

## Potential Asteraceae Invaders in Taiwan: Insights from the Flora and Herbarium Records of Casual and Naturalized Alien Species

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**ABSTRACT:** Naturalization has been shown to be one of the primary stages of plant invasions; therefore, studies on naturalized plant species may generate valuable insights of possible invaders and invasions. Background information of casual and naturalized Asteraceae species provided by a comprehensive list of casual and naturalized species in Taiwan was examined to estimate the basic biological traits and geological origins of potential invasive species in this study. Besides, herbarium records were collected and analyzed to predict the invasiveness of casual and naturalized Asteraceae species. Our results showed that 44.0% out of the 51 casual and naturalized Asteraceae species were classified as invasive in the field, and a notable portion of these species were probably introduced accidentally. Tropical Americas were the most important origins of casual and naturalized Asteraceae species, followed by Europe and temperate Americas. Most of the casual and naturalized Asteraceae species were annual herbs, and a few perennial species categorized as invasive may cause profound environmental problems. The herbarium record showed that species possessed different numbers of localities within the same time frame. We suggested that casual and naturalized Asteraceae species collected in more localities are more invasive than those species found in fewer localities within the same period of time.

**KEY WORDS:** Invasion, Taiwan, Asteraceae, alien species, casual and naturalized species, herbarium records.

### INTRODUCTION

Plant invasions have been recognized as one of the most serious environmental problems which impact the structure, composition and function of natural and semi-natural ecosystems (Mooney and Hobbs, 2000; Vitousek *et al.*, 1997). Although occasional attention has been paid to the taxonomical research on naturalized plants in Taiwan (e.g., Peng *et al.*, 1998; Chen *et al.*, 1999; Kuoh and Chen, 2000; Chen and Wu, 2001; Yang, 2001; Yang and Peng, 2001; Tseng and Peng, 2004), ecological studies on plant invasions are still scanty. Insufficient background information of potential invasive species and plant invasions has been shown to impede both ecological and conservation studies (Wu *et al.*, 2004a, 2005). In the past decades, plant invasions were not concerned in Taiwan and the word “invasive” was rarely mentioned in most documents and reports. However, adequately documented studies on naturalized species may generate powerful insights of plant invasions and potential invaders (Wu *et al.*, 2005).

A “naturalized” species is defined as an introduced (non-native, exotic) species, that can consistently reproduce and sustain populations over many generations without (or in spite of) direct intervention by humans. After successful local establishment, some naturalized species

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disperse and produce viable offspring in regions distant from the sites of introduction. Such species are called “invasive” (Richardson *et al.*, 2000; Pyšek *et al.*, 2002). Therefore, analysis of the biological traits, geographical origins as well as herbarium records of naturalized species would positively generate penetrating hypothesis of ecological studies on plant invasions (Wu *et al.*, 2003, 2005).

Asteraceae are one of the most contributive families to the naturalized flora of Taiwan (Wu *et al.*, 2004a), and it is served as a model family for this study. The family Asteraceae not only is an important contributor of naturalized flora in Taiwan, but also is the largest dicotyledonous family and one of the notorious contributors to the naturalized flora of the world (Binggeli, 1996; Pyšek, 1998). Furthermore, this family has been studied extensively by many taxonomists, therefore, relatively comprehensive data are available and abundant specimen collections are accessible in local herbaria.

The goals of this study are to analyze biological and geographical patterns of naturalized Asteraceae species and to estimate the invasiveness of naturalized Asteraceae species for future studies on plant invasions in Taiwan.

## MATERIAL AND METHODS

Asteraceae is one of the largest plant families in the world. There are about 21,000 species in 650 genera world wide (Mabberley, 1998), and approximately 240 species are included in the second edition of the Flora of Taiwan (Huang *et al.*, 1998). Among 159 native species, 59 are endemic to Taiwan (Peng *et al.*, 1993). All species documented as naturalized, escaped or persistent after cultivation, or invasive in Taiwan with an origin in foreign regions (Wu *et al.*, 2004b), have been compiled for this study. Life form, invasion status, and origins stated on this list were analyzed. The main herbaria in Taiwan (TAI, HAST, and TAIF) were visited during the summer of 2002, and information on the labels of specimens of naturalized species was examined, including locality and year of collection.

Approximately 669 specimens of naturalized Asteraceae were examined. To summarize general trends in the development of the naturalized chrysanthemum flora, the cumulative number of recorded species was plotted against time (1875-2002). However, the year of the first record in Taiwan was not available for all species. Therefore, only 50 out of 51 species could be used for this analysis. The number of localities (distance  $\geq 5$  km apart) per species was plotted against minimum residence time (time between the first herbarium record in Taiwan and 2002). The relationship between these two variables was then quantified by a linear regression. Species distributed above the regression line were assumed to be more invasive, while species below the line seemed to be less invasive (Wu *et al.*, 2005).

According to Pyšek *et al.* (2004) and Wu *et al.* (2004a), alien species were categorized into three groups, “Casual”, “Casual or Naturalized”, and “Naturalized”. Species documented as rare in Wu *et al.* (2004b) are here classified as casual species; established and consistently reproducing species are classified as naturalized species; and, species without information on their actual status are grouped as “casual or naturalized” (C/N, hereafter, not applicable in this study). Three subcategories, local, common, and invasive, are applied to naturalized species to clarify the field status of these species. Naturalized species producing offsprings in large numbers and at considerable distances from the parent plants are classified as invasive (Pyšek *et al.* 2004). Plant species that cause economic and/or environmental damage, are commonly referred to as exotic “pests” or “weeds” (Richardson *et al.*, 2000; Booth *et al.*, 2003).

## RESULTS

Based on the examination of Wu *et al.* (2004b), 96.1% of the naturalized Asteraceae are herbaceous species. Among them, annuals are the most common life form, followed by perennials, facultative annuals/biennials and a few unknowns. Usages of many naturalized Asteraceae are not well documented. Known usages include cultivation for forage, ornament, or medicine. At least 6 naturalized species were introduced as ornamentals, at least one as forage plants, and at least one for medicinal purposes. Approximately 94.1% of the naturalized Asteraceae species were listed as weeds in other regions of the world.

Two thirds of the naturalized Asteraceae species originated from the tropics, mostly from Tropical Americas, followed by Tropical Asia, and Tropical Africa (Fig. 1). Europe, as well as temperate Americas, is the most important temperate origin of naturalized Asteraceae species in Taiwan.

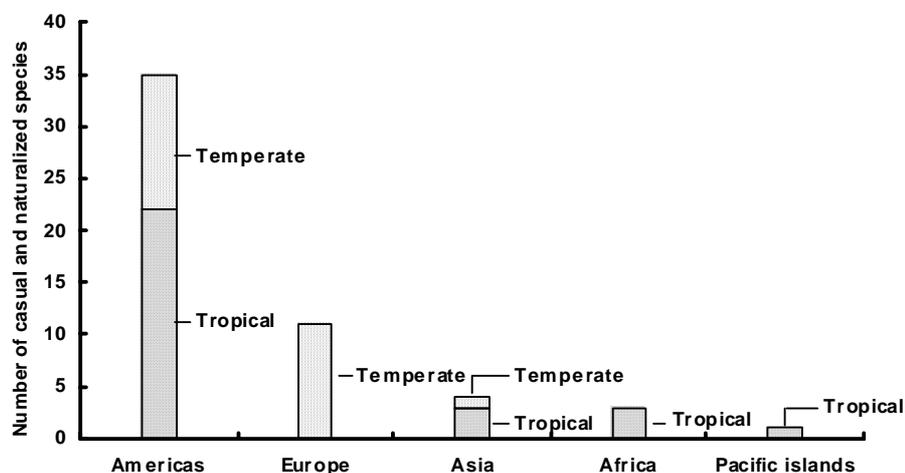


Fig. 1. Native areas and climates of casual and naturalized species in Taiwan.

Approximately 40.0% of the naturalized Asteraceae species are invasive, followed by casual, local and common (Fig. 2). Among invasive species, 75.0% are annual species and the rest 25.0% are perennials. Annual Asteraceae species are dominant in every category of naturalization status, except the category “Local”. Among local naturalized species, perennial species represent the most (55.6%).

The accumulation of casual and naturalized Asteraceae species shows an approximately linear increase from 1875 to 2002 (Fig. 3). Number of alien Asteraceae species increased slowly from 1875 to 1910, and then substantially increased from 1910 to 1940. No new species were recorded between 1940 and 1965. The number of recorded naturalized Asteraceae species increased rapidly again from 1965; approximately one naturalized species every 15-month.

The species with the longest minimum residence time (MRT) was *Ageratum houstonianum* Mill, followed by *Elephantopus mollis* Kunth, *Spilanthes acmella* (L.) Murr., *Bidens pilosa* var. *radiata* L., and *Pseudelephantopus spicatus* (Juss.) C. F. Baker (Fig. 4). The species collected from the largest number of localities was *Elephantopus mollis*, followed by *Bidens pilosa* var. *radiata*, *Synedrella nodiflora*, *Sonchus arvensis* L., and *Tridax procumbens* L.

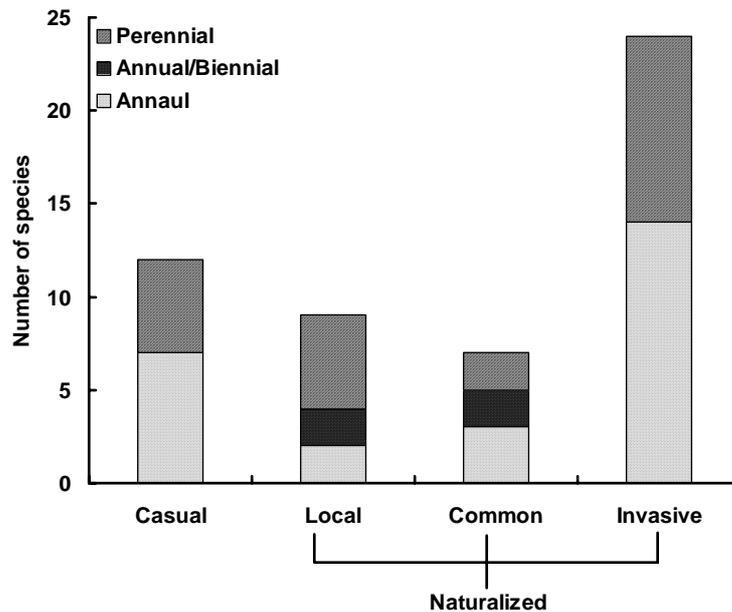


Fig. 2. Field status and life form of casual and naturalized Asteraceae species in Taiwan.

Species differed in their number of localities when plotted against minimum residence time (MRT) (Fig. 4). Approximately 44.0% of the naturalized species have been present in Taiwan for more than 60 years, and about two thirds of the naturalized Asteraceae species lay under the regression line (Fig. 4). Several genera are represented by more than one naturalized species and show various patterns in the relationship between minimum residence time and number of localities (*Bidens*, *Conyza*, *Gnaphalium* and *Sonchus*; Fig. 4). *Bidens* has two naturalized congeners, and both of them have been collected for more than 85 years. *B. polisa* var. *radiata* has been collected in 81 localities, but *B. bipinnata* L. has only been collected in 30 localities. *Conyza*, which has four naturalized species, is the largest genus contributing to the naturalized Asteraceae flora. Two of the four naturalized *Conyza*, *Conyza canadensis* L. var. *canadensis* and *C. sumatrensis* (Retz.) Walker, have a similar minimum residence time, ca 70 to 80 years, and both of them have more than 50 localities in the same time frame. The other two species have relatively shorter MRT, 18 and 2, but have already been collected in more than one locality (Fig. 4). *Gnaphalium* has two naturalized congeners: *G. pensylvanicum* Willd. has been collected for 12 years in seven localities while *G. calviceps* Fernald. has been collected in four localities in only 2 year (Fig. 4). *Sonchus* has two naturalized species; both of which have been collected for more than 70 years. *S. arvensis* has been collected in 61 localities during 88 years, but *S. asper* (L.) Hill in only 18 localities in 74 years (Fig. 4).

## DISCUSSION AND CONCLUSION

Geographical origin of naturalized Asteraceae is often difficult to discern. Many statements in the literature are rather ambiguous, such as “old world”, “cosmopolitan” or “pantropical”. Many species introduced from Europe also occur in West Asia and/or North Africa. Many of them were very likely brought in to Taiwan from Europe and are treated here as European. Most naturalized species are from the Americas (Fig. 1), especially from the American tropics. Europe is the second most important source of naturalized species, especially for temperate species. In general, this is in agreement with the belief that species

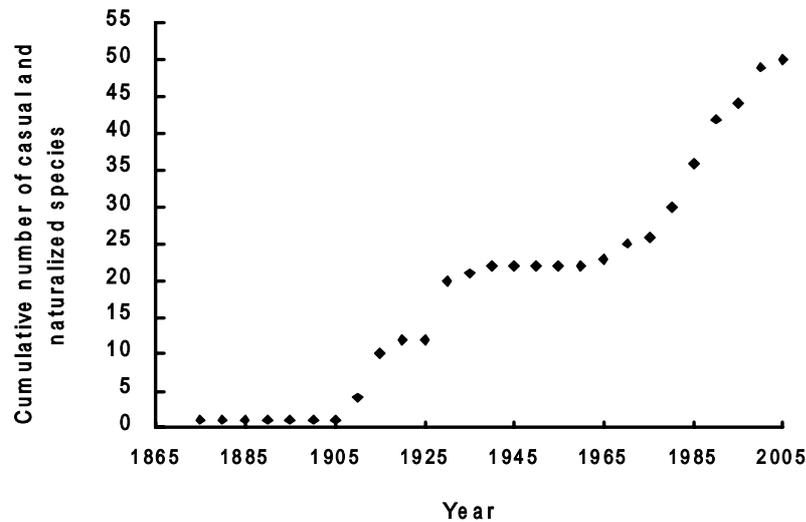


Fig. 3. Cumulative number of casual and naturalized Asteraceae species from 1875 to 2004 in Taiwan.

might adapt well to a new environment with a climate similar to their “homeland” (Corlett, 1988). Taiwan has both tropical and temperate climates, and most of the naturalized American, Asian and African species are of either tropical origin or temperate origin (Fig. 1).

Most naturalized Asteraceae species in Taiwan are annual herbs (Fig. 2), and this pattern coincides with the features of this family. Despite of the species introduced for ornament, forage, or medicine, many species have no information of introduction available. These species with no records of human uses were probably introduced into Taiwan accidentally by international trades or tourism (Wu *et al.*, 2004b).

It is concerned that 40.0% of the naturalized Asteraceae species are categorized as invasive (Fig. 2), especially, perennial invasive species. The population of annual species usually fluctuates with the change of environmental factors, such as weather, floods, etc. In the other hand, perennial species may impact the environments and the ecosystems by multi-year regenerations and competition with local native species (Rejmánek and Richardson, 1996). Therefore, additional attention is highly required on those perennial invasive species.

It has been shown that species that invade one place tend to be invasive also in other regions (Meyer, 2000); therefore, it is not surprising to have approximately 94.1% of the naturalized Asteraceae species in Taiwan categorized as weeds in other regions of the world (Randall, 2002). These weed species may cause large scale environmental problems and economic loss once they become invasive; therefore, further evaluation of impacts and field status of these weed species should be important.

The number of naturalized Asteraceae has been increasing continuously since 1875 (Fig. 4). Some African, Asian, and European species were probably brought onto the island by sailors, traders and immigrants during the nineteenth century or even earlier (Wu *et al.*, 2004a). However, it is still not clear how so many successful American species were introduced into Taiwan.

One of the most robust generalizations of invasion biology is that the probability of invasion success increases with residence time (Rejmánek, 2000). However, a long minimum residence time does not always correlate with more localities. Several genera, including *Bidens*, *Conyza*, *Gnaphalium*, and *Sonchus*, have more than one naturalized species with similar minimum residence times and show conflicting patterns (Fig. 4). Among the species

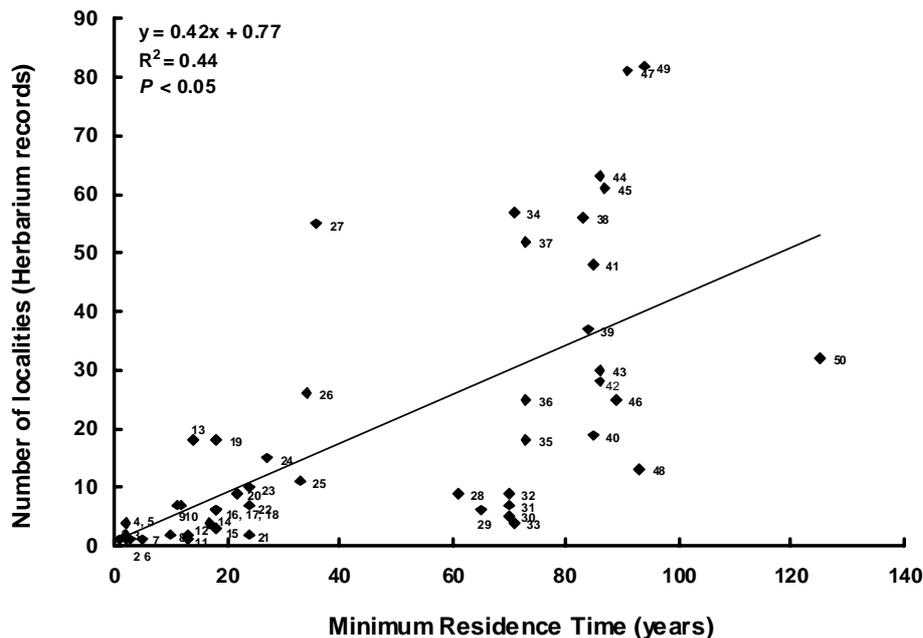


Fig. 4. Number of localities per species vs. minimum residence time of naturalized Asteraceae in Taiwan. 1. *Eclipta zippeliana* Blume, 2. *Emilia fosbergii* Nicolson, 3. *Conyza canadensis* var. *pusilla* (Nutt.) Cronq., 4. *Gnaphalium calviceps* Fernald., 5. *Pluchea sagittalis* (Lam.) Gabera, 6. *Pluchea carolinensis* (Jacq.) G. Don, 7. *Vernonia elliptica* DC., 8. *Soliva pterosperma* (Juss.) Less, 9. *Chromolaena odorata* (L.) R. M. King & H. Rob., 10. *Gnaphalium pensylvanicum* Willd., 11. *Galinosoga quadriradiata* Ruiz & Pav., 12. *Ageratina adenophora* (Spreng.), 13. *Parthenium hysterophorus* L., 14. *Centratherum punctatum* ssp. *fruticosum* S.H. Chen, 15. *Wedelia trilobata* (L.) Hitchc., 16. *Aster subulatus* var. *sandwicensis* (A. Gray) A. G. Jones, 17. *Calyptocarpus vialis* Less., 18. *Crassocephalum crepidioides* (Benth.) S. Moore, 19. *Conyza bonariensis* (L.) Cronq., 20. *Ambrosia elatior* L., 21. *Cichrium intybus* L., 22. *Taraxacum officinale* L. Weber, 23. *Tithonia diversifolia* (Hemsl.) A. Gray, 24. *Hypochaeris radicata* L., 25. *Galinosoga parviflora* Cav., 26. *Erigeron annuus* (L.) Pers., 27. *Erechtites valerianaefolia* (Wolf ex Rchb.) DC., 28. *Erechtites hieracifolius* (L.) Raf. ex DC., 29. *Cosmos bipinnatus* Cav., 30. *Solidago altissima* L., 31. *Gaillardia pulchella* Foug., 32. *Senecio vulgaris* L., 33. *Leucanthemum vulgare* H. J. Lam., 34. *Tridax procumbens* L., 35. *Sonchus asper* (L.) Hill, 36. *Soliva anthemifolia* R. Br. ex Less., 37. *Conyza sumatrensis* (Retz.) E. Walker, 38. *Conyza canadensis* L. var. *canadensis*, 39. *Ageratum conyzoides* L., 40. *Gynura bicolor* (Willd.) DC., 41. *Sonchus oleraceus* L., 42. *Xanthium strumarium* L., 43. *Bidens bipinnata* L., 44. *Synedrella nodiflora* (L.) Gaertn., 45. *Sonchus arvensis* L., 46. *Pseudelephantopus spicatus* (Juss.) C. F. Baker, 47. *Bidens pilosa* var. *radiata* Sch. Bip., 48. *Spilanthes acmella* (L.) Murr., 49. *Elephantopus mollis* Kunth, 50. *Ageratum houstonianum* Mill.

present in Taiwan for at least 70 years, some occupy many habitats, whereas others have never spread out (Fig. 4). We have two explanations of this phenomenon. One is that species with more localities have been spread by human activities (Williamson, 1996); the other one is that these taxa differ in their invasiveness. The first explanation seems less likely to be correct because most of the naturalized Asteraceae species were introduced with unknown reasons. Furthermore, it has been shown that minimum residence time and number of localities represented the invasiveness of the naturalized legume in the field adequately (Wu *et al.*, 2005). Therefore, we hypothesized that the species lay above the regression line with notable localities in the certain period of time are more invasive (Wu *et al.*, 2005), e.g. *Ageratum houstonianum*, *Elephantopus mollis*, *Spilanthes acmella*, *Bidens pilosa* var. *radiata*, and *Pseudelephantopus spicatus* (Fig. 4). However, our results in this study did not present the invasiveness of several well-known invasive Asteraceae species, such as *Aster subulatus* Michx. var. *subulatus* and *Micania mikrantha* Kunth, probably due to their short minimum

residence times and limited amount of herbarium records of these species. Besides, some invaders have prolonged lag phases lasting hundreds of years (Crooks and Soulé, 1999). Therefore, further studies are highly recommended in the near future.

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## 菊科外來歸化植物之入侵性初步探討

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### 摘 要

有鑒於外來植物在侵入原生環境之前皆須經過歸化 (naturalization) 階段,本研究依據先前所發表的台灣歸化植物名錄,針對歸化之菊科植物基本資料進行整理與探討,藉以瞭解潛在入侵菊科植物之生物特性及來源。並藉由分析標本記錄,預測菊科歸化植物之入侵性 (invasiveness)。結果顯示,菊科歸化植物共有 51 種,其中 44% 為入侵物種,然而,多數的物種的引進原因不明。美洲的熱帶地區是台灣菊科歸化植物的主要原生地,歐洲及美洲溫帶地區其次。大多數的菊科歸化植物為一年生,入侵性強的多年生植物則可能造成環境問題。這些外來的植物多以不同的速度擴散,即使是具有相同駐在時間 (minimum residence time) 的同屬種類,亦有不同的表現。據我們的推測及分析顯示,此一不同的擴散趨勢,可作為這些物種入侵能力的指標。

關鍵詞：入侵、台灣、菊科、外來種、歸化種、標本記錄。

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