of the bio-control agent 6 months after release, although commendable control of the weed was recorded. In the Subang Water Reservoir, Selangor very good control of *S. molesta* was achieved. However, low population counts of the weed in the reservoir following the release of the bio-control agent, did not sustain the weevil populations. This situation was aggravated by the succession of *S. molesta* by *Ipomoea aquatica*, leading to the subsequent loss of *C. salviniae* populations. No beetles were observed in the subsequent surveys conducted at the release sites in 1992 in the drainage and irrigation canals of the Tanjung Karang granary and Subang Water Reservoir, Selangor [Baki, B.B., and unpublished data].

Biological control initiatives against waterhyacinth (*Eichhornia crassipes* (Mart.) Solms- Laubach) started in 1983 with the liberation of the curculid beetle, *Neochetina eichhorniae* Warner (Coleoptera: Curculionidae). Anwar *et al.* [116] made post-quarantine field liberations of *N. bruchi* Hustache in 1994 to three sites in Perak and Johore, and *Sameodes albiguttalis* Warren in 1996 to sites in Selangor, Perak and Johore. Both bio-control agents established themselves, albeit low recovery percentages at the release sites. Despite the establishment of *N. bruchi* and *S. albiguttalis,* there were few indications that the introductions of these agents had translated into something that indicated a measurable impact, such as curtailing the spread of the weed. Caunter *et al* [117] recorded complete destruction of waterhyacinth by the fungal pathogen, *Myrothecium roridum* at concentrations exceeding 6.0 x 10^6 spores ml^{-1}. Invariably, synergistic destruction of the waterhyacinth was observed when the weevils were applied together with the fungal pathogen. *Pistia stratiotes* was diseased on parallel scale by the pathogen with severe lesions.

Although *Echinochloa* aggregates are the primary scourges, especially in Malaysian rice granaries [56], effort in the biological control against these weeds have not yielded practical results. Larvae of the moth *Emmalocera* sp. bore in the stems of *E. crus-galli, E. oryzicola* and *E. picta* but not in *E. colona* [118]. Itoh [119] noted the insect *Tagosodes pusanus* (syn. *Sogatodes pusanus*) was specific to *E. crus-galli;* Caunter *et al.* [120] experimented with isolates of *Bipolaris/Exserohilum* sp. and recorded highly virulent actions on barnyardgrass with >85 % infection after 11 days of inoculation. Some of the past and present biological control initiatives against invasive weeds in Malaysia are listed in (Table 6).

Chemical control

Weed management against invasive weed species in Malaysian agriculture is dominated by the use of herbicides. This contention is reflected in the amount of herbicides used for weed control operations in the country. For the period of 1991-1999, herbicides accounted for RM220–230 millions or 76-79% of the total pesticide sales in Malaysia [97]. These herbicides are applied manually using knapsack sprayers or tractor-mounted applicators. Applications can be made as PRE#, PPI#, or POST#, depending on the herbicides, crops situation or weed spectrum.

Herbicides commonly used in Malaysian agriculture are listed in (Table 7). Of these the auxin or growth regulator herbicides, paraquat, glyphosate, and glufosinate ammonium have played the most important role in noxious weed control in Malaysian agriculture or in weed clearing operations in non-crop areas. The phenoxy group and auxin herbicides include picloram, 2, 4-D, dicamba and triclopyr. For many annual crops like rice, maize or vegetables, paraquat, glyphosate or glufosinate ammonium sprays get rid of volunteer seedlings (in case of rice) from previous crops and other weeds prior to tillage.

In young rubber and oil palm estates, and fruit orchards these non-selective wide spectrum herbicides are used in inter-rows and circle weedings, devoid of leguminous cover crops [121, 122, 123] The invasives like *A. intrusa, I. cylindrica, Panicum repens, Ischaemum* spp. aggregates, and *M. micrantha*, among others, are controlled by these herbicides. When leguminous cover crops are in place in most young oil palm, rubber, and cocoa estates, sulfonylureas such as metsulfuron-methyl are used, killing invasive weeds leaving the crops and legumes intact. In non- crop situations (roadsides, railway tracks, rivers, drainage and irrigation canals) maintenance requires routine sprays of paraquat, glyphosate, glufosinate ammonium, or 2,4-D sprays to arrest the uncontrolled invasion of terrestrial and aquatic weed invasives.

Rice crops harbour a host of invasive weed species, including weedy rices grasses and other recalcitrant species [101], and some of them are resistant to herbicides. Herbicide resistance aside, management of these invasives requires herbicide mixtures, often augmented with adjuvants to achieve good control efficacy. This includes pyrazosulfuron-ethyl applied as PRE (14 - 21 g a.i ha^{-1}) or early post-emergence (EPOST) (21–42 g a.i ha^{-1}) after tillering, offering good control with a wide spectrum of rice weeds under moist and flooded soil conditions [124]. Setoff or CGA 142'464, a sulfonylurea herbicide, applied at 20 g a.i ha^{-1} 3-9 DAT, was safe for rice and gave good control of broadleaves and a partial activity against *Echinochloa* spp. [125]. Mefenacet, NSK-850, or BAS 625 H (150 g a.i ha^{-1}) + additive Dash (0.5%) (175 g a.i ha^{-1}) or additive Assist (1%) (175 g a.i.ha^{-1}) applied PRE or POST controlled many rice weeds especially against a host of invasive grasses, *viz. E. oryzicola, E. crus-galli, E. colona, B. decumbens, E. indica, I. rugosum, R. indica*, and *Digitaria ciliaris* [20]. The biological efficacy of tank mixtures of cyclosulfamuron + pendimethalin (20 40 + 330 – 750 g ha^{-1} a.i.) applied at 5 –12 DAS or 3 DAT were effective in controlling *Echinochloa* spp., *L. chinensis, I. rugosum, M. vaginalis, S. zeylanica, Fimbristylis* spp. and *Cyperus* spp. (Azmi, unpublished data). The early stage herbicide combination CG155 BL quinclorac + cinosulfuron + pretilachlor) (0.7 + 0.15 + 1.0 % a.i. ha^{-1}) gave very good control of *E. crus-galli, S. juncoides, C. difformis*, and *M. vaginalis* at the 2-leaf stage with no selectivity problems with rice. The middle stage herbicide combination BAS 521 of quinclorac and bentazon (1.3 + 11% a.i. ha^{-1}) offered good control of *E. crus-galli* at the 3.5 - 5.0-leaf stage and all other weeds except *P. distinctus*. The fields should be kept drained for 3-4 days after treament. - The early-to-middle stage herbicide combinations include triple mixtures NC 311 BCG (quinclorac + pyrazosulfuron + pretilachlor) (0.9 + 0.007 + 1.5 % a.i. ha^{-1}) and NC 311 BS (quinclorac + pyrazosulfuron + bromobutide) (0.9 + 0.007 + 1.5 % a.i. ha^{-1}) accorded very stable control of *E. crus-galli* and *S. juncoides*, respectively. Safened pretilachlor (pretilachlor + fenclorim) (350 g a.i. ha^{-1} + CGA 142'464 (10 g a.i. ha^{-1}) while safe for rice var. MR84 and RD23, controlled a host of weed species [125, 126].

PRE – pre-emergence; PPI, pre-plant incorporated, POST, post-emergence.

Table 6. Bio-control agents and natural enemies of selected invasive weed species in Malaysia [a].

Weeds	Agents/Natural Enemies	References
Asystasia gangetica [c]	sheep	[107]
A. coromandeliana [c]	sheep	[107]
Chromolaena odorata	*Apion brunneonigrum* Beguin-Billecoq	[109, 108]
	(Coleoptera: Apionidae)	
	Pareuchaetes psuedoinsulata	[127, 128, 112 and 108]
	(Lepidoptera: Arctiidae)	
Clidermia hirta [b]	sheep	[107]
Cordia curassavica [c]	*Metrogaleruca obscura* Degeer	[129, 130 and 112]
	syn. *Schematiza cordiae* Barb.	
	(Coleoptera: Galerucidae)	
	Eurytoma attiva Burks.	[129, 128]
	(Hymenoptera: Eurytomidae)	
Echinochloa crus-galli	*Emalocera sp.*	[118, 119]
	(Lepidoptera: Pyralidae)	
	Tagosodes pusanus	[119]
	(Hemiptera: Delphacidae)	
	Fungus isolates [e]	
	Bipolaris/Exserohilum [f]	[120]
Eichhornia crassipes	*Nechetina bruchi* Hustache	[116]
	(Coleoptera: Curculionidae)	
	N. eichhorniae Warner	[115, 48]
	Coleoptera: Curculionidae)	
	Sameodes albiguttalis Warren	[116]
	Cercospora rodmanii [g]	
	Myrothecium roriidum [d]	[117]
Hydrilla verticillata	*Nymphula diminutalis* [h]	
Ischaemum muticum [c]	sheep	[107]
I. rugosum [c]	sheep	[107]
I. timorense	sheep	[107]
Lantana camara	*Calymcomyza lantanae* Frick.	[112]
	Ophiomyia lantanae Frogatt.	[112]
	(Diptera: Agromyzidae)	
Melastoma malabatricum	*Altica cyanea*	[131]
	(Coleoptra: Chrysomelidae)	
Mikania micrantha	*Liotrips mikaniae* Priesner [h]	[114]
	(Thysanoptera: Phlaeothripidae)	
Mimosa pigra	*Acanthoscelides quadridentatus*	[132]
	A. puniceus	[132]
	(Coleoptera: Bruchidae)	
	Chlamisus mimosae [i]	
	(Coleoptera: Chrysomelidae)	
	Neurostrota gunniella [i]	
	(Lepidoptera: Gracillariidae)	
	Carmenta mimosa [i]	
	(Lepidoptera: Sessidae)	

Table 6 *(continued)*

Weeds	Agents/Natural Enemies	References
Pennnisetum polystachion	sheep	[107]
	Parnara bada bada [j]	
	(Lepidoptera: Hesperiidae)	
	Cnaphalocrosis medinalis [j]	
	(Lepidoptera: Pyralidae)	
Rottboellia cochinensis	*Fungus isolates* [e]	
Salvinia molesta [c]	*Cyrtobagous salviniae* Calder and Sands	[115, 48]
	(Coleoptera: Curculionidae)	

[a] List modified from Baki [18]; [b] Not successful; [c] Successful; [d] Fungus; [e] S.S. Soetikno *(pers. comms.)*; [f] Bioherbicide, [g] A.J. Kuthubutheen *(pers. comms.)*; [h] Abdul Latiff, A.Z. *(pers. comms.)*; [i] A. Sivapragasam *(pers. comms.)*; [j] Tan, C.L. *(pers. comms)*.

Ooi and Chong [124] observed that pretilachlor + fenclorim when applied at 450-600 g a.i. ha^{-1} 1 day or 3 days after seeding offered measurable control of *E. crus-galli, F. miliacea, S. grossus* and *M. vaginalis* in wet-sown rice. The herbicide is taken up by the shoot and to a lesser extent by the roots of emerging weeds, which die shortly after treatment. As a formulated product, safened pretilachlor (pretilachlor + fenclorim) (350 g a.i. ha^{-1} and CGA 142'464 (10 g a.i. ha^{-1}) offered wider application windows and was capable of controlling a host of weed species dominated principally by *E. crus-galli, L. chinensis, S. zeylanica, L. flava, M. crenata, S. guyanensis, C. difformis, C. iria* and *F. miliacea* in Malaysia and yet safe for rice var. MR84 at the 0.5-2 leaf-stages [125, 126]. Baki and Azmi [125] reported that fenoxaprop-ethyl at the respective rates of 0.5 and 1.0 kg a.i. ha^{-1} under dry and flooded conditions, and applied at 14-25 DAS demonstrated good control of *E. colona, E. crus-galli, I. rugosum* and *L. chinensis* at the 3-leaf stage.

In fact, Azmi [56] advocated that the most effective time to control these recalcitrant rice weeds is between 15 and 30 DAS. The period between 15 and 30 DAS represents the most critical period of rice-weed competition (Figure 5 and 6).

The extensive and continuous use of herbicides over the last three or four decades has resulted in the evolution of weeds resistant to normally phytotoxic chemicals [133, 134]. Malaysian agriculture being essentially monocultural in nature with vast acreages of rubber, oil palm, cocoa, and rice, recorded increasing incidences of herbicide-resistant weeds, and some of these weeds are invasive in nature [125]. These include *E. indica* to glyphosate [19, 135], *C. crepidiodes, Conyza sumatrensis* and *A. lividus* have been reported resistant to paraquat [136], *Lindernia* spp. and *R. indica* and *S. guyanensis* to sulfonylureas [137], *L. flava, M. vaginalis,* and *F. miliacea* to 2, 4-D [138, 139] among others.

Table 7. Some of the commonly used herbicides in Malaysian agriculture [a]

Common name	Trade name	Comments	References
2,4-D/2,4-DIBE	Many trade names	Foliar applied, POST at 0.56 –2.24 kg ae/ha in turf; POST at 0.28 – 0.56 kg ae/ha in rice, maize; POST at 0.56 –2.24 kg ae/ha in fallow prior to tillage in rice, maize; 22.4 kg ae/ha for. Aquatic weeds control in irrigation and drainage canals; directed POST at 1.12 kg ae/ha in fruit orchards, oil palm, rubber, and cocoa (devoid of legumes cover). Controls many broadleaves, and young sedges, with little or on activity against grasses	[125, 140]
Bensulfuron-methyl	Londax	PRE or POST at 0.04 – 0.07 kg a.i./ha (wet-seeded). POST, 6- 8 DAS and 1-7 days before flooding (dry-seeded). Controls many emerged and submerged broadleaves and sedges, *viz.* hemp sesbania, eclipta, purple ammania, yellow nutsedge, gooseweed, rice flatsedge, but not barnyard-grass completely.	[125, 140]
Bentazon	Basagran	POST at 0.84 –1.12 kg ae/ha. Controls hemp sesbania, eclipta, purple ammania, but not barnyardgrass completely. Drain before application. Improved efficacy by adding nonionic surfactant, oil adjuvant, ammonium sulphate, or 28% urea ammonium nitrate fertilizer	[125, 140]
Benthiocarb	Bolero	PRE or early POST, at 3.4 – 4.5 kg a.i./ha, 4-10 DAT. Maintain flooding 3-5 days after treatment but not submerging the rice plants. Controls certain grasses, broadleaves and sedges, *viz.* barnyardgrass, sprangletop, junglerice, spikebrush, flatsedge, signalgrass, weedy rice and dayflower.	[125, 140]
Bispyripac sodium	Nominee	Early POST, 0.015 – 0.04 kg a.i/ha, 7- 20 DAS excellent control of *Aeschomene indica, R. indica, Echinochloa* spp., *Cyperus* spp., *Lindernia* spp., *L. epilobioides, B. platyphylla, P. oleracea F. miliacea, Scirpus* spp., *Sagittaria* spp., *S. zeylanica* and *L. octovalvis* under wet- or dry-seeded or transplanted rice but with no standing water. More efficacious against *L. hexandra* with surfactant A-100. Better efficacy against *L. chinensis when* tank-mixed with clefoxydim, cyhalofop-butyl, fenoxaprop pendimethalin or sethoxydim. Efficacious against *L. chinensis* when applied at <4-leafstage.	Azmi, M. *(pers comm.)*
Butachlor	Machete	POST, 0.60 kg a.i./ha, 3 –7 DAT maintaining water depth 5-10 cm up to 5 days after treatment in transplanted rice. POST, apply at 6 – 8 DAS in	[125, 140]
Dicamba	Banvel	PRE or POSTat 0.56 kg ae/ha. Controls many broadleaves in maize or rice. Higher rates in young oil palm, rubber, and cocoa (devoid of legumes cover crops)	Azmi, M. *(pers. comm.)* Chung, G.F. *(pers. comm.)*
Fenoxaprop-ethyl	Whip	POST, 0.05 –0.12 kg a.i./ha, 26 – 30 DAS controls *E. crus-galli,* and other grasses but poor on sedges and broadleaves. Causes transient injury to rice. Controlled *Aeschynomene indica*. Efficacy varies with soil moisture contents. Synergism prevailed with tank-mix combinations of > 2.7 kg a.i./ ha fenoxaprop + >2.2 kg a.i./ ha pendimethalin.	[125, 140]
Fluazifop-P	Fusilade	POST, at 0.10 – 0.21 kg a.i./ha. Controls most annulas and perennial grasses, viz. barnyardgrass, crabgrass spp., *Panicum* spp., foxtail spp., volunteer rice and weedy rice (applied PRE before tillage at 2 – 4 leaf-stages). No activity against broadleaves. An oil adjuvant or anionic surfactant is required for maximum activity	[125, 140]
Glufosinate ammonium	Basta	POST, 0.35 – 1.7 kg a.i./ha in non-crop areas and as directed spray in field-grown rice on bunds or levees. PRE prior to tillage or zero tillage in transplanted- or dry or water-seeded rice. Non selective, and controls a broad spectrum of weeds especially annual or perennial grasses, and broadleaves. For general weed control in fruit orchards, young oil palm, rubber and cocoa (devoid of legume cover crops)	Azmi, M. *(pers. comm.)* Chung, G.F. *(pers. comm.)*
Glyphosate	Roundup	POST, 0.21 – 2.24 kg ae/ha in non-crop areas and as directed spray in field-grown rice on bunds or levees. PRE prior to tillage or zero tillage in transplanted- or dry or water-seeded rice. Non selective, and control a broad spectrum of annual and perennial weeds, including weedy rice. Especially toxic to grasses, such as perennial weeds, including weedy rice. Require a non-ionic surfactant for maximum efficacy. Effective against formation of new tubers in *C. rotundus* .Widely used in estates weed control programmes against a wise spectrum of weeds.	[141] Azmi, M. *(pers. comm.)* Chung, G.F. *(pers. comm.)*

Table 7 *(continued).*

Common name	Trade name	Comments	References
MCPA	Many trade names	Similar to 2,4-D. POST 0.26 – 2.0 kg ae/ha. Controls a wide spectrum of young broadleaves and sedges in rice, maize oil palm, rubber, cocoa. Toxic to legume cover crops. Also used for general weed control on bunds, levees, drains and irrigation canals Especially toxic to grasses, such as perennial weeds, including weedy rice. Require a non-ionic surfactant for maximum efficacy. Effective against formation of new tubers in *C. rotundus*. Widely used in estates weed control programmes against a wise spectrum of weeds.	[125, 140]
Molinate	Ordram	PPI, preflood in water-seeded rice. POST, postflood in water- seeded or drilled rice with deepened water at application to cover foliage. POST, preflood in dry- or water-seeded rice. POST, 6 – 7 DAS at flooding into irrigated dry- or wet-seeded rice. Controls annual and perennial grasses such as red rice, *Echinochloa* spp. *Leptochloa* spp.	[98, 125, 142 and 49]
MSMA	Ansar/Target	POST at 2.50 –3.00 kg a.i./ha in turf and non-crop areas, or in between rows of young oil palm, rubber, cocoa. Controls crabgrass nutsedge, and other grasses. Require a surfactant for improved efficacy	[143, 140 and 144]
Oxadiazon	Saturn-D	PPI at 2.21 – 4.48 kg a.i./ha before weed emergence. POST, 3 - 6 DAT Controls many broadleaves and grasses applied POST. Mixture with cumyluron, dymuron and bromobutide broadens the weed spectrum. Treated fields inundated 3 - 5 cm and maintained at that depths for 2 - 4 DAT.	[125, 140]
Paraquat	Many trade names	PRE or preplant for land preparation prior to tillage or in manyt agronomic crops and non- till rice crops. POST-directed for rice bunds and levees. A non-ionic surfactant or oil adjuvant is required for maximum efficacy	[20, 49]
Picloram	Tordon	POST, foliar applied at 0.14 – 1.12 kg ae/ha in forest plantings and non-crop areas, killin old trees by stump, treinjection or girdle in replanting of oil palm and rubber. Controls certain annual broadleves at low rates, and many annuals and perennial broadleaves at high rates. Grasses are not controlled.	[125, 121]
Propanil	Stam-F	POST, 3.60 – 5.60 kg a.i./ha, 10 DAS. Controls mainly broadleaves and grasses, principally barnyardgrass, crabgrass spp. goosegrass. Drain inundated fields 24 h before treatment reflood 3 – 6 after application	[125, 140]
Quinclorac	Facet	PRE or delayed PRE and early POST at 0.28 – 0.56 kg a.i./ha. Controls certain annual rasses such as *Echinochloa* spp. *D. sanguinalis, Brachiaria* spp., foxtail spp. and certainannual and perennial broadleaves such as *Aeschynomene* spp., *Ipoemea* spp., *S. exaltata.* Wider weed control spectrum in combinations with propanil, bensulfuron benthiocarb, bentazon and sulfonylures. Propanil-resistant barnyardgrass could be controlled with 0.75kg a.i. /ha quinclorac applied at 2-3 leaf stage. PPI or PRE applications to dry- or moist-soil controlled >80% barnyrdgrass, pitted morninglory and hemp sesbania.	[125, 140]
Triclopyr	Garlon	POST at 0.28 – 0.42 kg ae/ha. Controls many broadleaves. Requires a non-ionic surfactant in waterin water application. Foliar applied at 1.12 – 10.1kg ae/ha for total spray in noncrop land areas such as utility and of-way, roadsides, railway side tracks, forestry sites. Injected into stem cuts for controlling large trees, applied to cut stumps, such as *Acacia mangium* in rubber, oil plam estates. Mixed with oil for bark treatment on young trees. Controls many annual broadleaves, treeand brush species.	[145, 140]

[a] including weed clearing in irrigation and drainage canals, and non-crop areas, singularly applied or in combinations, including safeners. PRE – pre-emergence; PPI – preplanting incorporation; POST – postemergence; DAS, days after seeding; DAT, days after transplanting

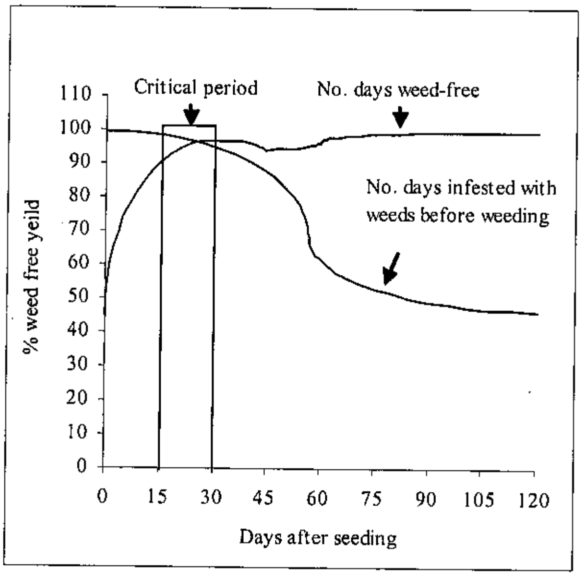

Figure 5. Critical period of competition of barnyardgrass in direct-seeded rice in main season of 1988/1989 in Malaysia (Adapted from Azmi [57]).

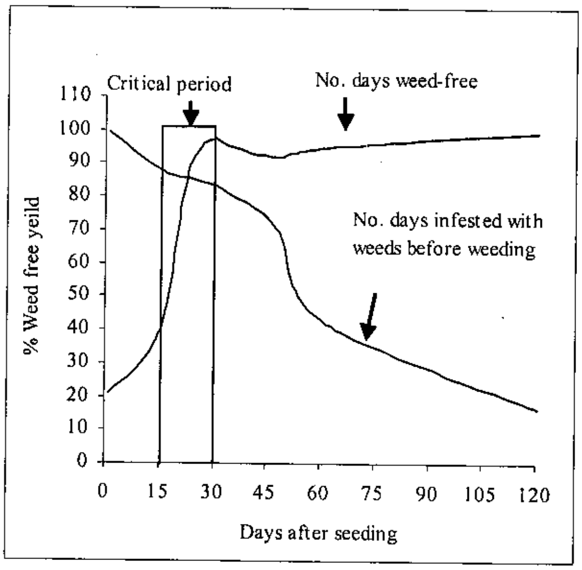

Figure 6. Critical period of multiple species weed competition in direct-seeded rice in off- season of 1989 in Malaysia (Adapted from Azmi [57]).

The advent of these herbicide resistant weed species, if ill managed would lead to nation-wide problems at monumental scale. With increasing incidences of herbicide-resistant weeds in rice, and other crops, the conventional protocol of chemical weed regimes cannot offer or sustain good control over the targeted weeds. New control regimes need to be formulated to overcome this challenge. Serious coorodinated plans need to be formulated among agricultural-based agencies need to manage this emerging problems through research, extension services and development. The paucity of such plans of action is worrisome, lest these herbicide-resistant weeds become invasive.

Integrated Approaches

More often than not a single method is not effective for controlling any invasive weed species. Appropriate integration of chemical, mechanical practices with non-chemical and cultural practices to include combinations of mechanical options such as delayed crop seeding, tillage, black fallow, handweeding, crop rotation, increased crop competition, as well as decision aids that directly lower selection pressure, restrict or delay the the growth of resistant populations, is desirable [103, 147, 148, 149, 150, 151, 152, 153 and 154]. Non-chemical practices can increase weed mortality and decrease the fitness of surviving weeds to delay the evolution of resistant populations. Understanding the effect of these practices on weed population dynamics is needed in order to more precisely predict their contributions toward resistance management. Most cultural weed control practices do not provide acceptable levels of weed control. However, they reduce weed population numbers without exerting a chemical selection pressure. Handweeding can be used to remove resistant weeds in small patches [150, 153]. Cultural practices in place of herbicides, while delaying the development of resistance, only partly control weeds. Assuming equal fitness, this, in effect, would maintain both susceptible and resistant genes. Maintaining susceptible genes has little application for preventing weed resistance unless the weed is outcrossed and resistance is recessive.

Crop rotation disrupts weed life cycles because of the different cultural practices and growth characteristics of each crop. Rotation of different weed control practices would delay resistance, compared to continuous monoculture. Such delay is dependent on the genetics of resistance, weed reproduction traits, weed seed survival, and fitness of resistant weed plants [153]. Cultural practices associated with different crops will cause a shift in weed species. In general, resistance management practices, and not crop rotations, are selected to delay resistance from occurring, because the former are made available by rotational crops.

Advances in genetic engineering have allowed incorporation of herbicide resistance into crop plants [155, 156, 157 and 158]. One of the key advantages of herbicide resistant (HR) crops is the opportunity to use herbicide with an alternative mode of action to control resistant weeds. Wilcut *et al.* [159] argued a central benefit from HR crops is the opportunity for new strategies and increased flexibility in the management of problem weeds. The HR crops can also facilitate increased use of conservation tillage crop production practices as POST herbicides can be used to effectively control weeds. In addition, HR crops potentially provide opportunities for the use of more environmentally benign herbicides and lower application rates of herbicides than many soil-applied herbicides [26]. While HR transgenic rice, maize, soyabean varieties are shown to be popular in the USA, acceptance of agricultural produce by consumers in Europe and elsewhere is rather pathetic. In Malaysia, there is a paucity of information on the possible introduction, and subsequent commercialisation of HR crops by farmers. A national regulation policy on transgenic and HR crops is yet to be formulated by the authorities.

FUTURE TRENDS

It is often argued that the wave of globalisation and increased international trade in the 21^{st} century has led to the breakdown of biogeographical barriers, with yet higher plateaux of species invasions [80]. Intentional and clandestine introductions of plant and animal materials are going at unprecedented scales threatening the community structure, and species interactions of the native species to a certain extent.

In the contexts of intensive agricultural activities especially in our pursuits to increase food production in Malaysia, liberalization of international trade, increased import of grains, fruits, animal feeds, and leguminous cover crops, the risks of further introduction and subsequent invasion and spread by plant invasives (weeds!) will likely increase in the future, despite the stringent rules and regulations imposed by the authorities to prevent the unwarranted introduction of exotic plant materials into the country. The total absence of WRA within the framework of quarantine protocols and infrastructures may aggravate the situation, coupled with the insufficient properly trained manpower for monitoring and enforcement at every entry points – airports, ports of call, border check point, etc. The strong dependence on herbicide-based control measures, notably in estates, will lead to a parallel increase in herbicide-resistant weed species. There are evidences of increased incidences of endemics becoming invasives – this is worrisome as native species can become naturalized and become weedy and invasive quite quickly, especially in disturbed habitats, as most Malaysian agro-ecosystems are.

It is heartening to note that The Scientific Committee on Problems of the Environment (SCOPE) in collaboration with the United Nations Environment Programme) (UNEP), the International Union for the Conservation of Nature (IUCN), and Commonwealth Agricultural Bureau International (CABI) is embarking on a new programme on invasive species, this time with the explicit objective of providing new tools for understanding and dealing with invasive species [160]. This venture is under the umbrella of the Global Invasive Species Program (GISP) where the scientific community along with policy makers, legal experts and people from industry and government are engaged in serious deliberations under 11 elements on building a comprehensive approach needed for dealing with invasive species. Four of these elements deal with synthesizing our current knowledge on invasives, and these include

(i) the ecology of invasive species,
(ii) the current status of invasive species and new methods for assessing their changing distributions and abundance,
(iii) how society views and evaluates invasive species, and
(iv) how global change will impact the success of invaders. It is my hope that the Malaysian scientific community plays its role in GISP.

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