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Survey of invasive plants on Guam and identification of the 20 most widespread

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Abstract—Invasive plants are introduced, nonnative species that thrive and spread spontaneously in areas beyond their natural range. They are characteristically adaptable and aggressive and have high reproductive capacity. Their vigor, combined with escape from their natural enemies, often leads to extensive outbreak populations. The many invasive species on Guam constitute a growing problem. A survey of invasive plants in five habitat types across the 20 municipalities of Guam identified the 20 most widespread: *Bidens alba, Panicum maximum, Stachytarpheta jamaicensis, Antigonon leptopus, Paspalum paniculatum, Miscanthus floridulus, Euphorbia heterophylla, Chromolaena odorata, Mikania micrantha, Chamaesyce hirta, Synedrella nodiflora, Mimosa pudica, Leucaena leucocephala, Pennisetum polystachion, Euphorbia cyathophora, Sida rhombifolia, Chrysopogon aciculatus, Momordica charantia, Chamaesyce hypericifolia* and *Chloris barbata*. At present, the best option for managing them could require more work on the possibility of biological control and may be to adopt preventive and mechanical control methods.

Introduction

Invasive species are typically nonnative species introduced, accidentally or intentionally, by humans, and they often threaten environmental, agricultural, forestry, or other resources. The introduction of many herbs, shrubs, vines, and trees for ornamental and other purposes has had profound effects on the environment on Guam and in Micronesia. Because introduced plants are freed from their natural enemies, which would usually keep them under control, these plants can come to dominate the ecosystem (Muniappan et al. 2002). Lee (1974) reported that introduced plants originating in the New World outnumber those from the Old World on Guam and that the invaders made up 3.4% of plants in limestone forest, 9.4% in ravine forest, 13.3% in savanna, 17.3% in strand, and 32.4% in wetland ecosystems. McConnell & Muniappan (1991) listed 12 species of introduced ornamental plants that became weeds on Guam.

Many invasive plants continue to be admired by farmers or gardeners who may not be aware of their weedy nature (Muniappan et al. 2008). Others are rec-

Figure 1: Map of Guam showing different villages

ognized as weeds, but property owners fail to take action to prevent their spread. Some species do not become invasive until they are neglected for a long time. Invasive plants are not all equally invasive. Some only colonize small areas and do not do so aggressively. Others may spread and come to dominate large areas in just a few years (http://www.usna.usda.gov/Gardens/invasives.html). Many such rapidly spreading invasive plants are found on Guam; *Chromolaena odorata* (L.) R.M. King and H. Robinson and *Coccinia grandis* (L.) Voigt are examples. They compete for large areas of land and threaten the existence of Guam's native plants. *Chromolaena odorata,* for example, is a pithy plant, so it is a fire hazard during the dry season, but it sprouts readily at the onset of the rainy season because the stubble remains in the ground. In addition, it has allelopathic capabilities, which add further to its dominance over native vegetation on Guam (Cruz et al. 2006). *Coccinia grandis,* on the other hand is a strong and fast-growing vine that easily

Figure 2. Line-intercept-transect device in place in one of the study plots. The white-flowered plant is *Bidens alba*.

climbs atop other vegetation and strangles it or shades it out (Reddy et al. 2009). Replacement of native vegetation by invasive species not only causes an ecological disturbance by altering habitats but also decreases biodiversity. Drucker et al. (2008) stressed the importance of improving our ability to predict which nonnative species will become invasive, so as to prevent their introduction and spread. Currently, no systematic information is available on the identities or habitats of invasive species occurring on Guam.

The overall goal of the study reported here was to survey invasive plant species occurring on Guam and to identify the 20 most widespread. I therefore estimated total areas infested and habitat occurrence and produced a listing of all the inventoried invasive plants on Guam.

Materials and Methods

Study Area

The 20 survey sites were chosen to be representative of the entire geographic area of the island; one was placed within the boundaries of each of Guam's 20

Table 1. Locations of the 1-acre sites surveyed for the present study of invasive plants on Guam.

Site number	Municipality	Location
1	Mangilao	13°26.978' N, 144°48.737' E
2	Yigo	13°31.869' N, 144°52.291' E
3	Dededo	13°30.700' N, 144°51.173' E
4	Tumon	13°31.997' N, 144°48.510' E
5	Tamuning	13°30.109' N, 144°46.939' E
6	Agaña Heights	13°28.161' N, 144°44.817' E
7	Mongmong-Toto-Maite	13°28.121' N, 144°46.627' E
8	Barrigada	13°28.385' N, 144°48.132' E
9	Yoña	13°24.359' N, 144°46.352' E
10	Talofofo	13°23.025' N, 144°46.342' E
11	Malojloj	13°19.395' N, 144°45.885' E
21	Inarajan	13°15.259' N, 144°43.300' E
13	Merizo	13°15.058' N, 144°43.071' E
14	Umatac	13°18.194' N, 144°40.131' E
15	Agat	13°21.789' N, 144°39.001' E
16	Santa Rita	13°23.481' N, 144°42.909' E
17	Piti	13°25.656' N, 144°40.727' E
18	Asan	13°28.285' N, 144°42.484' E
19	Hagatña	13°28.598' N, 144°44.313' E
20	Ordot-Chalan Pago	13°26.963' N, 144°45.547' E

municipalities, which, together, cover the entire area of the island (Figure 1). The locations of the 20 sampling sites, determined with a 12-channel global positioning system (Garmin Corp., Taiwan), are listed in Table 1. They were chosen to include forested areas, residential areas, roadsides, vacant lots, and agricultural areas. Within each 1-acre site, 10 1-m^2 plots were randomly chosen for assessment of the population of invasive plants occurring in the different habitat types. A line-intercept transect-method (Brower et al. 1998) quadrat (1×1m) was used as a standard measure for the study and was laid flat over the vegetation on each of the 10 plots. Invasive plants falling within the perimeter of the quadrat were identified, and the total number of individuals of each was recorded (Figure 2).

Data Analysis

From the survey data, the percentage occurrence of each invasive plant at each sampling site was calculated ((total number of the invasive plant/overall number of plants) × (100)), as was the total area it covered within the one-acre area ((total number of the invasive plant)/(overall number of plants)). The 20 most widespread

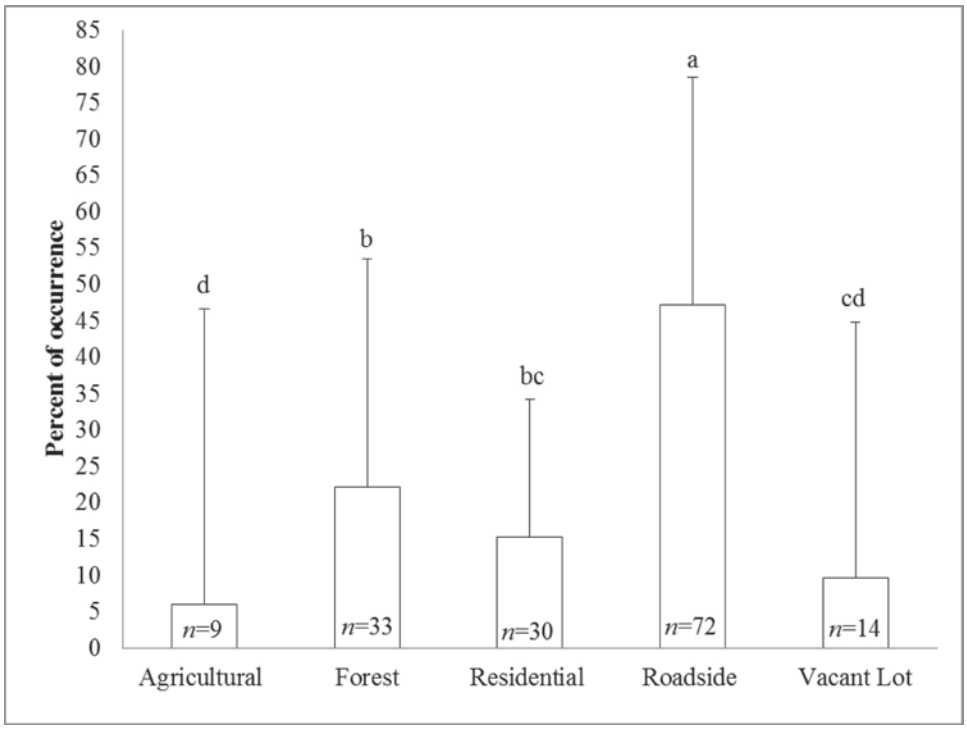

Figure 3: Occurrence (mean percentage ± SE) of top 20 most widespread invasive plants in the five habitat types. Bars with identical letters are not significantly different from each other (Multiple comparison's test; $P<0.05$).

invasive plants (the "top 20" species) were identified on the basis of percentage occurrence. The overall area coverage (acres) for each invasive plant on Guam was estimated as the total number of each plant species (from all 20 sites), divided by the overall number of individual plants counted (3524), multiplied by the total size of Guam, in acres (133,758.1).

The habitats in which each of the top 20 invasive plants occurred within the 20 survey sites was tabulated. The total number of the top 20 plants occurring in each habitat type was then divided by the total number of the top 20 plants occurring in all five habitat types, and then multiplied by 100 to yield the percentage habitat occurrence. The habitat-data were analyzed by means of the multiple-comparisons test in PASW 18.0 version.

Results

The 20 Most Widespread Invasive Plant Species on Guam

Bidens alba was present at every location surveyed and was the predominant species (see Table 2). The second most widespread plant species found was *Panicum maximum*. *Stachytarpheta jamaicensis* and *Antigonon leptopus* occurred

Table 2. List of invasive plant species recorded on Guam, in descending order of estimated coverage of the island.

Species	Total number of individual plants collected	Total acreage covered on Guam (estimated)	Percentage of Guam covered (estimated)
Bidens alba	1,313	49,836.66	37.26
Panicum maximum	328	12,449.68	9.31
Stachytarpheta jamaicensis	231	8,767.91	6.56
Antigonon leptopus	217	8,236.52	6.16
Paspalum paniculatum	174	6,604.40	4.94
Miscanthus floridulus	164	6,224.84	4.65
Euphorbia heterophylla	135	5,124.10	3.83
Chromolaena odorata	94	3,567.89	2.67
Mikania micrantha	68	2,581.03	1.93
Chamaesyce hirta	66	2,505.12	1.87
Synedrella nodiflora	66	2,505.12	1.87
Mimosa pudica	65	2,467.16	1.84
Leucaena leucocephala	60	2,277.38	1.70
Pennisetum polystachion	60	2,277.38	1.70
Euphorbia cyathophora	45	1,708.03	1.28
Sida rhombifolia	37	1,404.38	1.05
Chrysopogon aciculatus	35	1,290.52	0.96
Momordica charantia	35	1,290.52	0.96
Chamaesyce hypericifolia	35	1,138.69	0.85
Chloris barbata	35	1,138.69	0.85
Passiflora foetida	34	1,100.73	0.82
Cenchrus echinatus	34	948.91	0.71
Dactyloctenium aegyptium	34	873.00	0.65
Saccharum spontaneum	34	759.13	0.57
Macroptillium atropurpureum	32	645.26	0.48
Ipomoea pes-caprae	32	607.30	0.45
Cyperus rotundus	32	569.34	0.43
Echinochloa colona	32	569.34	0.43
Conyza canadensis	32	493.43	0.37
Cuscuta campestris	32	493.43	0.37
Cyperus brevifolius	32	455.48	0.34
Eleusine indica	32	417.52	0.31

Table 2. Continued.

Species	Total number of individual plants collected	Total acreage covered on Guam (estimated)	Percentage of Guam covered (estimated)
Cynodon dactylon	32	265.69	0.20
Passiflora suberosa	32	265.69	0.20
Desmanthus virgatus	32	227.74	0.17
Sida acuta	32	227.74	0.17
Cyanthillium cinereum	32	189.78	0.14
Cassytha filiformis	30	151.83	0.11
Cyperus polystachyos	30	151.83	0.11
Eragrostis spp.	30	151.83	0.11
Spermacoce assurgens	30	151.83	0.11
Cyperus spp.	30	113.87	0.09
Lantana camara	30	113.87	0.09
Hyptis capitata	30	37.96	0.03
Luffa cylindrica	30	37.96	0.03
Manihot esculenta	30	37.96	0.03
Blechum pyramidatum	30	303.65	0.23%

about equally frequently. Table 2 summarizes the total numbers of plants and area coverages of the 20 most widespread species, and Table 3 the percentage coverage by each species in the 20 municipalities.

Habitat Occurrence

At the 20 survey sites, *B. alba,* was found mostly in agricultural areas but was also very abundant along roadsides and in forested areas, covering more than 10,000 acres of each. It was also the most frequently encountered species in vacant lots and residential areas. *Panicum maximum* was found mostly along roadsides; its estimated coverage for this habitat type approached 14,000 acres. *Chromolaena odorata* and *M. micrantha* were relatively abundant along roadsides, covering almost an estimated 2000 acres. In addition, in forest habitat, *C. odorata* covered more than 1500 acres (Table 4). Of the five habitat types surveyed, roadsides were the most frequently inhabited by the top 20 species, followed by forest and residential areas. Agricultural areas were the least inhabited (Figure 3).

Discussion

The results of the study reported here provide quantitative information on the presence and distribution of invasive plant species on Guam, previously reported only anecdotally. *Bidens alba* is clearly the most widespread such plant on Guam. Although it has been used for healing cuts, injuries, swellings, hypertension, jaun-

dice, and diabetes in some countries, and the protein extract from it might also have therapeutic value against human colorectal cancer (Ong et al. 2008), *B. alba* is undesirable because it is so aggressively invasive and suppresses native vegetation. The results presented here are in accord with those of Wagner et al. (1999), who reported that, in Hawaii, it occurs in lowland disturbed areas. On Kwajalein (Marshall Islands), it is common to locally abundant in disturbed areas such as roadsides and lawns (Whistler & Steele 1999). On Guam, *B. alba* is now extremely common all over the island, not only on waste ground but sometimes at the fringes of forest, forming dense thickets nearly 1 m tall (Stone 1970). As shown in Table 4, it was found mostly in agricultural areas but was also abundant along roadsides and in forested areas. Waterhouse & Norris (1987) listed a number of natural enemies of *B. alba,* but no attempt has been made to suppress this plant by biological control, nor has much work been done or information gathered on the control methods readily available for many of the invasive plant species reported in Table 2.

Biodiversity is considered an important component of ecosystem functioning (Loreau et al. 2002), and concern has been growing that exotic grasses adversely affect diversity of native fauna and flora (Bock et al. 1986, Gabbard & Fowler 2007, Sands et al. 2009) and disrupt ecosystem process such as energy and nutrient flows (Christian & Wilson 1999). Particularly in areas of recent disturbance, exotic grasses can modify ecosystems (Butler & Fairfax 2003, see also Sands et al. 2009), displace native species, and reduce soil nutrient levels (see Sands et al. 2009). The present study documents that six grasses—*P. maximum, P. paniculatum, M. floridulus, S. nodiflora, P. polystachion, C. aciculatus,* and *C. barbata*—are among the 20 most widespread invasive species on Guam. If appropriate control measures are not taken, invasive grass species are likely to affect the native species on Guam severely. A strategic plan is therefore outlined here for control of the 20 most widespread invasive plant species on Guam. Many of these species could be suppressed by the use of integrated pest management.

Strategic plan

1. Host-specificity trials should be conducted in areas where agriculture is diverse, to ensure that any biocontrol agents introduced to control invasive species will not also endanger crop species. The existing natural enemies of the top 20 invasive plants should also be surveyed on Guam before any biological control program is undertaken.
2. A number of organisms are known to attack *S. rhombifolia* on the U.S. mainland and in South America, and several are worthy of further study. The chrysomelid beetles *Calligrapha polyspila* and *C. felina* are good candidates, and the former is already known to be virtually confined to *S. rhombifolia* under field conditions in Argentina. These species should be investigated further.
3. The Guam Department of Agriculture, Forestry Division should pursue sufficient funding for exploratory trips aimed at controlling at least the following top-priority invasive species: (a) *Sida rhombifolia,* an important weed on Guam but of little or no economic importance in Argentina, Paraguay, and Uruguay; (b) *M. micrantha,* which is subject to attack by the fungus *Puccinia*

Table 3. Percentage of area of each of the sampling sites occupied by each of the 20 most widespread invasive plants on Guam.

	Site number																			
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
B. alba	48.68	63.86	40.41	48.04	30.28	15.43	45.51	65.79	8.38	32.00	76.34	10.13	43.08	6.61	63.29	31.58	2.83	2.91	54.27	20.62
P. maximum	2.97	0.00	0.00	0.00	3.67	3.72	5.13	7.24	27.23	19.50	12.37	53.16	0.00	0.00	8.86	52.63	31.13	0.00	4.02	0.00
S. jamaicensis	30.57	5.94	26.94	13.41	6.42	3.19	4.49	3.29	0.00	0.00	0.00	1.27	0.00	0.00	1.27	0.00	0.00	1.94	1.01	10.82
A. leptopus	0.00	0.00	0.00	0.00	22.48	19.15	26.92	0.00	17.28	17.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.05	2.58
P. paniculatum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	76.65	0.00	0.00	0.00	0.00	0.00	0.00
M. floridulus	1.13	6.93	3.11	5.03	6.42	2.66	0.00	0.00	0.00	0.00	2.15	0.00	38.46	0.00	0.00	0.00	16.98	15.53	0.00	0.00
E. heterophylla	4.53	0.00	0.00	7.26	0.00	19.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.54	2.06
C. odorata	0.00	71.98	7.77	0.00	0.00	0.53	1.92	8.55	0.00	0.00	0.54	0.00	12.31	0.00	0.00	4.51	13.21	0.00	0.00	6.70
M. micrantha	0.00	0.00	0.00	1.12	0.00	0.00	1.92	0.00	0.00	0.00	0.00	0.00	0.00	7.93	0.63	0.00	10.38	0.00	0.00	17.01
C. hirta	3.77	0.00	2.59	2.23	4.59	9.57	0.00	0.00	0.00	3.50	0.00	0.00	0.51	0.00	0.00	1.50	0.00	0.00	0.00	3.09
S. nodiflora	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	64.08	0.00	0.00
M. pudica	1.89	0.00	0.00	0.00	0.46	0.00	0.00	2.63	0.00	0.00	0.00	1.27	1.03	8.37	9.49	0.00	0.00	1.94	3.02	2.58
L. leucocephala	0.00	1.49	1.04	2.79	1.38	3.72	0.00	0.00	0.00	1.00	1.61	0.00	1.03	0.00	3.16	0.75	16.04	6.80	0.00	0.52
P. polystachion	0.75	2.48	6.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.66	1.54	0.00	7.59	0.00	5.66	0.00	0.00	0.00
E. cyathophora	0.00	5.45	4.15	14.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
S. rhombifolia	0.00	0.00	0.00	1.68	3.67	1.06	11.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.09
C. aciculatus	0.00	0.00	3.11	0.00	0.00	0.00	0.00	0.00	0.00	9.50	0.00	0.00	0.00	0.00	5.06	0.00	0.00	0.97	0.00	0.00
M. charantia	0.00	0.00	0.00	0.00	5.50	1.60	0.00	0.00	0.00	6.50	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.00
C. hypericifolia	3.40	0.00	0.00	0.00	1.83	6.38	0.00	3.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C. barbata	0.00	0.00	0.00	0.00	3.21	6.38	0.00	3.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Sites-1: Mangilao, 2: Yigo, 3: Dededo, 4:Tumon, 5: Tamuning, 6: Agana Heights, 7: Mongmong-Toto-Maite, 8: Barrigada, 9: Yoña, 10: Talofofo, 11: Malojloj, 12: Merizo, 13: Umatac, 14: Agat, 15: Piti, 16: Asan, 17: Inarajan, 18: Santa Rita, 19: Hagatña, 20: Ordot-Chalan Pago.

Table 4. Invasive plant occurrence (acres) for the different habitat types on Guam

Species	Agricultural	Forest	Residential	Roadside	Vacant lot
B. alba	14,472	11,824	2,112	13,677	3,882
P. maximum	673	0	160	13,963	416
S. jamaicensis	1,346	7,590	622	268	184
A. leptopus	0	0	1,023	4,281	52
P. paniculatum	0	0	0	5,150	0
M. floridulus	1,571	2,336	174	3,289	0
E. heterophylla	0	362	75	3,644	49
C. odorata	449	1,520	267	1,957	464
M. micrantha	0	10	642	1,564	0
S. nodiflora	0	6,633	0	0	0
C. hirta	0	774	237	699	0
M. pudica	561	324	106	1,108	160
L. leucocephala	337	228	56	2,783	0
P. polystachion	561	1,266	94	1,484	179
E. cyathophora	1,234	942	0	0	0
S. rhombifolia	0	15	349	7	0
M. charantia	0	0	150	1,175	0
C. aciculatus	0	709	0	1,316	0
C. hypericifolia	0	223	50	42	179
C. barbata	0	0	87	380	214

spegazzinii, imported from the South Pacific Commission to Guam and other Pacific islands for its control.

4. Although a moth, *Pareuchaetus pseudoinsulata,* was established on Guam in 1985, followed by the gall fly *Cecidochares connexa,* their host, *C. odorata,* is still among the top eight invasive weeds on Guam. Therefore, *P. pseudoinsulata* should be mass reared and released at various locations on Guam; this defoliating moth will suppress *C. odorata*.
5. Glyphosate/Roundup, 2,4-D, dicamba, and triclopyr appear to control most of the top 20 invasive plants on Guam, so the Guam Department of Agriculture should work with the University of Guam to register these chemicals with the U.S. Environmental Protection Agency for use on these weeds. The recommended mechanical control methods can be applied without regulation, but chemical applications and biological-control agents must comply with legal requirements.
6. The public should be educated about the danger of introductions and encouraged to use native species instead. The public should also be made aware that the immediate control or eradication of invasive species, even if it involves the

use of herbicides, may be the best alternative. A public education al program must therefore be instituted. The Guam Department of Agriculture should plan such a program in collaboration with scientists from the University of Guam and should request funding for it.

7. Funds should also be requested for a joint training session/workshop, for foresters, land managers, extension agents, quarantine officers, and other interested individuals and organizations, on the recognition, exclusion, eradication, and control of invasive plant species. Its goal should be to foster cooperation and joint action against invasive species.
8. Species like *S. nodiflora, E. cyathophora, M. charantia, C. aciculatus, C. hypericifolia,* and *C. barbata,* although among the top 20 invasive plants on Guam, may not be presently causing serious damage to wildland ecosystems, but they are certainly not desirable species. Management practices must be developed immediately that prevent their further spread.
9. Now that the 20 most widespread invasive species have been identified, individual species of concern should be more carefully evaluated as to extent, invasiveness, and the possibility for additional control or eradication methods.
10. Special measures should be developed for *A. leptopus, B. alba, P. maximum, M. micrantha, C. odorata,* and *S. jamaicensis*. Their incidence should be monitored, and measures for their eradication or control should be taken immediately.

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