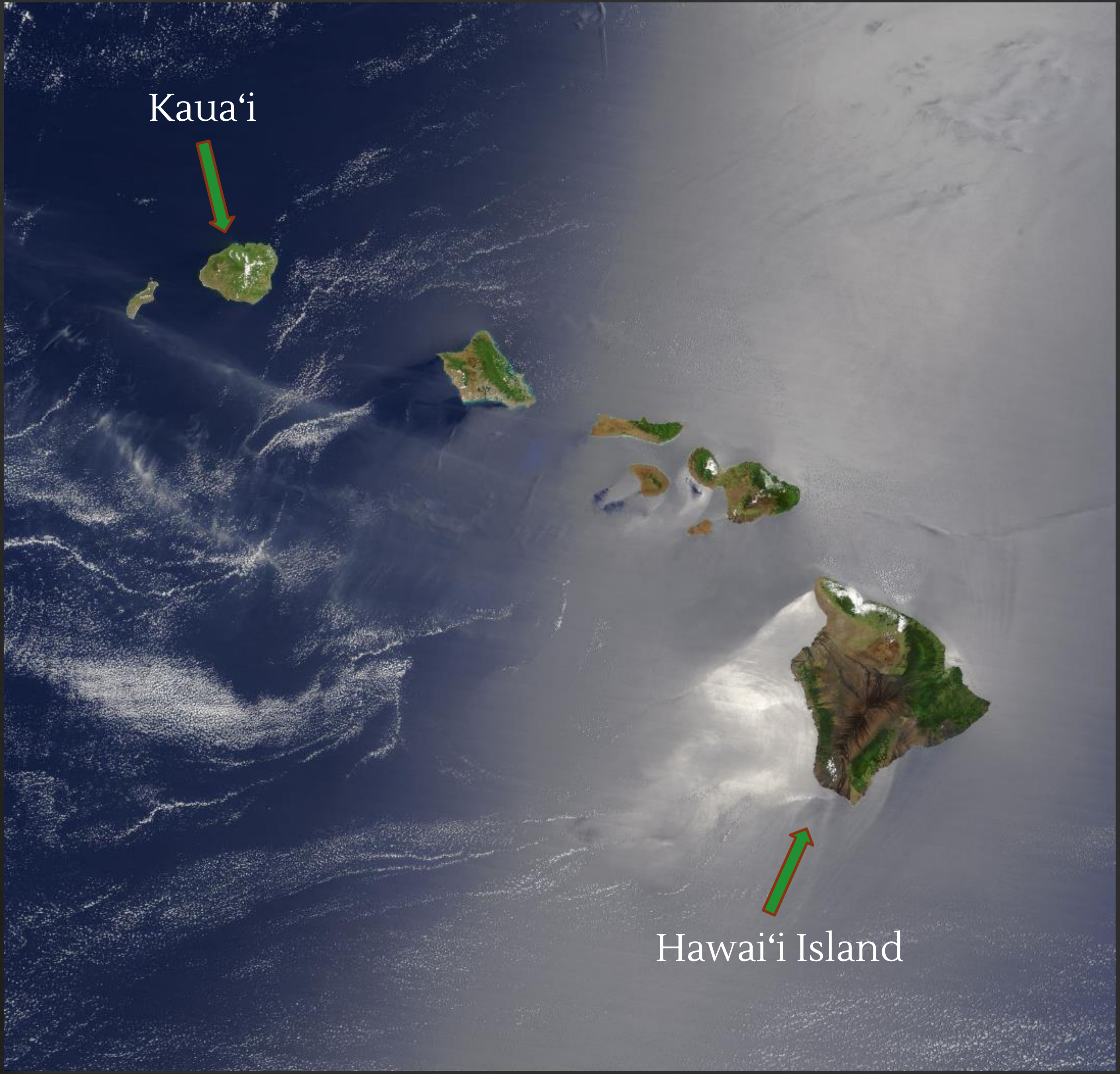
Provisional seed zones for ‘ōhi‘a (*Metrosideros* spp.) on Kaua‘i:

a mitigation strategy for a new fungal pathogen

Adam Williams, Dustin Wolkis, Ben Nyberg, Seana Walsh

Hawaiʻi – most remote archipelago on Earth

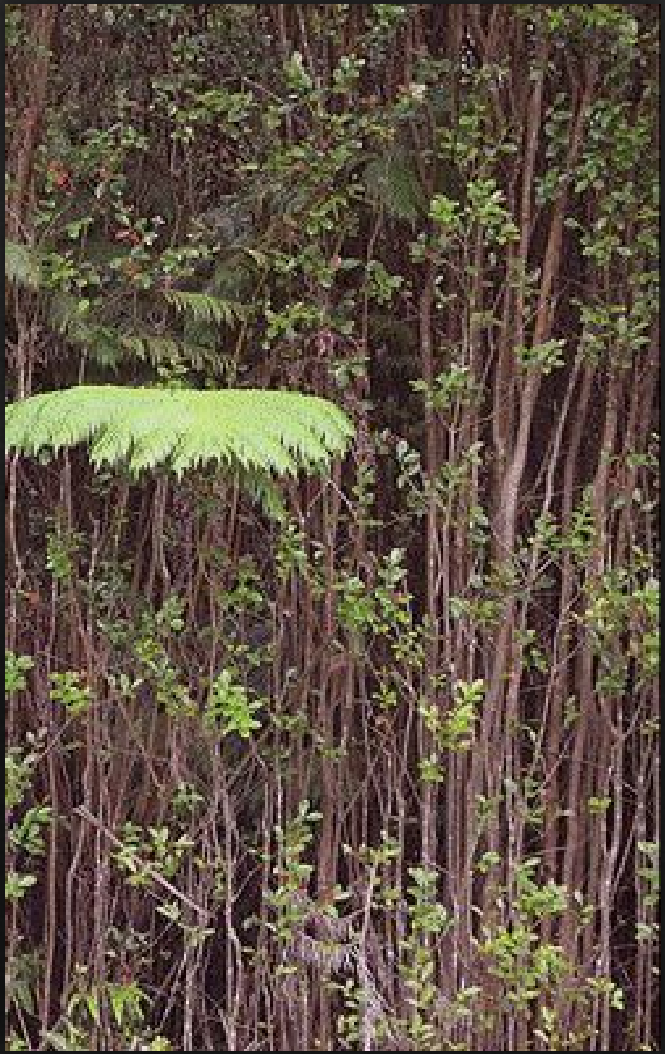
- Formed by volcanic "hotspot"
- Kauaʻi, around 5 myo, oldest of major islands
  - Hawaiʻi Island aka "the Big Island" youngest ~400k – 500k yo
- Plant colonization of islands:
  - Birds (internal and external)
  - Ocean
  - Wind
- Stepping stone pattern, oldest to newest e.g. progressive colonization



90% endemism of flowering plants

Extreme Isolation = Ecological fragility

- Land clearing for agriculture
  - Especially sugar
- Fire: avg. .5% of total area/year*
  - Larger proportion than other States
- Invasive species
  - Ungulates, weeds, inverts, and pathogens



*From Hawai'i Wildfire Management Organization

Endangered Species Capital of the U.S.

- 443 Endangered plant taxa, 10 Threatened species
  - >40% of ESA plant listings, <1% of landmass
  - At least 100 plant species already extinct in historical times (i.e. since 1778 European contact)
- Native land cover gone in many places, often restricted to middle or high elevation reserves/ conservation zoned lands

Cyanea superba subsp. *regina*, extinct
herbarium voucher in BISH

Metrosideros (Myrtaceae) in Hawai‘i

- One colonization event ~ 4 million years ago on Kaua‘i via wind dispersed seeds (Percy et al. 2008)
  - Probably from Marquesas (Wright et al. 2001)
- Spread to all high Hian Islands except Ni‘ihau and Kaho‘olawe, following rule of progression (older to younger islands)
- Keystone species in Hawai‘i
  - Nectar source for forest birds
  - Host for many endemic invertebrates
  - Nurse tree for epiphytic plants/seedlings

The Many Forms of ʻŌhiʻa

- Dominant tree in most HIan ecosystems from montane forest to new lava flows
- Extremely variable morphology



2. Metrosideros polymorpha Gaud.

[M. collina (J. R. Forster & G. Forster) A. Gray var. glabrifolia (A. Heller) Hochr.; M. c. var. hemilanata Hochr.; M. c. var. lutea (A. Gray) Hochr.; M. c. var. oahuensis Hochr.; M. c. var. parvifolia Hochr.; M. c. subsp. polymorpha (Gaud.) Rock; M. c. subsp. p. var. glaberrima (H. Lév.) Rock; M. c. subsp. p. var. g. f. sericea Rock; M. c. subsp. p. var. glabrifolia (A. Heller) Rock; M. c. subsp. p. var. haleakalensis Rock; M. c. subsp. p. var. imbricata Rock; M. c. subsp. p. var. incana (H. Lév.) Rock; M. c. subsp. p. var. i. f. lurida Rock; M. c. subsp. p. var. macrophylla Rock; M. c. subsp. p. var. newellii Rock; M. c. subsp. p. var. prostrata Rock; M. c. subsp. p. var. p. f. strigosa Rock; M. c. subsp. p. var. pumila (A. Heller) Rock; M. haleakalensis (Rock) Degener & I. Degener; M. lutea A. Gray; **M. polymorpha var. dieteri** J. Wyndham Dawson & Stemmermann; M. p. subsp. glaberrima (H. Lév.) Skottsb.; M. p. subsp. g. var. sericea (Rock) Skottsb.; **M. p. var. glaberrima** (H. Lév.) St. John; M. p. var. g. f. sericea (Rock) Degener & I. Degener; M. p. subsp. glabrifolia (A. Heller) Skottsb.; M. p. subsp. g. f. obovata Skottsb.; M. p. subsp. g. var. parviflora Skottsb.; M. p. subsp. g. var. p. f. calva Skottsb.; M. p. subsp. g. var. prostrata (Rock) Skottsb.; M. p. var. glabrifolia (A. Heller) St. John; M. p. var. haleakalensis (Rock) St. John; M. p. var. hemilanata (Hochr.) St. John; M. p. subsp. imbricata (Rock) Skottsb.; M. p. var. imbricata (Rock) St. John; M. p. subsp. incana (H. Lév.) Skottsb.; M. p. subsp. i. f. psilophylla Skottsb.; M. p. subsp. i. var. pumila f. perglabra Skottsb.; **M. p. var. incana** (H. Lév.) St. John; M. p. var. i. f. lurida (Rock) St. John; M. p. var. i. f. psilophylla (Skottsb.) St. John; **M. p. var. macrophylla** (Rock) St. John; M. p. subsp. micrantha Skottsb.; M. p. var. micrantha (Skottsb.) St. John; **M. p. var. newellii** (Rock) St. John; M. p. subsp. polymorpha f. humilis Skottsb.; M. p. subsp. p. var. macrostemon Skottsb.; M. p. subsp. p. var. nuda Skottsb.; M. p. subsp. p. f. pseudorugosa (Skottsb.) Skottsb.; M. p. subsp. p. var. pseudorugosa Skottsb.; M. p. subsp. p. var. subimbricata Skottsb.; M. p. var. prostrata (Rock) St. John; M. p. var. p. f. strigosa (Rock) St. John; **M. p. var. pseudorugosa** Skottsb.; M. p. subsp. pumila (A. Heller) Skottsb.; **M. p. var. pumila** (A. Heller) J. Wyndham Dawson & Stemmermann; M. p. f. strigosa (Rock) St. John; M. pumila (A. Heller) Hochr.; M. p. var. makanoiensis Hochr.; Nania × feddei H. Lév.; N. glabrifolia A. Heller; N. lutea (A. Gray) A. Heller; N. macropus (Hook. & Arnott) Kuntze var. microphylla H. Lév.; N. polymorpha (Gaud.) A. Heller; N. p. var. glaberrima H. Lév.; N. p. var. incana H. Lév.; N. p. var. nummularifolia H. Lév.; N. p. var. sessilis H. Lév.; N. pumila A. Heller]

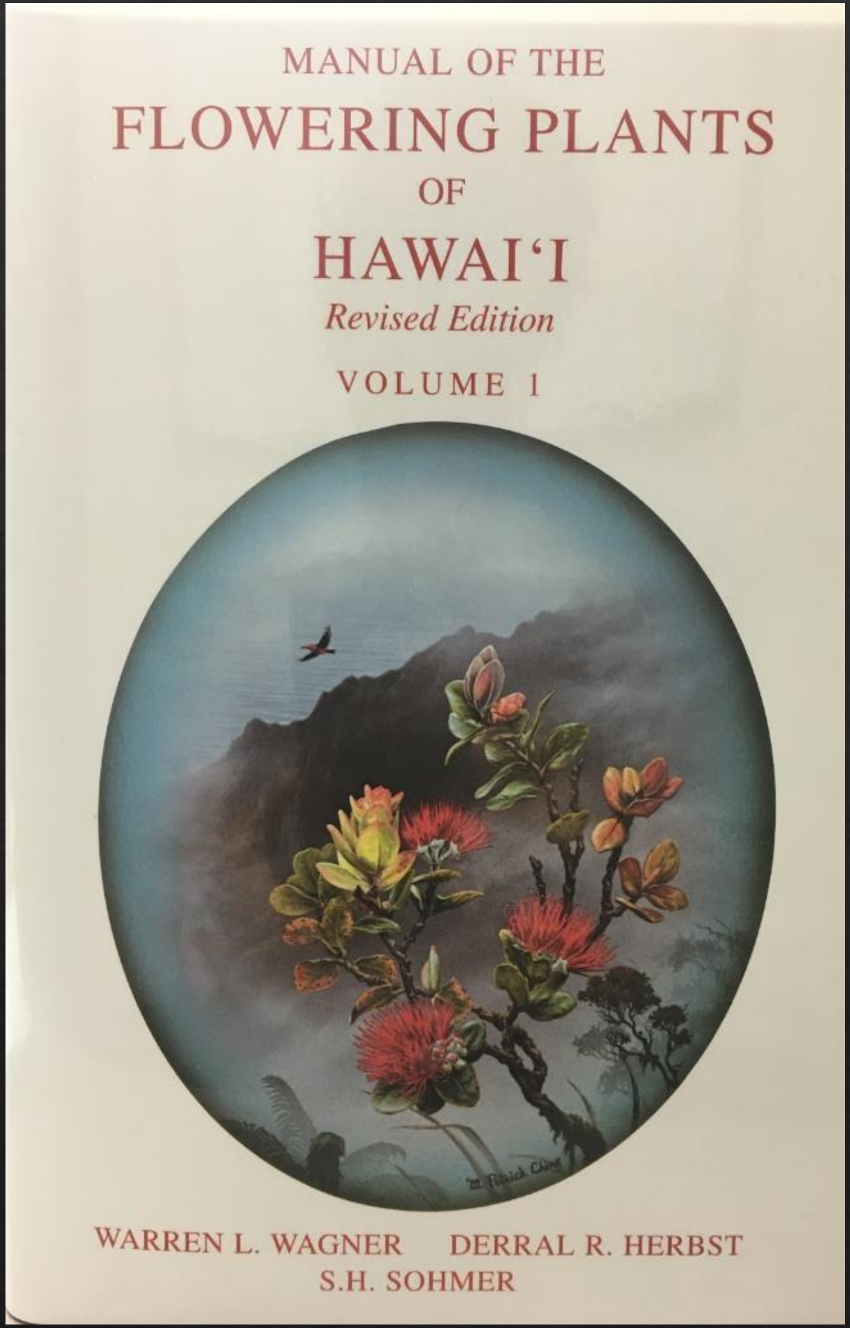
List of synonyms in Stemmermann and Dawson (1990). Recognized taxa shown in **bold**

Taxonomic history

- Rock (1917) – single widespread indigenous species *M. collina*, from S. Pacific to HI and French Polynesia
  - With endemic Hian varieties
- Skottsberg (1936) – single endemic species *M. polymorpha*

Difficulty in discerning taxonomic units:

- Overlapping ranges
- Rampant hybridization
- Gene flow through intra and inter-island dispersal
  - Tiny wind-dispersed seeds
  - Pollen movement from insects and birds



Current ʻŌhiʻa Taxonomy

- Dawson and Stemmerman (1990) treatment in Manual uses vegetative characters
- 5 species, 13 taxa
  - 8 varieties of *M. polymorpha*
  - 2 varieties of *M. waialealae*
- Each island has own unique combination of taxa
  - 7 of 13 are single-island endemics
  - Kauaʻi has 4 taxa, 2 island endemics

Emergence of Rapid ʻŌhiʻa Death (ROD)

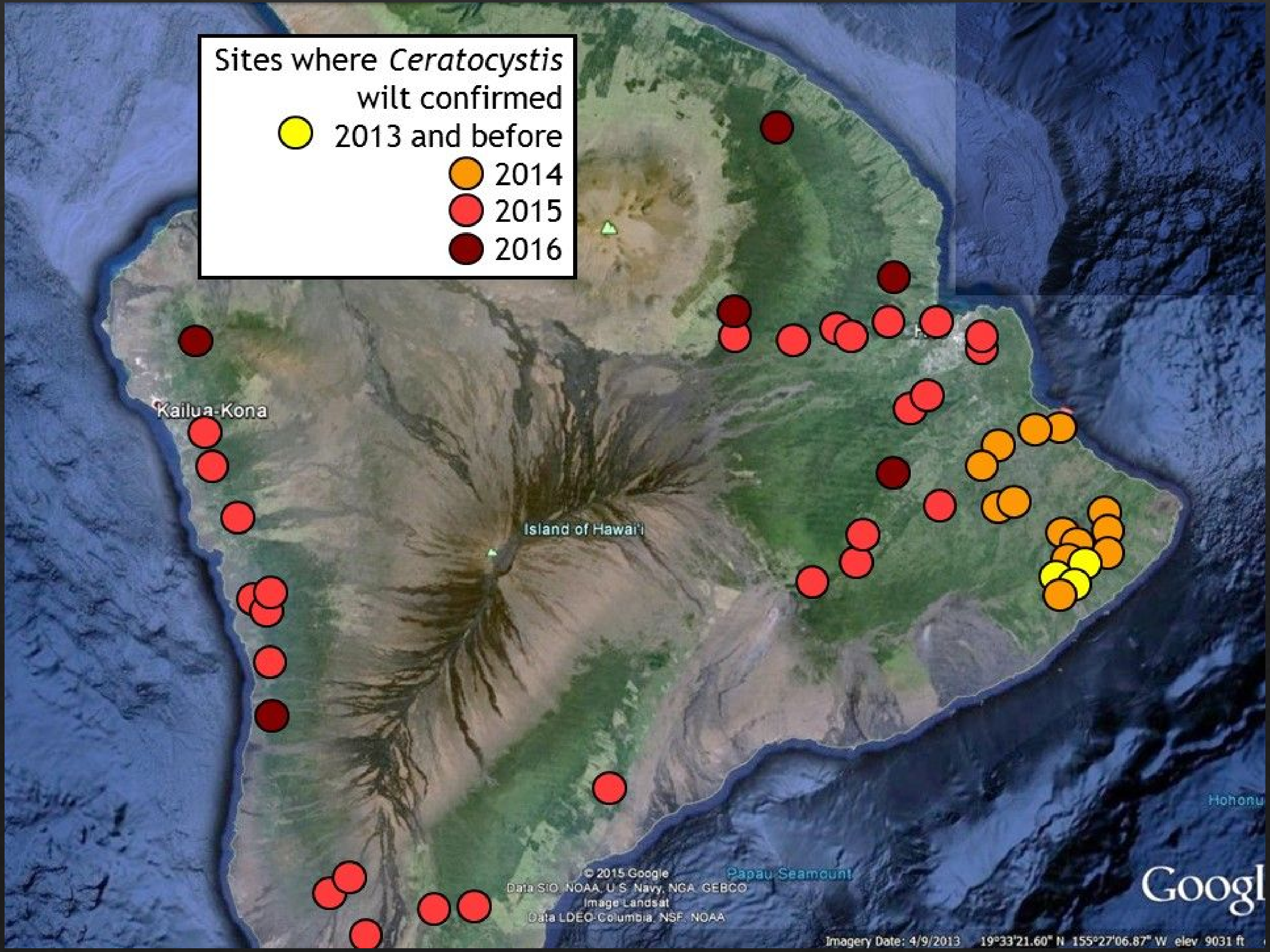
- 2013 – Trees dying of unknown cause, only in Puna District of Hawaiʻi Island
  - Trees completely dead within 2 – 3 weeks after first symptoms
- 2015 – fungal pathogen Identified, *Ceratocystis fimbriata*, a wilt disease

www.rapidohiadeath.com photo J.B. Friday

Rapid ‘Ōhi‘a Death (ROD)

- Latest estimate 47,000 acres affected on HI island
  - Hundreds of thousands of ‘ōhi‘a trees have died
- Other islands bracing for introduction
- Seed banking underway on all islands
- Ban on interisland movement of ‘ōhi‘a plants or plant parts
- Non-native ambrosia beetle possible vector

Map from www.rapidohiadeath.org



Creating Seed Transfer Zones for ‘Ōhi‘a

Ecological Applications, 24(5), 2014, pp. 913–919

Generalized provisional seed zones for native plants

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Abstract. Deploying well-adapted and ecologically appropriate plant materials is a core component of successful restoration projects. We have developed generalized provisional seed zones that can be applied to any plant species in the United States to help guide seed movement. These seed zones are based on the intersection of high-resolution climatic data for winter minimum temperature and aridity (as measured by annual heat : moisture index), each classified into discrete bands. This results in the delineation of 64 provisional seed zones for the continental United States. These zones represent areas of relative climatic similarity, and movement of seed within these zones should help to minimize maladaptation. Superimposing Omernik's level III ecoregions over these seed zones distinguishes areas that are similar climatically yet different ecologically. A quantitative comparison of provisional seed zones with level III ecoregions and provisional seed zones within ecoregions for three species showed that provisional seed zone within ecoregion often explained the greatest proportion of variation in a suite of traits potentially related to plant fitness. These provisional seed zones can be considered a starting point for guidelines for seed transfer, and should be utilized in conjunction with appropriate species-specific information as well as local knowledge of microsite differences.

Key words: adaptive traits; aridity; ecoregion; genetic variation; local adaptation; native plants; precipitation; restoration; seed transfer guideline; seed zone; temperature.

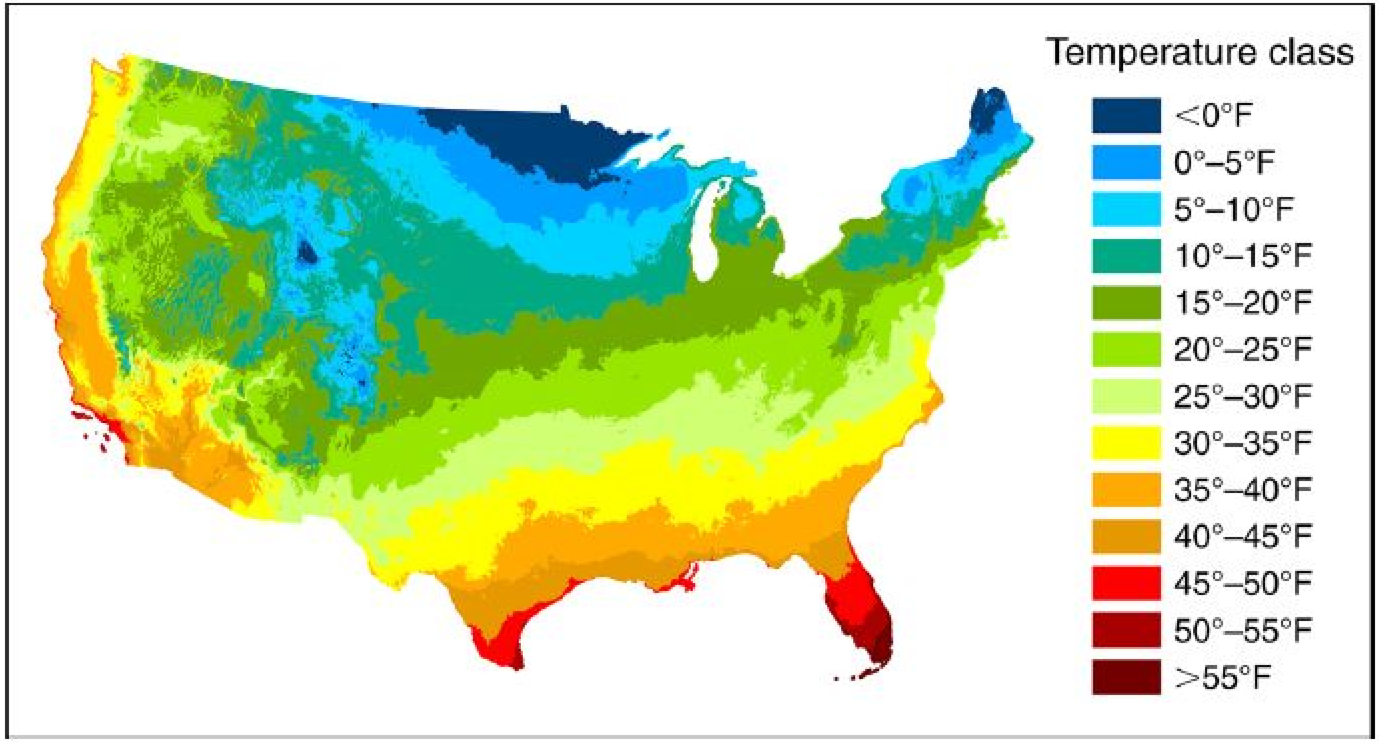


FIG. 1. Winter minimum temperature class bands. The 5°F bands correspond to 2.8°C.

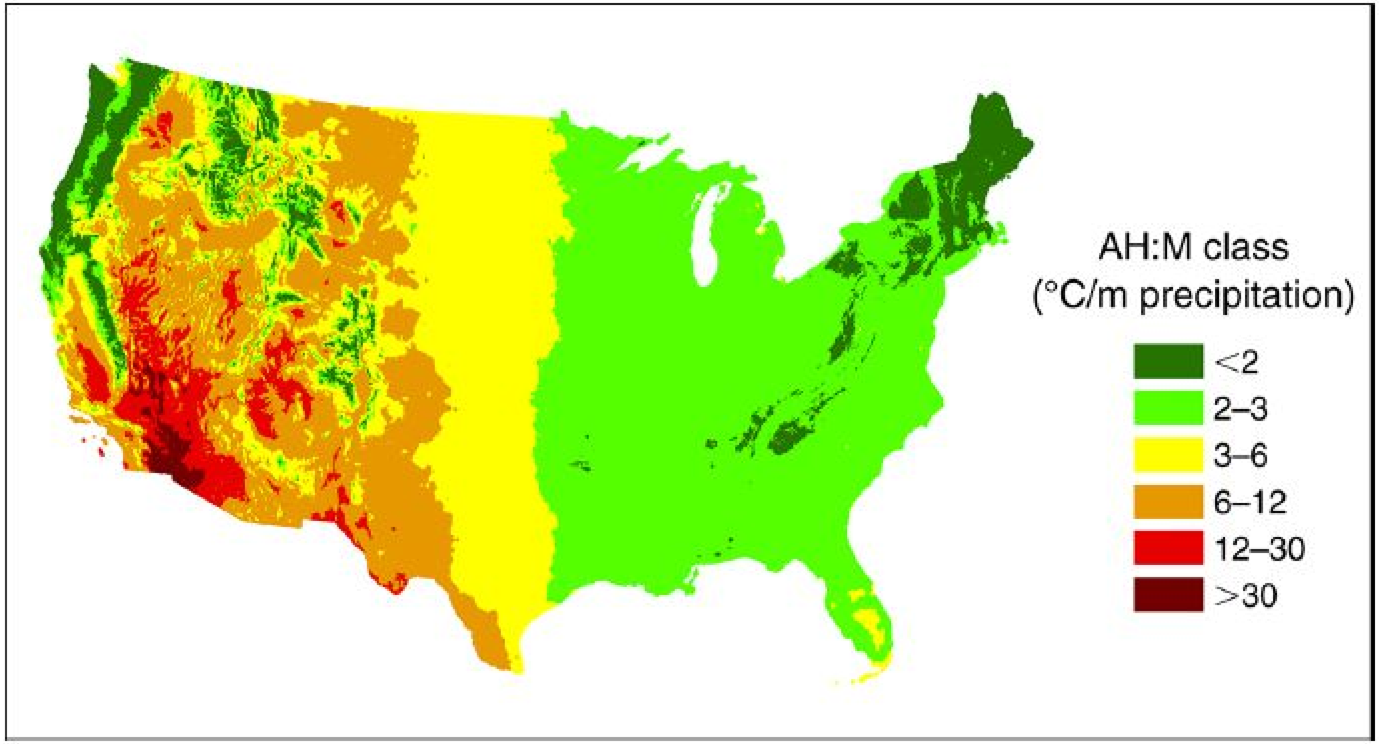


FIG. 2. Annual heat : moisture (AH:M) index class bands. AH:M was calculated as mean annual temperature (MAT, °C) plus 15°C (to obtain positive values) divided by mean annual precipitation in meters (Hamann and Wang 2005).

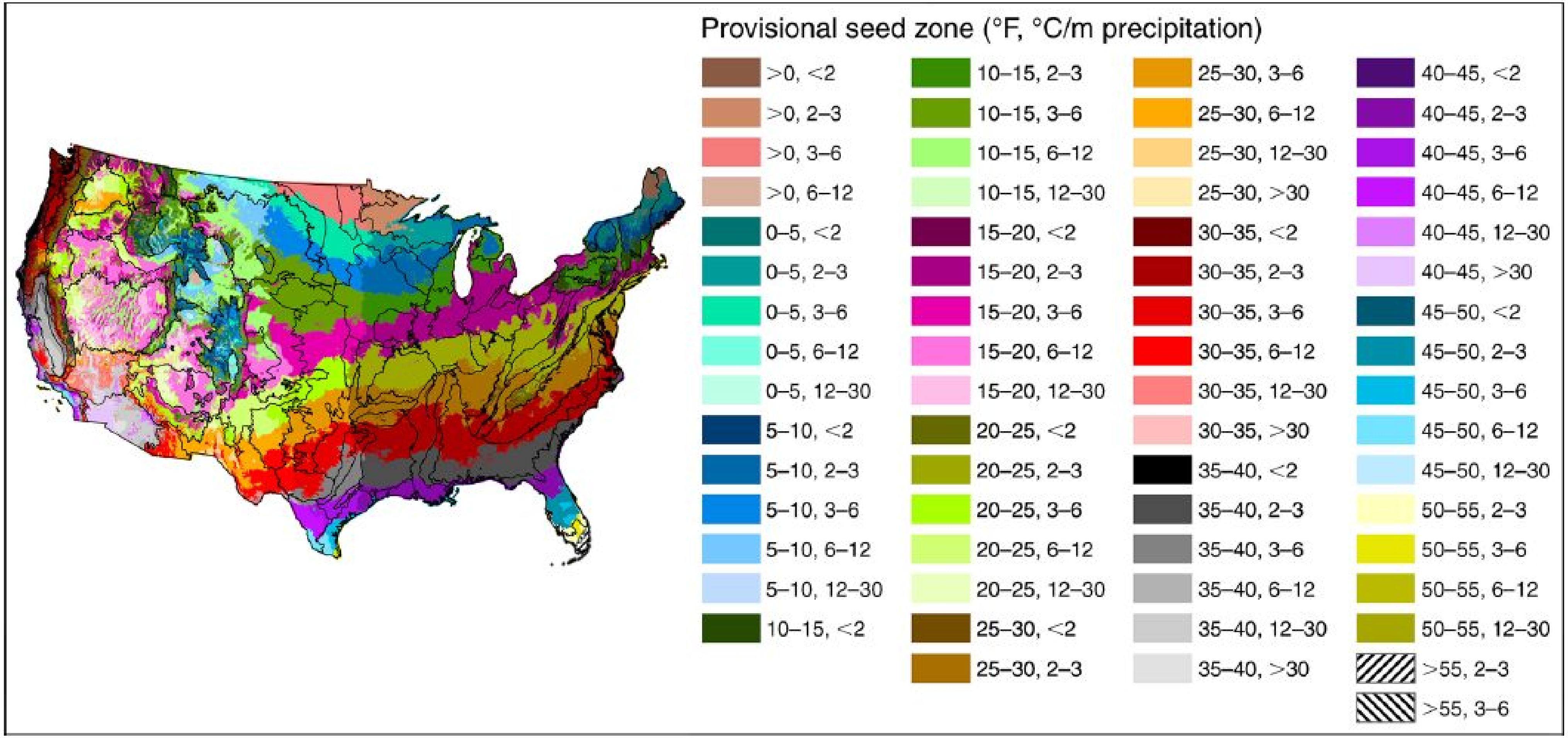


FIG. 3. Provisional seed zones for native plants (color polygons) overlain with Omernik's (Omernik 1987) level III ecoregion boundaries (black lines). We recommend using the provisional seed zones as the first step in defining seed transfer guidelines, and that level III ecoregions be used to refine seed movement within a provisional seed zone. In the legend, the first range of numbers is the temperature class band (°F) and the second range of numbers is the AH:M index class bands (°C/m precipitation). See the Appendix for a larger version of this figure.

Ecoregions – derived from Omernik 1987

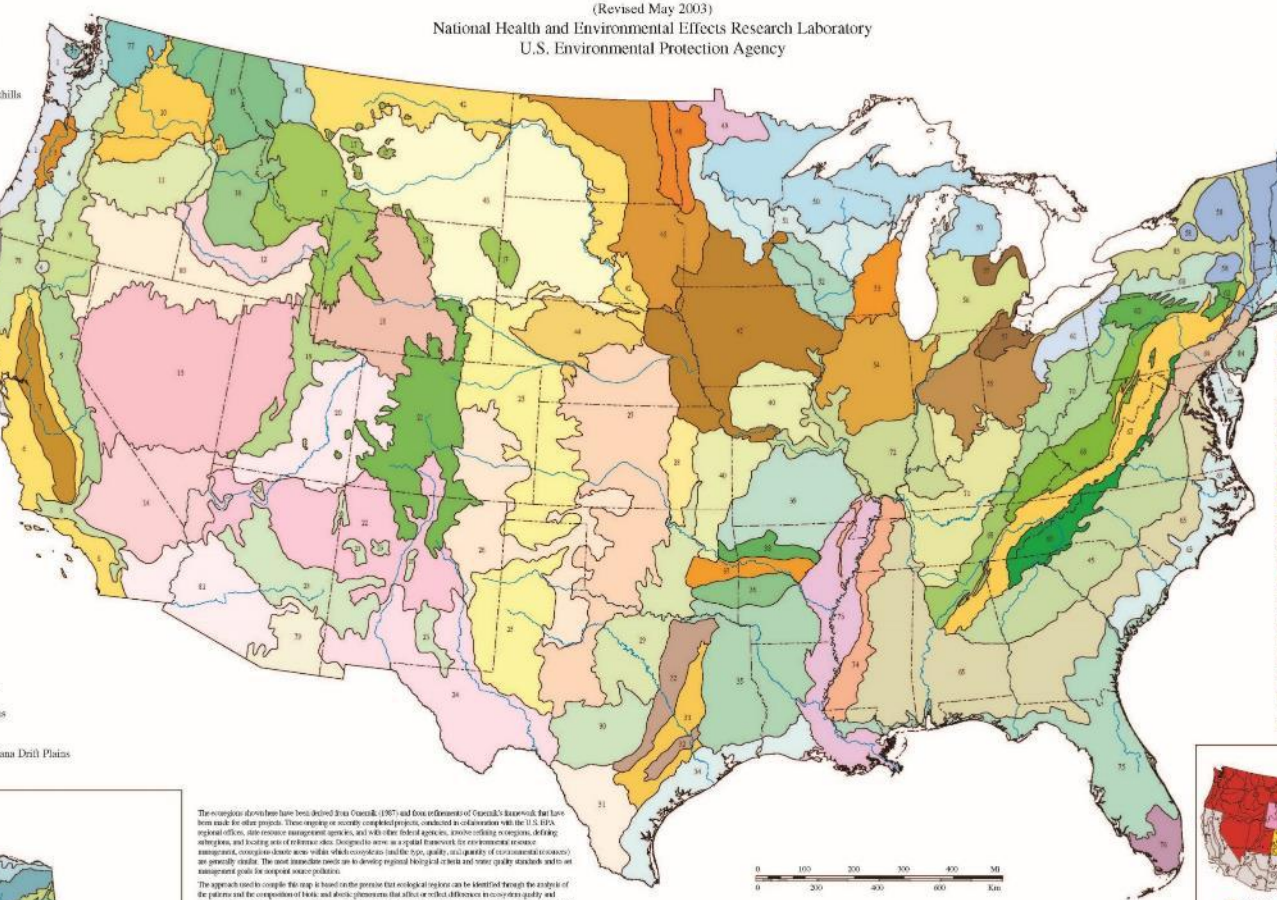
- the premise that ecological regions can be identified through the analysis of the patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Wiken 1986; Omernik 1987, 1995)

- geology,
- physiography
- vegetation
- climate
- soils
- land use
- wildlife
- hydrology

Level III Ecoregions of the Continental United States

(Revised May 2003)
National Health and Environmental Effects Research Laboratory
U.S. Environmental Protection Agency

1. Coast Range
2. Puget Lowland
3. Willamette Valley
4. Cascades
5. Sierra Nevada
6. Southern and Central California Chaparral and Oak Woodlands
7. Central California Valley
8. Southern California Mountains
9. Eastern Cascades Slopes and Foothills
10. Columbia Plateau
11. Blue Mountains
12. Snake River Plain
13. Central Basin and Range
14. Mojave Basin and Range
15. Northern Rockies
16. Idaho Batholith
17. Middle Rockies
18. Wyoming Basin
19. Wasatch and Uinta Mountains
20. Colorado Plateaus
21. Southern Rockies
22. Arizona/New Mexico Plateau
23. Arizona/New Mexico Mountains
24. Chihuahuan Deserts
25. Western High Plains
26. Southwestern Tablelands
27. Central Great Plains
28. Flint Hills
29. Central Oklahoma/Texas Plains
30. Edwards Plateau
31. Southern Texas Plains
32. Texas Blackland Prairies
33. East Central Texas Plains
34. Western Gulf Coastal Plain
35. South Central Plains
36. Ouachita Mountains
37. Arkansas Valley
38. Boston Mountains
39. Ozark Highlands
40. Central Irregular Plains
41. Canadian Rockies
42. Northwestern Glaciated Plains
43. Northwestern Great Plains
44. Nebraska Sand Hills
45. Piedmont
46. Northern Glaciated Plains
47. Western Corn Belt Plains
48. Lake Agassiz Plain
49. Northern Minnesota Wetlands
50. Northern Lakes and Forests
51. North Central Hardwood Forests
52. Driftless Area
53. Southeastern Wisconsin Till Plains
54. Central Corn Belt Plains
55. Eastern Corn Belt Plains
56. Southern Michigan/Northern Indiana Drift Plains

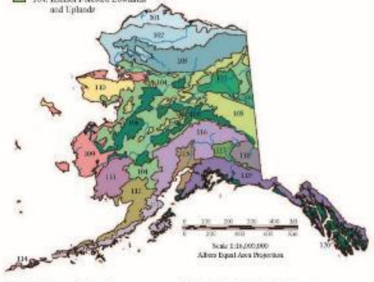


57. Huron/Erie Lake Plains
58. Northeastern Highlands
59. Northeastern Coastal Zone
60. Northern Appalachian Plateau and Uplands
61. Erie Drift Plain
62. North Central Appalachians
63. Middle Atlantic Coastal Plain
64. Northern Piedmont
65. Southeastern Plains
66. Blue Ridge
67. Ridge and Valley
68. Southwestern Appalachians
69. Central Appalachians
70. Western Allegheny Plateau
71. Interior Plateau
72. Interior River Valleys and Hills
73. Mississippi Alluvial Plain
74. Mississippi Valley Loess Plains
75. Southern Coastal Plain
76. Southern Florida Coastal Plain
77. North Cascades
78. Klamath Mountains
79. Madrean Archipelago
80. Northern Basin and Range
81. Sonoran Basin and Range
82. Laurentian Plains and Hills
83. Eastern Great Lakes and Hudson Lowlands
84. Atlantic Coastal Pine Barrens

0 100 200 300 400 Mi
0 200 400 600 Km

Albers Equal Area Projection

101. Arctic Coastal Plain
102. Arctic Foothills
103. Brooks Range
104. Interior Forested Lowlands and Uplands



105. Interior Highlands
106. Interior Bottomlands
107. Yukon Flats
108. Ogilvie Mountains
109. Subarctic Coastal Plains
110. Seward Peninsula
111. Ahklun and Kilbuck Mountains
112. Bristol Bay-Nushagak Lowlands
113. Alaska Peninsula Mountains
114. Aleutian Islands (Western portion not shown)
115. Cook Inlet
116. Alaska Range
117. Copper Plateau
118. Wrangell Mountains
119. Pacific Coastal Mountains
120. Coastal Western Hemlock-Sitka Spruce Forests

The ecoregions shown here have been derived from Omernik (1987) and from refinements of Omernik's framework that have been made for other projects. These ongoing or recently completed projects, conducted in collaboration with the U.S. EPA regional offices, state resource management agencies, and with other federal agencies, involve refining ecoregions, defining subregions, and locating sets of reference sites. Designed to serve as a spatial framework for environmental resource management, ecoregions denote areas within which ecosystems (and the type, quality, and quantity of environmental resources) are generally similar. The most immediate needs are to develop regional biological criteria and water quality standards and to set management goals for nonpoint source pollution.

The approach used to compile this map is based on the premise that ecological regions can be identified through the analysis of the patterns and the composition of biotic and abiotic phenomena that affect or reflect differences in ecosystem quality and integrity (Wiken 1986; Omernik 1987, 1995). These phenomena include geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another regardless of the hierarchical level. Because of possible confusion with other meanings of terms for different levels of ecological regions, a Roman numeral classification scheme has been adopted for this effort. Level I is the coarsest level, dividing North America into 15 ecological regions, whereas at Level II the continent is subdivided into 52 classes (CEC 1997). Level III is the hierarchical level shown on this map. For portions of the United States (see map inset) the ecoregions have been further subdivided to Level IV. The applications of the ecoregions are explained in Gallant et al. (1989) and in reports and publications from the state and regional projects. For additional information, contact James M. Omernik, U.S. EPA National Health and Environmental Effects Laboratory (NHEERL), 200 SW 35th Street, Corvallis, OR 97333; phone: (541) 754-4458, email: omernik@mail.cor.epa.gov.

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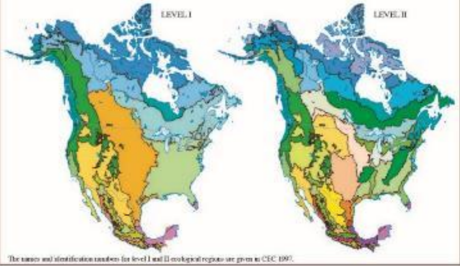
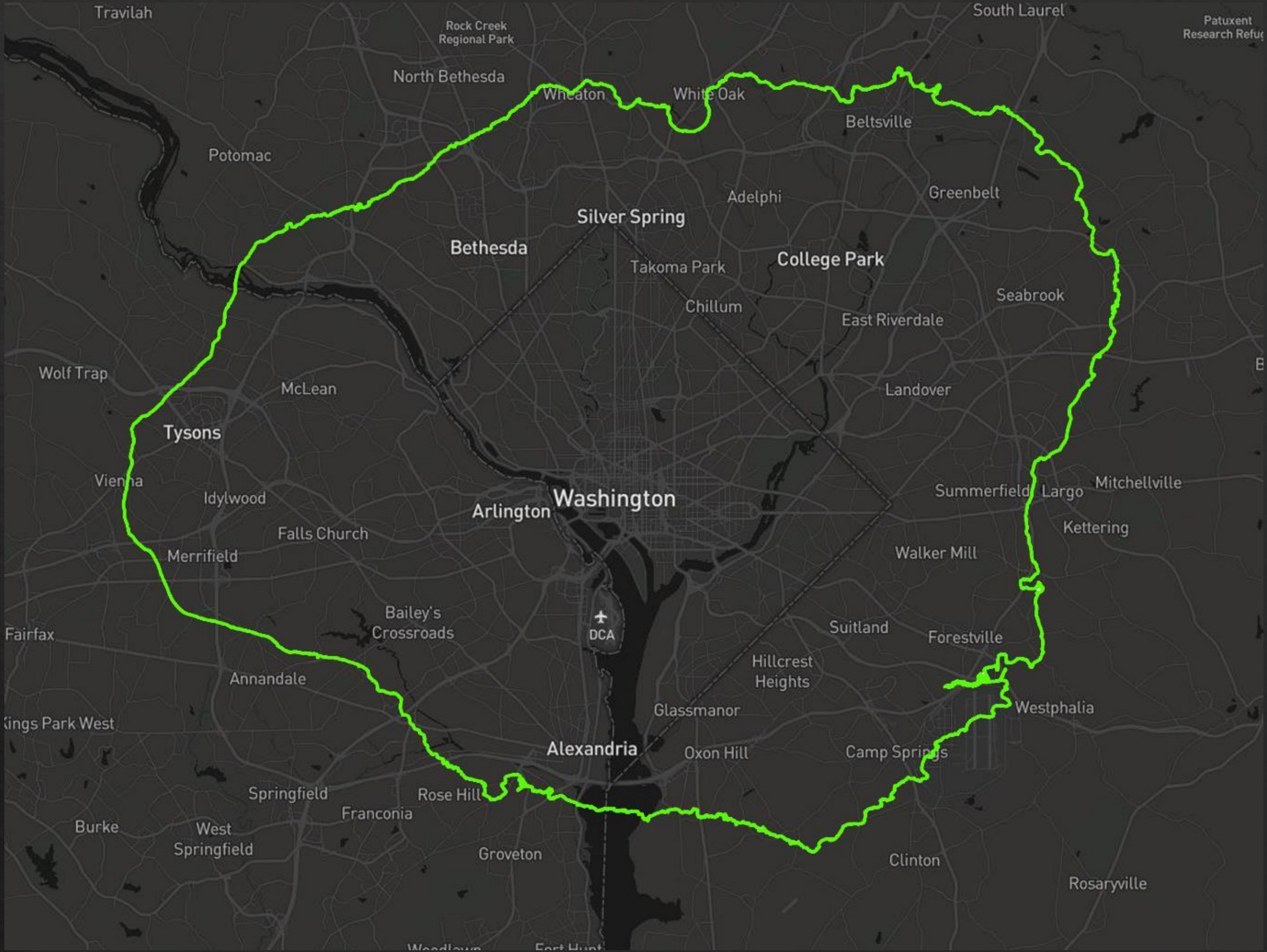
ECOLOGICAL REGIONS OF NORTH AMERICA



The names and identification numbers for level I and II ecological regions are given in CEC 1997.

How to tackle this issue on fine scale for diverse topography and vegetation types of Kaua'i?

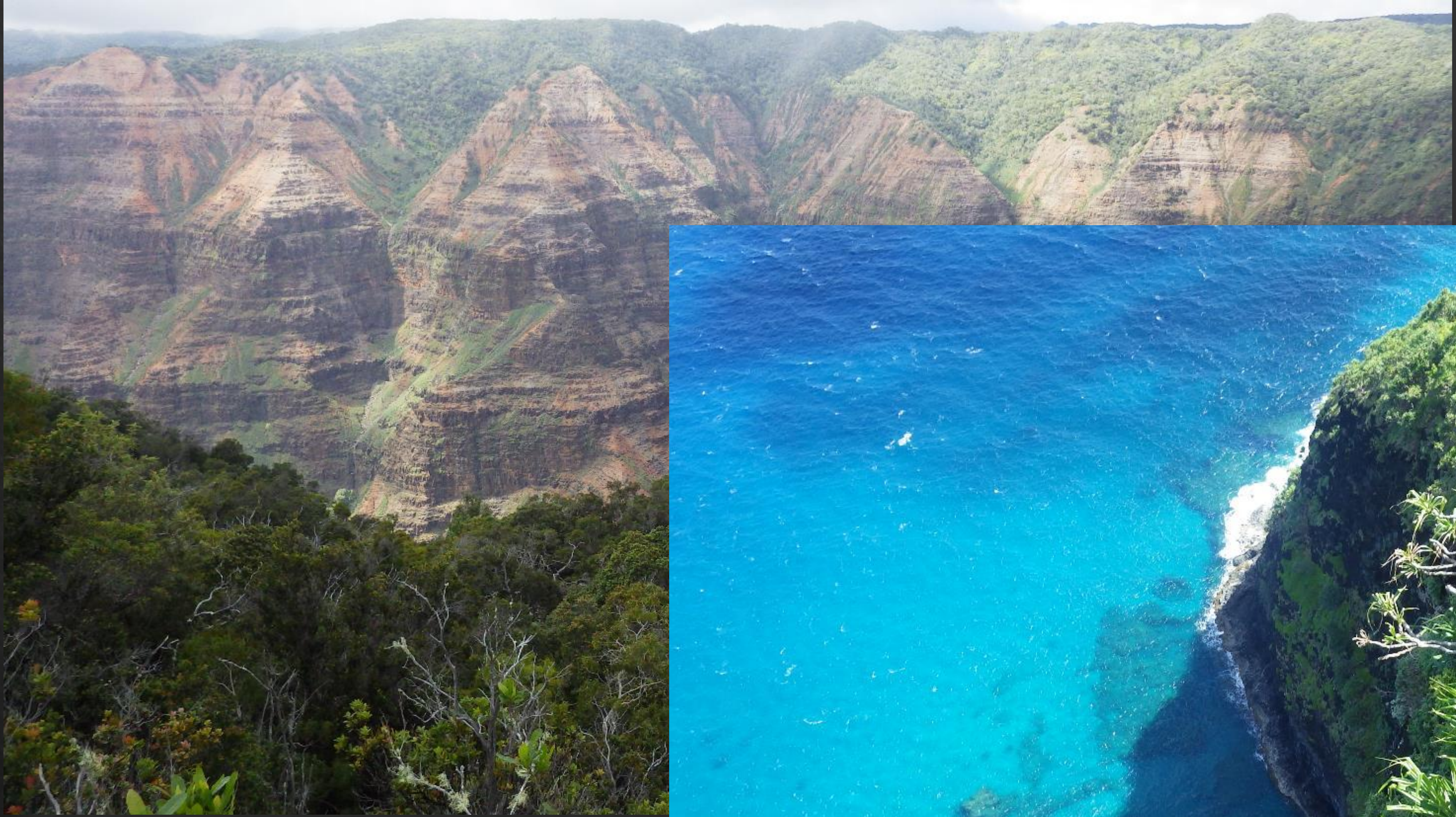
- 562 square miles
  - Only 33 miles long by 25 miles across



... and 16 miles (25.7 km) west

Dunes of Polihale, ~18 in. (458 mm)/year average

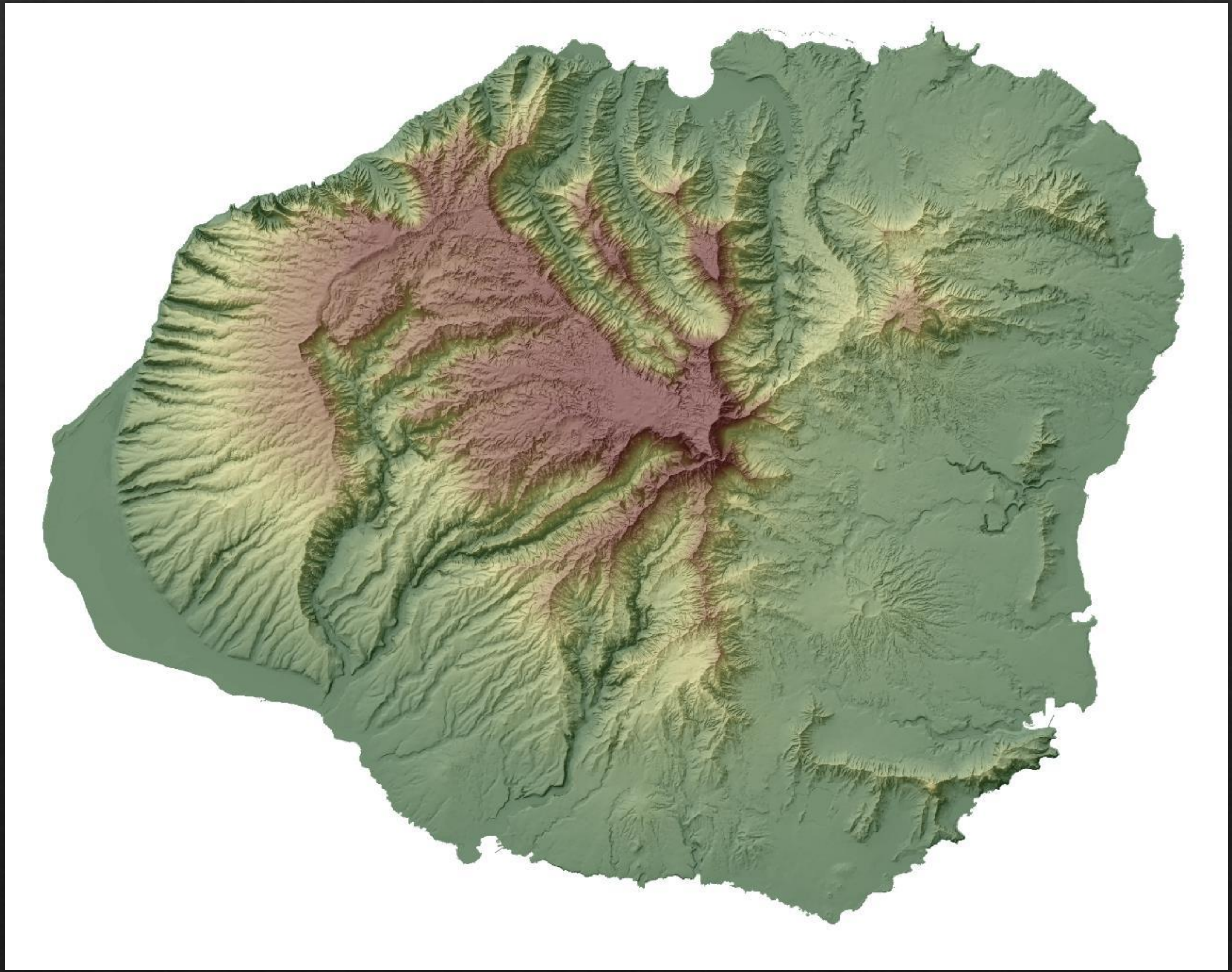
… and 6 miles (9.6 km) North



Mesic *Pandanus* Forests of the Na Pali Coast

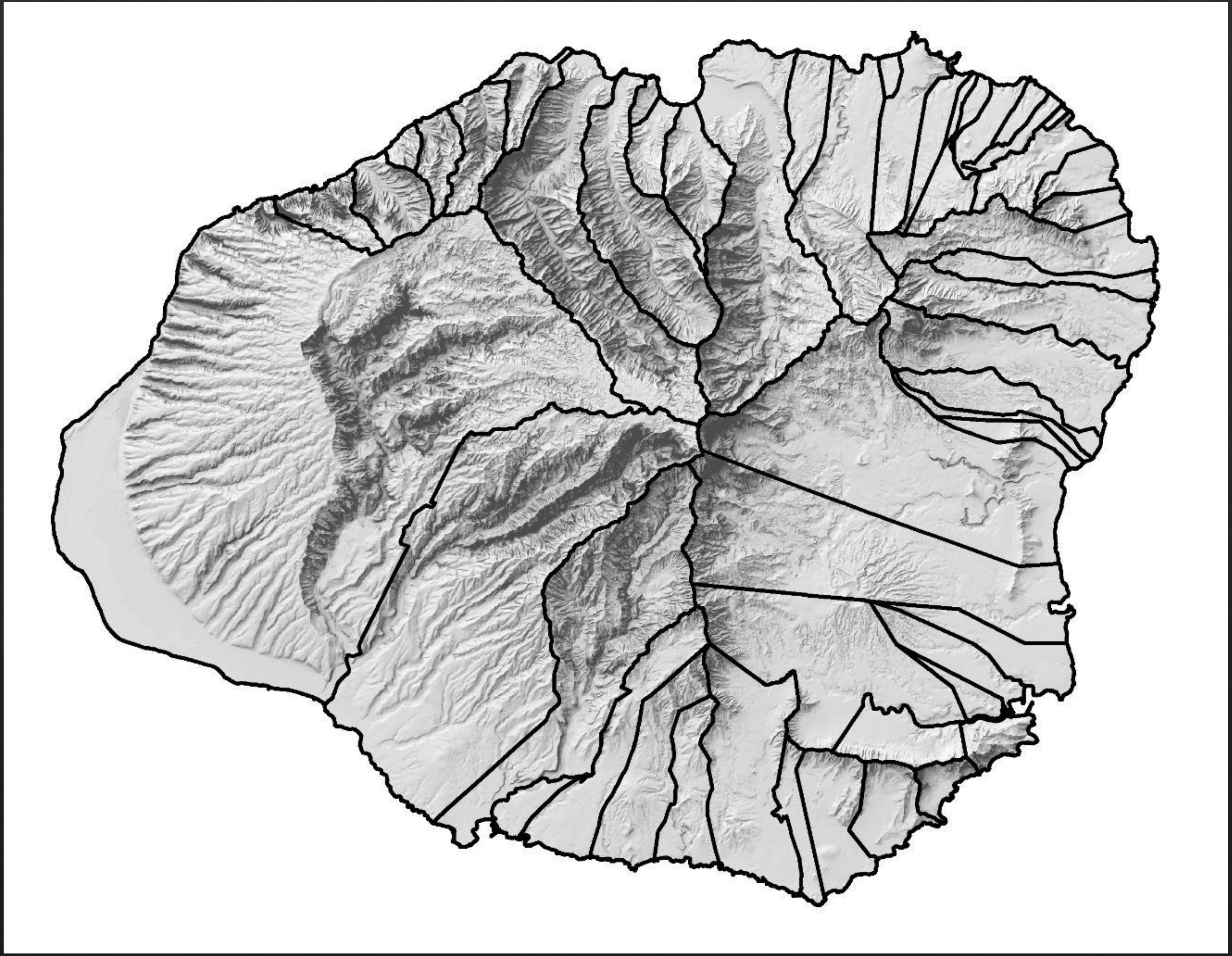
Elevation

- Sea level to summit of Kawaikini, 5,243 feet (1,598 m)
- Many steep cliffs define landscape



Ahupuaʻa

- Indigenous Hawaiian land management units
  - Contained within Moku
  - Often represented a watershed
  - Usually followed natural geographic features
  - Political division

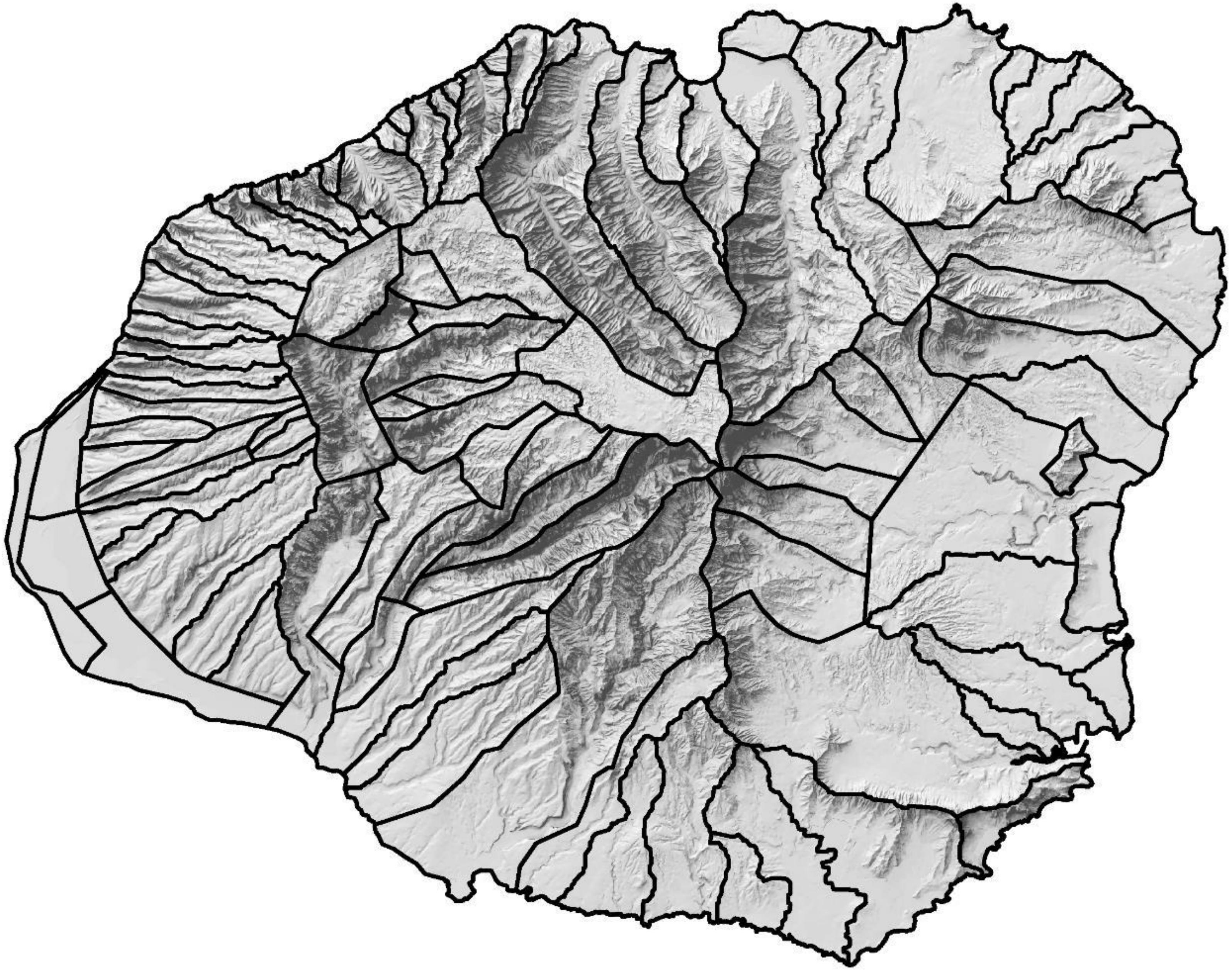


Ahupua‘a cont’d

- Typical “pie slice” from mountain headwaters to shore, ridge to ridge

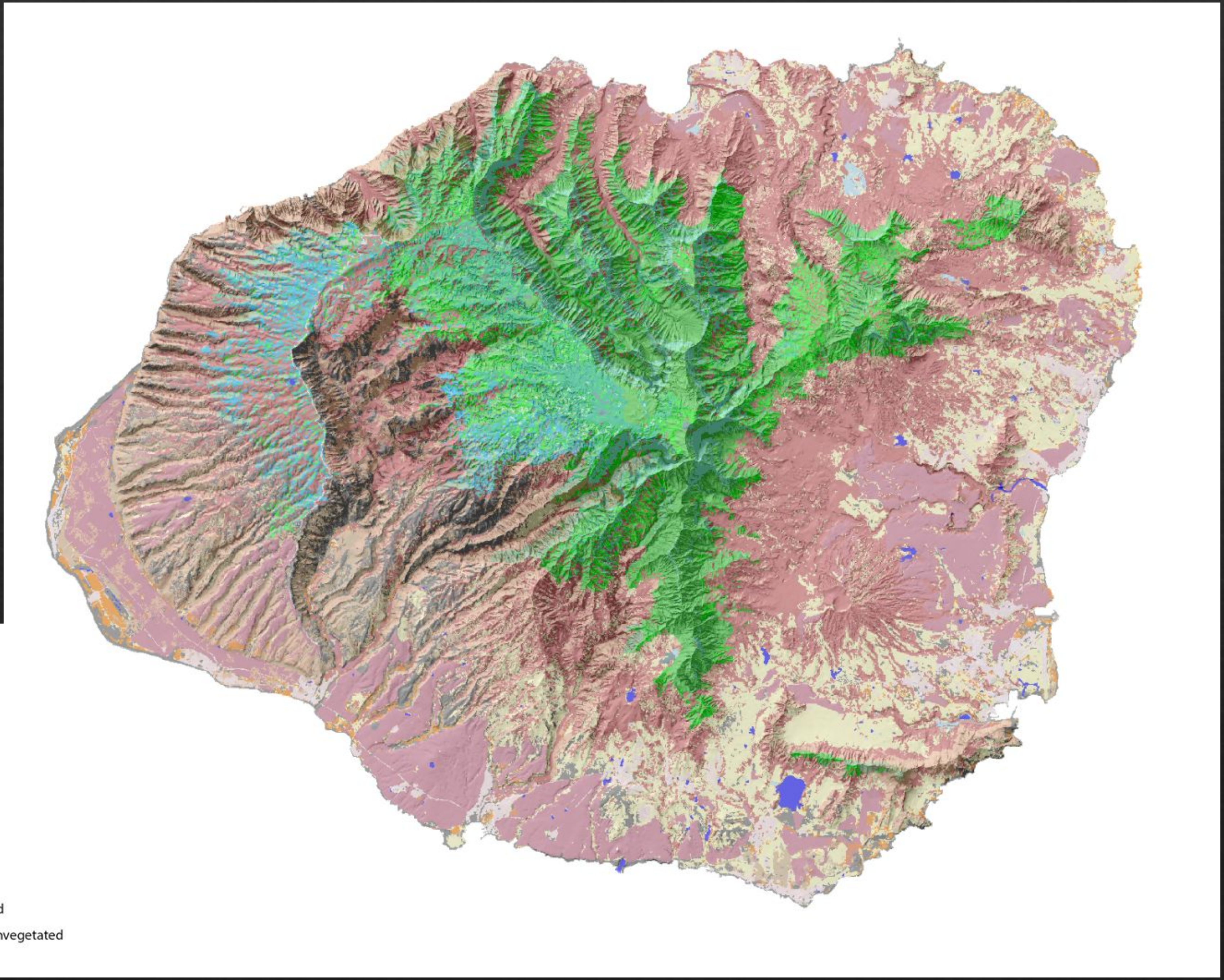
Population Reference Polygons
(aka PopRefs)

- Modern Plant Conservation Divisions
  - Often mirror auh'pua'a/watersheds
  - Usually followed natural geographic features
  - Represented in biological databases by 3-letter abbreviation, combined with 6-letter taxon code and plant #
- Ex. GERKAU-KA-ALW-A-0 003



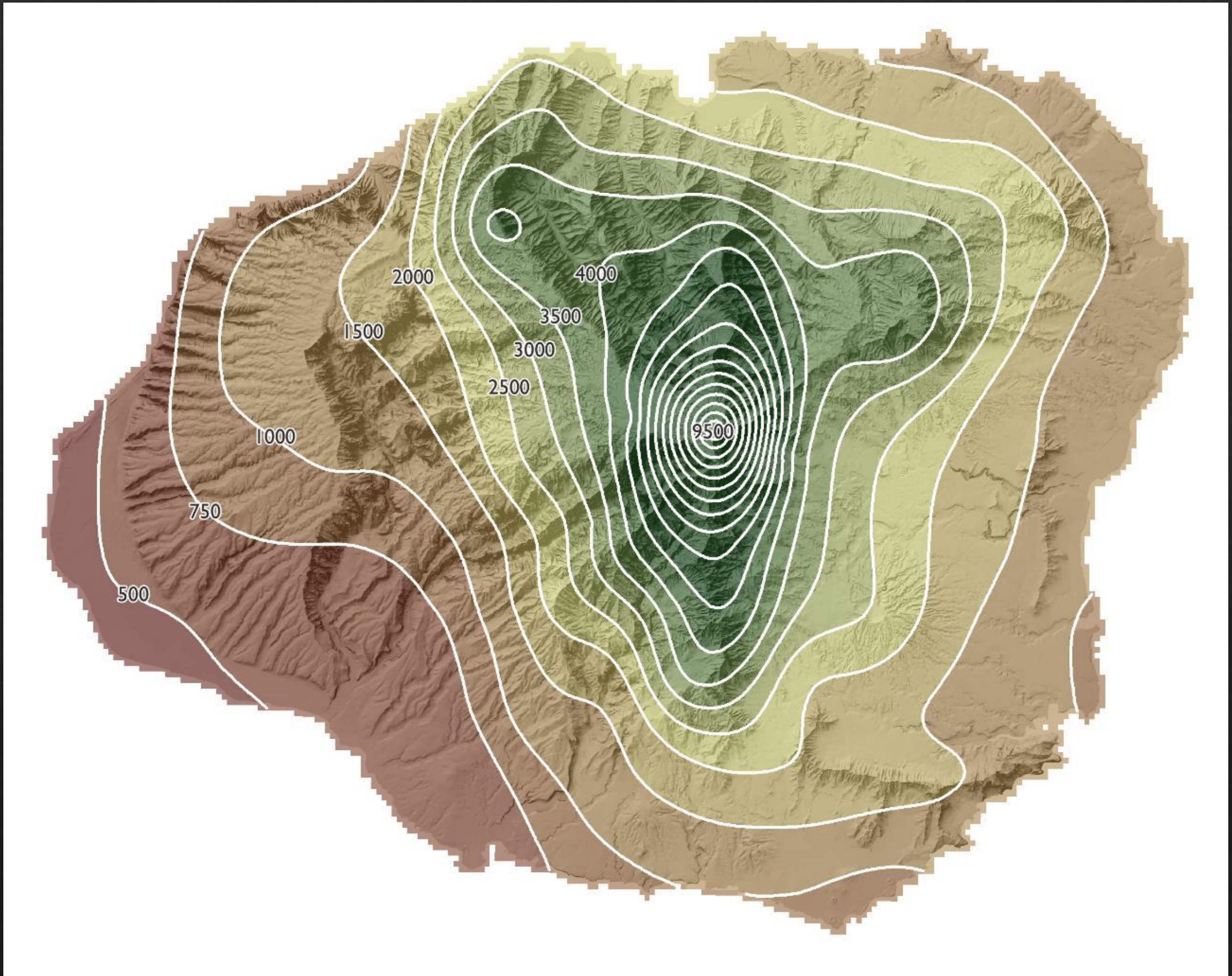
Landcover

- US Geological Survey, Gap Analysis Program (GAP). August 2011. National Land Cover, Version 2
- Different Broad Categories of vegetation types
  - 11 categories of Native and 12 non-native



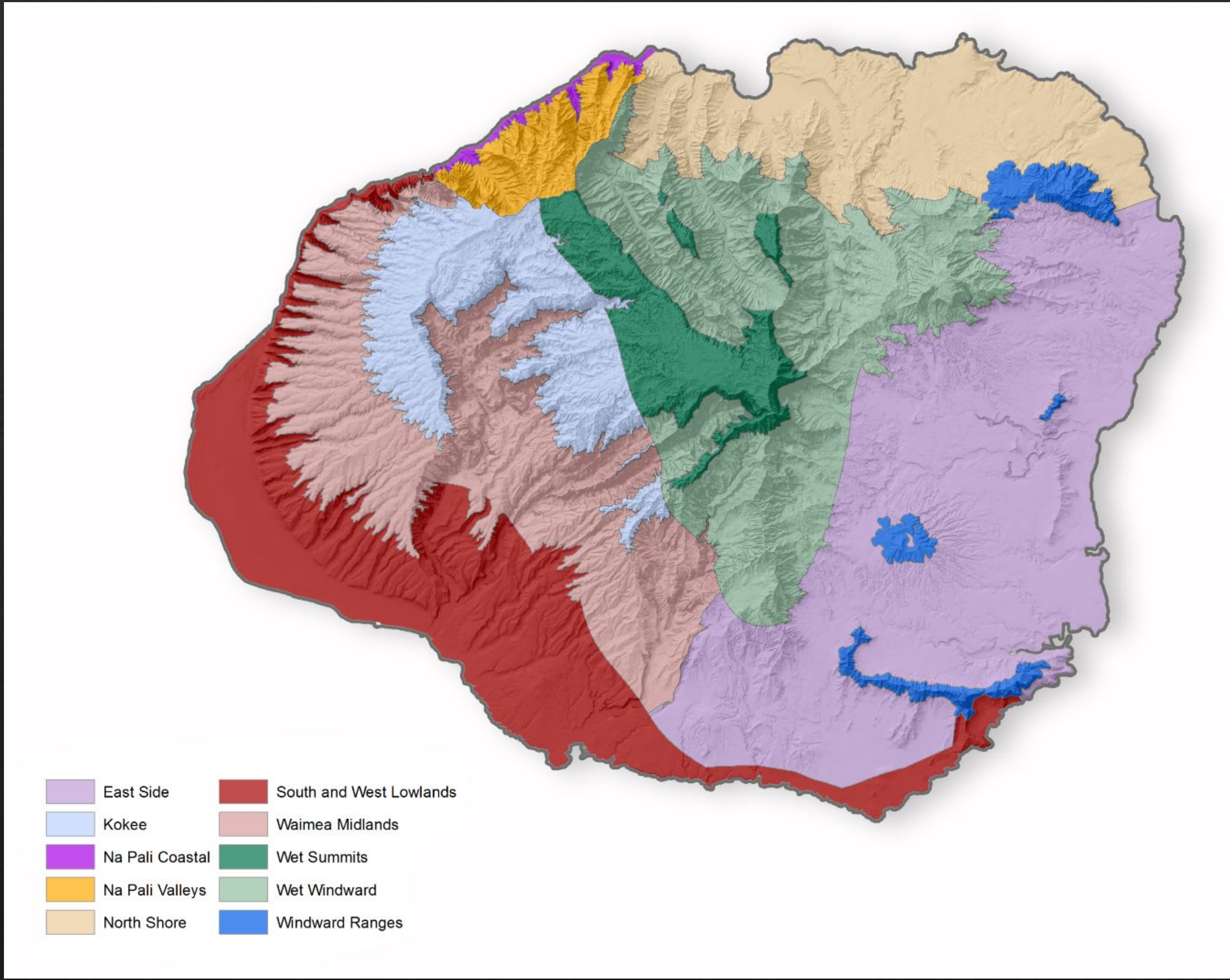
Rainfall

- Wet Windward and summits, North and East
- Dry Leeward, South and West

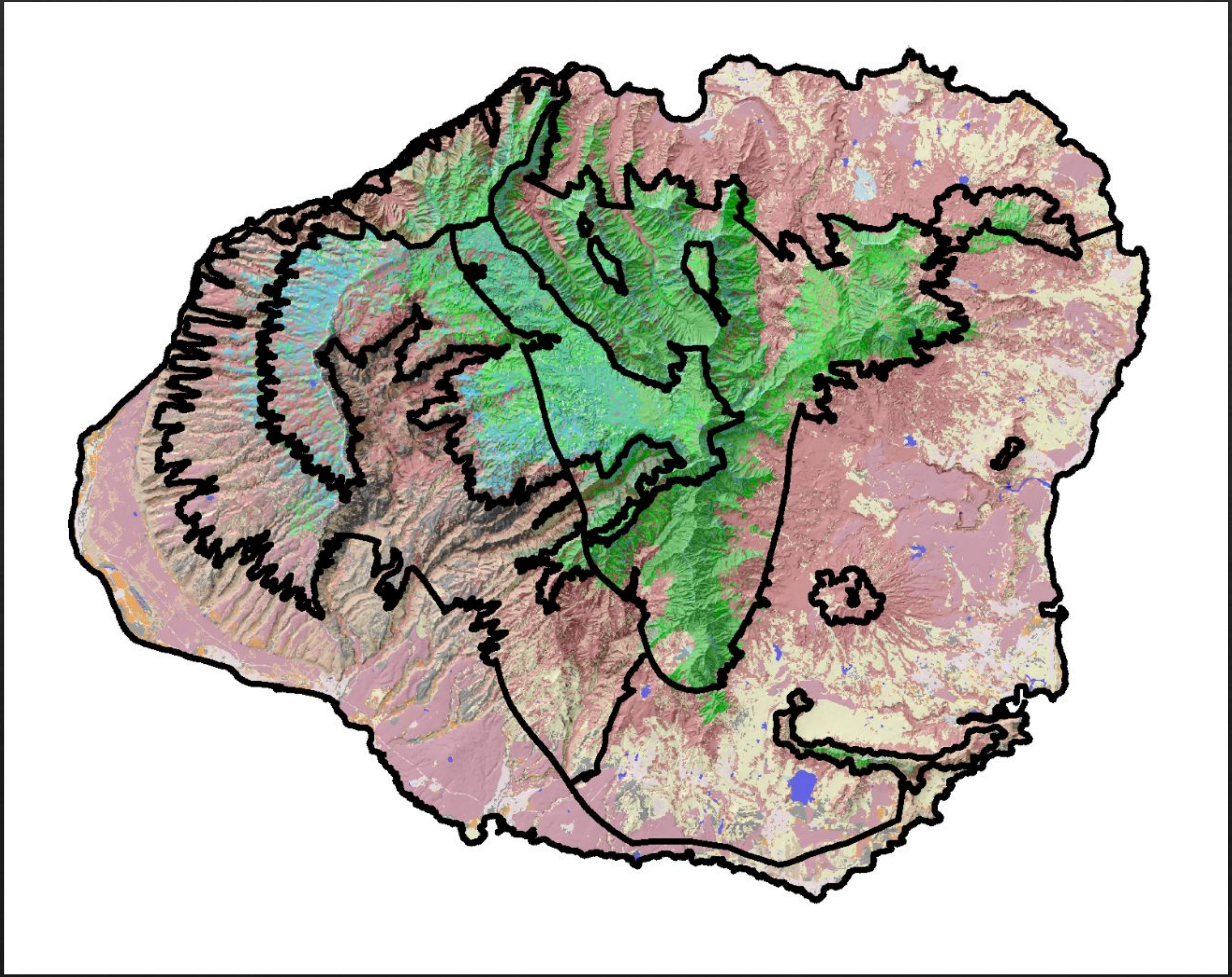


Our approach

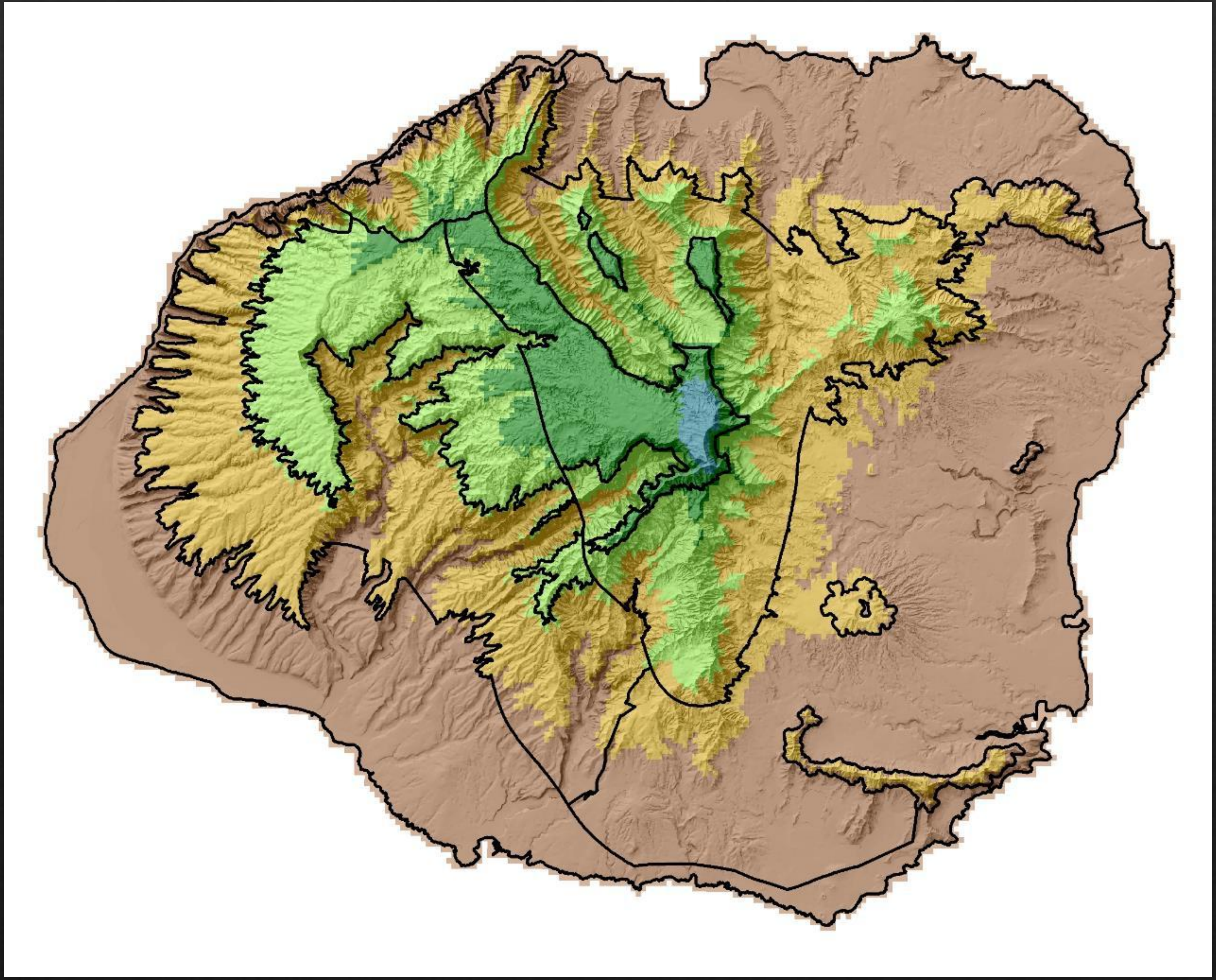
- We used a combination of
  - Rainfall Isohyets
  - GAP Landcover
  - Ahupuaa/PopRef boundaries
- Local Ecological Knowledge and experience on the ground with vegetation communities to combine and/or separate areas with similar rainfall/elevation
- Refined by picking certain elevational ranges (rather than isohyet lines) and defining minimum and maximum rainfall amounts
- Came up with 10 distinct zones


East Side
Kokee
Na Pali Coastal
Na Pali Valleys
North Shore
South and West Lowlands
Waimea Midlands
Wet Summits
Wet Windward
Windward Ranges

Seed Zones + USGS GAP Landcover

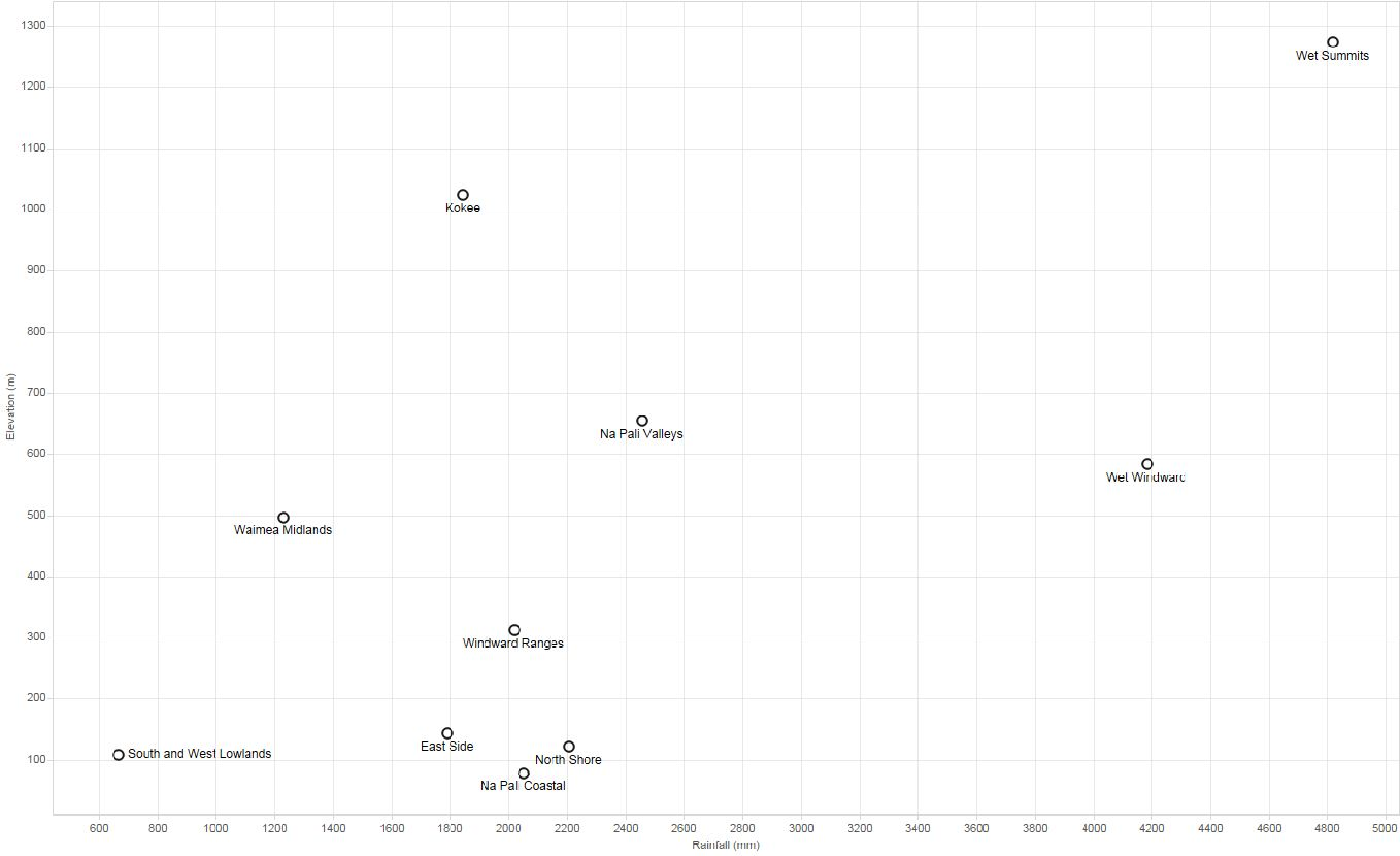


Seed Zones + Temperature



X = Mean annual rainfall

Y = Mean elevation




Wet Summits
Wet Windward
Windward Ranges
North Shore
East Side
Kokee
Waimea Midlands
South and West Lowlands
Napali Coastal
Napali Valleys
Native Land Cover
Non-Native Land Cover

What do we hope to use these zones for?

- Setting seed collecting priorities – for ʻōhiʻa or any widespread native taxa
  - Specific objectives to meet preparation goals for known threat of ROD
  - Helping to define "suites" of common species to bank and where to collect them from
- Guiding where it is appropriate to reintroduce banked collections during restoration projects for "common" Hawaiian plant species, like ʻōhiʻa



NTBG Herbarium Search

Seed Zone	Number of Herbarium Specimens at PTBG					
	M. polymopha var. dieteri	M. polymopha var. glaberrima	M. polymopha var. pumila	M. polymorpha (unspecified)	M. waialealae	Taxa per Zone
East Side	0	5	0	6	0	1
Kokee	7	45	6	4	6	4
Na Pali Coastal	0	1	0	5	0	4
Na Pali Valleys	0	9	0	9	3	2
North Shore	0	0	0	0	0	0
South and West Lowlands	0	1	0	1	0	1
Waimea Midlands	0	3	0	0	0	1
Wet Summits	0	1	5	2	3	3
Wet Windward	2	1	0	5	3	3
Windward Ranges	0	1	0	2	0	2
Zones per Taxa	2	9	2	na	4	Total taxa per zone = 21

Next Steps

- Test the model with more expansive herbarium searches specific to *Metrosideros* taxa
  - Determine seed zones that each taxon occurs within – augment herbarium record for undercollected areas
  - possibly establish collection/banking goals per seed zone/taxa
- Test with other widespread taxa that have noticeable local adaptation/morphological variation
  - e.g. *Dianella* taxa, *Acacia koa, Dodonaea viscosa, Pipturus* spp., *Sida fallax*
- Replace elevation with temperature in analysis
  - Correlate with climate change models to help prioritize collections

Want to hear more about Rapid ʻŌhiʻa Death?

- Marian Chau "The #OhiaLove Project: Banking Seeds of a Hawaiian Keystone Species During the Rapid ʻŌhiʻa Death Crisis"
  - Wednesday @ 1:20 p.m. in the Cabinet Room

- Dustin Wolkis "Picking From the Past in Preparation for a Pest: Assessing the Potential for Herbarium Seeds to Combat ROD"
  - Thursday @ 9:10 a.m. in the Cabinet Room


Questions or comments?

The preceding presentation was delivered at the

2017 National Native Seed Conference

Washington, D.C. February 13-16, 2017

This and additional presentations available at http://nativeseed.info

NATIVE SEED NETWORK

Institute for Applied Ecology