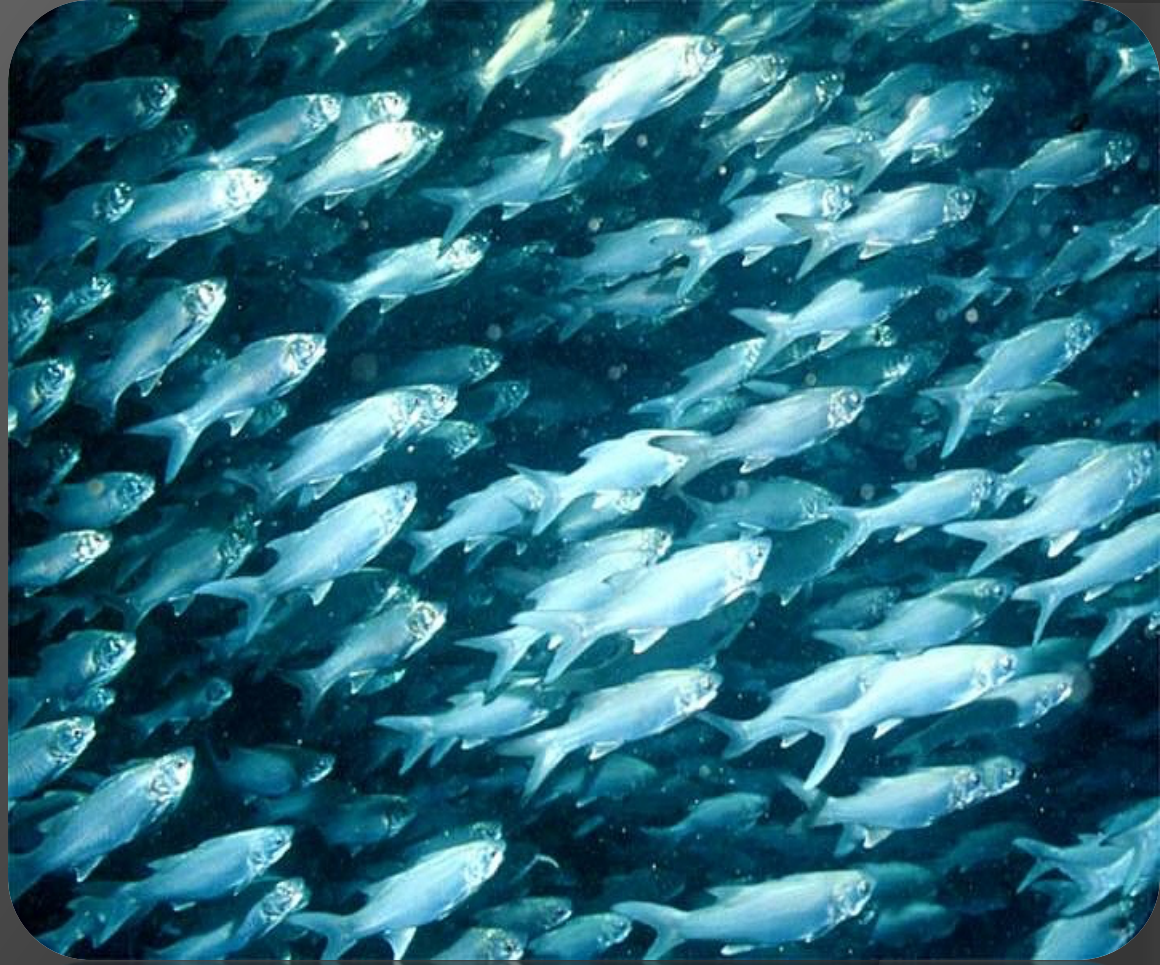
A SITE SUITABILITY FRAMEWORK FOR AQUACULTURE IN OFFSHORE ZONES; THE HAWAIIAN CASE OF *MŌʻĪ* (*POLYDACTYLUS SEXFILIS*) ON OʻAHU

Tomáš Jan Oberding, Carl Evensen (chairperson), PingSun Leung, Michael Robotham, Brian Szuster, Clyde Tamaru

Topics

- Introduction
  - Problem
  - *Mōʻī*
  - *History*
  - Offshore
  - GIS
  - Selection v Suitability
  - Objective
- Models
  - Basic
  - Environmental
  - Economic
  - Social
  - Combined
- Conclusions
- Questions?

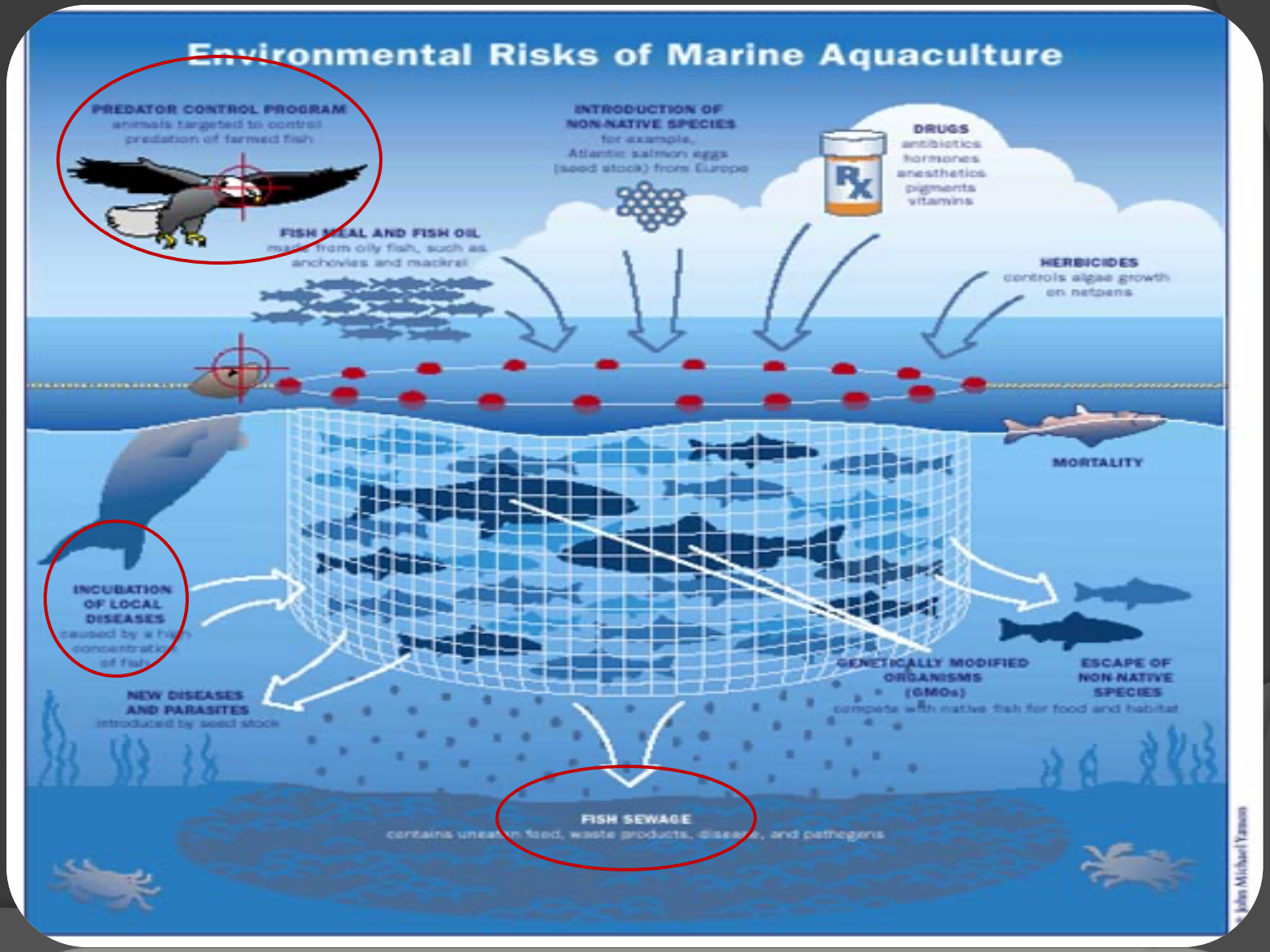
Introduction



Statement of Problem

- Siting issues worldwide & Hawai‘i
  - Environmental, cultural issues, economics
- Goal:
  - Bridge environmental, social, and economic
  - Increase aquaculture production
    - Lessen demand on wild stocks
- How?
  - Simple Multi-Criteria Decision Making Model

Problems

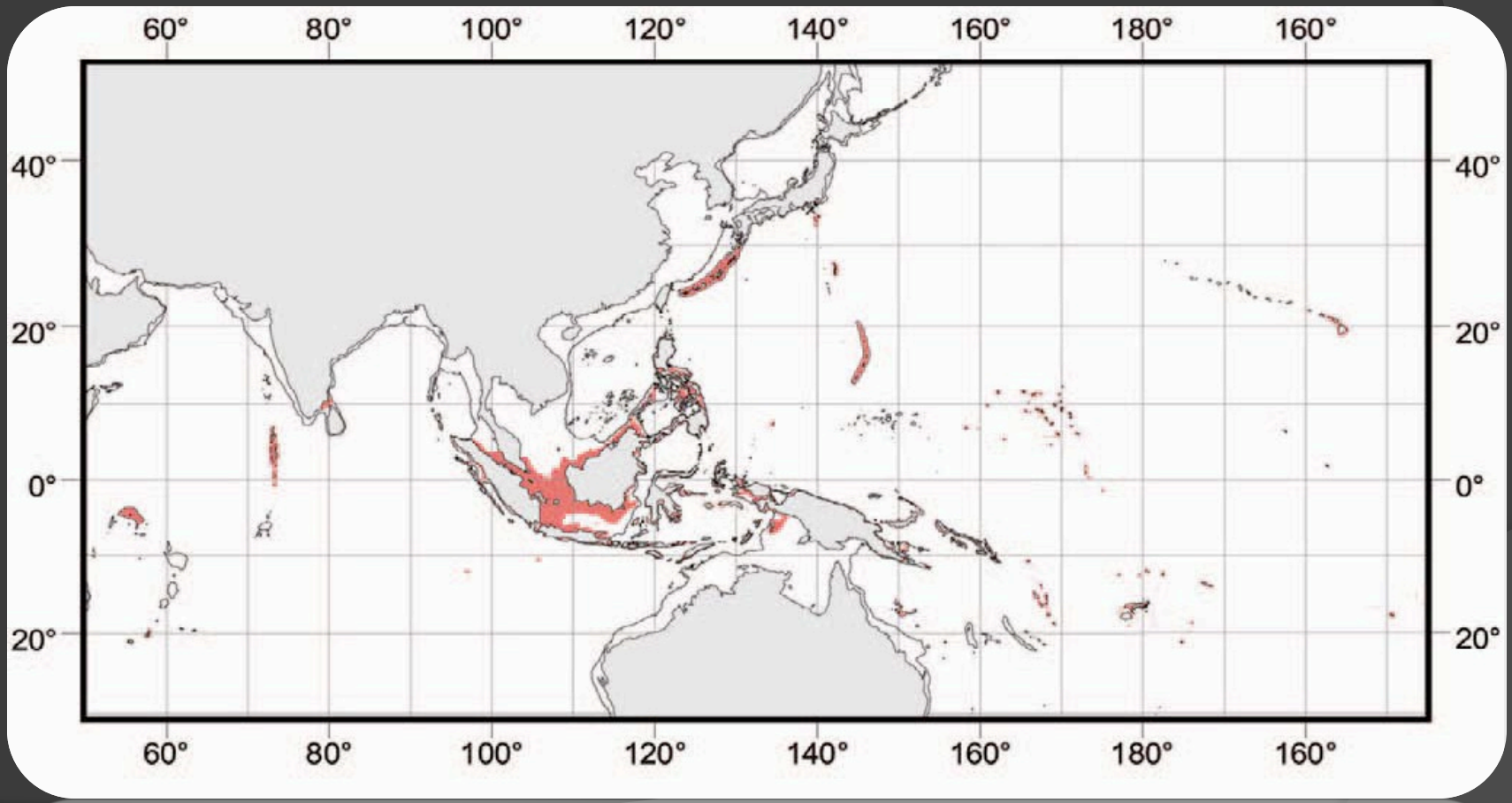

Environmental Risks of Marine Aquaculture
PREDATOR CONTROL PROGRAM
animals targeted to control predation of farmed fish
INTRODUCTION OF NON-NATIVE SPECIES
for example, Atlantic salmon eggs (seed stock) from Europe
DRUGS
antibiotics
hormones
anesthetics
pigments
vitamins
Rx
FISH MEAL AND FISH OIL
made from oily fish, such as anchovies and mackrel
HERBICIDES
controls algae growth on netpens
MORTALITY
INCUBATION OF LOCAL DISEASES
caused by a high concentration of fish
NEW DISEASES AND PARASITES
introduced by seed stock
GENETICALLY MODIFIED ORGANISMS (GMOs)
compete with native fish for food and habitat
ESCAPE OF NON-NATIVE SPECIES
FISH SEWAGE
contains uneaten feed, waste products, disease, and pathogens
John Michael Vanen

Why *Mō‘ī*?

- Long history
- Markets
  - Local
  - Export
  - Stock enhancement
- Native species

Species Limitations

- *Mōʻī* schooling species turbulent coastal waters, prefer sandy or rocky bottoms, up to 50 meters



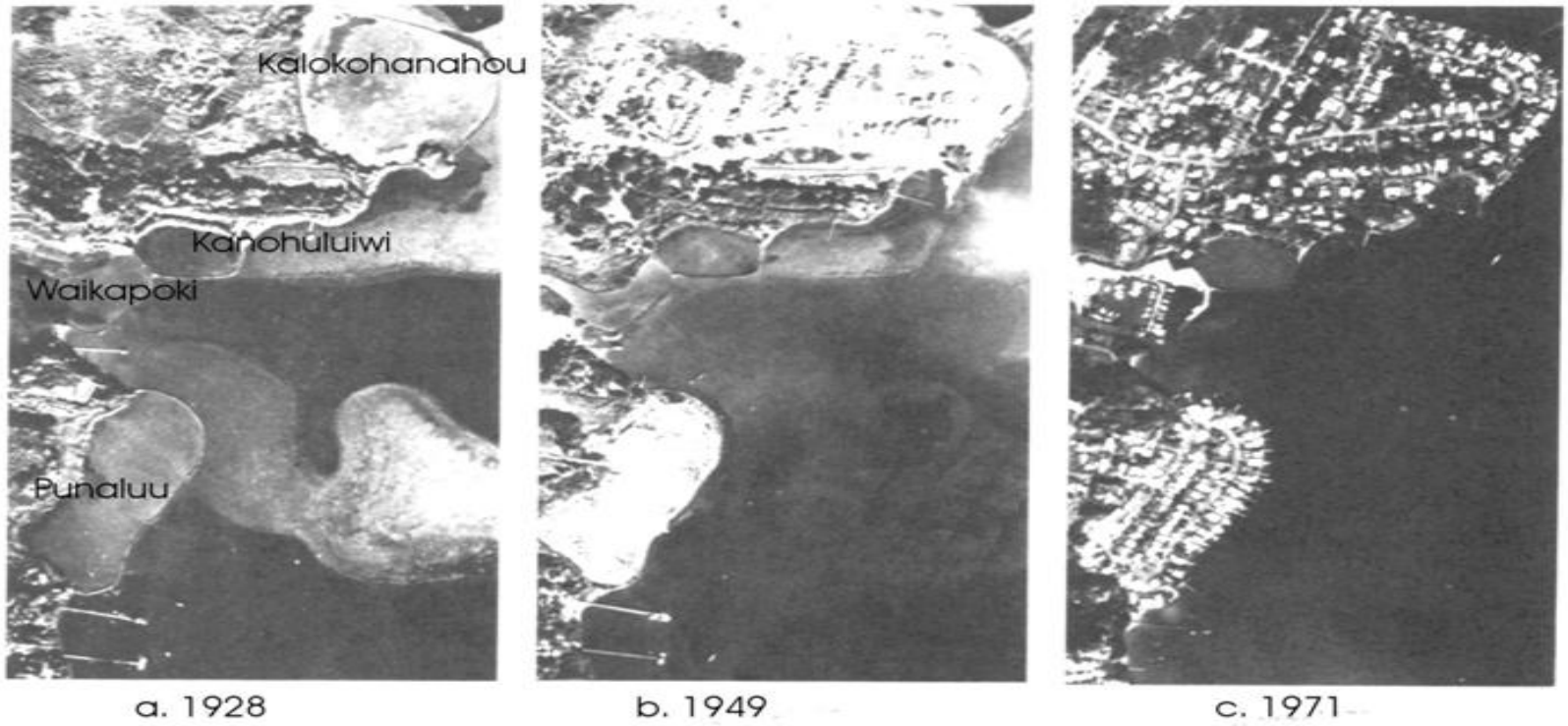
A Bit of History

Hawaiian Aquaculture

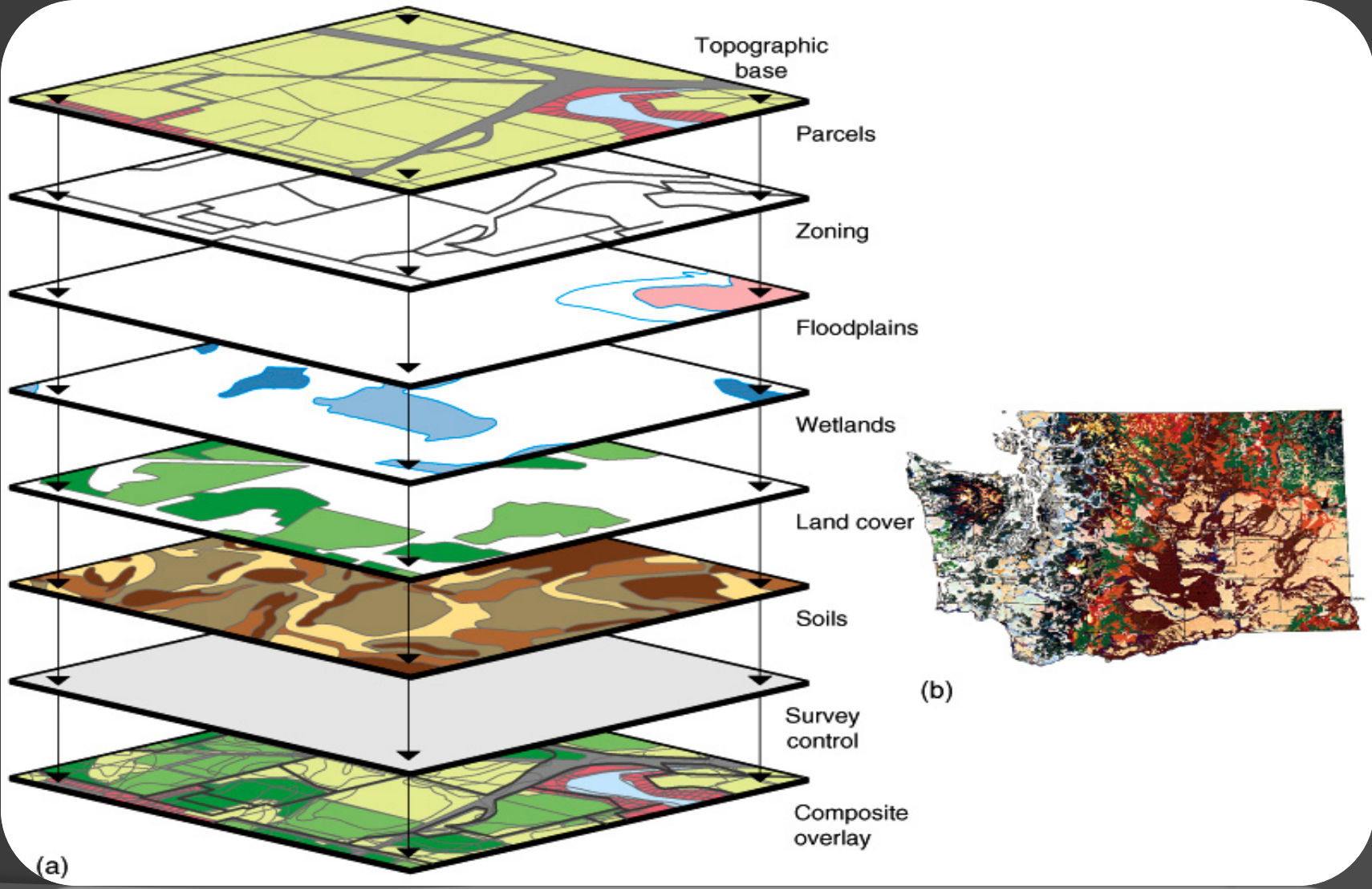
- Practiced extensive & semi-intensive aquaculture
- 488 total ponds ID on 6 main Hawaiian Islands
  - O‘ahu and Hawai‘i had most (178 and 138 ponds)
- Historical estimates in 1800
  - 350 ponds operating
    - >1.5 millions #s

Why Offshore?

- 1990, 6 ponds: 31,639 pounds/year

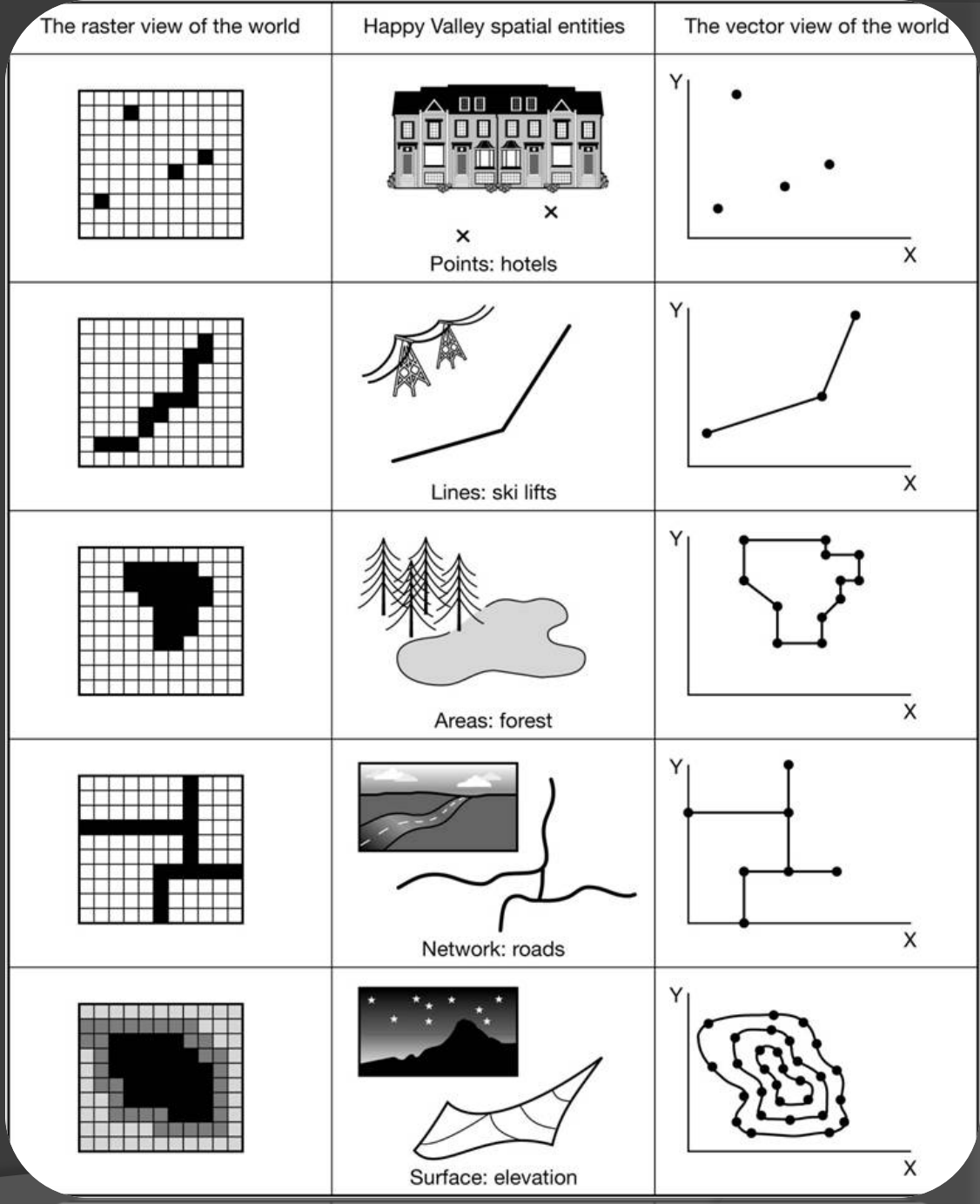


GIS Overview



GIS Overview

- Raster
  - Continuous
  - Discrete
- Vector
  - Areas
  - Discrete



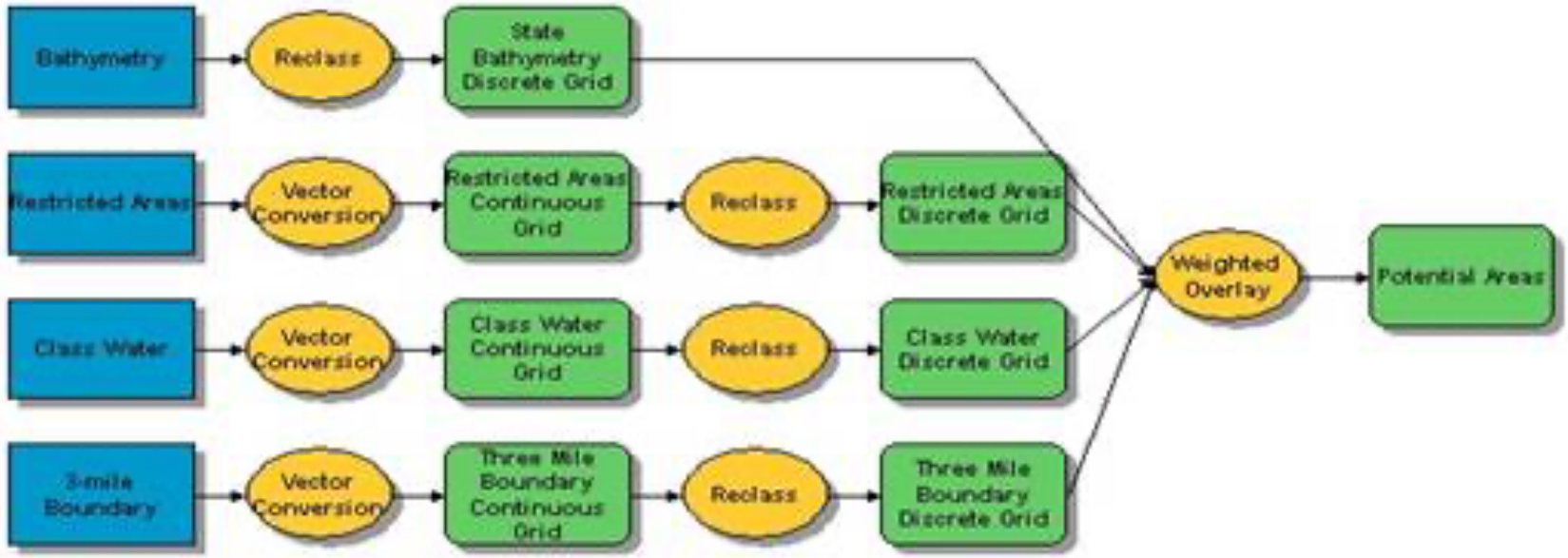
GIS in Aquaculture

- 1980's Malaysia
  - Winds, waves, currents, bathymetry
- 1993 Water quality for salmon in Scotland
  - Overlaying successive data
    - Floating cages
      - Bathymetry, currents, waves, water quality
- 2002 Canary Islands
  - Data overlay methods and MCDM
    - pH, DO, turbidity and temp

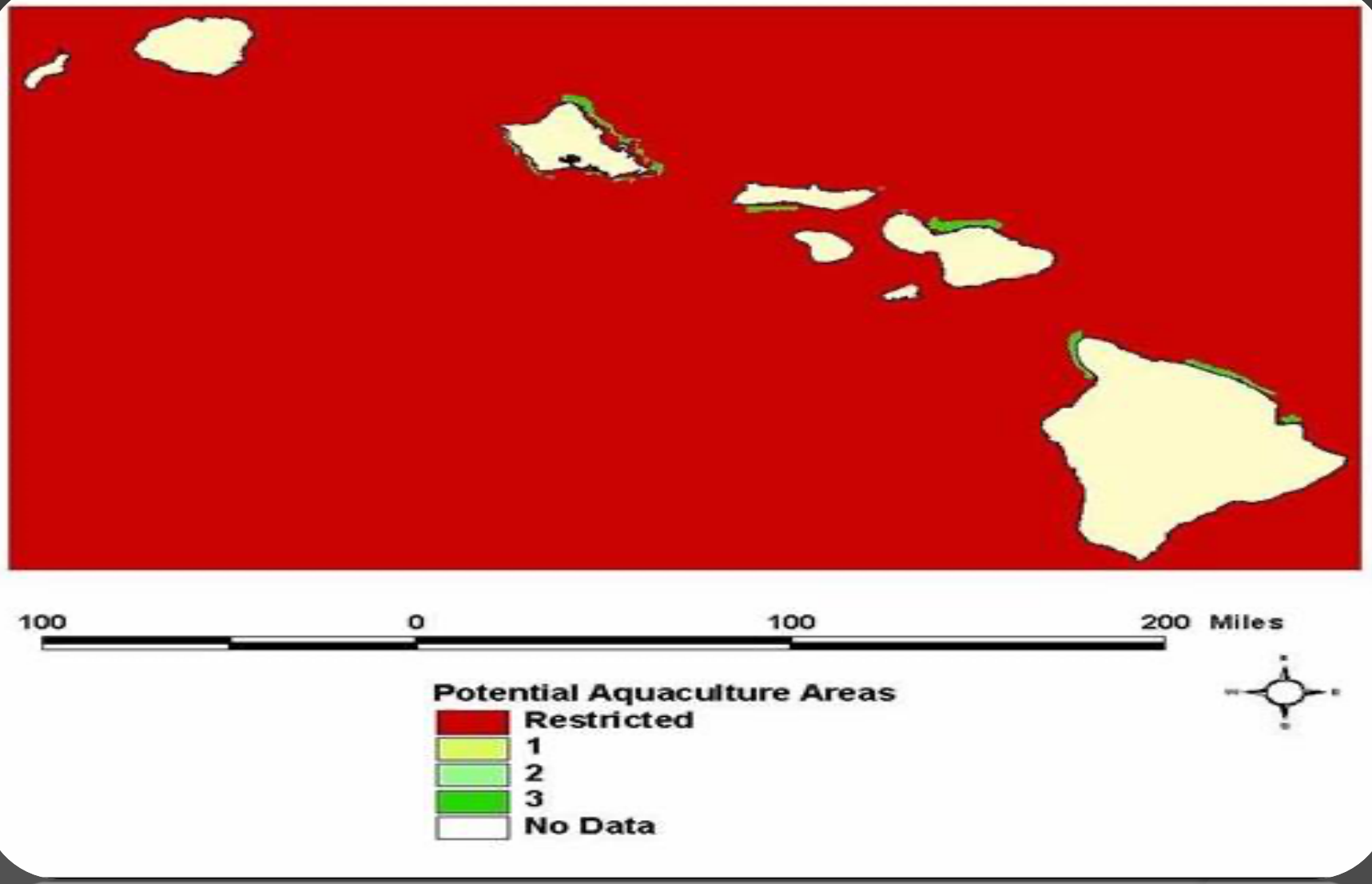
GIS in Aquaculture

- 2003, Young et al in Hawai‘i
  - Examined: bathymetry, restricted, water classifications, 3-mile boundary
  - ID minimal conflicting sites
    - High
    - Marginal
    - No potential for aquaculture

GIS in Aquaculture



GIS in Aquaculture

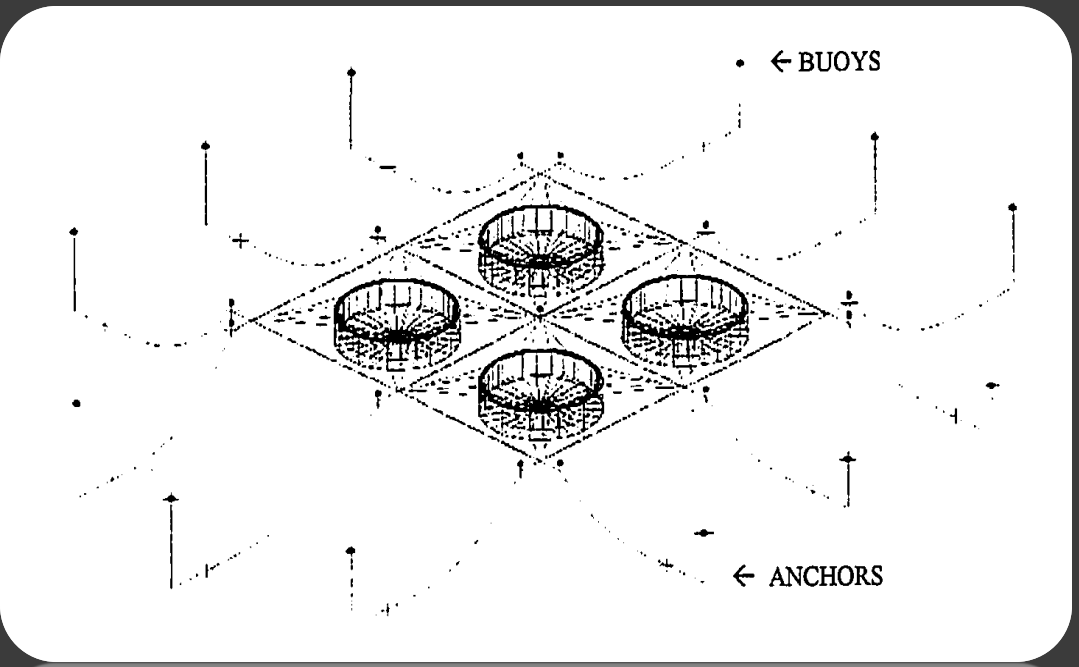


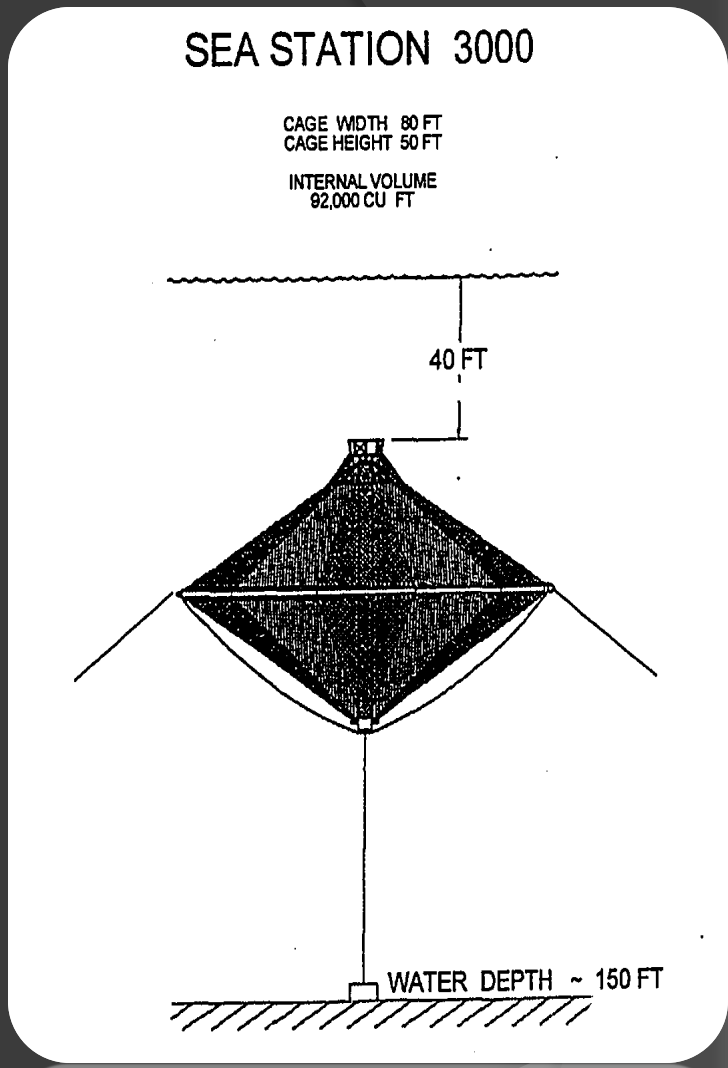
GIS in Aquaculture

- Radiarta et al (2009)
  - Bio-physical; social-infrastructure; constraints
  - Many factors: most important is based on culture system used by farmers

TYPE	WINDS	SURGE	DEPTH	CURRENT	CAPACITY	FETCH
Offshore	Winds of 131-155 mph	13 to 18 feet above normal	Deeper >25m	2.25.-2.5 knots	600-6,000 m^3	unlimited
Nearshore	x	x	Moderate 15-30m	2.25.-2.5 knots	5,000-40,000 m^3	moderate

Technology


← BUOYS
← ANCHORS


SEA STATION 3000
CAGE WIDTH 80 FT
CAGE HEIGHT 50 FT
INTERNAL VOLUME
92,000 CU FT
40 FT
WATER DEPTH ~ 150 FT

Selection VS Suitability

- Matter of scale
  - Selection:
    - ID specific spot where to place farm
    - Local
    - Well studied, data rich environments
  - Suitability
    - ID general areas that may be possible (planning, environmental management)
    - Regional
    - National level models (LENKA), rely on statutes and laws as well as science

Objectives

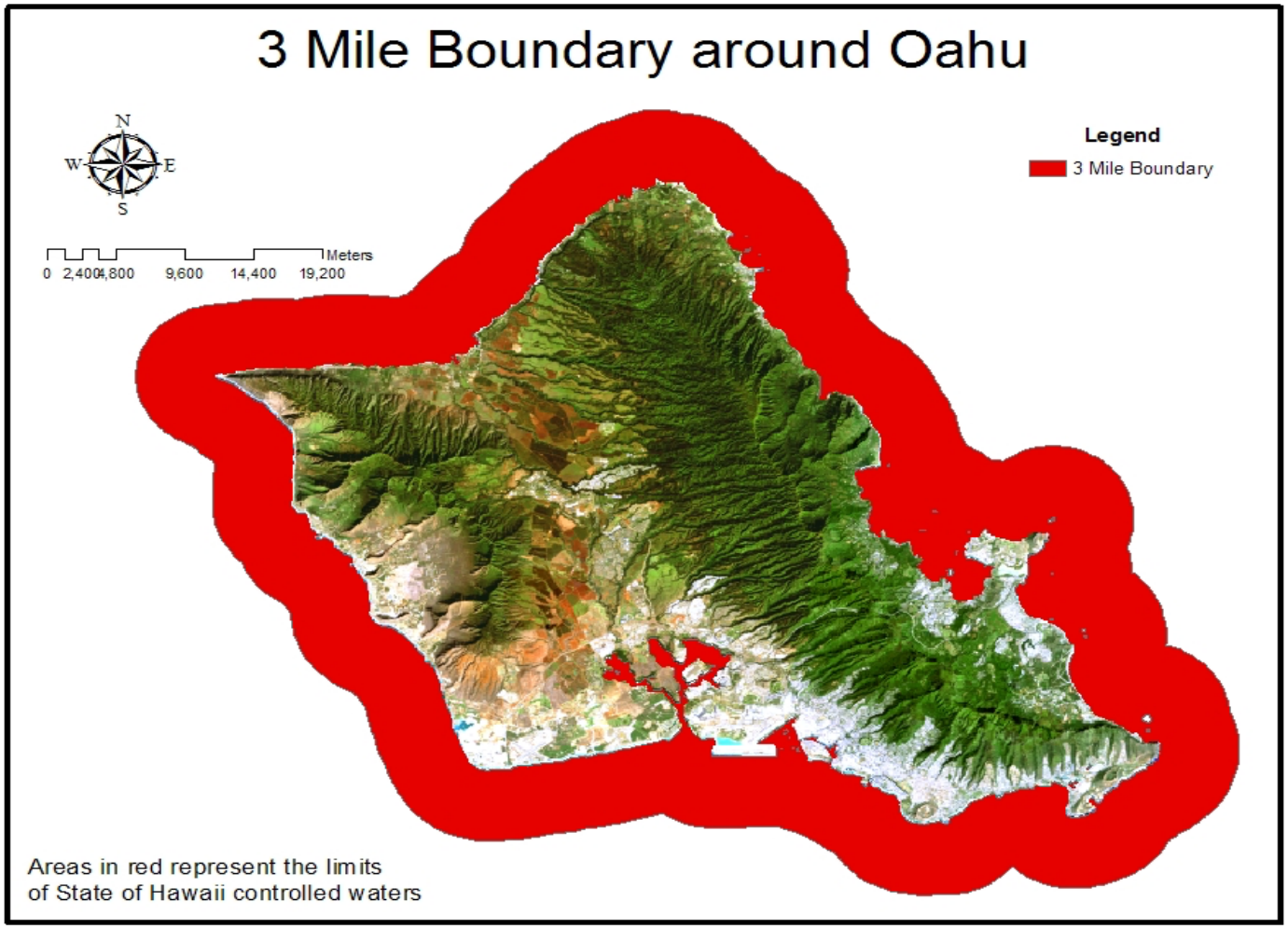
- Create a minimal data-set framework based on publically available data
  - Identifying suitable areas for further detailed research (adapted from FAO)
    - Most Suitable
    - Moderately Suitable
    - Least Suitable
- Transferable with low overhead cost
  - Home computer with moderate specs and ArcGIS software
  - Free /low-cost information

The Model Components

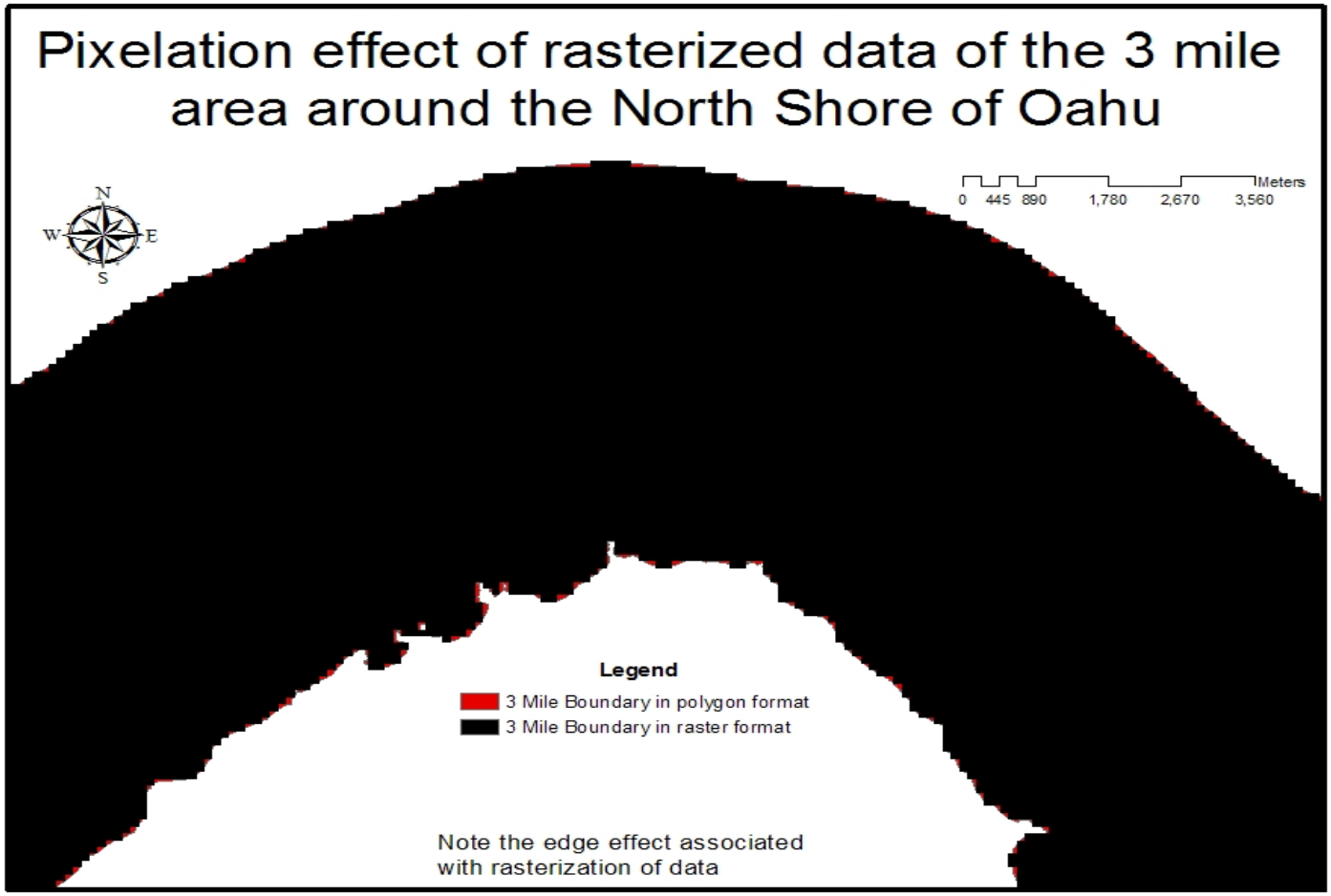
Model Components

- Basic & Military Constraints:
  - Areas incompatible with offshore cages
- 3 broad criteria
  - Environment
  - Economics
  - Social -scenarios
- WLC
  - Environment + Economic

Limitations



Rasterization



Rasterization

Layer	Area (m^2)
O‘ahu Polygon	1,310,550,814
O‘ahu Raster	1,310,550,784
Difference	30

Basic Map Contents

- Anything that can conflict (the kitchen sink approach)
  - If point data, created buffer
  - Buffers based on published data (some layers no buffer)
    - Wrecks assumed average was 30m
- Has to be detailed as possible
  - Offshore farms have exclusive use zones

Basic Layers

Layer	Buffer (m)	Notation on Buffer
Anchor	100	Assuming various vessel sizes and drift
Cables	350	Based on repair ship limitations
Coral (NOAA Navigation Charts)	30	From Cates EIS, 30m is distance from cage where bacterial levels reach ambient concentrations
Dumping	None	Buffer assumed during designation
Explosive Dumping	None	No areas within 3mile limit of O‘ahu, added for completeness
Fish Aggregating Device	100	Analogous to buoys, State statutes prevent encroachment on Buoys
Fish Haven	None	Buffer assumed during designation

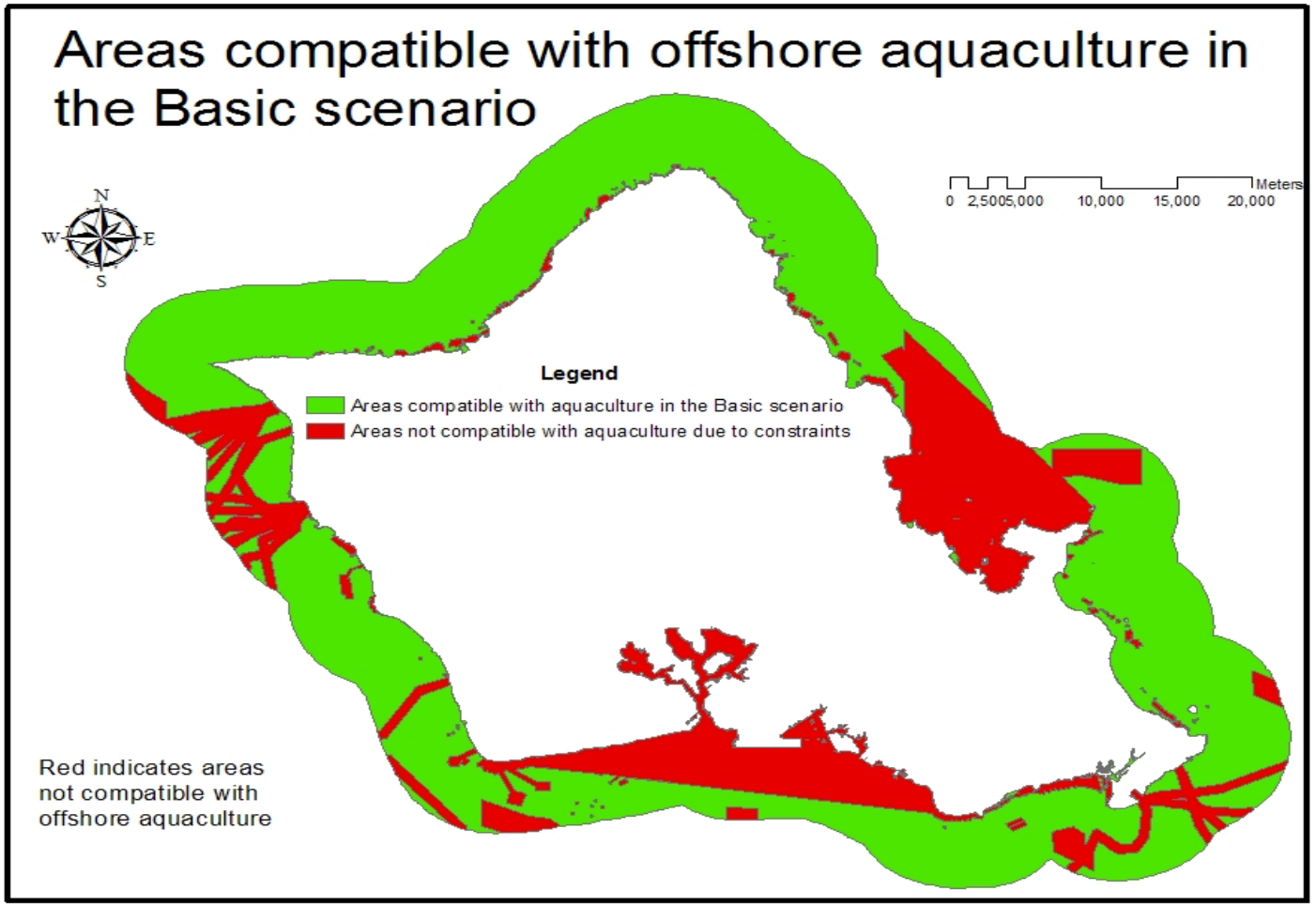
Basic Layers

Layer	Buffer (m)	Notation on Buffer
Natural Area Reserve	None	Only on Maui, added for completeness
Fish Management Area	None	Buffer assumed during designation
Marine Life Conservation District	30	From Cates EIS, 30m is distance from cage where bacterial levels reach ambient concentrations
Marine Managed Area	None	Buffer assumed during designation
Navigational Aide	100	Analogous to buoys, State statutes prevent encroachment on Buoys
Obstruction	30	Point file, buffer added for safety of

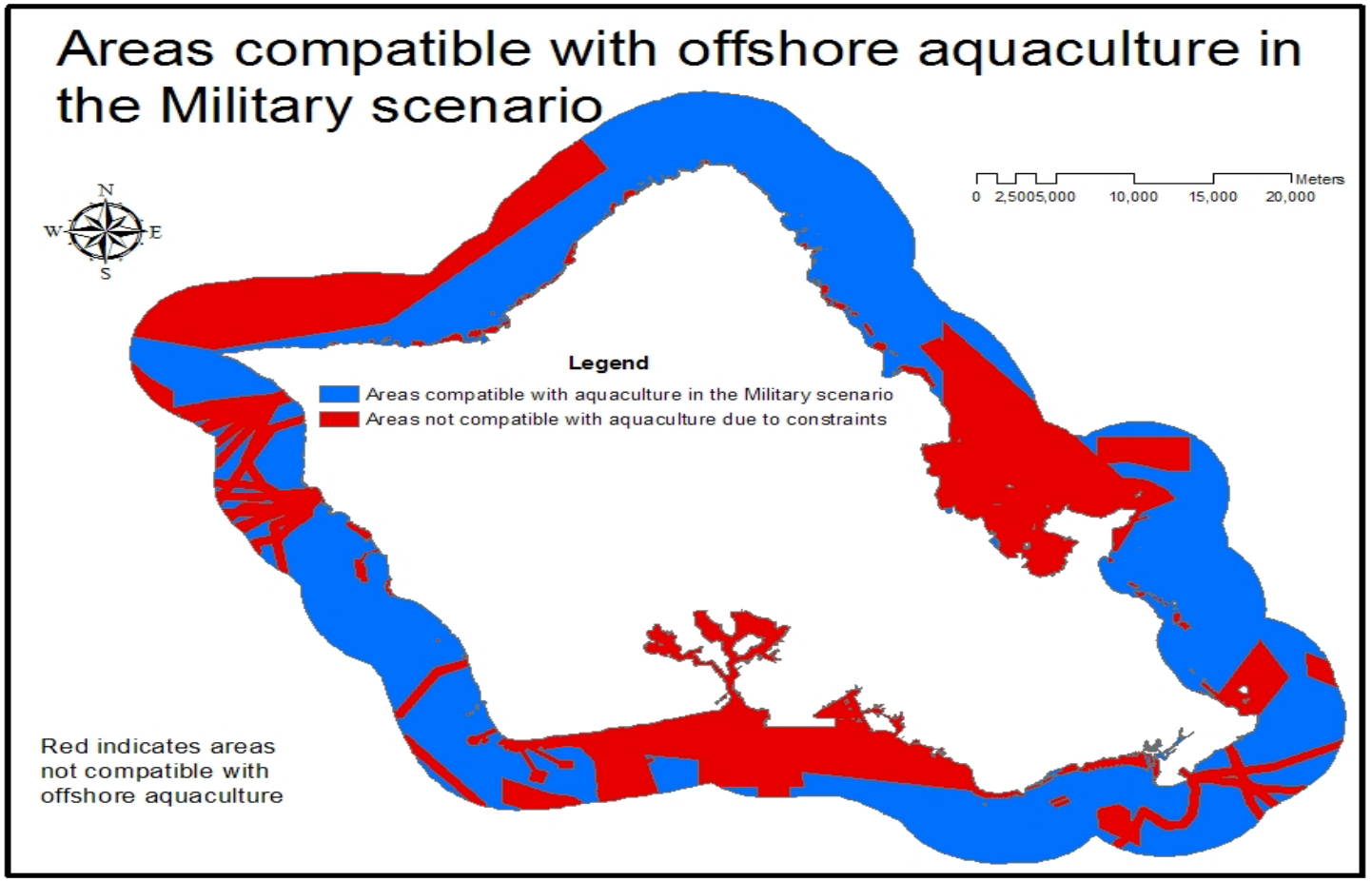
Basic Layers

Layer	Buffer (m)	Notation on Buffer
Offshore Installation	100	Based on point data, prevent overlap of exclusive use zones
Sub-surface Buoys	100	Analogous to buoys, State statutes prevent encroachment on Buoys
Sewer lines	100	Additional safety margin to prevent contamination during a sewage spill
Unexploded Ordinance	100	Point File and none within O‘ahu 3 mile area
Wrecks	100	Averaged size of various wrecks (planes and ships)
Military	None	*Contains Multiple layers which author does not have permission to disclose

Basic


Areas compatible with offshore aquaculture in the Basic scenario
N
W
E
S
0 2,5005,000 10,000 15,000 20,000
Meters
Legend
Areas compatible with aquaculture in the Basic scenario
Areas not compatible with aquaculture due to constraints
Red indicates areas not compatible with offshore aquaculture

Military


Areas compatible with offshore aquaculture in the Military scenario
N
W
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S
0 2,5005,000 10,000 15,000 20,000
Meters
Legend
Areas compatible with aquaculture in the Military scenario
Areas not compatible with aquaculture due to constraints
Red indicates areas not compatible with offshore aquaculture

Area

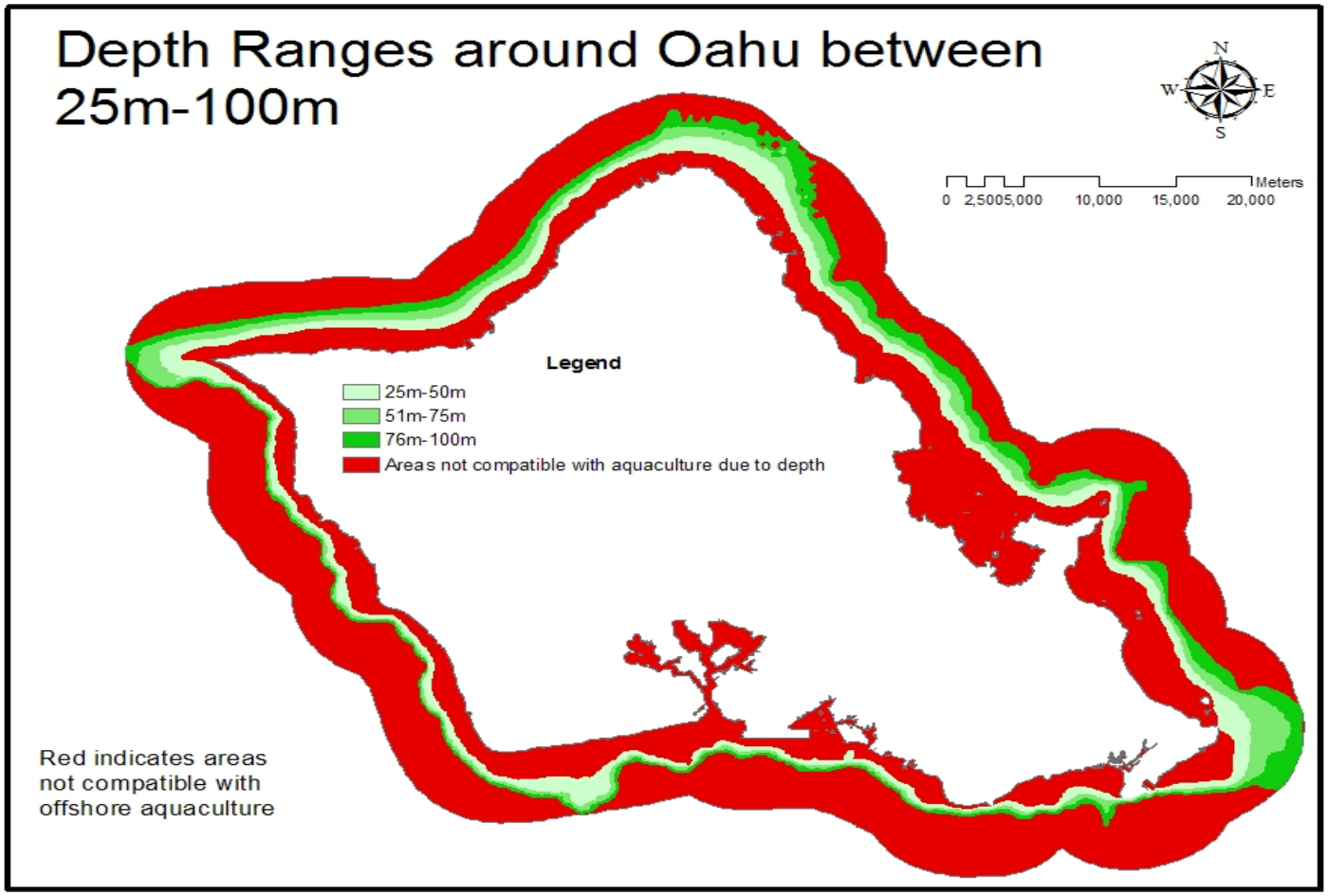
Layer	Size (m^2)	%
O‘ahu Full Extent	1,310,550,784	100
Basic	924,000,191	70.5
Military	769,486,606	58.7

Environmental

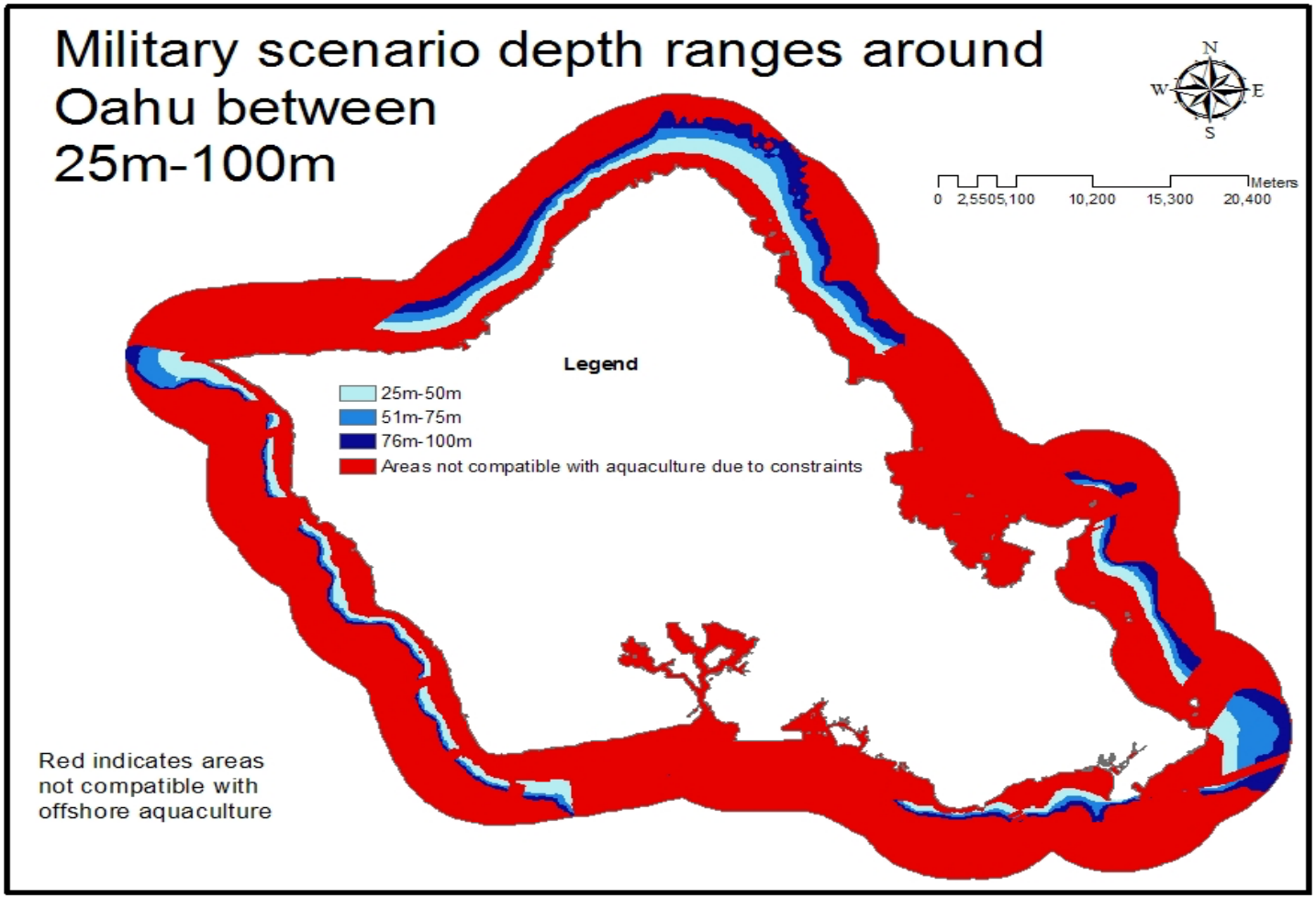
Environmental

- Based on publications and existing site suitability models
  - Basic and near-ubiquitous trait: Bathymetry
    - Missing data interpolate using Natural Neighbor
- 3 classifications
  - 25m-50m
  - 51m-75m
  - 76m-100m

Bathymetry


Depth Ranges around Oahu between 25m-100m
N
W
E
S
0 2,5005,000 10,000 15,000 20,000
Meters
Legend
25m-50m
51m-75m
76m-100m
Areas not compatible with aquaculture due to depth
Red indicates areas not compatible with offshore aquaculture

Bathymetry Military



Environmental

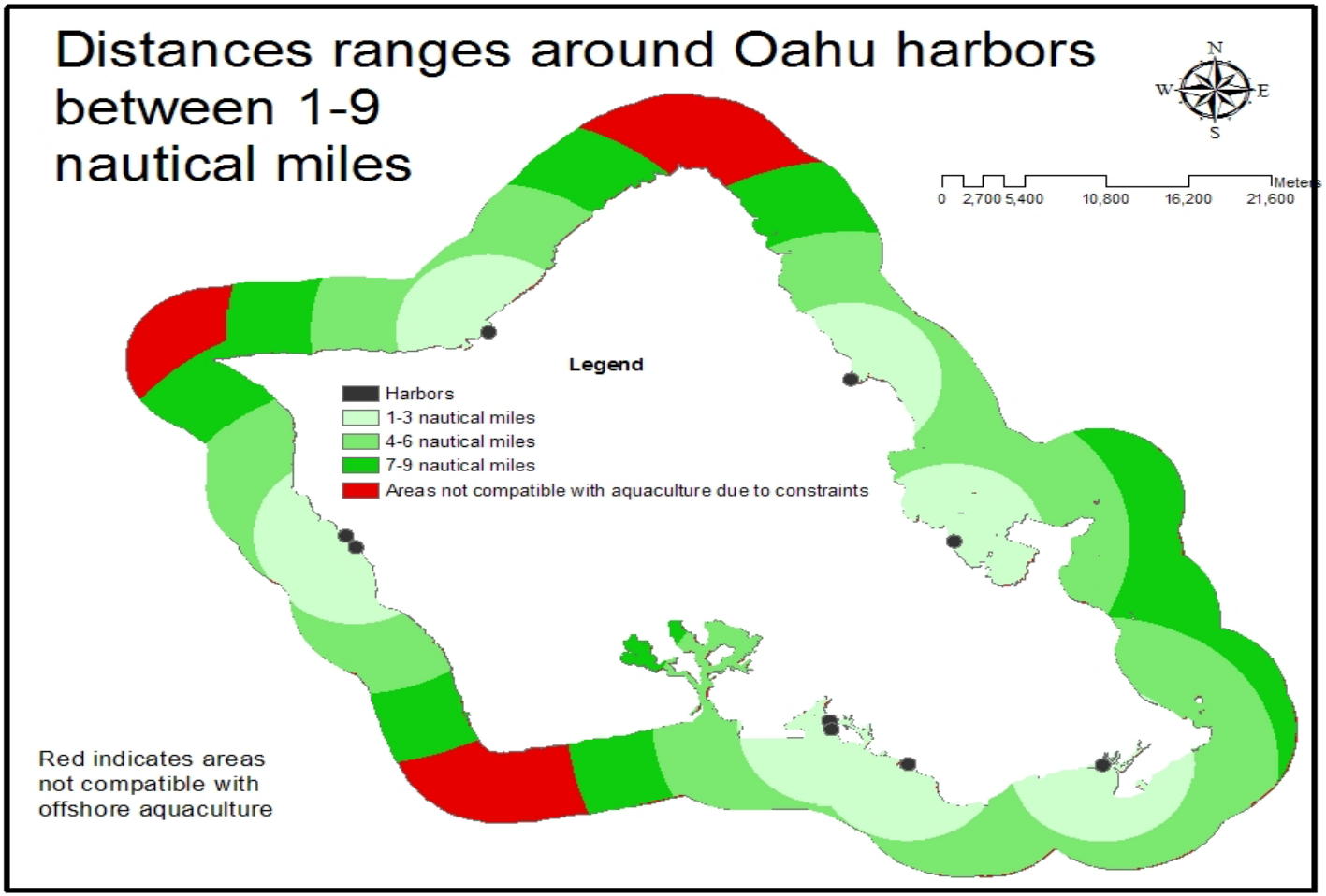
Depth	Full Extent Size (ha)	Base Size (ha)	Military Size (ha)
25m-50m	1,196,870	9,895	8,151
51m-75m	950,858	7,692	6,431
76m-100m	925,996	8,253	6,900
Total	3,073,724	25,840	21,482

Economics

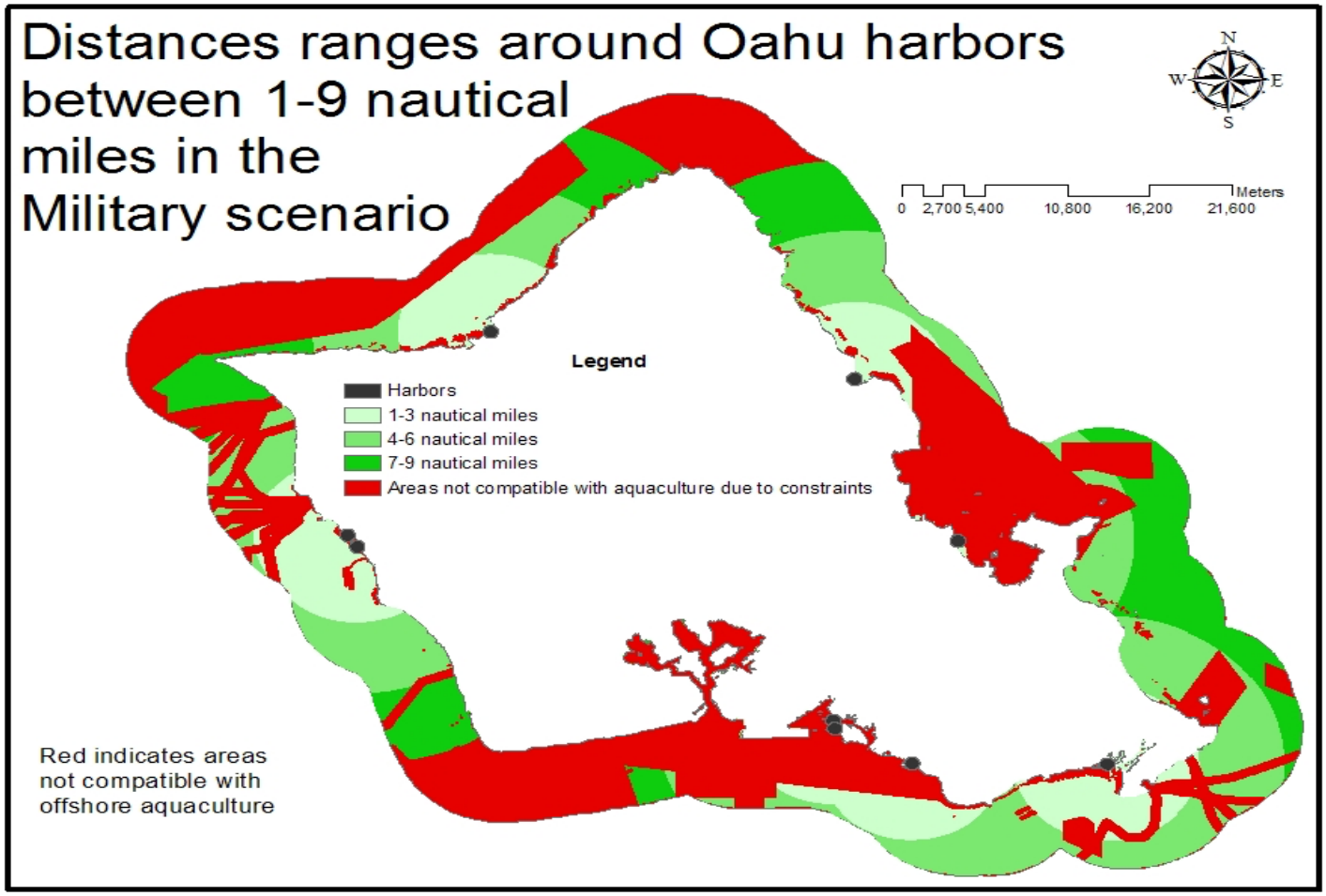
Economics

- Any harbor with reasonable area around it can be used
  - Storage space for feed maintenance equipment
- Why only distance from harbor?
- 3 classifications
  - 9 knots typical ship
  - 1-3 nautical miles
  - 4-6 nautical miles
  - 7-9 nautical miles

Economics


Distances ranges around Oahu harbors between 1-9 nautical miles
N
W
E
S
0 2,700 5,400 10,800 16,200 21,600
Meters
Legend
Harbors
1-3 nautical miles
4-6 nautical miles
7-9 nautical miles
Areas not compatible with aquaculture due to constraints
Red indicates areas not compatible with offshore aquaculture

Economics Military



Economic

Distance (nautical miles)	Full Extent Size (ha)	Basic Size (ha)	Military Size (ha)
1-3	33,008	17,361	16,995
4-6	51,878	36,186	29,078
7-9	30,441	25,490	20,284
Total	115,327	79,037	66,357

Social

Ocean Recreation

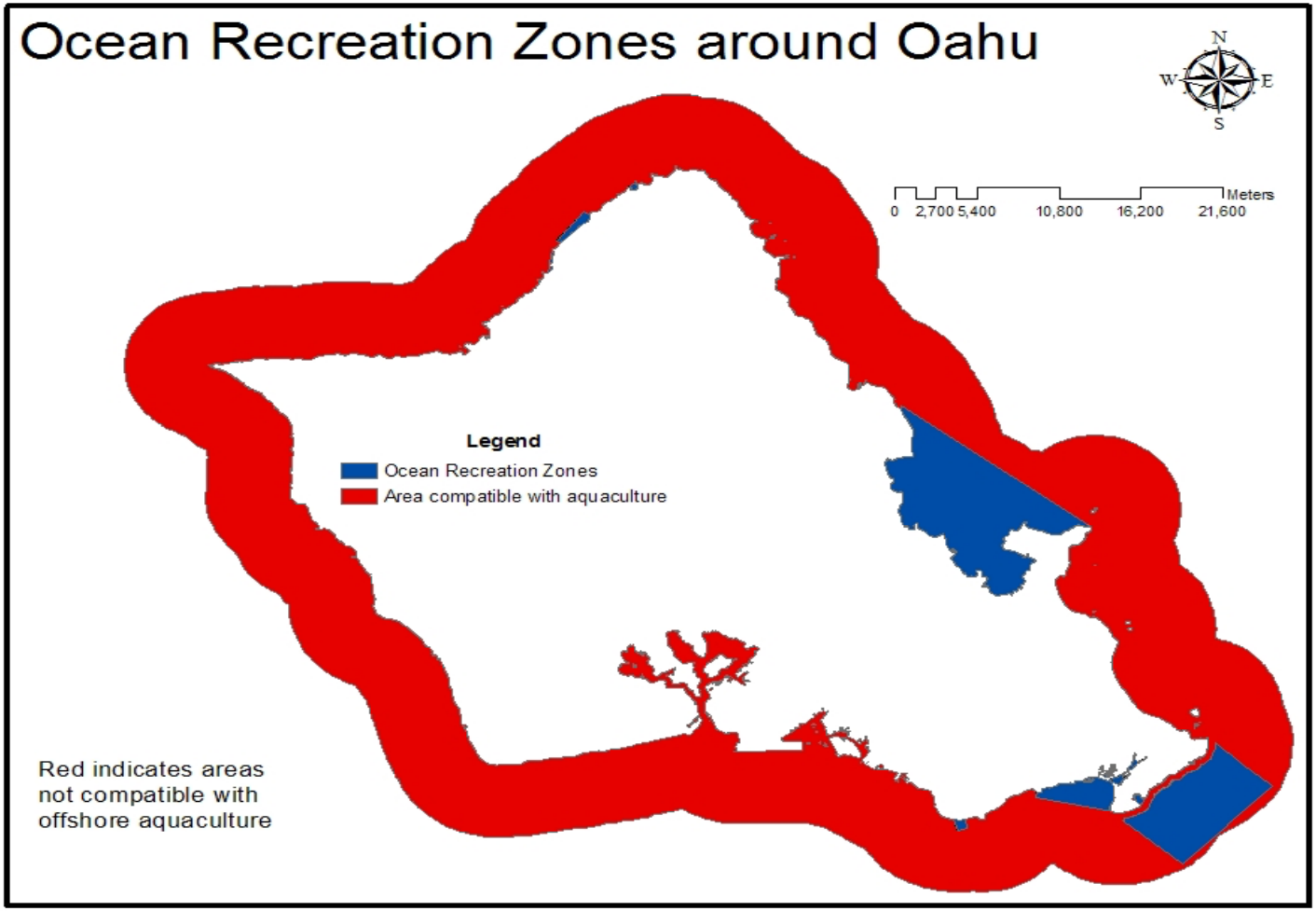
&

Konohiki

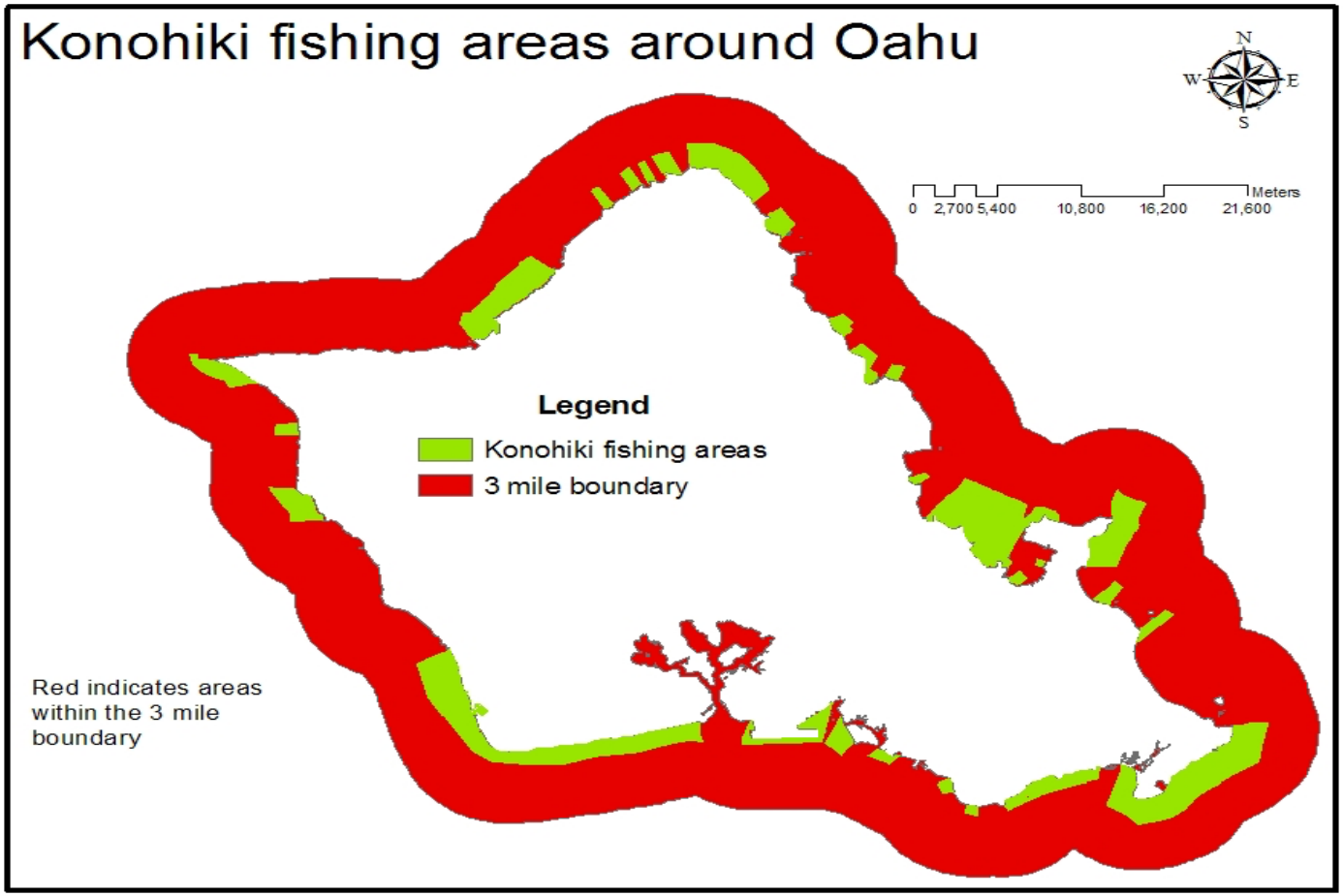
Social

- Modern use
  - Ocean Recreation Zone
    - Based on DLNR regulations
- Traditional use
  - Konohiki fishing area associated with Ahupua‘a
    - Historically important
    - Proxy for cultural uses

Ocean Recreation



Konohiki

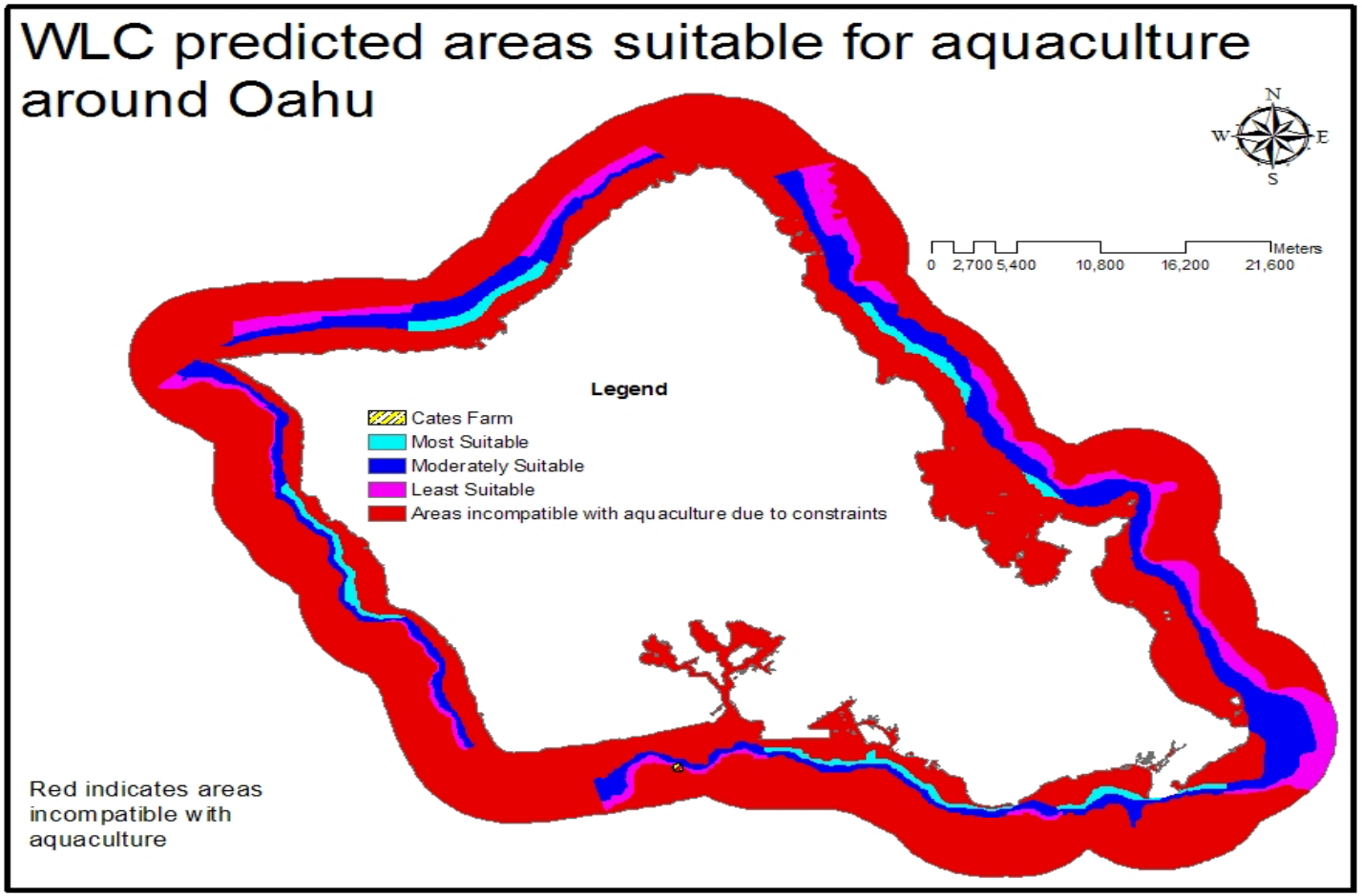

Konohiki fishing areas around Oahu
N
W
E
S
0 2,700 5,400 10,800 16,200 21,600
Meters
Legend
Konohiki fishing areas
3 mile boundary
Red indicates areas within the 3 mile boundary

COMBINED

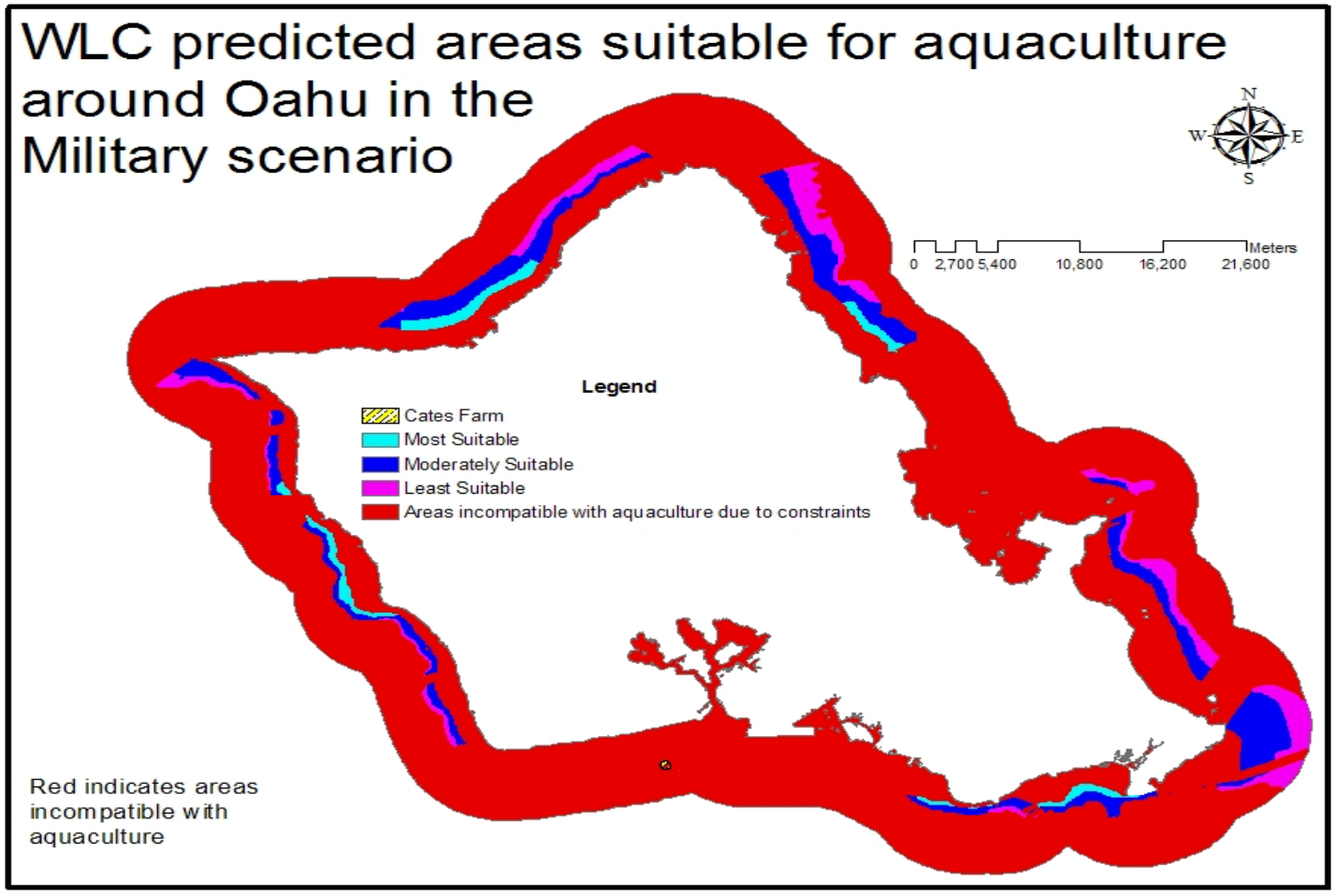
Combined

- Run WLC of Environment & Economics, equal weight, within the Social dataset
- Combination of Ocean Recreation and Konohiki Fishing areas:
  - All Ocean recreation and k*onohiki* Fishing areas are available
  - No Ocean Recreation or k*onohiki* fishing areas are available for exclusive lease,
  - Only Ocean recreation zones but no k*onohiki* fishing areas are available for exclusive use
  - Only k*onohiki* fishing areas but no Ocean Recreation Zones

WLC


WLC predicted areas suitable for aquaculture around Oahu
N
W
E
S
0 2,700 5,400 10,800 16,200 21,600
Meters
Legend
Cates Farm
Most Suitable
Moderately Suitable
Least Suitable
Areas incompatible with aquaculture due to constraints
Red indicates areas incompatible with aquaculture

WLC Military



WLC Sizes

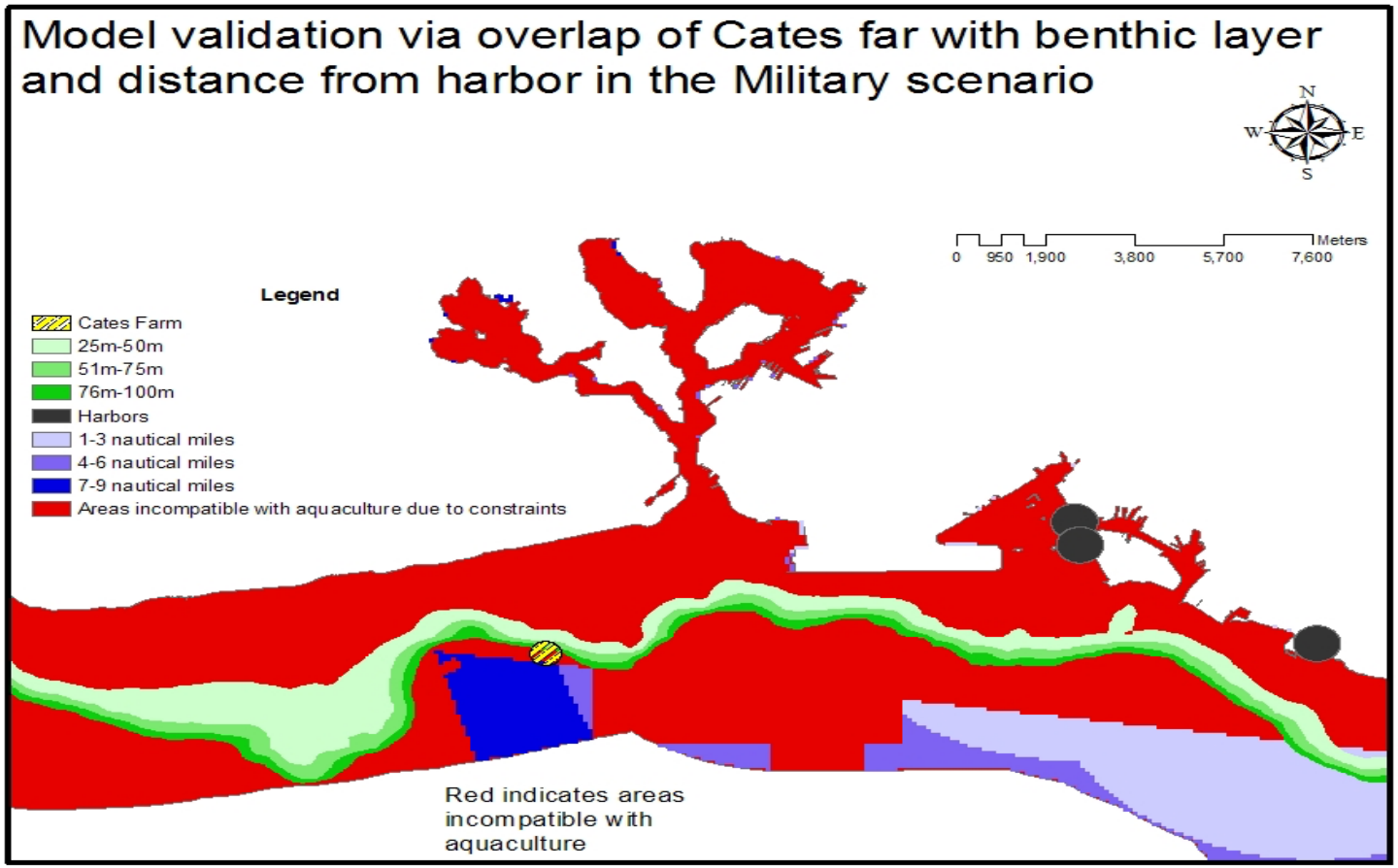
WLC Prediction	Full Extent Size (ha)	Basic Size (ha)	Military Size (ha)
Most Suitable	3,304	2,020	2,020
Moderately Suitable	15,430	11,547	9,532
Least Suitable	8,159	6,643	5,231
Total	26,893	20,210	16,783

Total Area
WLC in Social Scenarios

WLC Prediction	Basic(ha)	Military(ha)
Full	20,210	16,783
No Konohiki	17,779	14,549
No Orec/Konohiki	17,195	13,965

Discussions & Conclusions

Validation


Model validation via overlap of Cates far with benthic layer and distance from harbor in the Military scenario
N
W
E
S
0 950 1,900 3,800 5,700 7,600
Meters
Legend
Cates Farm
25m-50m
51m-75m
76m-100m
Harbors
1-3 nautical miles
4-6 nautical miles
7-9 nautical miles
Areas incompatible with aquaculture due to constraints
Red indicates areas incompatible with aquaculture

Discussion

- Results comparison to ADP Phase 1
  - Problematic at best
  - Low resolution state-wide map, no details or quantifiable numbers (Phase 2 never completed)
- Results comparison to other regional scaled models
  - Incorporates similar information
    - New to the Pacific Islands

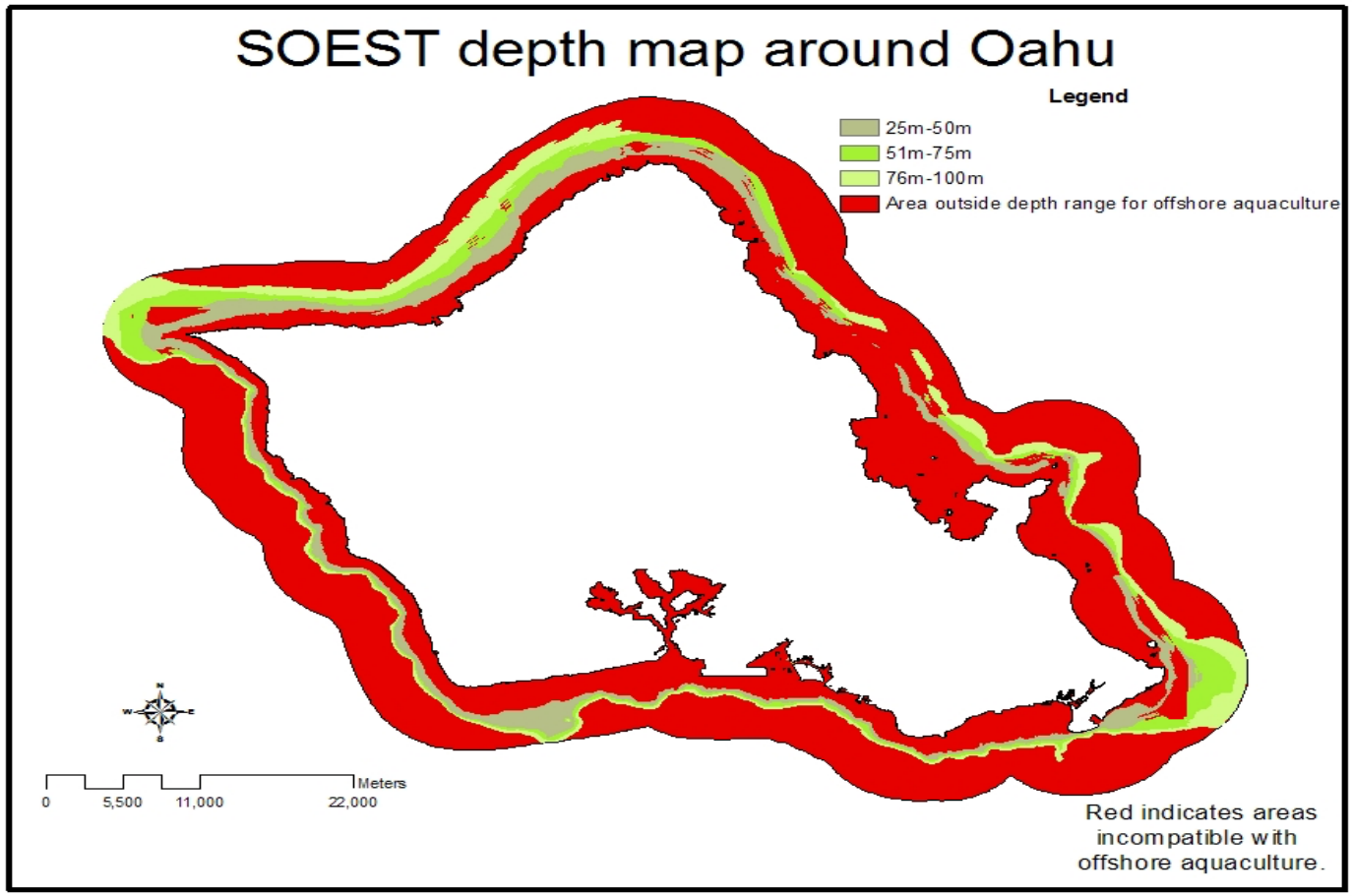
Discussion

Area	Site Boundary	Min Depth	Distance between farms	Distance from critical habitat	Distance from Ecologically sensitive area	Oceanographic	EIS or Similar	Zoning criteria
Ireland	x	x	>1000m	>1000m	considered	not in areas where currents <0.1m/s	yes if annual production >100t	yes must be designated
Norway	x	>20m	x	distance form mouth of salmon rivers	prohibited in certain fjords	see Lenka	x	Lenka
British Colombia	x	20m	>3000m	125m	considered	accounted for in biophysical rating	yes	CRIS

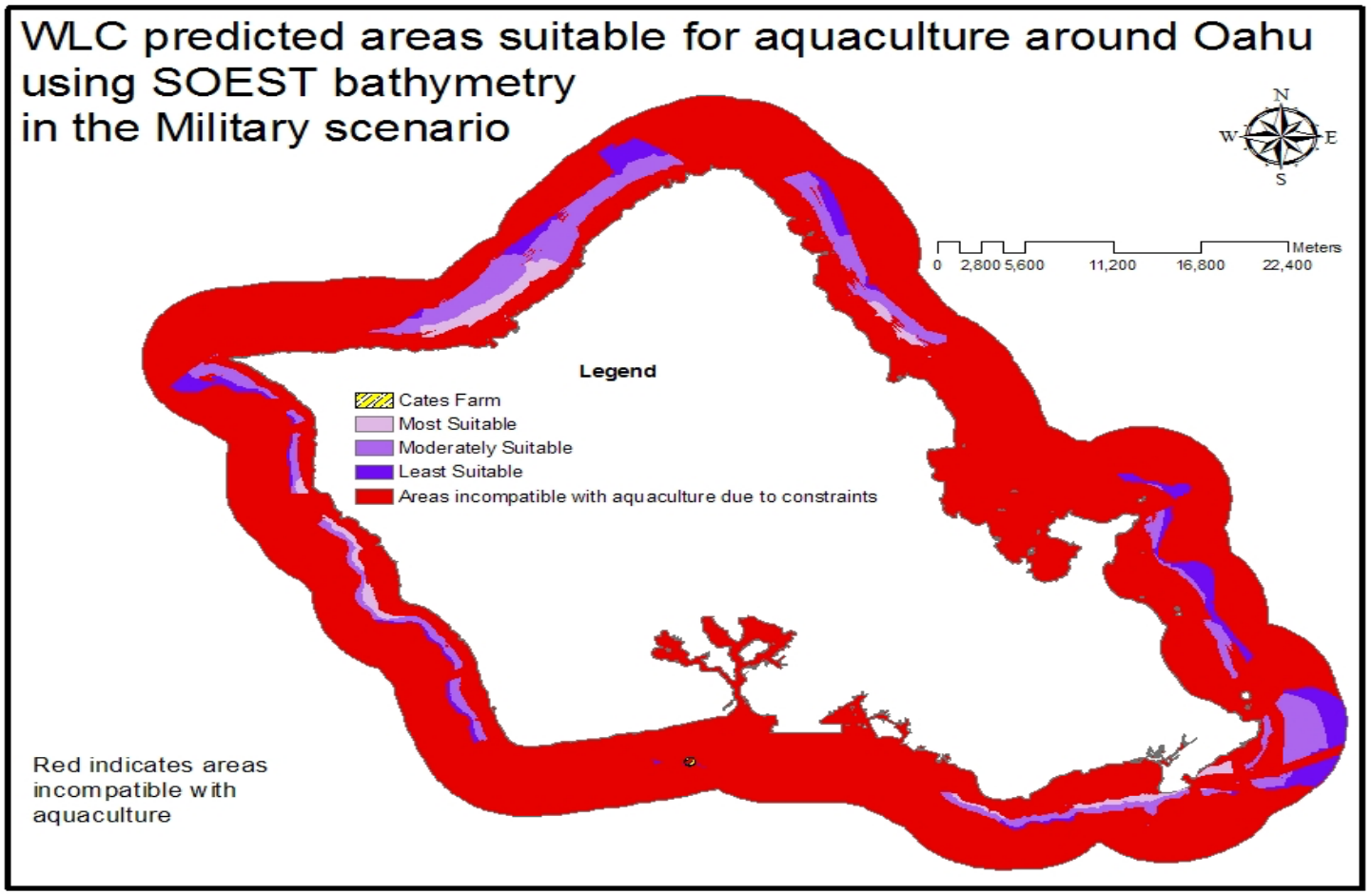
Discussion

- Errors
  - Rasterization
  - Public data
    - Poor metadata
    - Improper digitization
    - Interpolation
  - 10%-25% error not uncommon in GIS analysis
- Different data =?= different results

SOEST Bathymetry



SOEST WLC Military



Discussion

- Radiarta et al (2009)
  - Information about the relative importance of the criteria is required.
- Bio-physical
  - Sea temperature, food availability (measured as chlorophyll-a), suspended Sediment and bathymetry
- Social– infrastructural
  - Distance to town ; Distance to piers ; Distance to land-based facilities
- Constraint
  - Harbor (inside and entrance) ; Town/industrial ; River mouth
- Why mine is different?
  - Data availability

Conclusions

- Importance of suitability
- Proper siting
  - Saves:
    - Time
    - $ (governments, and businesses)
  - Eases growing pains in new markets
    - Local community support
- Few places around O‘ahu possible for expansion
  - State focus on Maui which is equally problematic
- Structure of model functions:
  - Cates operation within acceptable area

Conclusions

- Increasing accuracy of model results
  - WLC based on AHP
    - More data needed to utilize AHP
    - Interviews with community groups conflicting
      - Kona Blue and current Hawai‘i project
  - Increasing output resolution
    - Finer scale data, and smaller raster cells lead to more detailed maps with less induced error
      - Smaller rasters increase simulation time and file size

Conclusions

- Needed for next phase (Site Selection)
  - AHP based WLC with more detailed information
    - Information allows for alteration of weights
  - More accurate bathymetry
  - Currents
  - Waves
  - Temperature
  - Turbidity
  - Tides
  - More detailed infrastructure

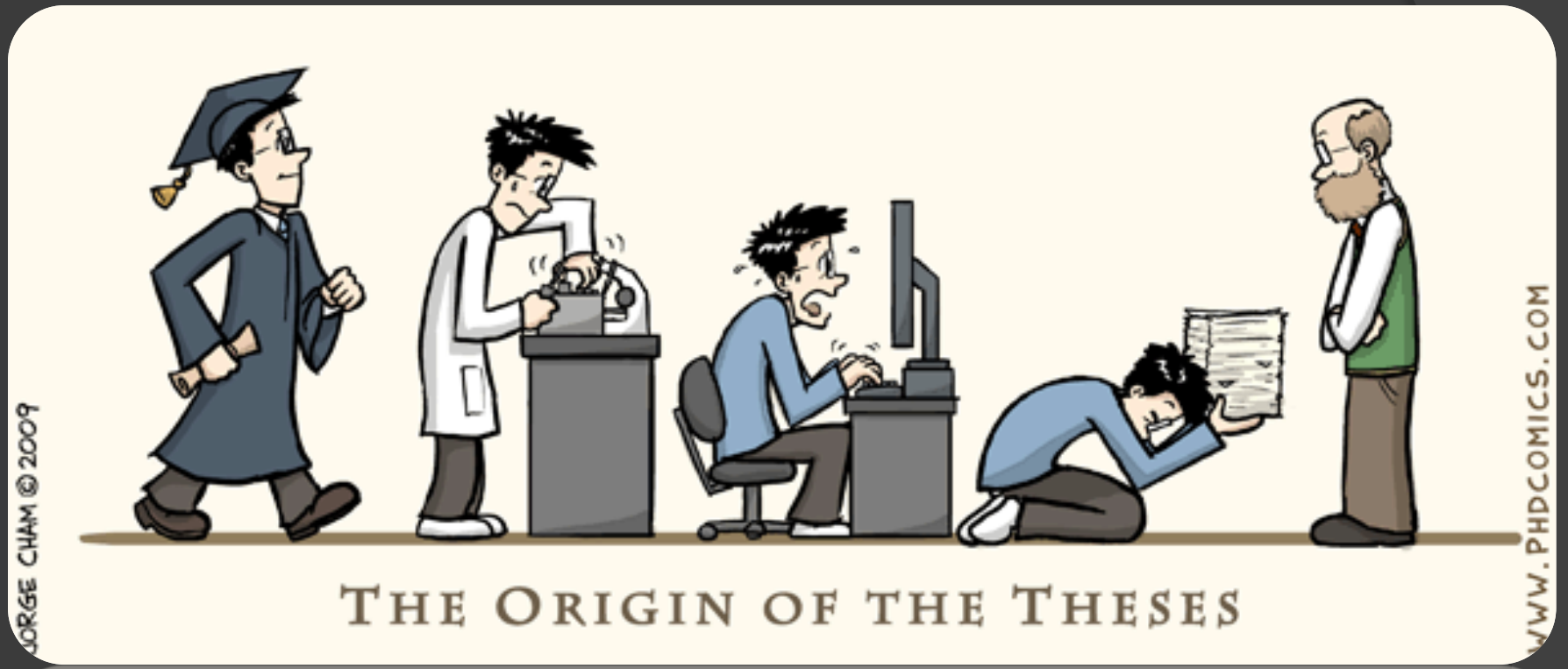
Conclusions

- Transferability
  - Framework applicable for majority of Pacific Islands / Tropical Coastal regions
    - Open source data (nautical charts)
      - Minimal financial commitment
    - Can be adapted to most coastal regions by expanding limitations in Basic layer
  - Identifies suitable areas for further in-depth research to determine specific sites

Mahalo nui

- Committee
  - Drs Evensen, Leung, Robotham, Szuster, Tamaru
- HI ADP
  - Dr Young
- DURP
  - Dr Minerbi
- Kona Blue
  - Neil Sims
- UH Hilo
  - Drs Haws, Gibson, Potemra
  - Noe, Lisa

Questions?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THE ORIGIN OF THE THESES