

Miconia control on Hawaii Island: NFWF Project Report and Recommendations

April 6, 2007

Julie S. Denslow¹, Jean Franklin², Anne Marie LaRosa¹ and Melora Purell²

¹Institute of Pacific Islands Forestry, USDA Forest Service, Hilo, HI 96720

²Big Island Invasive Species Committee, Hilo, HI 96720

I. Introduction

Miconia calvescens DC (Melastomataceae) was first introduced from Central America to Hawaii Island in the 1960's as an ornamental tree in the nursery trade. It rapidly naturalized from multiple early planting locations, primarily on the windward side of the island with isolated populations in north and south Kona. Particularly high densities were reached around Onomea Bay north of Hilo. In the 1990's the threat posed by this species came to the attention of conservationists and land managers familiar with its devastating impact in French Polynesia where it thrives under similar environmental circumstances (Meyer 1998, Medeiros and Loope 1997). The Big Island Invasive Species Committee (BIISC), originally formed in 1995 as the Big Island *Miconia* Action Committee (BIMAC) to focus attention on this pest, has been the principle entity responsible for its control on the Island of Hawaii.

The size and distribution of the *Miconia* population, its ease of spread and the magnitude of effort devoted to its control mandate periodic evaluations of the effectiveness of BIISC's efforts. An opportunity became available in 2004 as a grant from the National Fish and Wildlife Foundation to assess progress to date and to recommend revisions in the current management protocol for future efforts. Here we report the results of that effort. The evaluation was based on four primary sources of information: 1) evaluation and analysis of data on trees and saplings treated between 1996 and 2006; 2) resurveys of selected treatment blocks in 2005-2006; 3) 2005-2006 surveys via transects of 50 x 20m blocks distributed upland of the core population; 4) 2006 helicopter surveys of gulches and upland areas.

II. History of *Miconia* control on Hawaii Island

While eradication of *Miconia* was the objective of control efforts on other Hawaiian islands, BIISC focused on eradication of outlier populations, containment, and protection of priority natural and agricultural areas in the hopes of buying time to develop an effective biological control agent (Leialoha, 1997; BIISC Strategic Plan, 2000, 2002, 2004 drafts). In 1997 BIMAC estimated that 450,000 acres, about half on State land, were at risk of *Miconia* invasion. Control focused on the following efforts: 1) Increase public awareness and involvement in *Miconia* control through media and public information campaigns. 2) Open a *Miconia* hotline to receive reports of *Miconia* sightings; 3) Establish and monitor the distribution of *Miconia* on Hawaii Island through

public sightings and through ground and helicopter surveys. 4) Maintain a database to track and evaluate this information.; 5) Control/eradicate *Miconia* populations through a combination of mechanical removal and chemical treatment followed by repeated visits to control plants establishing from the seed bank; 6) Initiate research and development of effective biocontrol agents targeting *Miconia*.

On the ground, *Miconia* was controlled by basal bark herbicide (20% Garlon (tricyclopyr; Dow Chemical) in forest crop oil) or thin line herbicide (100% Garlon) applied directly to the trunk without cutting or frilling. The effectiveness of this treatment was established in field herbicide trials conducted by Duane Nelson (USDA FS) in which high kill rates and rapid knock down with no resprouting were observed (D. Nelson pers. comm.). *Miconia*'s thin tight bark permits rapid absorption of herbicides so that cutting, frilling and notching are not necessary. On windward Hawaii, stems greater than 3 ft tall were targeted. On leeward Hawaii, stems greater than 1 ft tall were targeted (L. Nelson pers. comm.). In practice, the field crews sometimes targeted seedlings as well.

Priority was given to isolated and outlying populations followed by peripheral plants in large populations. Finally flowering individuals in the core population were targeted to reduce spread by seed contamination of shoes and vehicles. All treated sites were to be monitored at regular intervals, eliminating missed individuals and newly established seedlings. Information on location and number of individuals treated and effort expended was to be maintained in a computer database. Crews were to place particular emphasis on phytosanitary practices to reduce introduction of *Miconia* seed into non-infested sites. In practice, blocks were visited at varying intervals, with no systematic revisit program implemented. For logistical and record keeping purposes, the infested area was divided into treatment plots or blocks (L. Nelson pers. comm.). Treatment records and control efforts and priorities were to be referenced to these blocks. In practice, use of the blocks for management was haphazard; surveys and treatments within the blocks often did not accomplish control of the complete block. Repeated visits often resurveyed areas previously visited but did not completely survey the entire block (L. Nelson pers. comm.). Evaluation of *Miconia* control on Hawaii Island as presented in this report thus is an evaluation of methods and strategies as applied in practice rather than as designed.

III. Methodology

A. *Miconia* ecology

Miconia calvescens DC (Melastomataceae) is a small tree 18-36 ft (45 ft) tall whose native range is southern Mexico to southern Brazil. However the purple-leaved form seen in Hawaii seems restricted to the northern portion of the range (southern Mexico to Costa Rica). Leaves are large (to 32 x 12 in) and, in the Hawaiian form, purple on the underside. Reproduction is via small bee-pollinated or cleistogamous flowers which produce small fleshy fruits with numerous small seeds. Meyer (1998) reports that a mature tree bearing 200 panicles of fruits can produce more than 8,000,000 seeds in a single season. Individual plants may flower 3 times a year. Meyer (1998) and Medeiros

et al (1997) provide details on *Miconia* biogeography, ecology and reproductive biology. *Miconia calvescens* is shade tolerant and forms high density thickets. Its large leaves cast a dense shade, effectively eliminating understory vegetation. Rapid decomposition rates of the litter combined with a sparse understory in *Miconia* stands expose top soil to surface erosion, although actual impacts of *Miconia* on slope stability as yet are undocumented.

B. Potential range of *Miconia* on Hawaii Island

We projected the potential range of *Miconia* on Hawaii island using two approaches. Data on the known range of *Miconia* in Tahiti (Meyer 1998) were used to project potential habitat area falling below 4300 ft and receiving more than 80 in annual rainfall.

Secondly, we used the niche-distribution program GARP (Genetic Algorithm for Rule Set Production, Stockwell and Peters 1999) to project the potential habitat range in Hawaii based on known occurrences of *Miconia* in the state. GARP uses an iterative process to incorporate GIS-based information on elevation, precipitation, slope and windwardness and known *Miconia* locations to develop a set of rules describing constraints on the distribution *Miconia* in the state. We used 1647 geo-referenced presence points collected between 1996 and 2006 and provided by the Invasive Species Committees statewide. Where presence points were highly spatially autocorrelated, e.g., in east Maui, one point was chosen haphazardly to represent each 100-m grid cell. The inputs into GARP for this model were the presence points along with four environmental layers, all projected in WGS 1984 geographic projections as ASCII raster grids created by the GARP Datasets extension in ArcView 3.3. An annual rainfall raster was interpolated from rainfall isohyets from the Hawaii Statewide GIS website using the “Topo-to-Raster” tool. Elevation was derived from the 10-m DEM from NOAA, re-projected to 100-m resolution. We used the slope tool in ArcMap and the 100-m DEM to derive slope; it was reclassified to adjust for z value in meters and x, y in decimal degrees. Windwardness was derived from the aspect tool in ArcMap then reclassified to values between 180 for NE and 0 for SW.

We used the “best subsets” approach to running GARP because it has been shown to accommodate the asymmetry in the input data (only presence points are used) as well as the stochastic elements of the iterative process. In running the GARP model we used all points as training points and chose 10 models that had a low omission error (<2% of presence points incorrectly predicted) and a commission index (23% of the map predicted as presence) close to the median of low-error models. The resulting 10 map files were added together in GIS producing a raster file which had cell values that represented the total number of maps which predicted each cell as present. Values ranged from zero, in which all 10 maps predicted absence, to 10, in which all 10 maps predicted presence. The resulting maps show predicted *Miconia* presence where at least 8 maps predicted presence. Details of the modeling process are provided in Appendix 1.

C. Estimated Current Distribution of *Miconia*.

Information from control operations. Between 1996 and 2006, BIMAC/BIISC collected detailed information from field crews on the number of trees and saplings killed and of the amounts, kind and application rate of herbicides used and worker hours expended. All field activities were geo-referenced. Data from each day's activity were recorded by blocks, areas established early in the development of the database to provide a reference for directing field crews and recording information. Block boundaries were roads, property boundaries, topographic features, water courses and the like. They were defined uniquely by and for BIISC and do not correspond well to TMKs.

High-priority blocks for *Miconia* control were located within 1500ft of reproductive trees or populations located on the upland perimeter of the core *Miconia* infestation centered on Onomea Bay and Hilo. However, correspondence to a 1500-ft perimeter zone was only approximate; control blocks extended beyond the 1500-ft radius and blocks fell within 1500 ft of more than one reproductive population. Perimeter reproductive populations were originally identified from public surveys and by ground and helicopter surveys. Block sizes ranged over five orders of magnitude (0.07-543.74 ac). To correct for this variation in sample sizes, small contiguous blocks were combined where possible to form units 24.7-123.5 ac in size. The new units are called "big blocks" and all subsequent analyses are referenced to them. We analyzed 879 blocks in the database analyzed ranging in size from 0.1-543.7 ac (Table 1).

In addition to data on *Miconia* densities, we also referenced information on mean slope and vegetation cover classes to the big blocks. The Hawaii Natural Heritage Program used a digital elevation model (DEM, State of Hawaii Office of Planning) to calculate slopes per pixel which were then averaged over the total area of the big block. Vegetation cover class data (NOAA, Coastal Services Program) were summarized as percent cover by big block in 7 classes: 1) grassland, scrub or shrub cover, 2) wetlands, 3) cultivated land, 4) deciduous or evergreen forest, 5) high or low intensity development, 6) coastal, 7) unclassified. We provide summaries of proportions of the big blocks in categories 1, 3, and 4 (Figure 1).

Limitations to the BIISC database. Although plants smaller than 3 ft were not targeted under BIISC's operation plan, they were sometimes killed and the information added to the database. Because seedling control was not systematic, these data were excluded from subsequent analyses. We combined data on trees and saplings treated.

The operating guidelines (L. Nelson pers. comm., D. Nelson pers. comm., Leialoha 1997) call for revisits regular intervals to monitor regrowth and to kill any new pre-reproductive individuals larger than 3 ft tall. In practice, sites were revisited at irregular intervals and with varying effort. Multiple visits were often required to completely treat a block and revisits were at inconsistent intervals. In general blocks were not systematically nor completely swept for *Miconia* plants at each revisit. Thus database information on *Miconia* plants killed in subsequent visits were not good estimates of plant regrowth on each block. For this reason we used all records of plants killed on a

block between 1996 and 2006 to estimate historic *Miconia* density on the plots, recognizing that some of these plants represent regrowth.

Some data records were incomplete or otherwise not referable to single blocks. These records were not included in the data summary. This factor contributes to an underestimate of *Miconia* densities and perhaps of distributions as well.

Analysis. Data from the BIISC *Miconia* monitoring big blocks between 1996-2006 (big_blocks_masterdata_rygh05, 498 polygons) were converted to geographic centroids and interpolated using the Inverse Distance Weighted (IDW) method based on density of *Miconia* trees (adults and sapling) using a 100-m cell size. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart. To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance. Centroids of blocks used to perform this analysis were overlain to visualize actual data points where values were calculated. Included in the analysis were data from the 14 re-surveyed blocks and the 285 20-x-50m strip transects at the upland edge of the infestation.

D. 2005-2006 *Miconia* distribution

i. Resurveyed blocks. Inconsistent application of the survey protocol precluded use of resampling information to estimate impacts of control efforts on most plots (see Data Limitations above). Nevertheless we were able to identify 14 plots (3 leeward and 11 windward) in which track logs indicated that protocol had been followed and that the sites were completely surveyed during 1996-2004. These sites were resurveyed in 2005-2006 for all *Miconia* saplings and trees. Results of the two surveys were compared to assess impact of the control protocol on *Miconia* populations.

ii. Transect surveys beyond known populations. We conducted ground surveys of 296 20-x-50-m strip transects distributed in a stratified random manner upland of the known *Miconia* populations. Our objective was to detect evidence of the upland spread of seedlings and saplings beyond the focal areas for control.

iii. Helicopter surveys. Aerial surveys (38 hours) were conducted in 2005-2006 throughout the known range of *Miconia* on eastern Hawaii Island. Flight lines targeted gulches and areas above known population concentrations.

E. Estimates of costs and effort

We estimated worker days necessary to treat an acre infested with *Miconia* using 2006 data collected from the 14 completely surveyed and resurveyed blocks described above. These were the only blocks for which we were confident that acres surveyed and

treated matched the spatial area of the blocks. We used cost estimates and total acres surveyed from the FY2006 BIISC budget to estimate costs per acre surveyed and treated.

IV. Results

A. Potential range of *Miconia* in the Hawaiian Islands. Projections of the potential ranges of *Miconia* on Hawaii Island are provided using published information on elevation and rainfall limits from Tahiti (Meyer 1998; Figure 2) and from GARP modeling based on known occurrences in the State of Hawaii (Figure 3). The GARP predicted range is somewhat narrower than that predicted from Tahiti data; maximum elevations in the GARP model are 2000-3000 ft depending on other environmental parameters vs 4,300 ft from the Tahiti data. Over much of the windward coast, the GARP model predicts an upper elevation limit of approximately 2500 ft. GARP predicts tolerance of somewhat drier conditions as well.

Both data sets are limited, although for different reasons. The Tahiti data pertain to *Miconia* populations on potentially different substrates at a lower latitude (17°33' S) than Hawaii (19° – 20°15' N). Estimations of upper elevation temperatures from adiabatic lapse rates (6.5°C/1000m elevation) suggest that mean annual temperatures at the upper limit of *Miconia* in Tahiti are approximately 17.6°C and in Hawaii 18.5-20.7°C. The GARP projections are based only on occurrences of *Miconia* within the State of Hawaii where *Miconia* may not yet have reached its physiologically tolerable limits. In either case an examination of the current distribution with potential ranges indicate the suitability of unoccupied habitat in the Kau region, south Puna, the northern Hamakua coast and windward Kohala as well as somewhat higher elevations in the Hilo, Onomea, and north Puna areas.

B. Big block characteristics.

Bar graphs (Figure 1, a-f) provide an overview of big blocks as the number of blocks exhibiting different characteristics. Labels on the x-axis represent the upper bound of the data range represented in the bar. Combining blocks largely eliminated the smallest blocks such that the majority of the big blocks are from 2.5-123.5 ac in size. The mean slopes of the big blocks are generally less than 30%, although some very steep areas occur around gulches. This analysis assumed that big blocks were completely surveyed; thus stem densities were estimated as stems killed divided by big block area. Most big blocks surveyed had low densities of *Miconia* (<25 stems/ac) and on about half of those sites, no *Miconia* are recorded. However, there are pockets of high density sites. Few big blocks had significant (>20%) coverage in agriculture. Most vegetation coverage was in forest or grass/shrubland, likely fallow cane fields. Table 1 provides summary statistics on *Miconia* control efforts over this period.

C. Distribution and density of *Miconia* (1996-2006).

i. Block re-surveys. We used 2005-2006 re-survey data from 14 blocks for which we were confident that 1996-2004 data represented complete spatial surveys to estimate

effects of control efforts on *Miconia* population densities. Statistics on trees and saplings killed and work hours expended for the original survey and for the re-survey of these 14 blocks are provided in Table 2. In neither leeward nor windward plots was there a significant change in *Miconia* stem density as a result of the control effort (leeward: Student's $t = 1.004$, $v=4$, ns; windward: $t= 0.247$, $v=20$, ns). These data suggest that BIISC has been unable to eliminate outlier populations or to reduce their densities.

ii. Estimated current density distribution. We present estimates of the 1996-2006 distribution of *Miconia* on eastern Hawaii Island in two forms. Data on numbers of *Miconia* saplings and trees killed per block are presented in Figure 4. Because block sizes vary, these data do not represent differences in density.

In Figure 5, we assume records of trees and saplings killed between 1996 and 2006 are a reliable basis for estimating current relative densities of *Miconia* in the big blocks. We also assume that blocks were completely surveyed to estimate the density of stems treated. These assumptions are based on results from the re-survey data presented above and from observations of BIISC staff that areas which previously supported high densities of *Miconia* continue to do so.

This projection should be interpreted with caution because of the data limitations discussed above. In addition, different parameters applied to the interpolation algorithm can produce strikingly different maps. We have been conservative in applying the interpolation to landscapes for which we have data and in specifying parameters that do not extrapolate far beyond the sample points. The resulting map (Figure 5) delineates a landscape in East Hawaii in which *Miconia* is widespread at low densities with multiple hot spots at Hilo, North Puna, Kurtistown-Mountain View, Paho, Nanawale, Onomea Bay, Hakalau, and Ninole.

iii. Aerial surveys. Figure 6 provides information from 2005-2006 aerial (helicopter) surveys based on track logs and GPS locations of sighted populations of *Miconia*. A 50m buffer is assumed to calculate area surveyed. *Miconia* visible above the canopy are widely distributed below 4000 ft elevation north of Hilo and in the S. Puna district. Many of these sightings are in gulches where BIISC has not been able to apply effective control treatments.

D. Costs of control

Data from Table 2 (2006 re-survey) suggest that at low stem densities (<40 stems/acre) ca. 1.52 ± 1.04 worker hours/acre (0.19 worker days/acre) are needed to survey *Miconia*. Data from 1999-2000 for *Miconia* survey and control operations at Honalo and Honaunau (Kona district) suggest an average of 0.16 worker days/acre for low density infestations (J. Leialoha and L. Nelson, pers. comm.). At an average salary cost of \$126/day (average FY06 field crew salary + fringes; BIISC records), field salary costs are projected to be \$22.05/acre for *Miconia* survey and control. This estimate does not include costs of travel time, vehicles, supplies, administration, sick and annual leave, training, database management, etc. Better estimates are needed of worker efforts to treat

and control *Miconia*. These data likely do not reflect effects of high *Miconia* densities and may not reflect dense vegetation or difficult terrain because they are not random samples of *Miconia* control efforts. They likely underestimate average worker efforts to control *Miconia*.

BIISC records (J. Leialoha, pers. comm.) indicate that \$682,909 (72%) of the BIISC budget was spent on *Miconia* survey and control in FY 2006. Of that amount (minus costs of aerial surveys: \$28,779), \$654,130 was spent on ground and roadside survey and treatment of 1742 acres at a cost of \$375/acre. This figure includes all ancillary costs, including training, travel, leave, administration and database management.

V. Synthesis, conclusions, recommendations.

A. Current status. The limitations of our database constrain our ability to evaluate the current density distribution of *Miconia* to broad generalities. Remeasurement data suggest that BIISC control methods as applied may have limited increases in sapling and tree density on the control blocks, but we do not see evidence that BIISC has been able to eliminate outlier populations or decrease *Miconia* density under this protocol. On the windward side of Hawaii island, projection of the current density distribution of *Miconia* suggests numerous hot spots of high density and potentially widespread low density infestations.

The potential habitat range as projected by GARP suggests that *Miconia* impacts may be limited to elevations below 2500 to 3000 ft. While there is some possibility that this range restriction reflects only a dispersal-limited rather than a physiologically limited population distribution, we believe this is unlikely given the high potential for dispersal and the abundance and distribution of reproductive adult trees revealed by the aerial surveys. Adult trees (detected by helicopters) are common in gulches throughout the north Hilo area, providing a source of seed to upland forests. BIISC has not been able to implement an effective control strategy for these gulch populations.

We were unable to evaluate the effectiveness of the BIISC protocol as designed because it was inconsistently applied. Survey blocks often were not completely surveyed and treated nor were they retreated at regular predefined intervals. Other blocks were visited multiple times, but with incomplete information on area covered. Data were lost because we were unable to associate records with survey blocks. We do not know what proportion of stems are missed or not killed by the herbicide application. We suspect that the risk of missing plants is high because vegetation cover in the treatment area can be dense and difficult to access, but were not able to provide a useful evaluation. Costs of *Miconia* control range between \$22 and \$375/acre depending on the costs included in the estimate.

Figure 7 combines information from these analyses to reflect current and potential distributions of *Miconia* together with its potential range against the locations of public and private forest reserves. Conservation areas under the most severe threat from *Miconia*

include several lowland wet forests in the Puna district, the newly declared Natural Area Reserve of Wao Kele o Puna, and Laupahoehoe Natural Area Reserve on the Hamakua coast.

B. Recommendations. The foregoing analysis and discussions with BIISC staff and committee members suggest the following recommendations:

1. Field crews should carefully follow pre-determined protocol regarding treatment methods, target areas, and data collection. We recommend development of a manual detailing recommended protocol for survey, control, and data collection so that BIISC can be confident that protocols are being followed and so that new field crew members can be efficiently trained. When protocols are not followed there is no way to evaluate efficiency of crews or effectiveness of control. This deficiency may jeopardize our ability to convince funding agencies that further support is warranted. Although we suspect that survey and treatment methods as designed were good ones, modifications may be called for from time to time to improve effectiveness and efficiency. If so then, modifications should be compared with previously used protocols to document improvements.

2. BIISC should develop quarterly and annual operation plans to guide crew activities and set priorities. Availability of quarterly and annual operation plans would allow field crews considerable latitude in determining their day-to-day activities within the larger scope of work. Operation plans would facilitate evaluation of progress toward targets, help BIISC adjust short- and long-term goals appropriate to the resources available. Operation plans should be in the form of written documents and should form a portion of the information used to evaluate worker performance.

3. BIISC should develop methods to more effectively evaluate worker effort per acre needed to control *Miconia* under different field conditions. Current data capture on worker efforts provide limited information for planning purposes. For example, *Miconia* density, terrain, vegetation, and access all may increase worker efforts per acre, yet this information is poorly captured under current data protocols. We suggest that the field crews work with the data manager to design a system of indexing field conditions that would be both useful and easy to implement.

4. Field crews and/or crew leaders should be responsible for weekly data entry and QA/QC. Closer familiarity with data and with factors affecting its utility will improve the ability of field crews to do their jobs and to see the effects of their work. Data entry and QA/QC by field crews will also free the database manager to conduct analyses, generate maps, and in general direct efforts of the crews in the most effective directions consistent with the protocol. Field crew leaders, the database manager and the ISC database coordinator should work together to design a system by which data can be efficiently and accurately collected, entered, and checked by designated members of each crew.

5. BIISC should incorporate scheduled re-survey and follow-up control of treated areas into its operation plan. All areas treated should be resurveyed at regular intervals (2 years?) as part of BIISC's basic management plan. The resurvey should cover the same area as that previously controlled and ideally should target complete monitoring blocks. Both initial treatments and each resurvey should be completed within a short period of time (few months?) to insure the integrity of the data and to facilitate effective evaluation of control efforts.

6. Where appropriate BIISC should develop effective methods for limiting the spread of *Miconia* in steep terrain such as gulches. Gulches and other steep areas are prime habitats for *Miconia* and other invasive exotic species. Because these ecosystems often extend deep into montane rain forests, they form an important pathway for the introduction of invasive species into conservation areas. While the elimination of populations within gulches is likely to be elusive, BIISC should explore the possibility of controlling reproductive individuals through aerial spraying or other means.

7. BIISC should re-focus its *Miconia* control strategy to more effectively protect Forest Reserves and conservation areas. Our analyses suggest that resources necessary to limit the density and spread of *Miconia* in lowland habitats may be beyond the capacity of BIISC. We suggest that efforts focused on protection and control within and adjacent to priority forest reserves and conservation areas will more effectively protect Hawaiian ecosystems at risk than will a strategy to contain the spread of *Miconia* in the lowlands. High priority areas for monitoring and control might include upland and lowland Puna forest reserves, upper gulches along the Hamakua coast, and the mid-elevation habitats along the Kona coast. We suggest that agricultural lands do not constitute priority areas at risk from *Miconia* invasions since these lands are similarly threatened by other woody invasive trees (including *Psidium*, *Falcataria*, *Casuarina*, *Trema*, *Melochia*, and many others).

This recommendation, if implemented, would constitute a significant shift from previous BIISC *Miconia* management strategies. It will entail working closely with those public agencies and private entities to accomplish effective *Miconia* control on all lands adjacent to targeted conservation lands and a recognition that BIISC alone is unable to marshal sufficient resources to protect these areas without cooperation of all stakeholders. BIISC may decide to target other species in addition to *Miconia* if such is necessary to ensure the integrity of the reserve. Appropriate protection strategies are likely to vary for different conservation areas. In some cases protection may entail repeated control of *Miconia* on reserves themselves. In other circumstances protection may entail periodic surveys of a buffer zone outside of the protected area. BIISC may want to initiate one or more pilot projects to develop guidelines for working with state and federal agencies, conservation organizations, private landowners, and citizen groups to accomplish its goals.

Acknowledgments. Many people contributed to the development of this evaluation. Their contributions were critical to the final usefulness of the report. Laura Nelson and Duane Nelson supplied background on history of BIISC and the control of *Miconia* on

Hawaii Island. Julie Leialoha made data from BIISC archives freely available. Christian Rygh (BIISC) and Shannon McElvaney (Hawaii Heritage Program) provided initial GIS analyses. The Invasive Species Committees of Kauai, Oahu, Maui, and Molokai provided data on the distribution of *Miconia* statewide. We are especially grateful to the University of Hawaii at Hilo Spatial Data Analysis Laboratory for use of their facilities and expertise in running the GARP analyses.

References.

BIISC. 2000, 2002, 2004. Strategic plan. Big Island Invasive Species Committee.

Leialoha, J. 1997. Operation Miconia: suppression of the noxious weed *Miconia calvescens* on the Island of Hawaii. Proposal to Pulling Together Initiative.

Medeiros, A., L. L. Loope, P. Conant, and S. McElvaney. 1997. Status, ecology and management of the invasive plant *Miconia calvescens* D. C. (Melastomataceae) in the Hawaiian Islands. Bish. Mus. Occ. Pap. 48:23-36.

Meyer, J.-Y. 1998. Observations on the reproductive biology of *Miconia calvescens* DC (Melastomataceae), an alien invasive tree on the island of Tahiti (South Pacific Ocean). *Biotropica* 30:609-624.

Stockwell, D., and D. Peters 1999. The GARP modeling system: Problems and solutions for automated spatial prediction. *International Journal of Geographic Information Science* 13:143-158.

Table 1. Statistics on the BIISC database on the *Miconia* control effort, 1996-2004, by big blocks.

	Count	Median	Mean	Range
Number of blocks surveyed	879			
Block area (acres)		27.1	39.0	0.1-543.7
Number of visits/block		2	3	1-35
Worker field hours/acre		4.9	22.6	0-575.4
Estimated stems treated/acre		0.1	43.7	0-2455.7
Saplings treated/block		1	206	0-9463
Trees treated/block		0	72	0-4701

Table 2. Summary of results from 2006 resurvey of 14 parcels completely surveyed in 1996-2004.

Site	Location	Acres	Original Survey (1996-2004)			Resurvey (2006)				Proportion change
			Trees Killed	Saplings Killed	Stems/acre	Total Work Hours	Total Trees Killed	Total Saplings Killed	Stems/acre	
Honaunau	Leeward	76.77	2	4	0.08	72	1	0	0.01	-0.83
Honaunau	Leeward	117.79	19	47	0.56	160	2	4	0.05	-0.91
Honaunau	Leeward	48.93	0	2	0.04	53	1	4	0.10	1.50
Makuu	Windward	37.32	9	36	1.21	92	12	53	1.74	0.44
Akaka	Windward	51.69	4	49	1.03	24	8	15	0.44	-0.57
Kopua	Windward	26.18	0	29	1.11	21	1	12	0.50	-0.55
Makuu	Windward	40.19	0	1	0.02	139	1	2	0.07	2.00
Hanawi	Windward	47.90	2	19	0.44	139	1	2	0.06	-0.86
Kukui Camp	Windward	47.08	7	13	0.42	40	1	11	0.25	-0.40
Puueo	Windward	34.90	0	1	0.03	19	0	1	0.03	0.00
Kurtistown	Windward	9.73	0	298	30.63	24	153	170	33.20	0.08
Hanawi	Windward	23.17	1	9	0.43	3	1	0	0.04	-0.90
Kukui Camp	Windward	30.92	0	0	0.00	42	0	1	0.03	
Makuu	Windward	9.57	1	0	0.10	24	0	1	0.10	0.00
mean stems/ac leeward					0.23					0.06
mean stems/ac windward					3.22					3.32

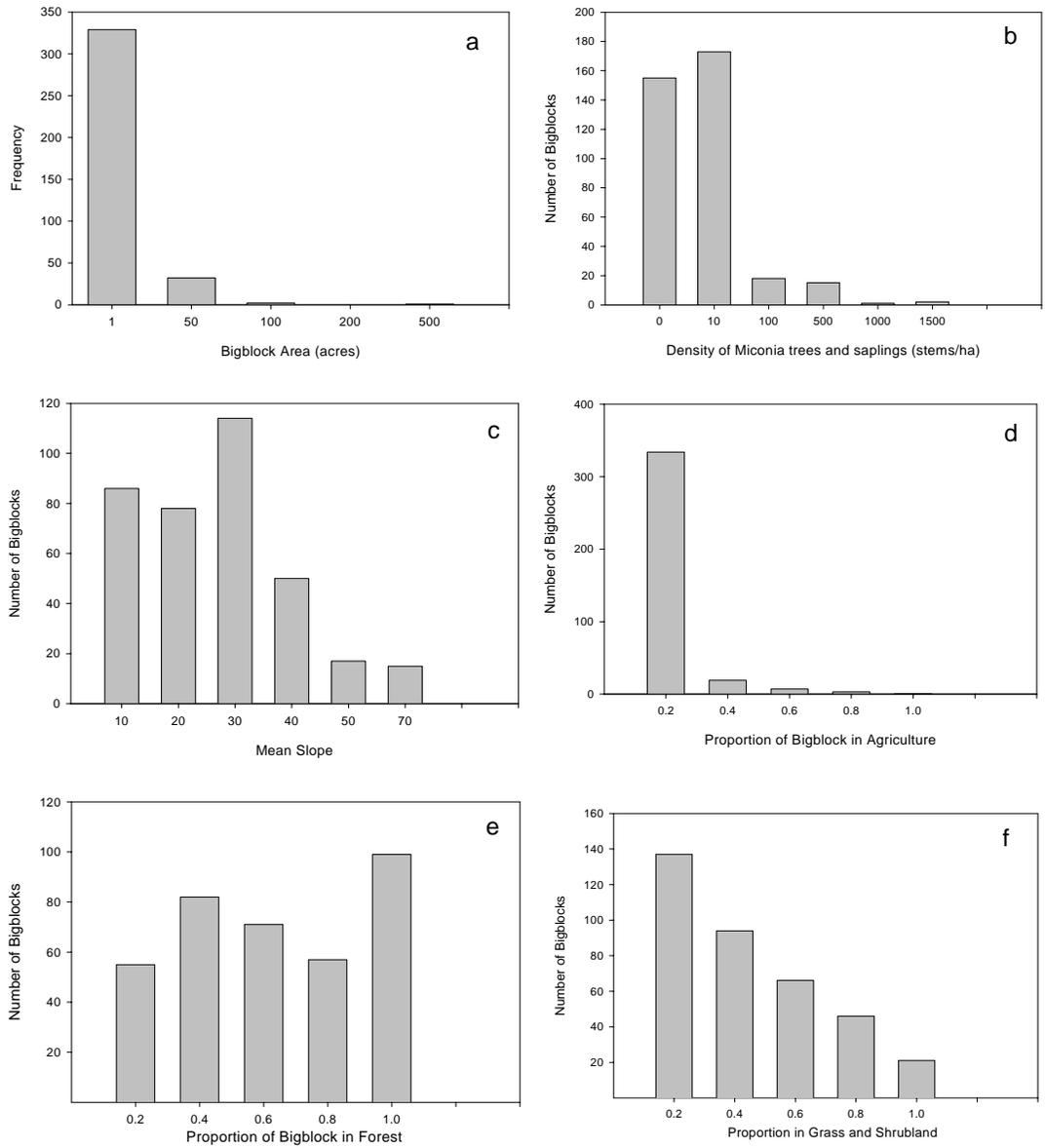


Figure 1. Frequency histograms of big block characteristics

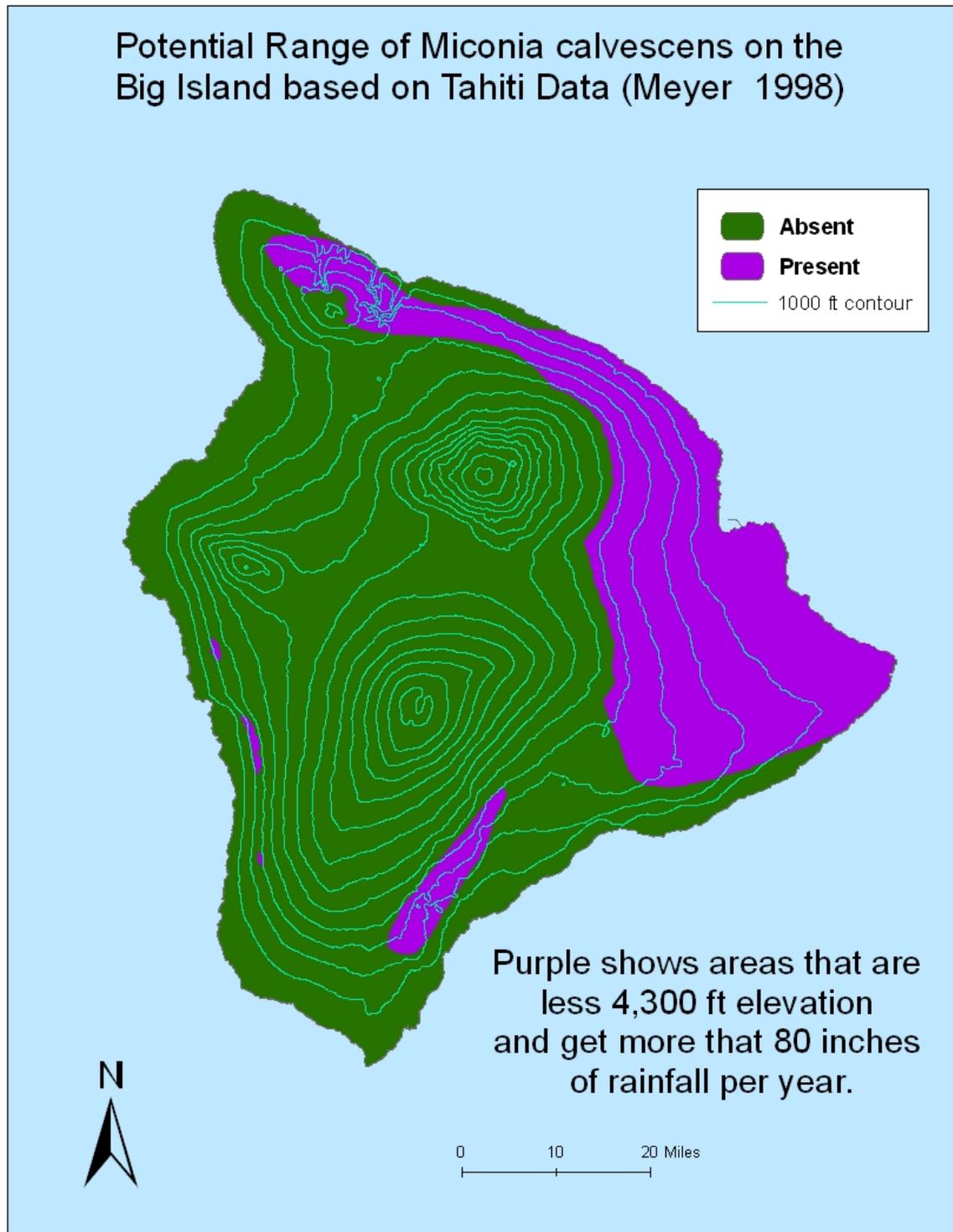


Figure 2. Potential distribution of *Miconia* based on the habitat distribution range in Tahiti (Meyer 1998)

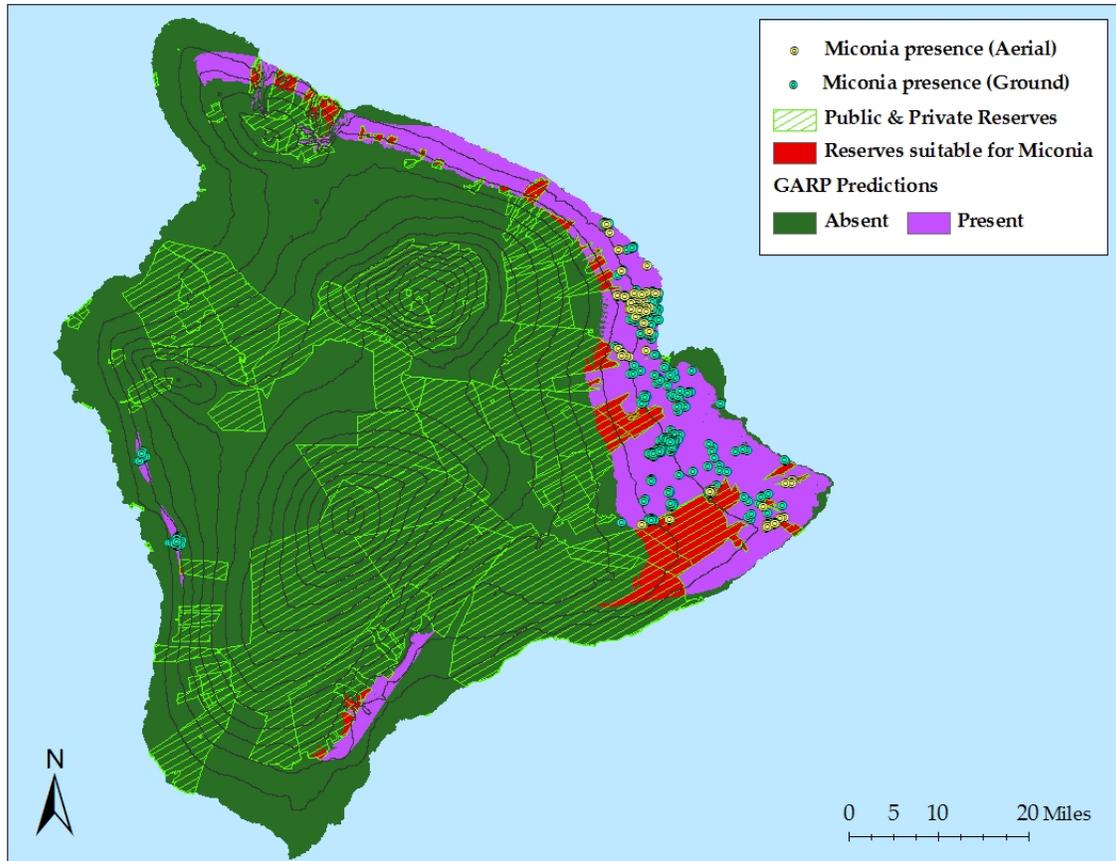


Figure 3. Potential distribution of *Miconia* on Hawaii Island based on GARP projections of data from the State of Hawaii collected between 1996 and 2006. Red polygons denote areas of overlap between conservation lands and the potential distribution of *Miconia*.

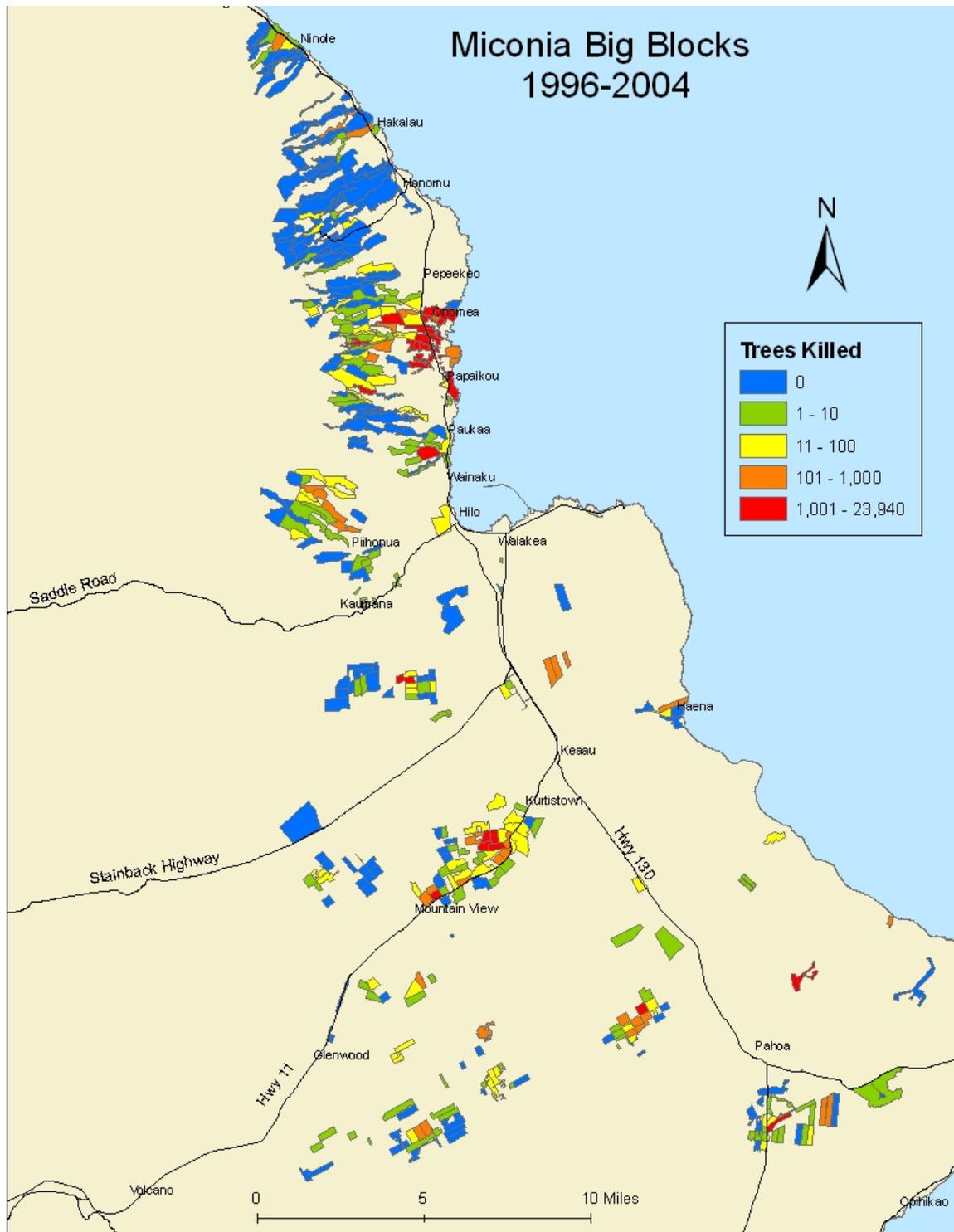


Figure 4. Numbers of trees killed per block in eastern Hawaii Island between 1996 and 2004.

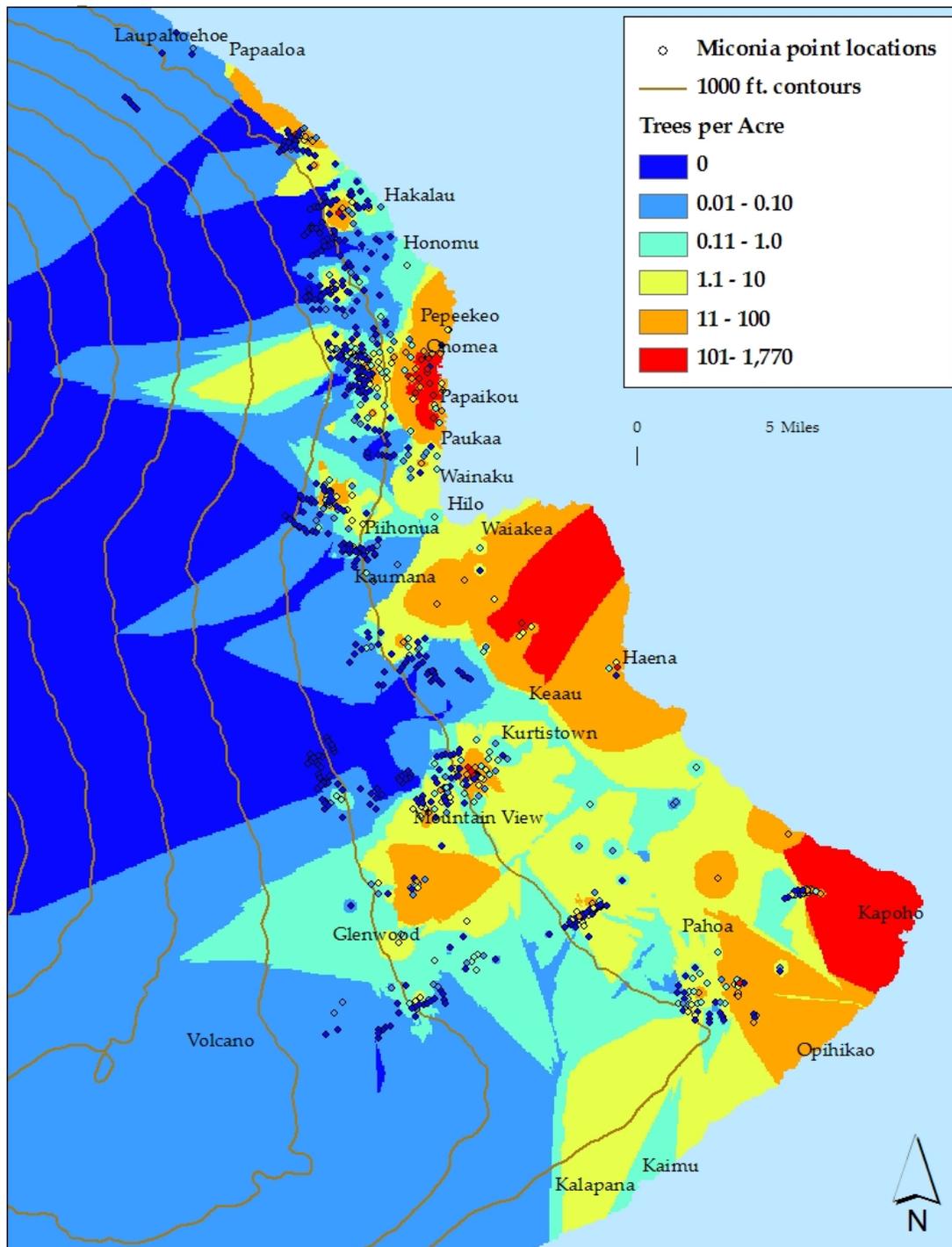


Figure 5. Projected historic *Miconia* densities on eastern Hawaii Island based on numbers of trees killed in treatment blocks between 1996 and 2006.

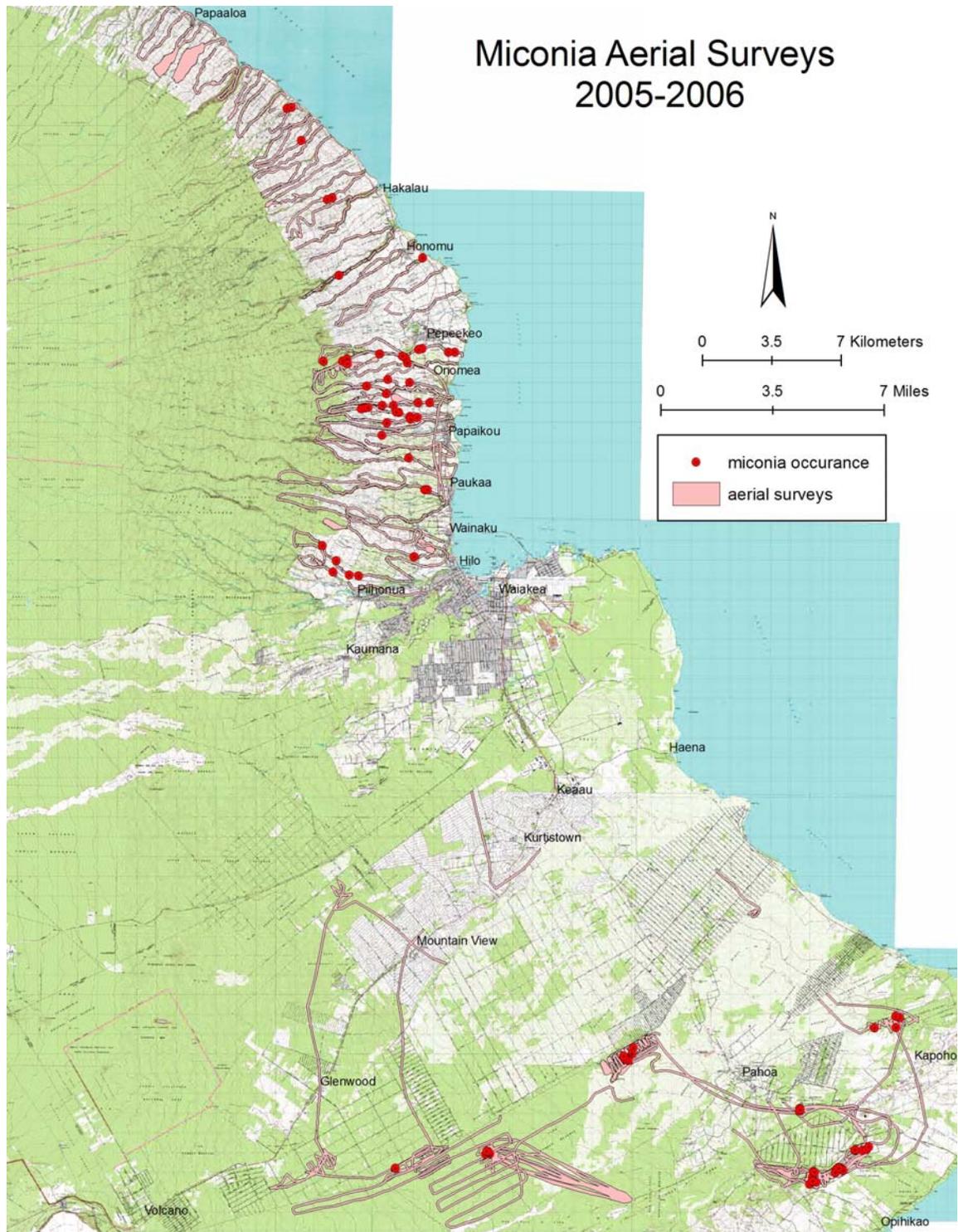


Figure 7. Recent (2005-2006) helicopter surveys for *Miconia* on eastern Hawaii Island with locations of detected trees.

Appendix 1. Protocol for GARP range projections for *Miconia*.

Miconia in Hawaii:
GARP model of potential distribution

February 9, 2007
Melora K. Purell

Folder: Miconia GARP

GARP model overview

The purpose of this analysis was to create an optimal model of the potential distribution of *Miconia* (*Miconia calvescens*) for the Hawaiian islands, based on 1647 presence points provided by the Big Island Invasive Species Committee (BIISC). The inputs into GARP for this model were the presence points (as an Excel file) along with four environmental layers, all projected as WGS 1984 geographic projections, as ASCII raster grids, created by the GARP datasets extension in ArcView 3.3.

Dataset Layer	Spatial resolution (dec. degrees)	Content	Source
hi_rain.asc	0.00085	raster interpolated from rainfall isohyets, using Topo to Raster tool	Hawaii Statewide GIS download website
hi_dem.asc	0.00085	from 10m DEM, reprojected to 100m resolution	NOAA's biogeography program website
hi_slope.asc	0.00085	from slope tool in ArcMap; reclassified to adjust for z value in meters, and x,y in dec. degrees	derived from 100 m DEM
hi_wind.asc	0.00085	"windwardness" from aspect tool in ArcMap; then reclassified by table (attached) to value aspect as 180 for NE and 0 for SW	derived from 100 m DEM

Sources of GARP environmental layers:

1. Hawaii State GIS program URL download site: <http://www.hawaii.gov/dbedt/gis/download.htm> (from 1986 report to Hawaii Division of Water and Land Development, Department of Land and Natural Resources, Honolulu)
2. The DEMs were downloaded from NOAA's biogeography program website URL <http://biogeo.nos.noaa.gov/products/mapping/dems/> & converted to ArcGIS-friendly grids in ArcView 3.3 using the Spatial Analyst Extension.

The NOAA site states, "The Digital Elevation Models for the Main Eight Hawaiian Islands derived from USGS 7.5' Quads. Individual quad DEM's were converted to a common projection, datum, and vertical unit, then mosaicked together. The projection for the DEM mosaics is as follows: Projection - Universal Transverse Mercator; Datum - NAD83; Spheroid - GRS80; Vertical and horizontal units - meters; Zone - 4 for all the Islands except for Hawaii which is Zone 5. The cell size for the DEM's is 10 meters."

GARP modeling process

The spatial model for predicting the potential distribution of *Miconia calvescens* was based on an analysis of the relationship between the presence of *Miconia* and four environmental gradients. To create this predicted distribution, I used the Desktop version of the Genetic Algorithm for Rule-set Production (GARP), a non-parametric habitat model which has been used for predicting distributions of species. GARP is well-validated and reliable, and has been applied with a variety of species and environments. Predictive habitat models have been produced for invasive plant species in Yosemite National Park, alien freshwater mussels in North America, and invasive grasses in Mexico.

GARP is a machine-learning computer program, which searches iteratively for non-random correlations between species presence locations and spatially-explicit variables like slope and elevation by creating and applying a set of rules that describe the environmental envelope of the presence points (see Desktop GARP website: www.lifemapper.org/desktopgarp/). Three types of rules used in GARP are if-then rules, range rules, and logit rules. If-then rules create crisp boundaries defined by a single value for one of the environmental layers, such as a lower limit to rainfall or elevation. Range rules are the most commonly applied rules in GARP, and involve defining a range of values for an environmental parameter. For example, a range rule might define presence as 300 - 1500 m elevation. Logit rules are an adaptation of logistic regression models to rules.

The goal of this rule-making process is to define an area of predicted presence that overlaps the training points used to build the model (see Table 1 for definitions used in modeling and error analysis). Each run of the model begins with a randomly generated rule. The program continues to add rules iteratively, testing them for significance then either rejecting or incorporating them into the model. These iterations continue until the program either reaches a predetermined limit of iterations, or achieves "convergence,"

the point at which new rules no longer create a significantly improved fit between the presence localities and the predicted distribution.

Input data: presence points and GIS layers

The presence localities for *Miconia* were provided to me from the Big Island Invasive Species Committee (BIISC) and represented GPS points for the locations of individual *Miconia* plants that had been identified during surveys and control operations across the state. In some locations, the points were highly spatially autocorrelated, especially in East Maui, where there were more than 40 points within a 100 m X 100 m grid cell. For these locations, I haphazardly chose one point to represent the environmental parameters for that cell, resulting in a final set of 1647 localities.

Table 1. Definitions of some terms used in habitat modeling and error assessment.

Term	Definition
Training points	Presence localities used in the construction of a model.
Test points	Presence or absence localities used to assess error of model predictions.
Omission error	Percentage of presence points that do not fit within predicted presence areas. Subdivided into intrinsic omission error, where training points are assessed, and extrinsic omission error, where test points are assessed.
Commission error	Percentage of absence points that fall within areas of predicted presence.
Validation	Assessment of omission and commission errors, usually with independent test points.
Over-fitting	Related to omission error. When a model is so closely fit to the training points that it excludes presence test points.
Over-prediction	Related to commission error. When a model is generalized in its prediction and includes absence test points.

I uploaded these presence points along with four environmental data layers (elevation, slope, windwardness, and rainfall) into the Desktop GARP program. Although the DEM originally had 10 m spatial resolution, the rainfall grid was derived from an isohyet shapefile of lower resolution. Therefore, I resampled all of the files to 100 m spatial resolution to account for the coarser rainfall layer as well as the scale of the sampling itself (*i.e.*, sample points were 100 m apart). The windwardness layer was created from a reclassification of aspect (the direction of slope measured in compass degrees). Aspect degrees were renamed with windwardness values between 180 (windward or NE) and zero (leeward or SW). In Hawai'i, prevailing trade winds produce windward and leeward micro-climates that vary in humidity and moisture inputs from rainfall and fog.

The GARP modeling process

Each run of GARP produced a unique map of predicted *Miconia* distribution, in the form of a grid where each cell was assigned either one for predicted presence or zero for predicted absence. A preliminary test run of GARP produced 100 models, directing the program to use all of the points for training. Models were produced using the default

settings for convergence (0.01) and maximum iterations (1000). The internal program assessments for chi-square and p values were analyzed and found to be significant ($p < 0.01$). This showed that the model predicted presence much better than random. After significance was demonstrated then the best-subsets procedure for choosing the best models was followed.

A best-subsets approach to GARP has been shown to accommodate the asymmetry in the input data (only presence points are used) as well as the stochastic elements of the iterative process, yet still produce high-quality models even with small numbers of presence localities. This approach involves using 100% of presence points for training and then creating as many models as necessary to ultimately achieve a subset of optimal models that fit predetermined criteria for omission error and commission index. Omission error is the percentage of presence points incorrectly predicted and commission error is the proportion of points incorrectly predicted as presence. Commission *index* is simply the proportion of map area predicted as presence. Omission error and commission index are inversely proportional in GARP models; as the commission index decreases, it becomes unlikely that the model will accommodate all the presence points and thus the omission error increases.

The best models, as evaluated by expert opinion as well as validation with independent test points, are those that (1) used all the presence points for training, (2) had low intrinsic omission error and (3) had medium-to-high commission index values.

In order to select the optimal models, I calculated the median commission index for an initial set of 25 low-error models and used it as a guide to choose the best models. From 100 total models produced from the full set of 1647 presence points, I chose 10 models that fit the best-subset criteria of low omission error (<2% mean omission error in this case) and commission index close to the median of low-error models (here 23%). These 10 map files were added together in GIS, with the resulting calculation (*i.e.*, the “optimal model”) saved as a raster. This file had cell values that represented the total number of maps which predicted each cell as present. Therefore, the values ranged from zero, where all 10 maps predicted absence, to 10, where all maps predicted presence.

Miconia GARP.mxd

This ESRI ArcMap 9.1 map document contains the output from the GARP model to predict Miconia distribution across the main Hawaiian islands.

GIS layer	Format	Source	Content
Miconia_opt	raster	GARP output	combined 10 optimal ASCII maps converted to ESRI raster files
All_Hawaii_Miconia_project	shapefile - point	Point files provided from BIISC	Combined points for all islands. Culled points to reduce spatial autocorrelation

Also included on the disk are the image files (.jpg format) of:

1. Overview of GARP prediction for main Hawaiian islands
2. Finer-scale maps of individual islands, showing the point localities and 1000 ft. elevation contours for Hawaii, Kauai, Maui, Molokai and Oahu
3. Prediction of Miconia distribution based on parameters from Tahiti: less than 4300 ft. elevation and greater than 80 in. annual rainfall.