Project Report
March 16, 2005

Survey of Invasive Exotic Plant Species in Conservation Areas on Oahu, Hawai'i

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Introduction

The spread of invasive species is cited increasingly as a major threat to the integrity of native ecosystems and to the persistence of threatened and endangered species (Mack et al. 2002, Sala et al. 2000). Control of weeds and their alien vectors are top priorities for managers of wildlands and conservation areas throughout the United States and particularly in Hawai'i (Loope and Mueller-Dombois 1989). Almost half of the flora of Hawai'i is naturalized exotic species, approximately 1100 species. Although we have county records for most of these species, their impacts on natural areas are for the most part undocumented. There is a need to identify those species that present the greatest ecological threat to prioritize species for control and to encourage limitations in their use for horticultural or forestry purposes. To effectively deploy scarce resources, forest managers should target those species posing the most severe threats to endangered species and natural areas.

In Hawai'i, it is believed that some 90 species of exotic weeds are invasive in native ecosystems (Smith 1985). While we have available several lists of alien plants believed to threaten natural areas in the state, we lack documented information on the distribution, abundance, and impacts of those species; on which of our native ecosystems are most heavily affected; and on the severity of the problem. Further we suspect that the we have underestimated the number of species constituting a significant threat to natural areas. Periodic weed surveys would allow us to track the spread of invasive species, identify incipient problems, and assess the scope and magnitude of impacts. In addition they would provide a basis for developing action priorities and support for funding requests.

In the absence of resources to conduct island- or state-wide ground surveys, we sought information available from agencies and land managers charged with management and conservation of natural areas in the state. In its absence, estimates of distributions and abundances of weeds by experienced land managers and their staffs provides an excellent, but largely untapped, source of information on invasive species to support planning efforts.The objective of the survey was to compile information on naturalized exotic plants on lands being managed or restored for conservation purposes. Such a survey might also form the basis for more intensive ground- or aerially-based evaluations of weed infestations in subsequent years.

We proposed to gather this information through interviews of resource managers of conservation lands in an MS Excel format that can easily be imported into other programs for data summarization, analysis and visualization. As originally conceived, surveys were to be conducted state-wide. However, such a wide scope proved to be

beyond the resources budgeted. Therefore we confined the survey to natural areas on the island of Oahu and report those results here. This pilot survey reveals limitations in the data available and suggests modifications in protocol for a statewide effort. We developed a summaries of the results for easy access and analysis and provide tables linked with ArcGIS/ArcMAP for ease in visualization of the distribution and abundances of weed patterns.

Compiled results will be returned to all participants in the form of GIS distribution maps and summary analyses. The information also will be posted on the web and made available to agencies, island-based committees, and managers. Raw data will be available on request as well. Julie S. Denslow was the FS Technical Representative. David Duffy of Pacific Cooperative Studies Unit, Dept. of Botany, Univ. of Hawai'i at Manoa was the principal investigator for UH. Several graduate students participated in the project (Table 1). However, two in particular were largely responsible for its successful completion. Veronica Hotton (Dept. of Geography, L. Wester advisor) helped to design and construct the interview materials and conducted the majority of the interviews. Tim Edmonds (Dept. of Botany, D. Drake advisor) performed the final data quality checks, prepared finished data sets, ran initial analyses, and constructed the GIS relational databases.

Objectives

1. Develop and refine an MS Excel-based survey instrument to collect information on the distribution, abundance, and impacts of invasive weeds at the level of the land management unit and collect relevant environmental, management and spatial information on each management unit.

2. Conduct interviews of managers or other designated staff for conservation areas on Oahu to collect information on weed distribution and abundance and on environmental, management and spatial characteristics of each management unit surveyed.

3. Incorporate quality control procedures during the initial and subsequent phases of the process to ensure that the data are appropriate, complete, and accurate.

4. Provide information collected from the surveys in a form accessible and useful for a variety of stakeholders, including land managers and state and federal agency personnel.

Methods

Geographic scope. We limited surveys in this phase of the study to lands managed for the conservation and restoration of native plant communities. These included state, federal, and private ownerships and lands managed as wildlife refuges, natural area reserves, state parks and forestlands and private conservation areas.

Environmental descriptions. Some information on habitat descriptions, such as vegetation type, were obtained in interviews with managers. Others were obtained by summarizing information from a variety of GIS files for each management area. Those sources are provided in Table 2. Summary statistics for individual polygons (land management units) were created using ArcGIS Zonal Statistics; the reliability of these synopses is unknown. Data should be checked for each management unit should be

confirmed before citing this information. It is provided here as a general reference only.

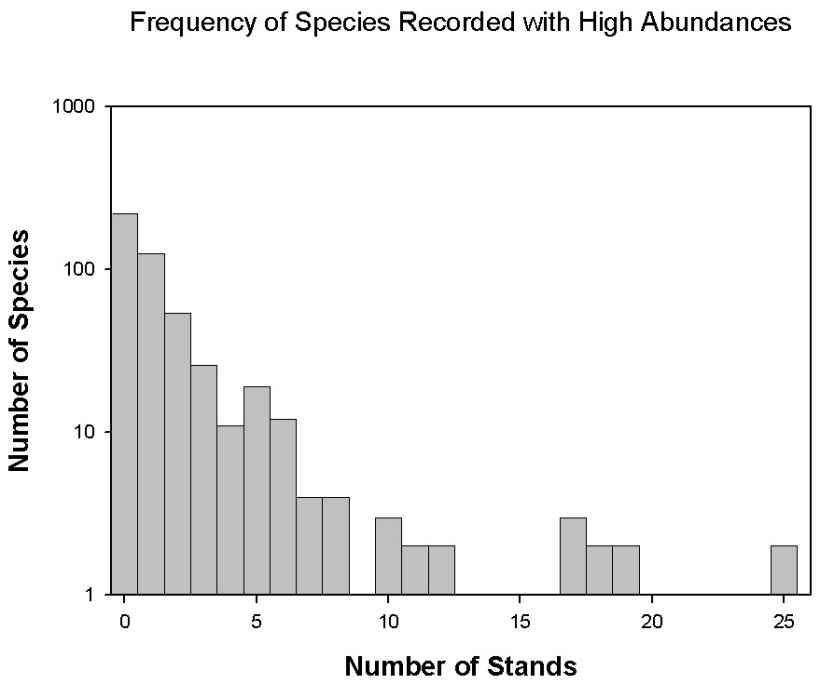
Species lists. After they agreed to provide information on exotic species in their management units, land managers were sent an information package that included a introductory letter explaining the rationale and approach of the study; a data form requesting information on the person interviewed, on the land management unit, and on each exotic species recorded from the management unit; and supporting information including definitions of terms and species lists with photographs where available. Copies of this information are provided in Appendices A-C. In most cases this information was provided digitally on CD as text and spreadsheet documents or as hardcopy as preferred. Completion of the data form was facilitated by the use of drop-down lists to standardize wording of the replies. Managers were presented with a list of approximately 90 species widely recognized as invasive in conservation areas in Hawai'i (Smith 1985). They were instructed to add to the list if necessary. We followed receipt of completed forms by telephone or on-site interviews with the land managers to resolve inconsistencies and identify missing information. Information on species characteristics presented in Table 4 were collected from Wagner et al. 1990 and from the following web sites: www.issg.org/database/welcome; www.hear.org/pier/species; plants.usda.gov/index.html; www.kew.org/searchepic/searchpage.do and www.fleppc.org/plantlist/03list.htm.

Results

We interviewed land managers responsible for 42 different management units on Oahu (Figure 1, Tables 4 and 5). The final species list completed from all 42 management units included 497 naturalized exotic species, 37 of which were identified only to genus. Management units ranged in size between 0.5 ha to over 9800 ha in size. Management objectives included watershed protection, public recreation areas, preservation of threatened and endangered species, waterbird habitat, and military reserves. A total of 31,400 ha was included in the 42 management units in the study. Mean annual precipitation varied between 496 and 7949mm in these units. Edmonds designed an impact index that combined scores for impact level, abundance and area affected. Habitat, range, and dispersal characteristics of species ranking highly on this index are provided in Table 4.

Raw data and summarized information as MS Excel and GIS files are available on the CD included with this report. A summary table (Appendix D) on the CD provides information on the abundance of each species in each management unit. Data also are presented as the number of management units (our of 42 total) for which the species is reported meeting specified levels of abundance, impacts, spread, and management strategy (Appendix E). Clearly, large units are likely to have more species than small units because large land areas tend to be more species-rich and encompass greater habitat diversity; we have made no attempt to standardize by size of the management unit or by heterogeneity of habitats for this reason. However this information on number of species recorded from each management unit can be calculated from data provided in Appendix D. Of the 497 species recorded, 277 species were recorded at high abundances at one or more management units, 211 species were seen to cause ecological damage due to competitive effects on native species or to alteration in ecosystem processes, and land managers report that they were actively controlling 173 species. Fifty-six species were recorded as abundant in at least 5 different management units (Figure 1).

Figure 2. Frequency distribution of species recorded at high abundances in different numbers of stands.



Data limitations

Information provided in these tables and files are subject to a number of limitations and therefore should be interpreted with caution. We had no way of confirming or cross checking identifications of species listed for each management unit and misidentifications remain a source of error for the database. Taxonomic nomenclature may not be current. We recommend that plants be vouchered and identifications confirmed before reporting distributions based on this database. At least 37 species are recorded only to genus; there may be some duplication with other species listed. Land units are heterogeneous, often with multiple management objectives. Large units in particular spanned multiple habitat types and wide elevational ranges. We cannot be certain always that data provided pertained only to those areas designated for restoration or restoration, although that was the intent of the survey. We are unable to assess invasibility as a function of habitat type for this reason. Species lists are likely to be incomplete as few managers have made thorough surveys of the exotic species present in the management units. Thus a better interpretation of the notation that a particular species is absent is that the species is unrecorded from that site.

In spite of its limitations, this survey provides one of the first island-wide assessments of the importance and distribution of naturalized exotic species in natural areas. It suggests that considerably more than 100 species are invasive in the sense that they are adversely affecting the ecology of land areas managed for conservation or restoration. The addition of data from similar surveys of the other main Hawai'ian

islands will undoubtedly further expand this list. This information should prove useful in identifying species likely to cause widespread ecological harm where they are yet in the early states of population expansion. This information should be useful in developign assessments of impacts and risks of invasiveness (Daehler et al. 2004). Species revealed to have significant impact on natural areas should not be used in landscape, agriculture or forestry plantings in the vicinity of conservation areas. Information provided here should contribute to impact assessments of species in the nursery trade.

Acknowledgments

I am grateful to all those who worked on the project in its many phases, but especially to the land mangers and their supervisors who provide the time and expertise to complete long survey forms. I particularly hope that the information available here will be useful to them. Graduate students at the University of Hawaii at Manoa made the vision of this survey a reality. Veronica Hotton and Tim Edmonds especially accomplished the lion's share of the work and not only were conscientious in carrying out their tasks but considerably improved the final outcome through the contribution of their creativity and imagination. Thanks also to UHM supervisors and administrators–David Duffy and the staff at the Pacific Cooperative Studies Unit, Lyndon Wester in the Department of Geography and Don Drake in the Department of Botany--who made the wheels run smoothly.

Literature Cited

Daehler, C. C., J. S. Denslow, S. Ansari, and H.-C. Kuo. 2004. A risk assessment system for screening out harmful invasive pest plants from Hawai'i and other Pacific Islands. *Conservation Biology*: 18:1-9.

Loope, L. L. and D. Mueller-Dombois. 1989. Characteristics of invaded islands, with special reference to Hawai'i. Pp. 257-280 in J. A. Drake, F. DiCastri, R. H. Groves, F. J. Kruger, H. A. Mooney, M. Rejmánek and M. H. Williamson (eds.) *Biological Invasions: A Global Perspective*. Wiley, New York.

Mack, R. N., D. Simberloff, W. M. Lonsdale, H. Evans and M. Clout 2002. Biotic invasions: Causes, epidemiology, global consequences and control. *Ecological Applications* 10:689-710.

Sala, O. E. Et al. 2000. Global biodiversity scenarios for the year 2100. 2000. Science 287:1770-1774.

Smith, C. W. 1985. Impact of alien plants on Hawai'i's native biota. pp 180-250. *In:* Stone, C. P. and Scott, J. M. (eds.) *Hawai'i's terrestrial ecosystems: Preservation and management*. University of Hawai'i Cooperative National Park Resources Studies Unit, Honolulu, Hawai'i.

Wagner, W. L., Herbst, D. R., and Sohmer, S. H. 1999. *Manual of the flowering plants of Hawaii*. University of Hawaii Press, Honolulu.

Table 1. Principle collaborators with their contributions and contact information.

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Table 2. Sources of habitat information for land management units.

Information type	Source	Notes	Web URL
Land cover	National Oceanic and Atmospheric Administration/ Coastal Services	Description of data and classification schemes	www.csc.noaa.gov/crs/lca/ccap.html www.csc.noaa.gov/crs/lca/tech_cls.html
Landsat image of Oahu	Hawaii Statewide GIS Program		ww.hawaii.gov/dbedt/gis
Temperature: Mean temperature Minimum temperature Maximum temperature	Climate Source	Resampled from 15 to 30 pixels	www.climatesource.com/hi/fact_sheets/fact_tmean_hi.html
Rainfall	National Cartography and Geospatial Center	Average annual ppt for 1961-1990; resampled from 15 to 30 pixels	www.ncgc.nrcs.usda.gov/proucts/datasets/climate/data/precipitation-state/hi.html
Oahu Outline	UHawaii Botany GIS Lab/PCSU		
Topography	UHawaii Botany GIS Lab/PCSU		
Topography-hill shade	UHawaii Botany GIS Lab/PCSU		
Polygons of management units	Land managers and their agencies provided		

Table 3. Persons interviewed for information on invasive exotic species on Oahu conservation areas. DOFAW=Hawaii Division of Forestry and Wildlife; HBWS=Hawaii Board of Water Supply; HIANG= Hawaii Army National Guard; HNHP=Hawaii Natural Heritage Program; RCUH=Research Corporation of the University of Hawaii; TNC = The Nature Conservancy of Hawaii; USFWS= US Fish and Wildlife Service; UHM= University of Hawaii at Manoa; USMC=US Marine Corp; USN=US Navy;

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Table 4. Oahu Pest Plant Survey. Land Management Units with habitat information. Ordered by manager.

Code	Name	Owner	Manager (1)	Area (ha)	Major Habitat	Min Elevation	Max Elevation	Mean Annual Precipitation (mm)	Land Cover (Percent) Grassland	Forest	Scrubland	Other	Management Objective	Weed Management Cost ($)
DILL	Dillingham Military Reserv.	federal_mil	Army	248.5	Coastal dry	0	157	842.1	21.1	2.3	51.3	25.3	Military, Conservation	10,000
KAHU	Kahuku Training Area	federal_mil	Army	3572.9	Lowland mesic	12	645	2915.6	2.6	55.4	42.0	0.1	Military, Conservation	25,000
KAWAC	Kawailoa Training Area, Castle Unit	private	Army	174.2	Montane wet	651	865	7949.1	0.3	65.0	34.7	0.0	Conservation	15,000
KAWAK	Kawailoa Training Area, Kahuku Cabin	private	Army	123.5	Montane wet	555	793	5809.5	0.1	60.2	39.7	0.0	Conservation	15,000
KAWAL	Kawailoa Training Area, Lower Peahinaia Unit	private	Army	74.4	Lowland mesic	496	669	6193.1	0.0	54.6	45.4	0.0	Conservation	25,000
KAWAM	Kawailoa Training Area & Schofield East	private	Army	9830.1	Lowland mesic	149	782	4046.3	1.0	56.7	41.7	0.6	Military, Conservation	100,000
KAWAP	Kawailoa Training Area, Poamoho Unit	state & private	Army	247.8	Montane wet	466	809	6570.0	0.0	48.1	51.9	0.0	Conservation	15,000
KAWAU	Kawailoa Training Area, Upper Peahinaia Unit	private	Army	255.5	Montane wet	615	866	7156.9	0.0	57.8	42.2	0.0	Conservation	50,000
MAKUK	Makua Military Reserv., Kahanahaiki Unit	federal_mil	Army	44.1	Lowland mesic	428	709	1551.3	0.0	30.7	69.3	0.0	Conservation	70,000
MAKUL	Makua Military Reserv, Kaluakauila Unit	federal_mil	Army	20.4	Lowland dry	189	474	828.1	0.0	0.0	100.0	0.0	Conservation	50,000
MAKUO	Makua Military Reserv., Lower Makua Unit	federal_mil	Army	106.1	Lowland dry	237	672	1609.3	0.0	10.7	89.3	0.0	Conservation	50,000
MAKUM	Makua Military Reserv.	federal_mil	Army	1543.5	Lowland mesic	0	908	1271.1	14.9	6.7	75.8	2.6	Military, Conservation	200,000
MAKUH	Makua Military Reserv, Ohikilolo Unit	federal_mil	Army	15.4	Lowland mesic	669	902	1553.9	4.8	0.0	81.9	13.3	Conservation	75,000
SCHOW	Schofield Military Reserv., Schofield-Waikane	state	Army	308.2	Montane wet	477	783	6609.2	0.6	30.9	68.5	0.0	Conservation	15,000
SCHOE	Schofield Military Reserv., W & S Train	state	Army	3521.2	Lowland mesic	146	1231	1392.8	17.7	21.9	42.7	17.8	Military, Conservation	60,000
KAAL	Kaala NAR	state	DOFAW	440.2	Lowland mesic	353	1232	1693.7	0.0	8.5	87.4	4.1	Conservation	-1

Code	Name	Owner	Manager	Area (ha)	Major Habitat	Min Elevation	Max Elevation	Mean Annual Precipitation (mm)	Land Cover (Percent) Grassland	Forest	Scrubland	Other	Management Objective	Weed Management Cost ($)
KAEN	Kaena Point NAR	state	DOFAW	4.4	Coastal dry	0	12	679.1	0.0	0.0	2.1	97.9	Conservation	-1
PAHO	Pahole NAR	state	DOFAW	266.4	Lowland mesic	315	778	1502.5	0.0	39.7	60.3	0.0	Conservation	-1
THRE	Three Points Sanctuary	state	DOFAW	1.0	Lowland mesic	794	851	1757.1	0.0	8.3	91.7	0.0	Restoration, Conservation	-1
FTRU	Ft Rugger Diamond Head	state	HIANG	197.9	Coastal wet	19	223	946.3	10.7	0.0	72.5	16.7	Conservation, Education	41,000
HARL	Lower Battery Harlow Diamond Head	state	HIANG	0.4	Coastal dry	50	56	1040.9	20.0	0.0	40.0	40.0	Conservation, Education	-1
NPLD	NPLD Wetlands Diamond Head	state	HIANG	1.4	Coastal dry	89	89	899.3	66.7	0.0	13.3	20.0	Education	-1
WETL	Wetland Diamond Head	state	HIANG	2.8	Coastal wet	89	89	903.4	14.7	0.0	85.3	0.0	Conservation	0
KALI	Kalihi	county	HWB	513.9	Lowland mesic	126	823	2994.3	1.2	43.5	54.5	0.8	Unknown	-1
MAKA	Makaha	county	HWB	1632.1	Lowland mesic	11	1195	1432.7	2.8	22.4	74.5	0.4	Unknown	-1
MANO	Manoa	county	HWB	149.9	Lowland mesic	87	674	2476.5	0.1	44.5	55.1	0.3	Unknown	-1
PALO	Palolo	county	HWB	148.8	Lowland mesic	297	746	2323.7	4.8	7.8	87.4	0.0	Unknown	-1
WAIH	Waihee	county	HWB	4.7	Lowland mesic	55	86	3137.1	1.9	78.8	19.2	0.0	Unknown	-1
KAWAI	Kawai Nui Marsh	state	DOFAW	274.4	Lowland wet	0	13	1447.8	8.5	2.1	17.0	72.4	Restoration, Conservation	-1
BELL	MCBH Bellows	federal_mil	USMC	604.3	Coastal dry	0	111	1274.2	6.4	19.9	56.4	17.3	Conservation	-1
NUUP	Nuupia Ponds	federal_mil	USMC	152.7	Coastal dry	0	14	1199.3	2.0	1.7	15.5	80.8	Conservation	-1
ULUP	Ulupau Head	federal_mil	USMC	10.1	Coastal dry	0	93	1228.5	43.0	0.0	47.4	9.6	Bird Habitat	-1
LUAL	Lualualei Valley	federal_mil	USN	3325.1	Lowland mesic	22	949	966.7	3.2	8.1	79.9	8.8	Military, Conservation	4,300
WAHI	Wahiawa	federal_mil	USN	77.7	Lowland mesic	276	392	2280.2	15.9	36.2	35.6	12.4	Military, Conservation	0

Code	Name	Owner	Manager	Area (ha)	Major Habitat	Min Elevation	Max Elevation	Mean Annual Precipitation (mm)	Land Cover (Percent) Grassland	Forest	Scrubland	Other	Management Objective	Weed Management Cost ($)
HONON	Honululi Preserve	private	TNC	1458.9	Lowland mesic	317	942	1097.8	1.4	22.6	76.0	0.0	Restoration, Conservation	24,000
LYON	Lyon Arboretum Restoration Area	state	UHM	17.4	Lowland wet	223	512	2948.7	0.0	12.8	87.2	0.0	Restoration	2,000
HONOU	Honululi	federal_non mil	USFW	10.6	Lowland wet	0	3	538.6	20.7	0.8	1.7	76.9	Bird Habitat	36,000
KALAE	Klaeloa	federal_non mil	USFW	15.2	Coastal dry	1	3	496.0	8.7	10.4	40.5	40.5	Conservation	-1
KII	Kii	federal_non mil	USFW	46.2	Lowland wet	0	4	1462.0	8.6	2.4	26.7	62.2	Bird Habitat	-1
PUNAM	Punamano	federal_non mil	USFW	15.8	Lowland wet	0	2	1536.7	2.3	5.6	19.2	72.9	Bird Habitat	20,000
WAIAW	Waiawa	federal_non mil	USFW	9.3	Lowland wet	0	1	573.1	1.9	1.0	23.8	73.3	Bird Habitat	1,000
WAIP	Waipio	federal_non mil	USFW	1932.4	Sub-alpine wet	254	845	5464.4	0.5	41.0	58.5	0.0	Conservation	-1

(1) DOFAW=Hawaii Division of Forestry and Wildlife; HBWS=Hawaii Board of Water Supply; HIANG= Hawaii Army National Guard; HNHP=Hawaii Natural Heritage Program; RCUH=Research Corporation of the University of Hawaii; TNC = The Nature Conservancy of Hawaii; USFWS= US Fish and Wildlife Service; UHM= University of Hawaii at Manoa; USMC=US Marine Corp; USN=US Navy