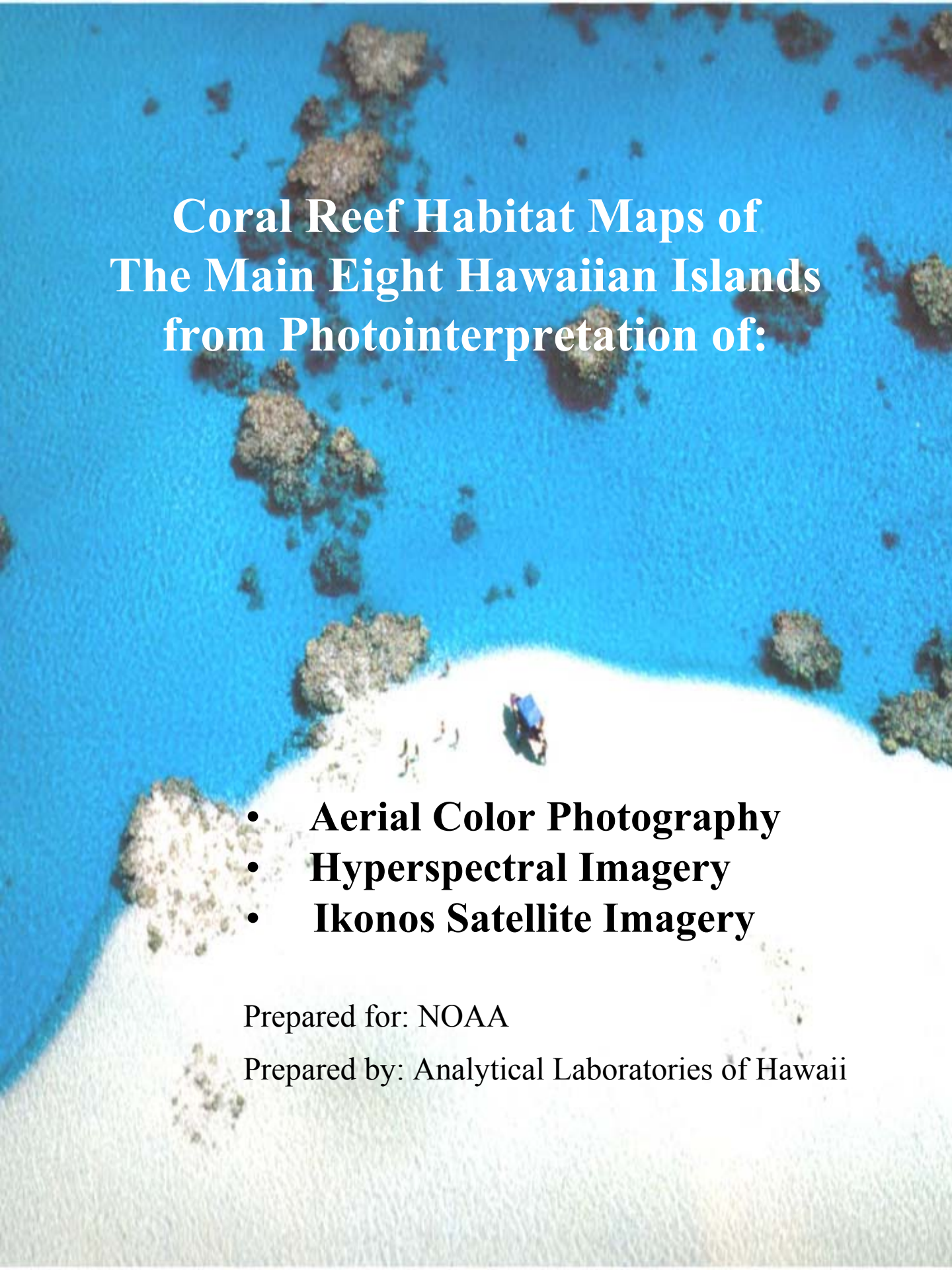


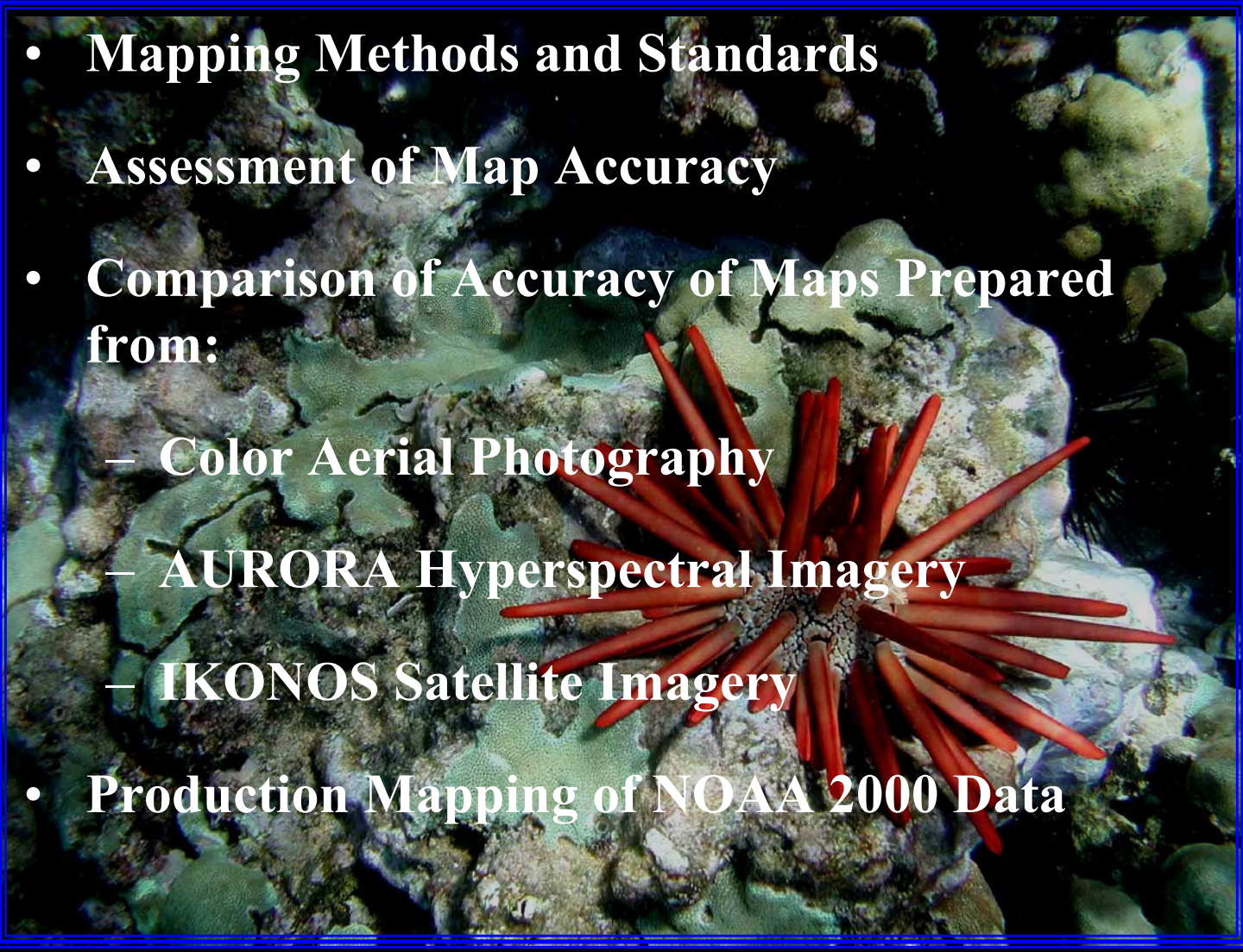
Coral Reef Habitat Maps of The Main Eight Hawaiian Islands from Photointerpretation of:

- **Aerial Color Photography**
- **Hyperspectral Imagery**
- **Ikonos Satellite Imagery**

Prepared for: NOAA

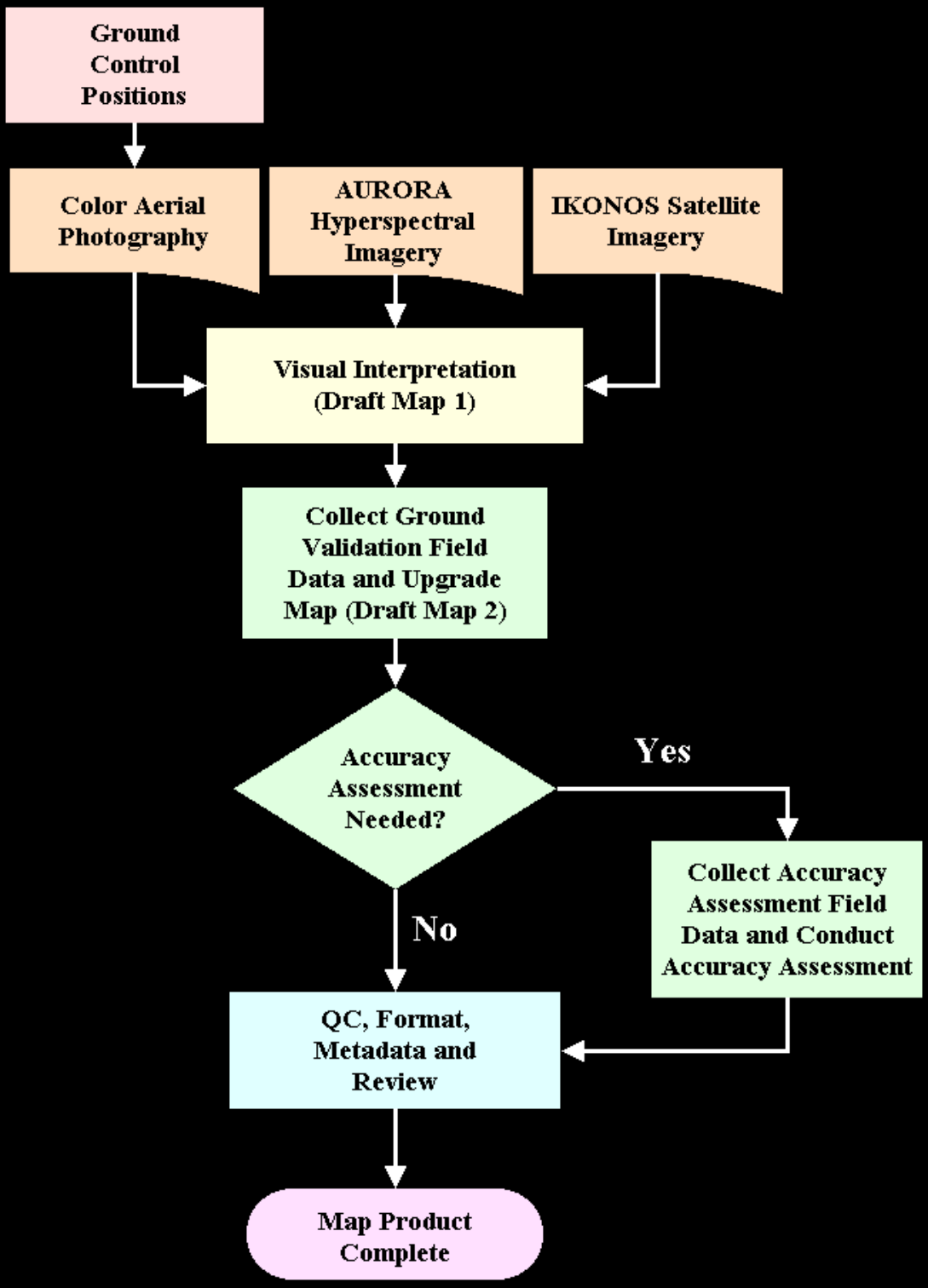
Prepared by: Analytical Laboratories of Hawaii

Approach



- Mapping Methods and Standards
- Assessment of Map Accuracy
- Comparison of Accuracy of Maps Prepared from:
  - Color Aerial Photography
  - AURORA Hyperspectral Imagery
  - IKONOS Satellite Imagery
- Production Mapping of NOAA 2000 Data

Map Production Flow Chart



Ground Control Position Collection

- Identify feature in imagery
- Navigate to and occupy position
- Record all data in GPS data logger
- Enter manual field notes
- Using stationary GPS, acquire minimum of 10 minutes uninterrupted carrier signal
- Collect photographic records of the site
- Post process for differential correction to CORS
- Incorporate data into ArcView GIS and Photoshop format

GCP Data Sheet

Date: _____ Time _____Initials _____

Unique Site ID _____ Location _____

Flight Line _____ Frame _____

X Pixel Position _____ Y Pixel Position _____

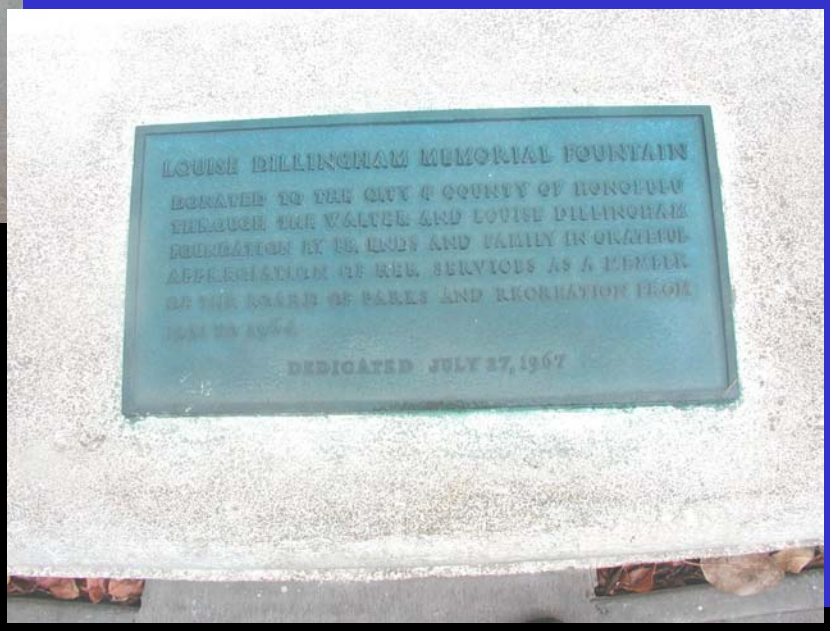
Description of Area _____

Comments _____

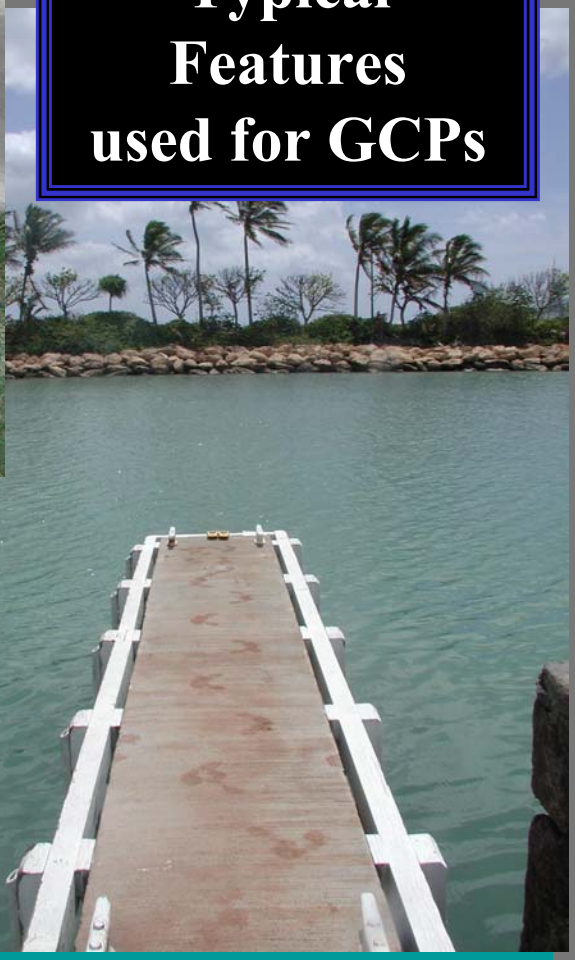
Color Aerial Photograph with Completed GCPs

Specific Pixel Selected for GCP

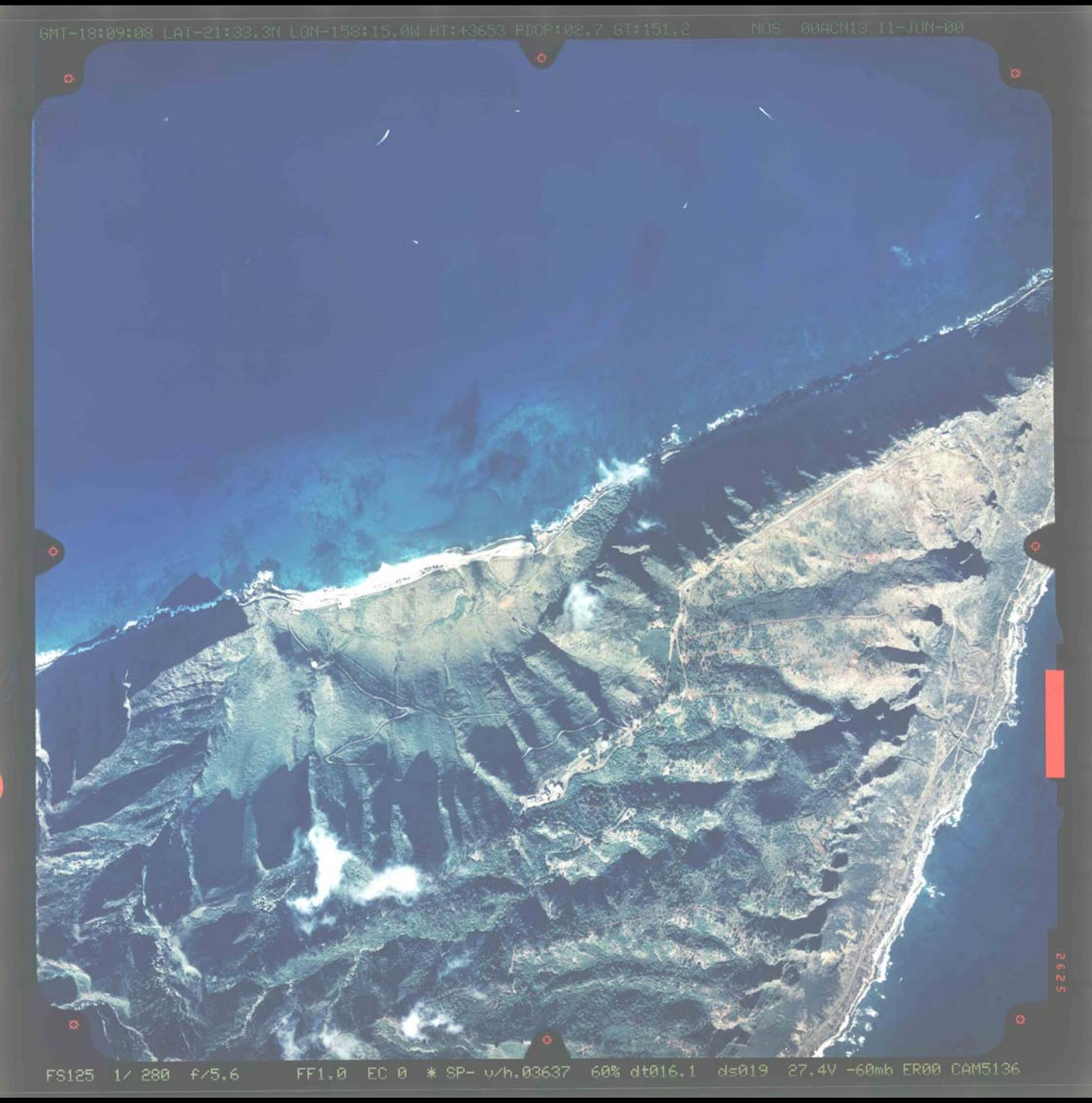
Photographic Records Collected for each GCP



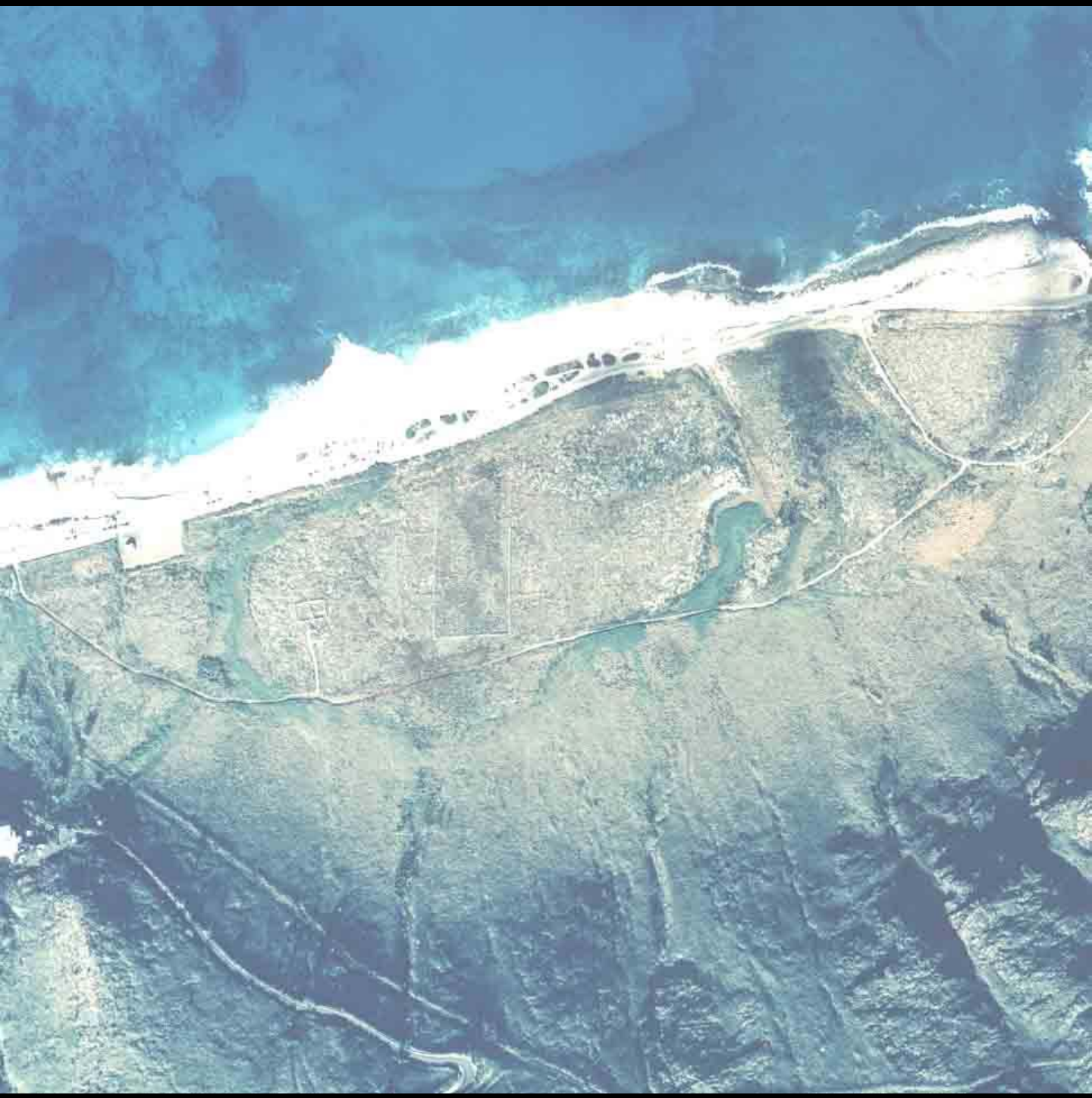
Typical Features used for GCPs

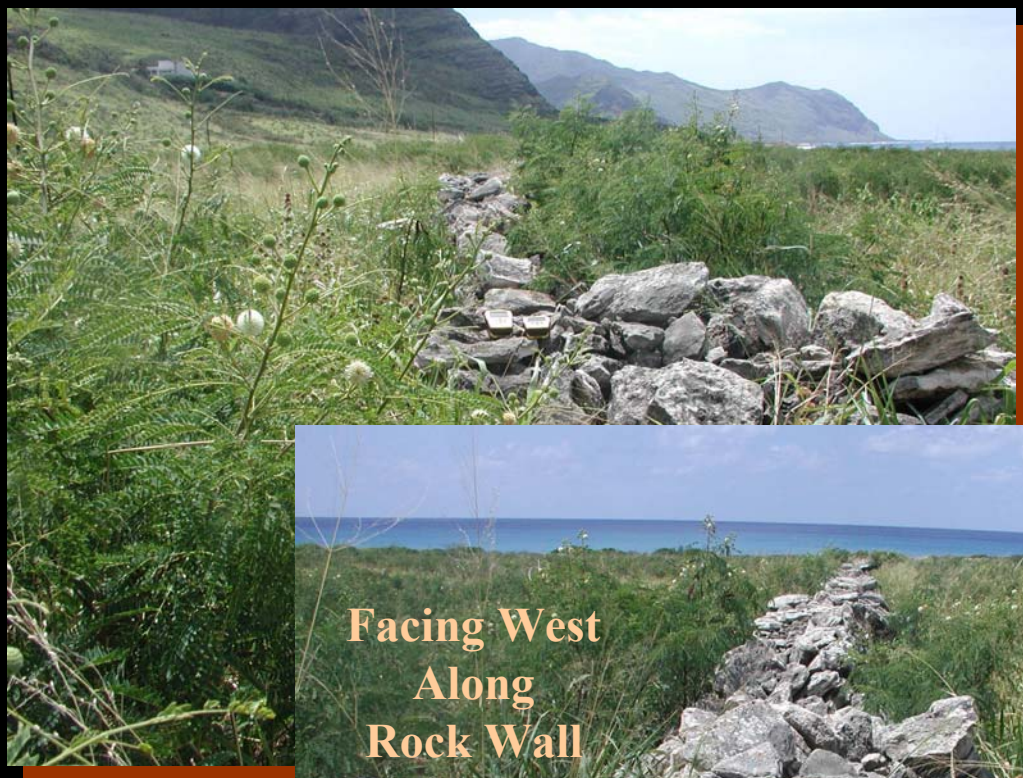


Country and Remote Area GCPs



Close-up of Country and Remote Area GCPs





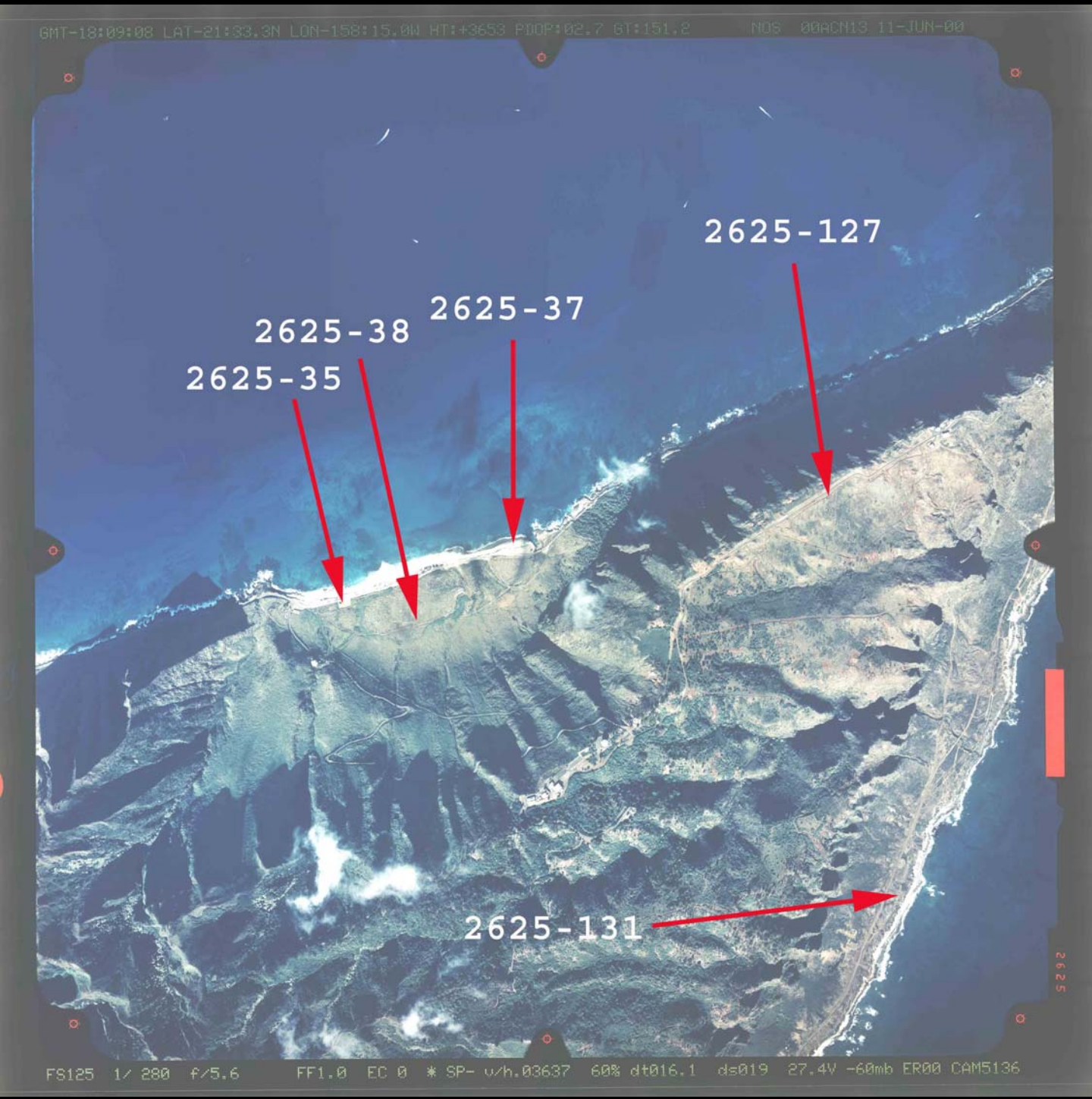
Facing South
Along
Rock Wall

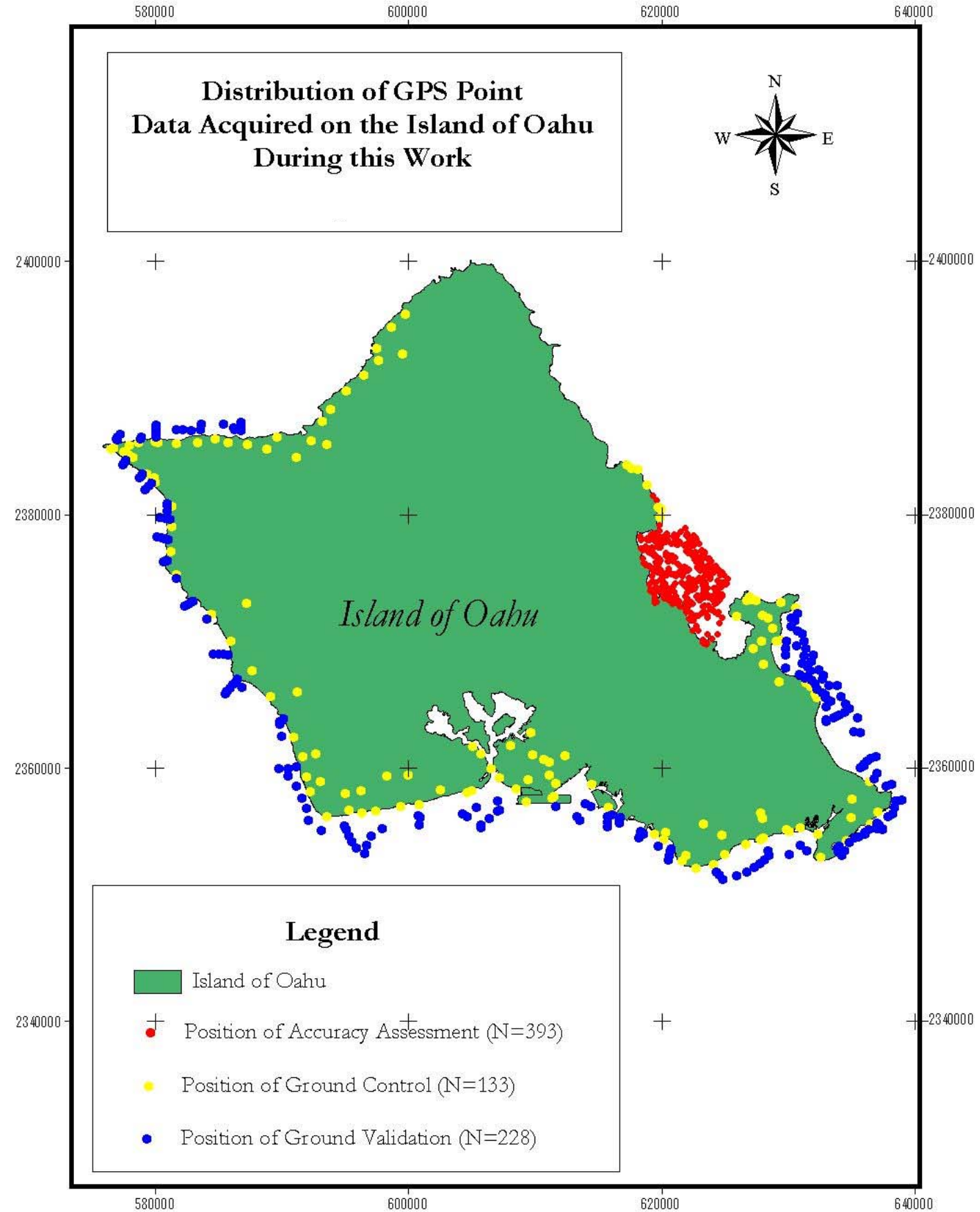
Facing West
Along
Rock Wall

GPS Placed
at Corner of
Rock Wall

Specific Pixel Selected for GCP

Color Aerial Photograph with Completed GCPs




Distribution of GPS Point
Data Acquired on the Island of Oahu
During this Work
N
W
E
S
580000
600000
620000
640000
2400000
2380000
2360000
2340000
Island of Oahu
Legend
Island of Oahu
Position of Accuracy Assessment (N=393)
Position of Ground Control (N=133)
Position of Ground Validation (N=228)


Color Aerial Photography
Raw Data Scale 1:24,000
Display Scale 1:12,000
Imagery Provided by NOAA
Prototype processing by NOS
http://biogeo.nos.noaa.gov/

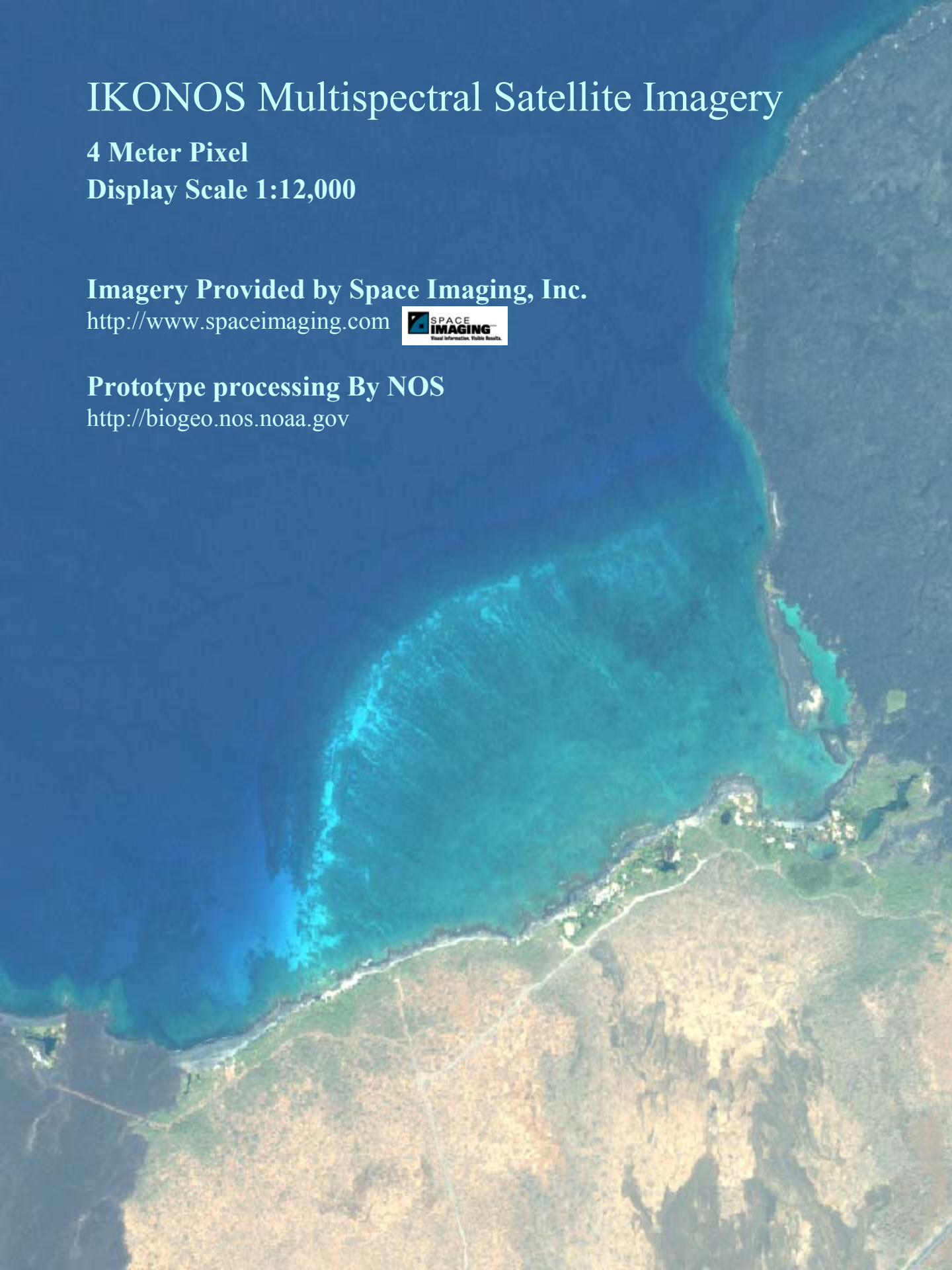

AURORA Airborne Hyperspectral Imagery
3 Meter Pixel
72 Bands
Display Scale 1:12,000
Imagery Provided by NOAA
Prototype processing by NOS
http://biogeo.nos.noaa.gov/

IKONOS Multispectral Satellite Imagery

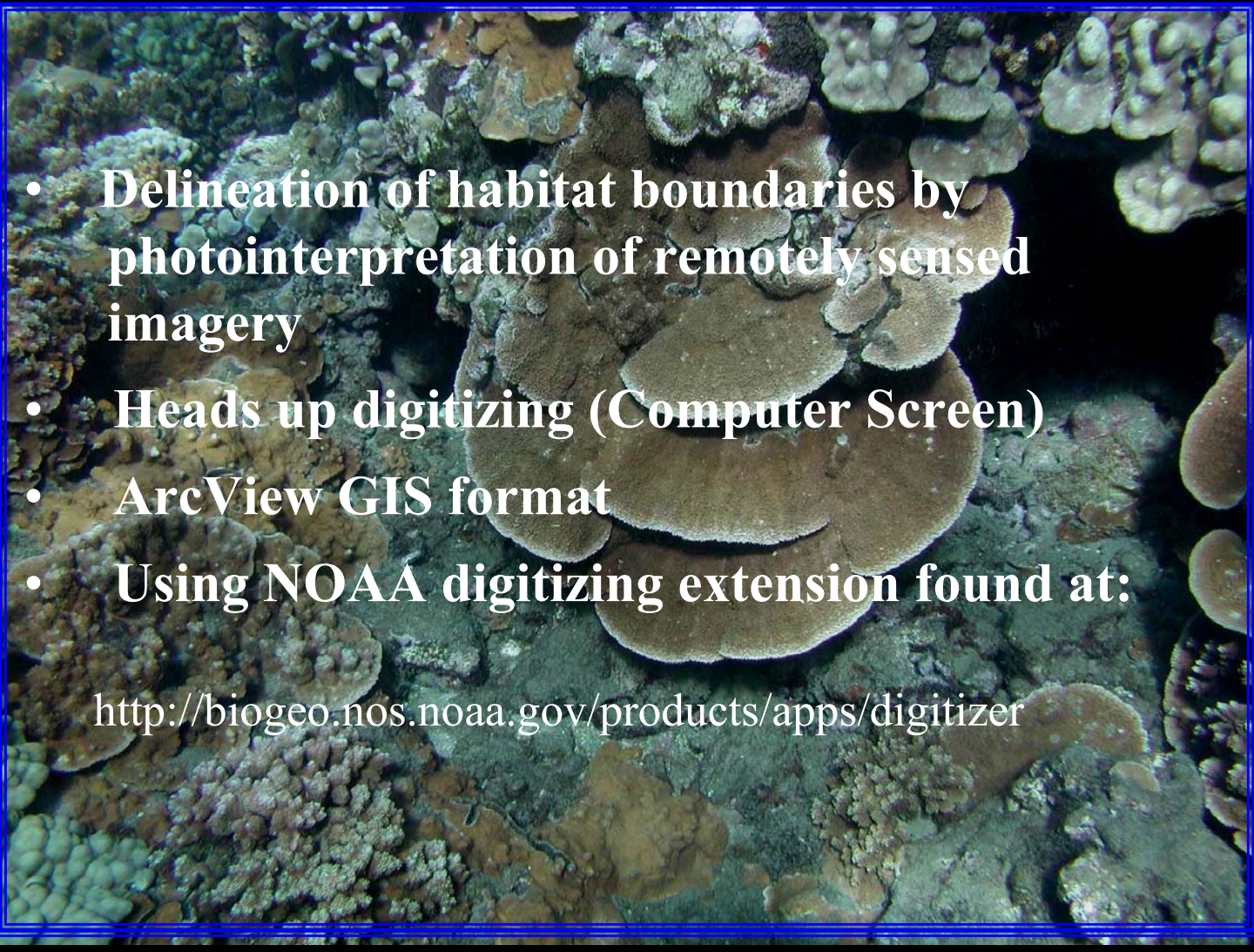
4 Meter Pixel
Display Scale 1:12,000

Imagery Provided by Space Imaging, Inc.
http://www.spaceimaging.com

Prototype processing By NOS
http://biogeo.nos.noaa.gov



Map Preparation Methods



- **Delineation of habitat boundaries by photointerpretation of remotely sensed imagery**
- **Heads up digitizing (Computer Screen)**
- **ArcView GIS format**
- **Using NOAA digitizing extension found at:**

http://biogeo.nos.noaa.gov/products/apps/digitizer

Coral Reef Habitat Classification Scheme

http://biogeo.nos.noaa.gov/projects/mapping/pacific/main8/classification/

Unconsolidated Sediments

Sand

Mud

Submerged Aquatic Vegetation

Macroalgae (fleshy or turf)

- Continuous Macroalgae (90%-100% Cover)
- Patchy (Discontinuous) Macroalgae (50%-<90% Cover)
- Patchy (Discontinuous) Macroalgae (10%-<50% Cover)

Seagrass

- Continuous (90%-100% Cover)
- Patchy (Discontinuous) Seagrass (50%-<90% Cover)
- Patchy (Discontinuous) Seagrass (10%-<50% Cover)

Coral Reef and Hard Bottom

Coral Reef and Colonized Hard Bottom

- Linear Reef
- Spur and Groove
- Patch Reef (Individual)
- Patch Reef (Aggregated)
- Scattered Rock and Coral in Unconsolidated Sediment
- Aggregated Coral
- Colonized Pavement
- Colonized Volcanic Rock/Boulder
- Colonized Pavement with Sand Channels

Uncolonized Hard Bottom

- Reef Rubble
- Uncolonized Pavement
- Uncolonized Volcanic Rock/Boulder
- Uncolonized Pavement with Sand Channels

Encrusting/Coralline Algae

- Continuous Encrusting/Coralline Algae (90%-100% cover)
- Patchy Encrusting/Coralline Algae (50%-<90% cover)
- Patchy Encrusting/Coralline Algae (10%-<50% cover)

Other

Land

Emergent Vegetation

Artificial

Unknown

Coral Reef Zone Classification Scheme

Land
Vertical Wall
Shoreline Intertidal
Reef Flat
Lagoon
Back Reef
Reef Crest
Fore Reef
Bank/Self
Bank/Shelf Escarpment
Channel
Dredged
Unknown

Mapping Standards

Spatial Quality

Imagery: Defined by provider
Digitizing accuracy (1 meter RMS)
Digitized at scale of 1:6,000
Accuracy assessment GPS (2-5 meters)

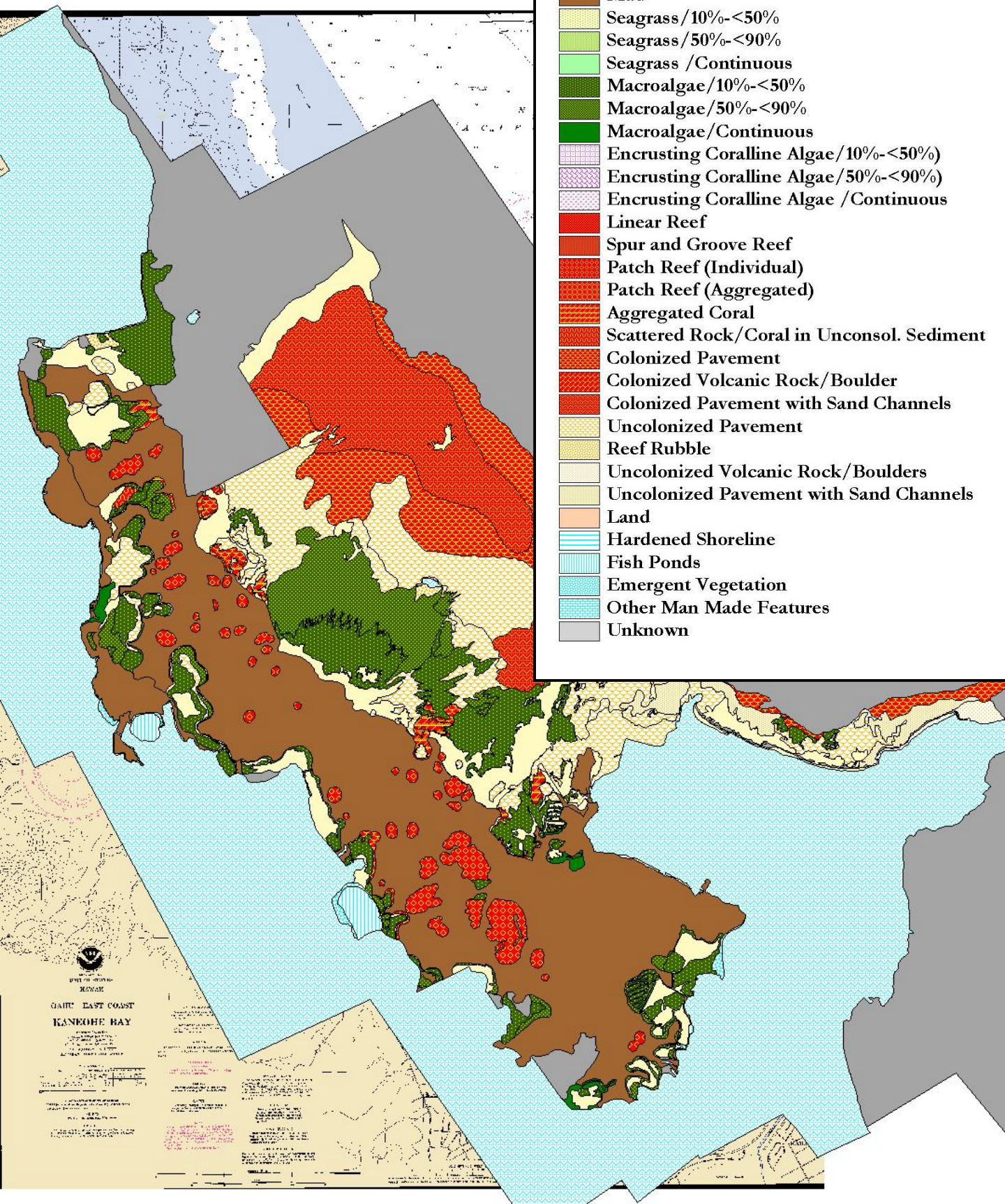
QA/QC

Void polygons
Overlapping polygons
MMU: 1 acre
Clean polygons
Adjacency
Concatenated field
Standardized table format

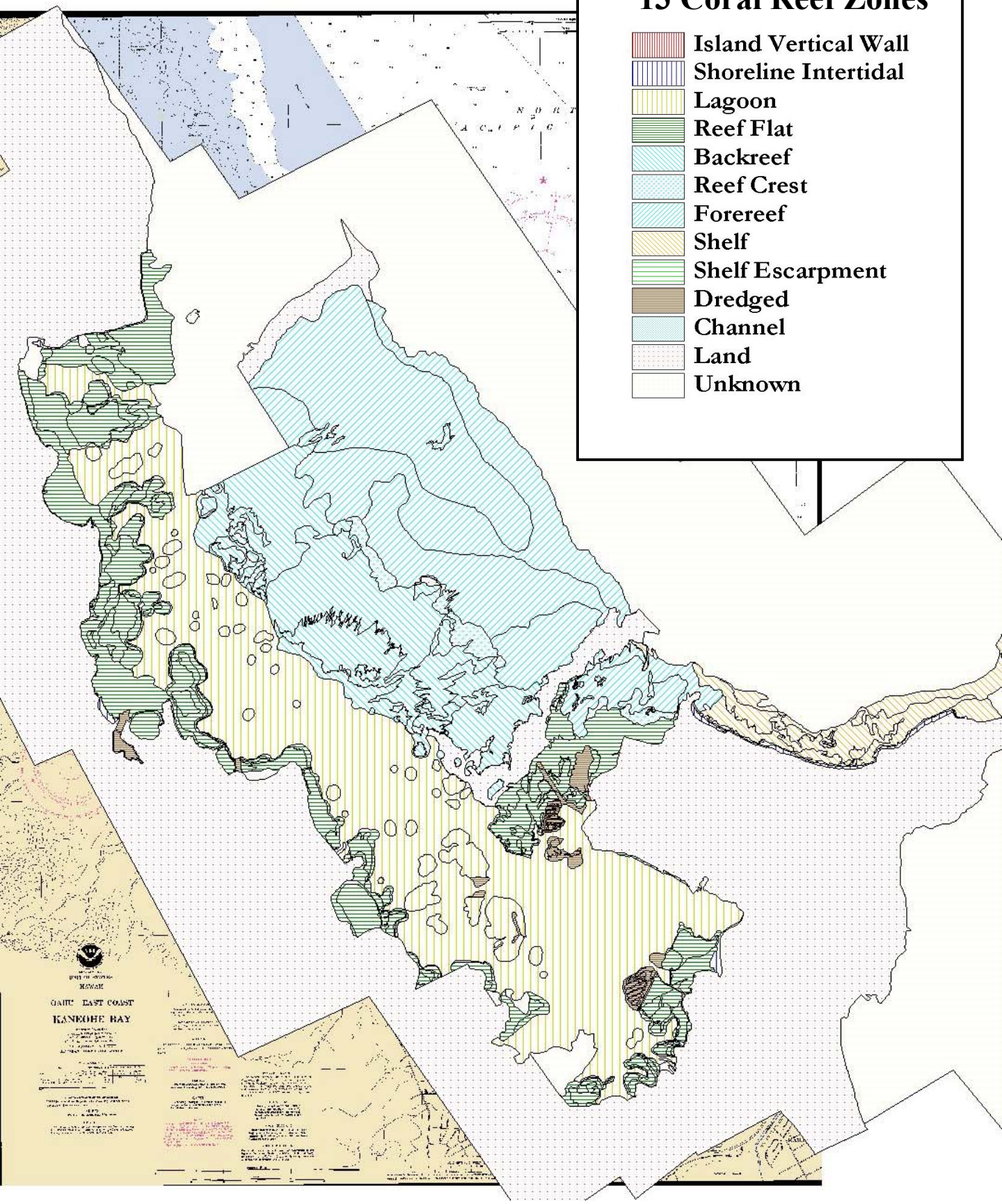
Metadata

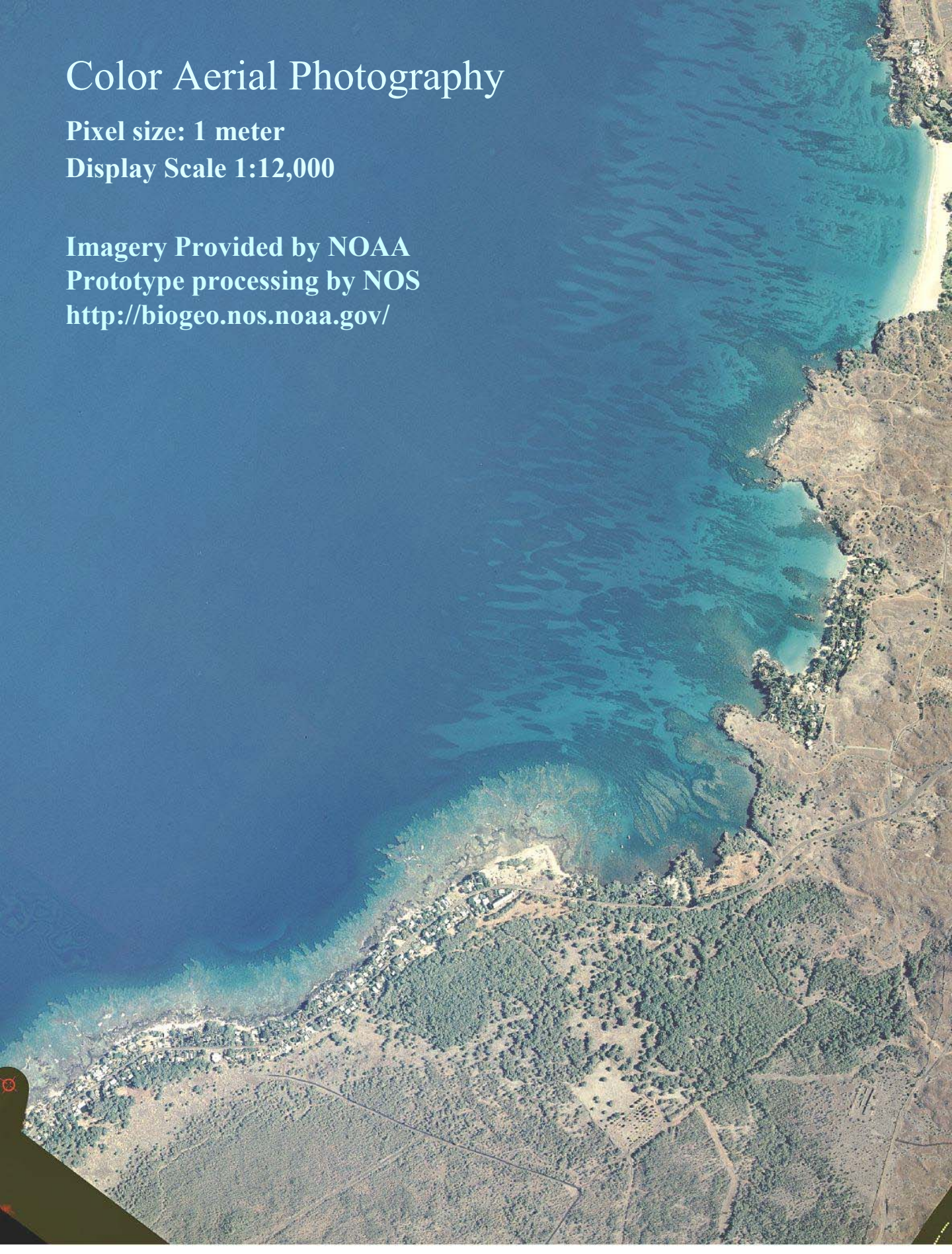
CSDGM standard parsable - no errors
Map review

Kaneohe Bay
Coral Reef Habitats

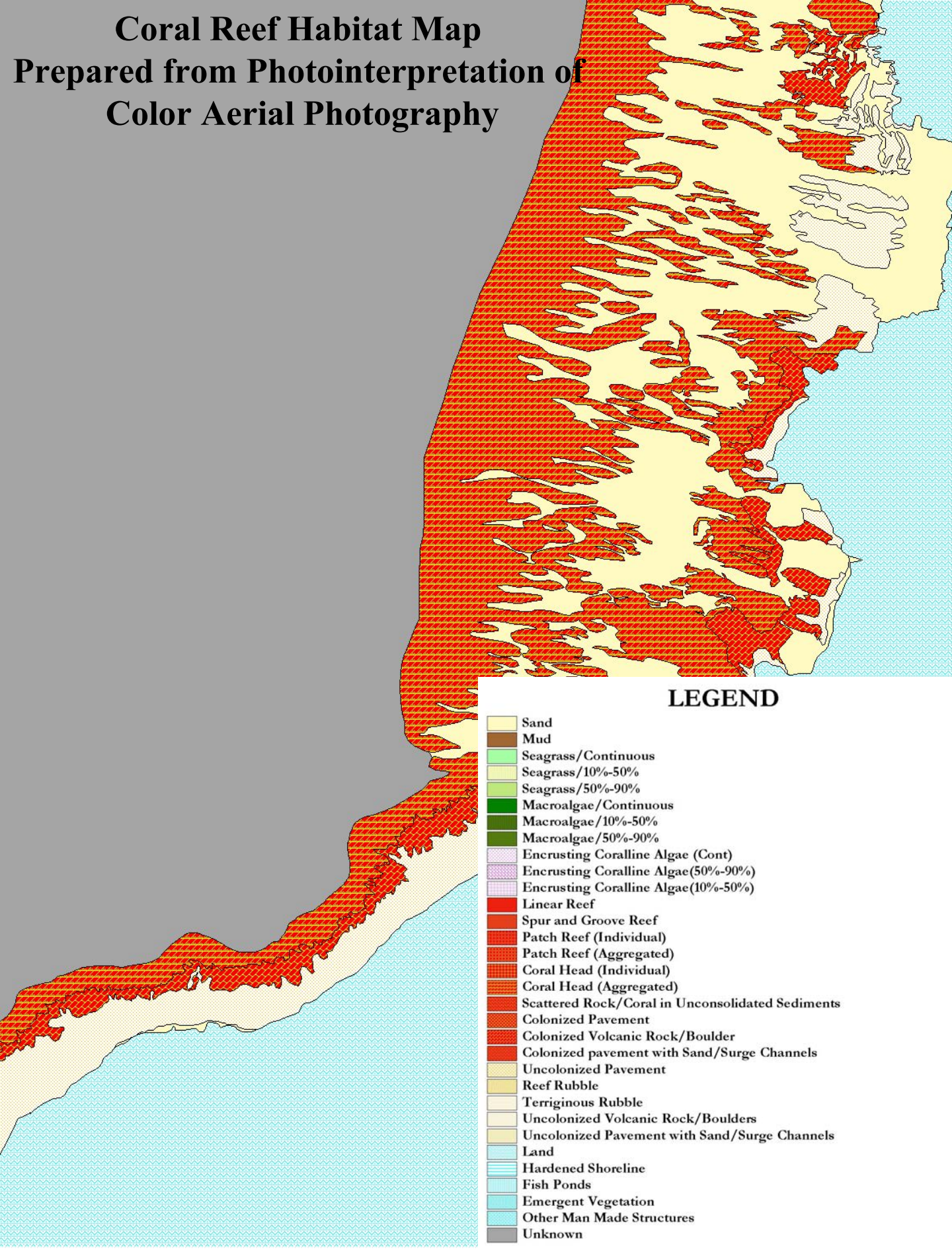


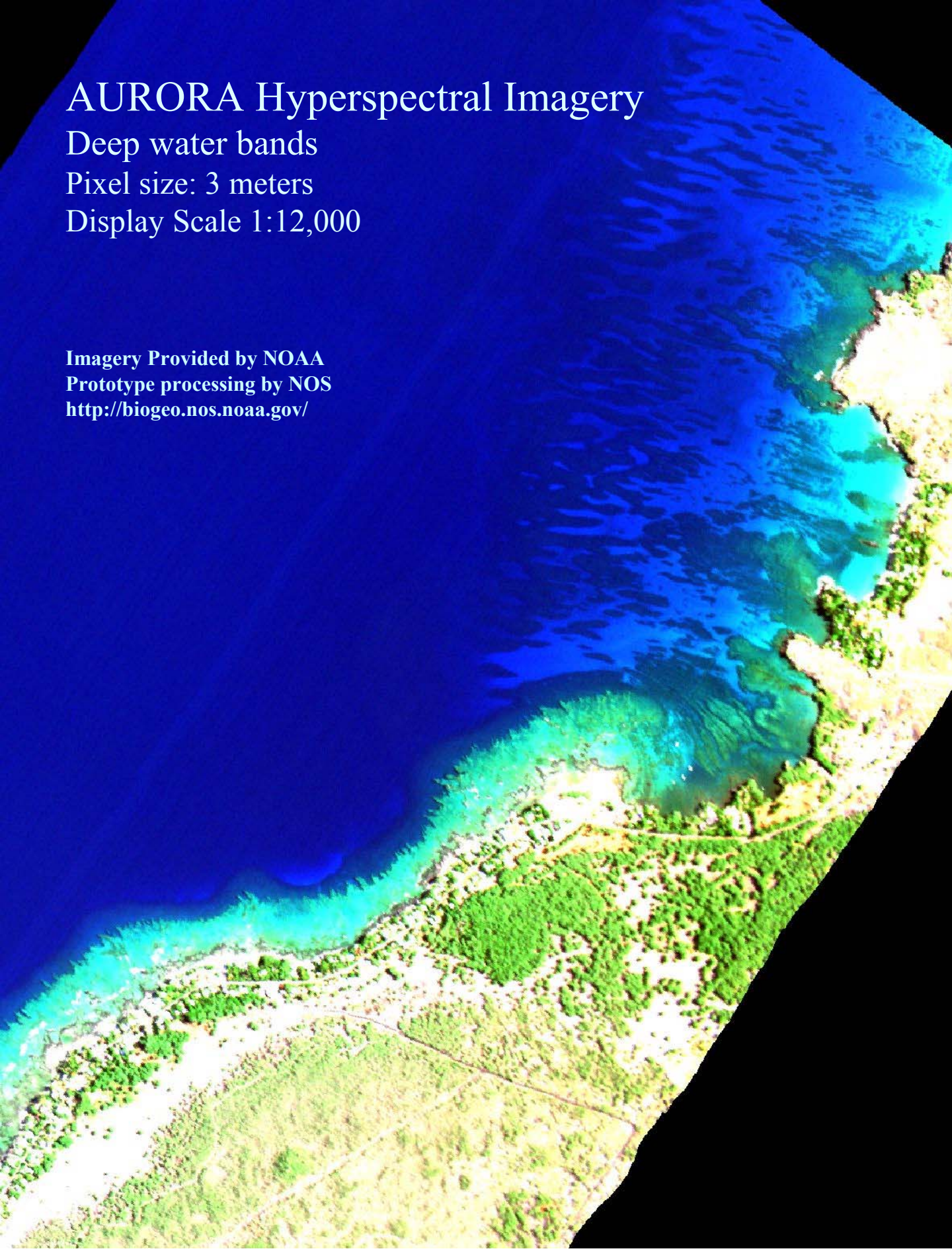
Kaneohe Bay
Coral Reef Zones




Color Aerial Photography
Pixel size: 1 meter
Display Scale 1:12,000
Imagery Provided by NOAA
Prototype processing by NOS
http://biogeo.nos.noaa.gov/

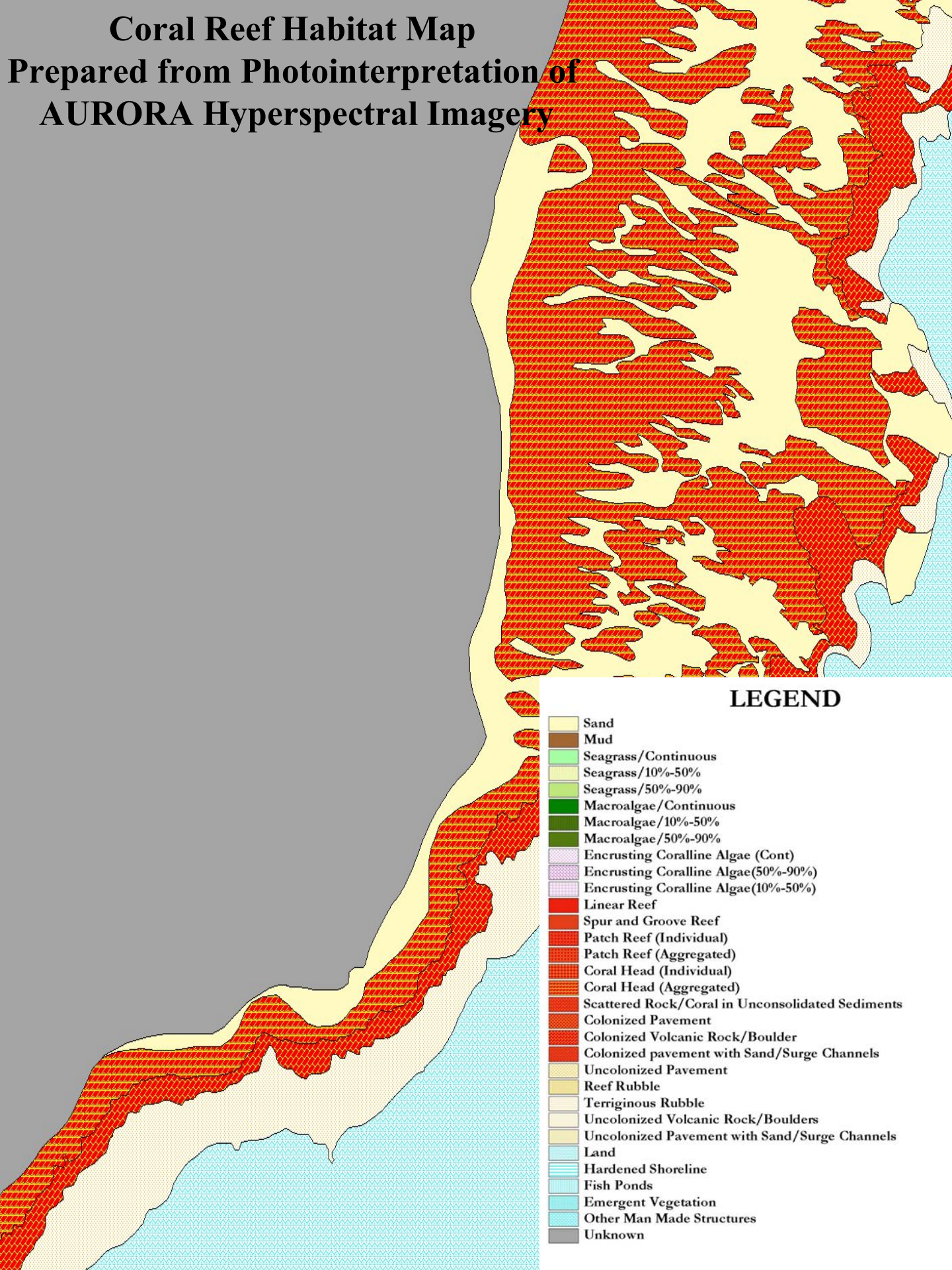
Coral Reef Habitat Map Prepared from Photointerpretation of Color Aerial Photography




AURORA Hyperspectral Imagery
Deep water bands
Pixel size: 3 meters
Display Scale 1:12,000
Imagery Provided by NOAA
Prototype processing by NOS
http://biogeo.nos.noaa.gov/


AURORA Hyperspectral Imagery
Shallow water bands
Pixel size: 3 meters
Display Scale 1:12,000
Imagery Provided by NOAA
Prototype processing by NOS
http://biogeo.nos.noaa.gov/

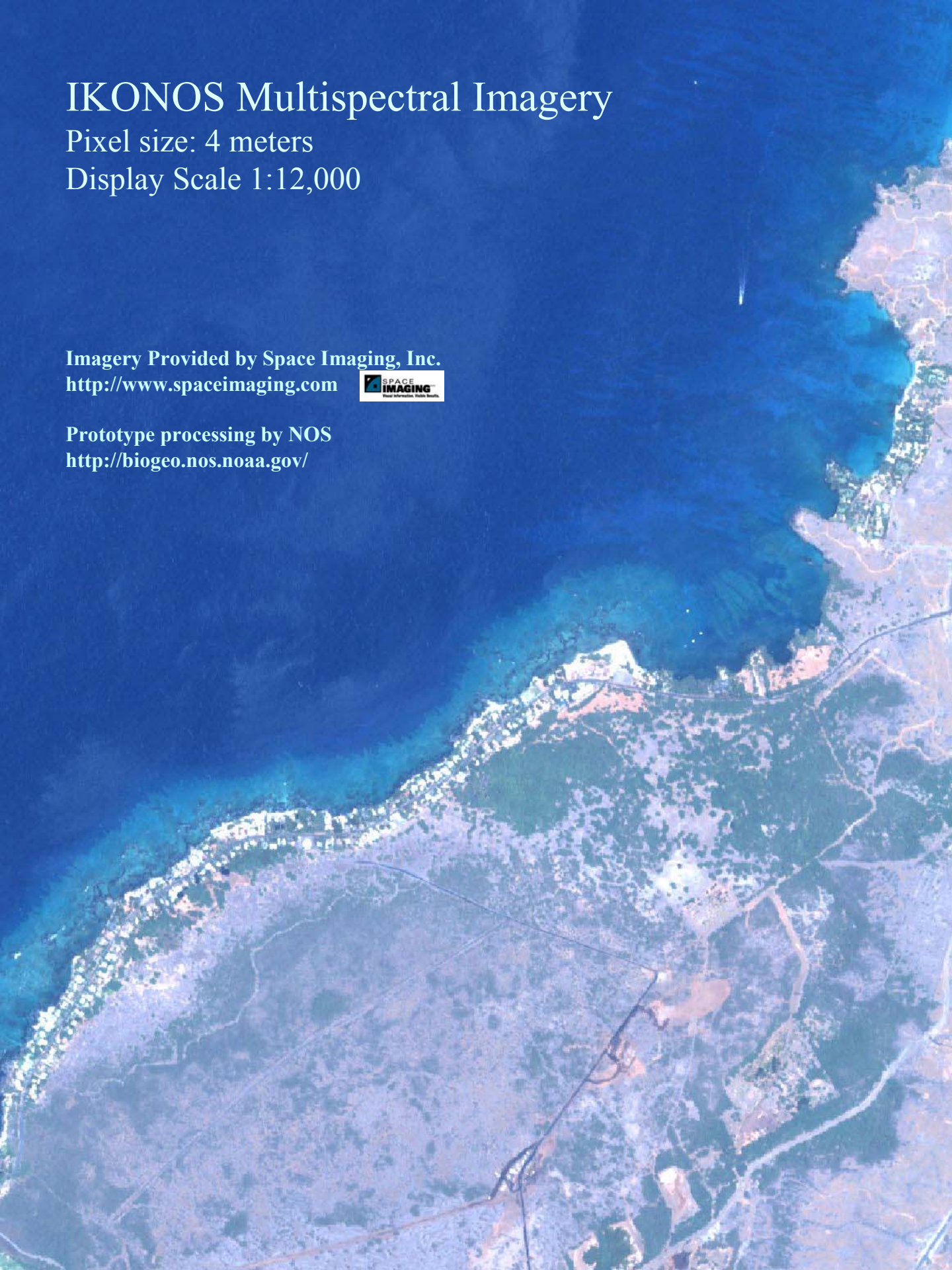
Coral Reef Habitat Map Prepared from Photointerpretation of AURORA Hyperspectral Imagery



IKONOS Multispectral Imagery

Pixel size: 4 meters

Display Scale 1:12,000



Imagery Provided by Space Imaging, Inc.
http://www.spaceimaging.com

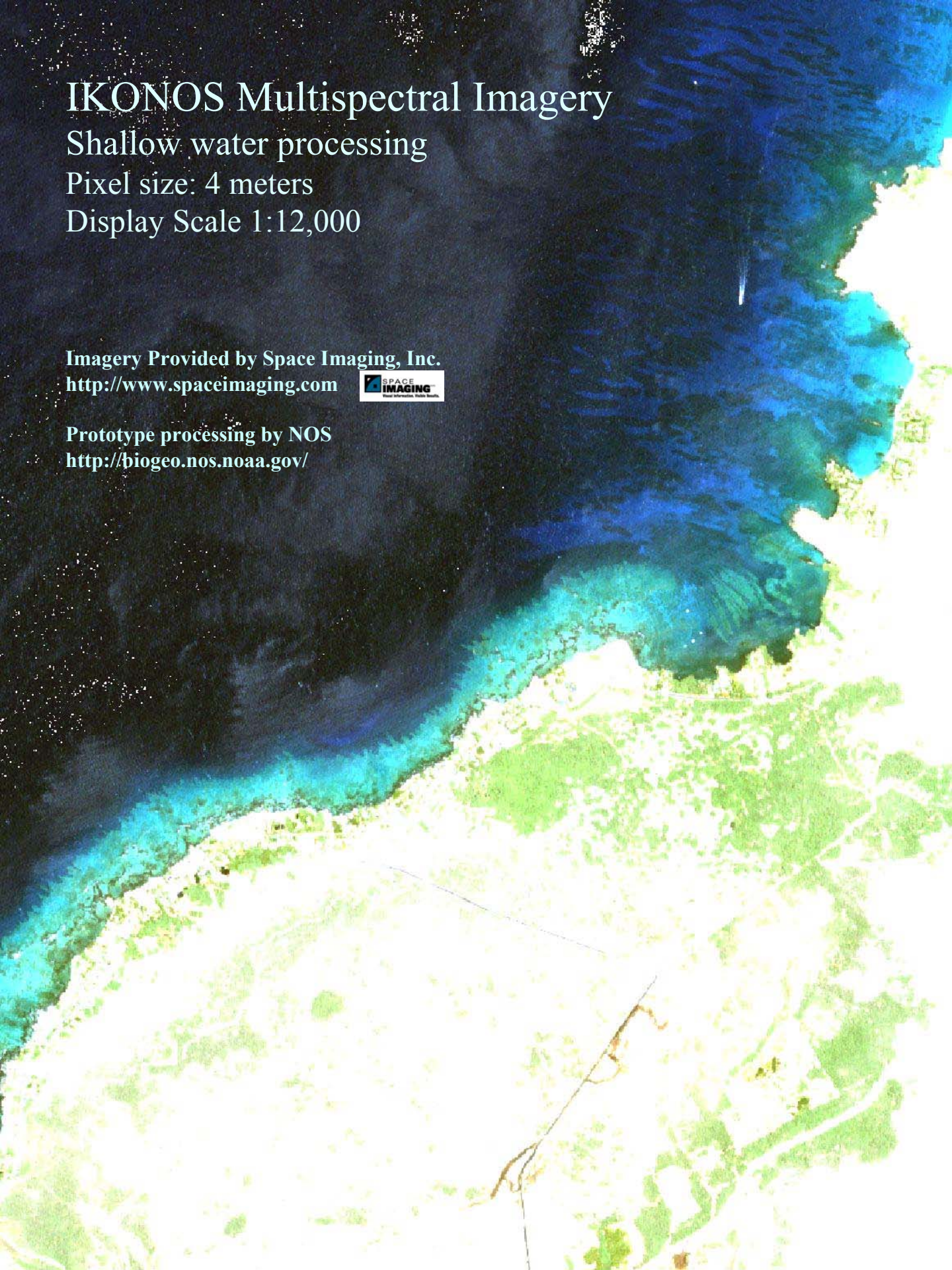
Prototype processing by NOS
http://biogeo.nos.noaa.gov/

IKONOS Multispectral Imagery

Shallow water processing

Pixel size: 4 meters

Display Scale 1:12,000



Imagery Provided by Space Imaging, Inc.
http://www.spaceimaging.com

Prototype processing by NOS
http://biogeo.nos.noaa.gov/

IKONOS Multispectral Imagery

Shoreline Processing

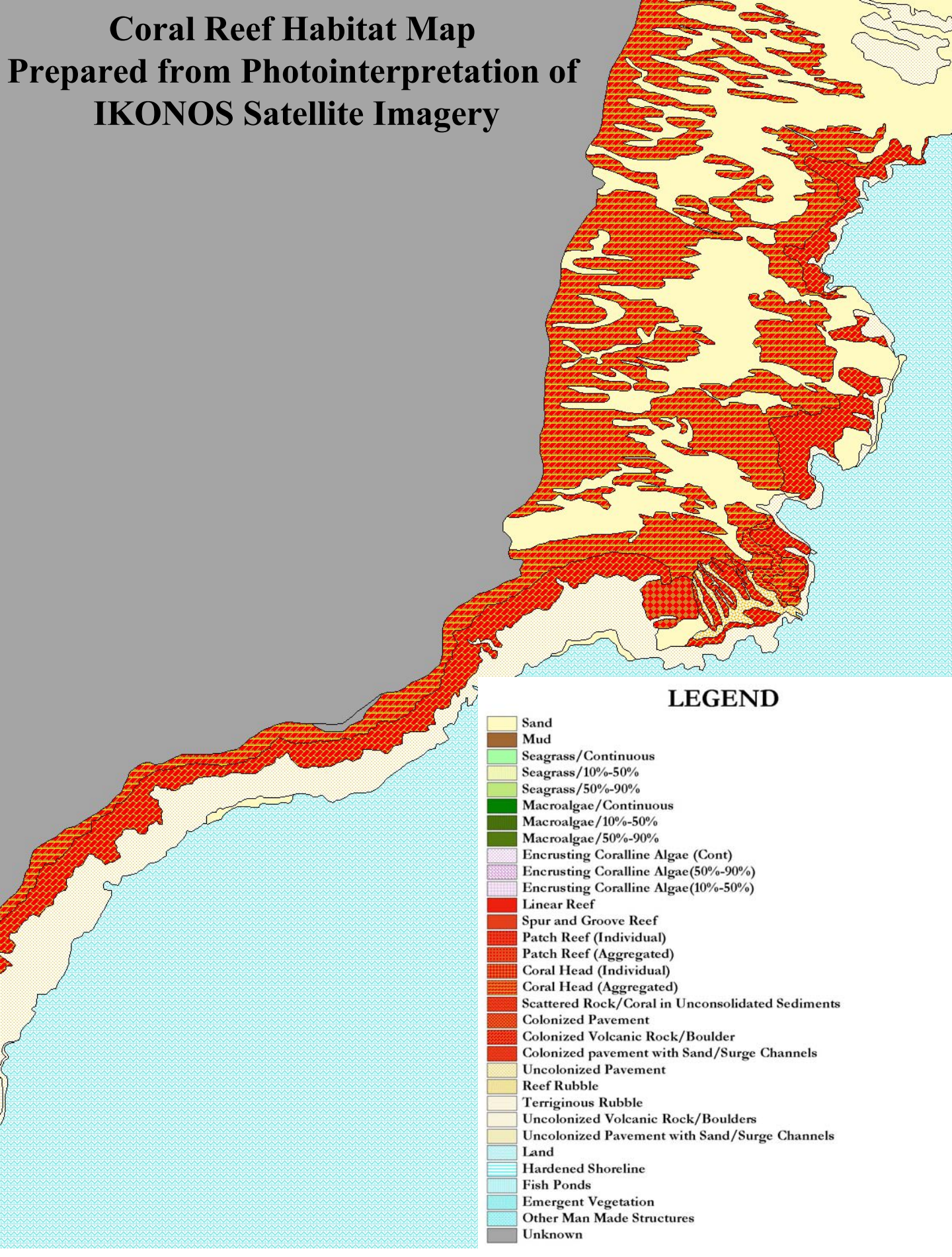
Pixel size: 4 meters

Display Scale 1:12,000

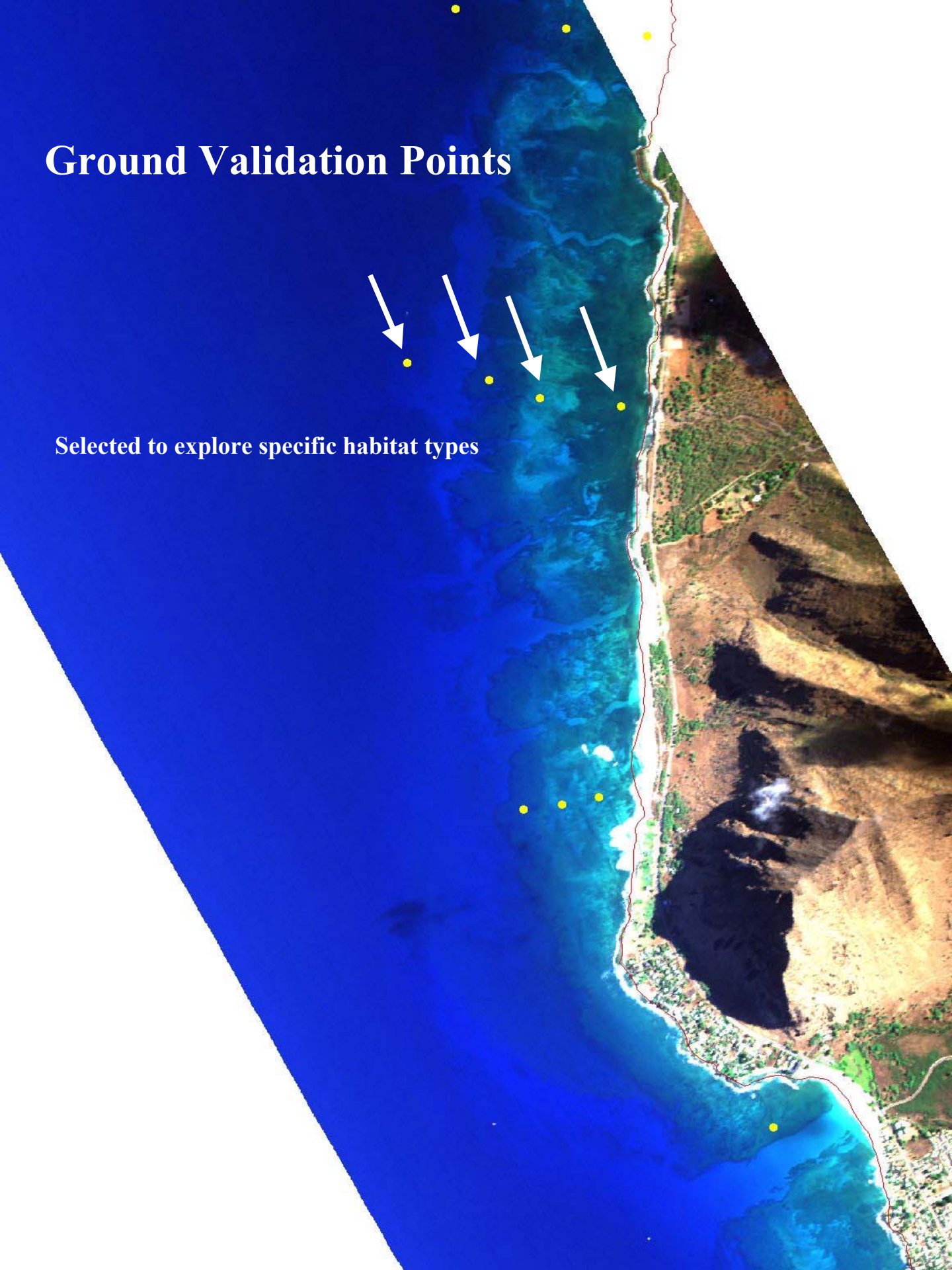
Imagery Provided by Space Imaging, Inc.
http://www.spaceimaging.com

Prototype processing by NOS
http://biogeo.nos.noaa.gov/

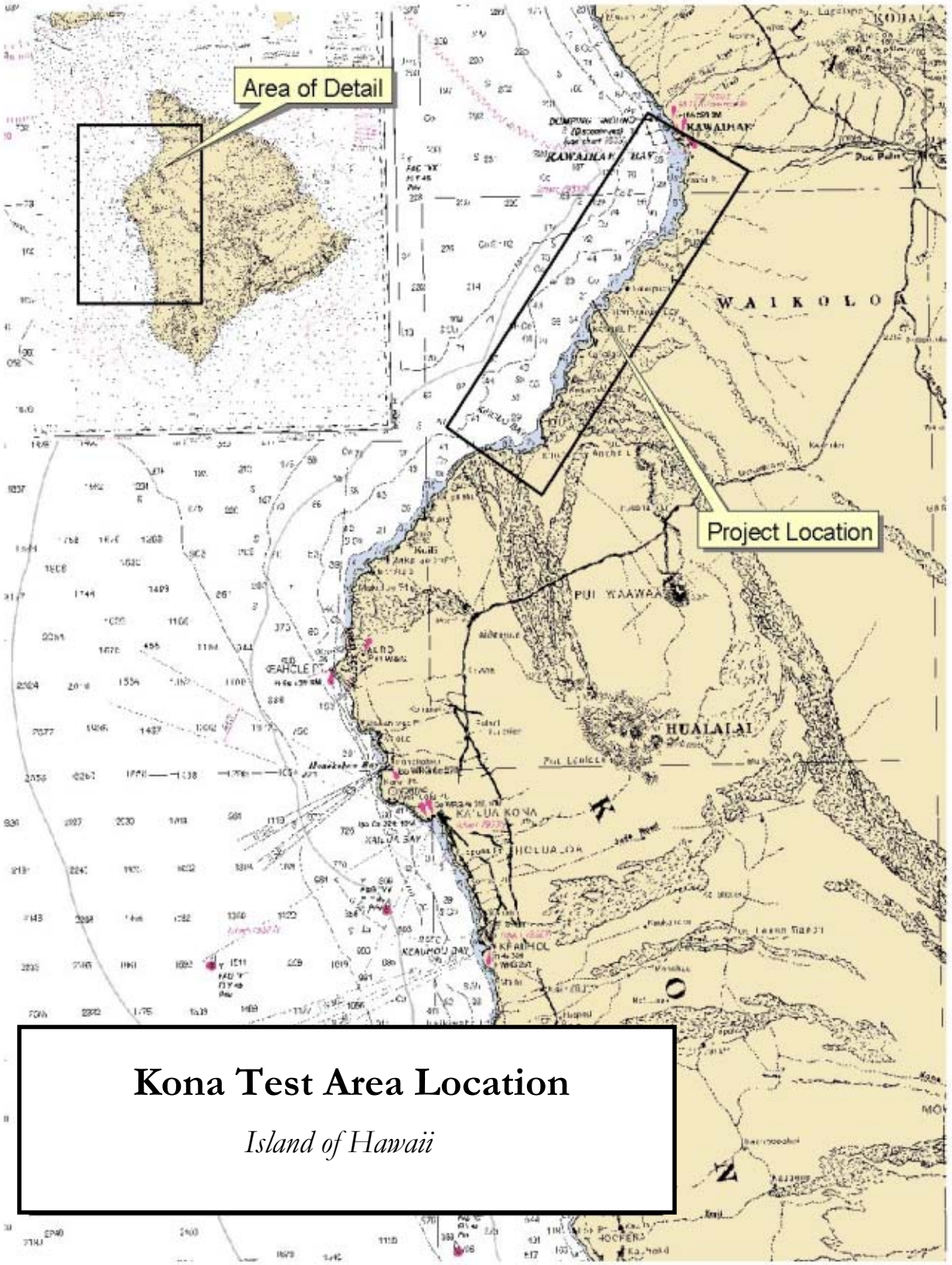
Coral Reef Habitat Map Prepared from Photointerpretation of IKONOS Satellite Imagery



Ground Validation Points



Selected to explore specific habitat types

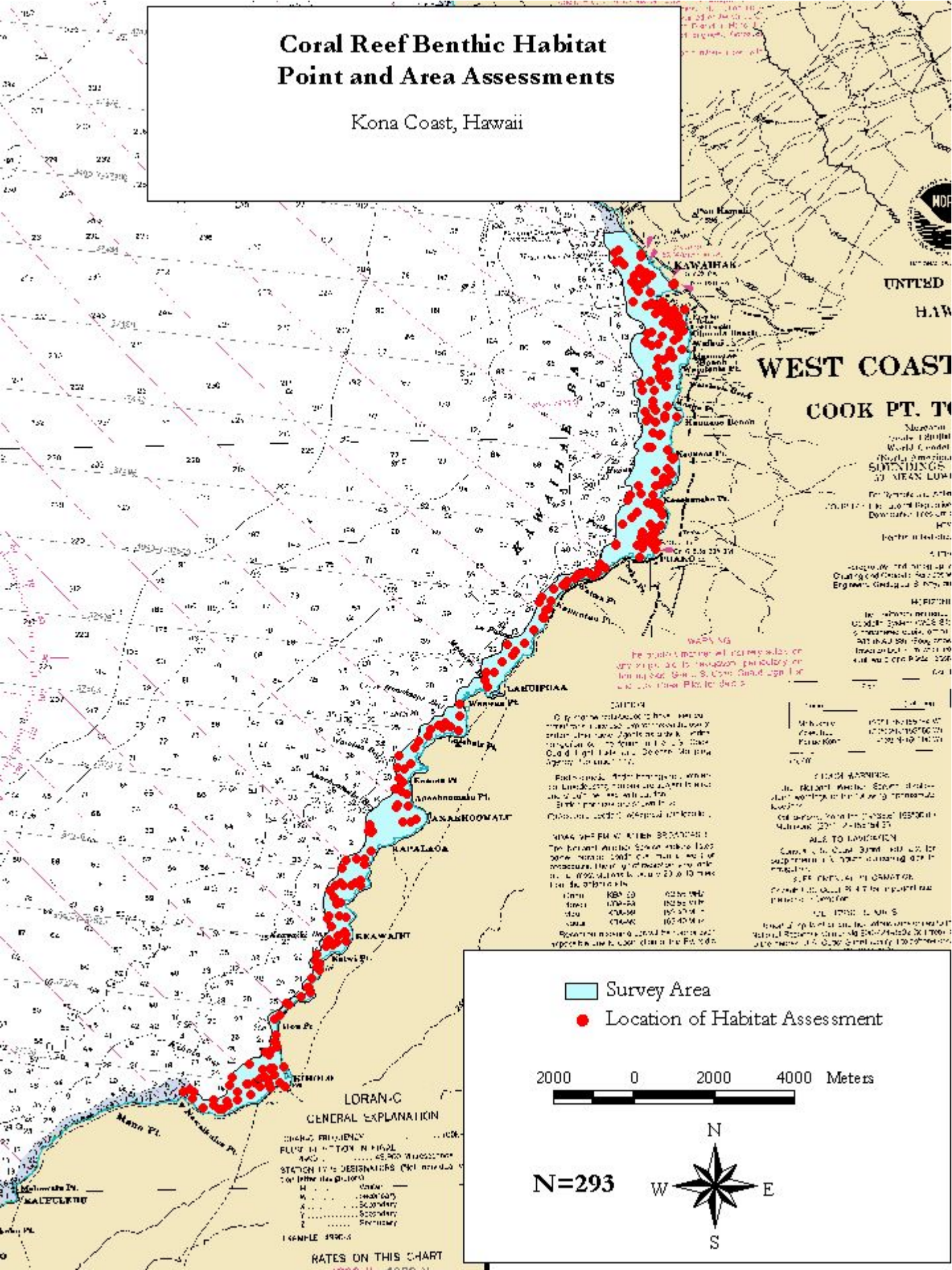


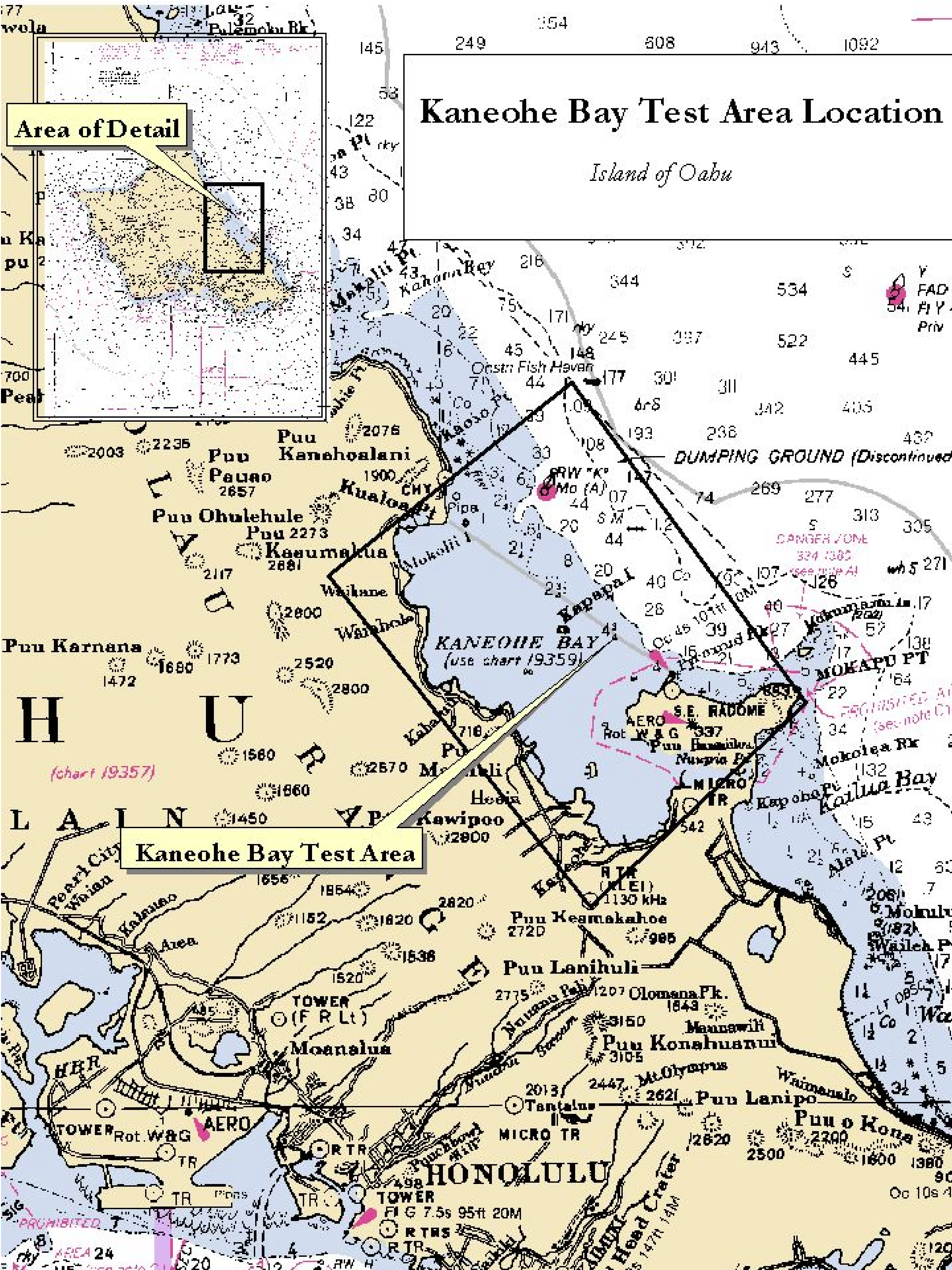
Kona Test Area Location

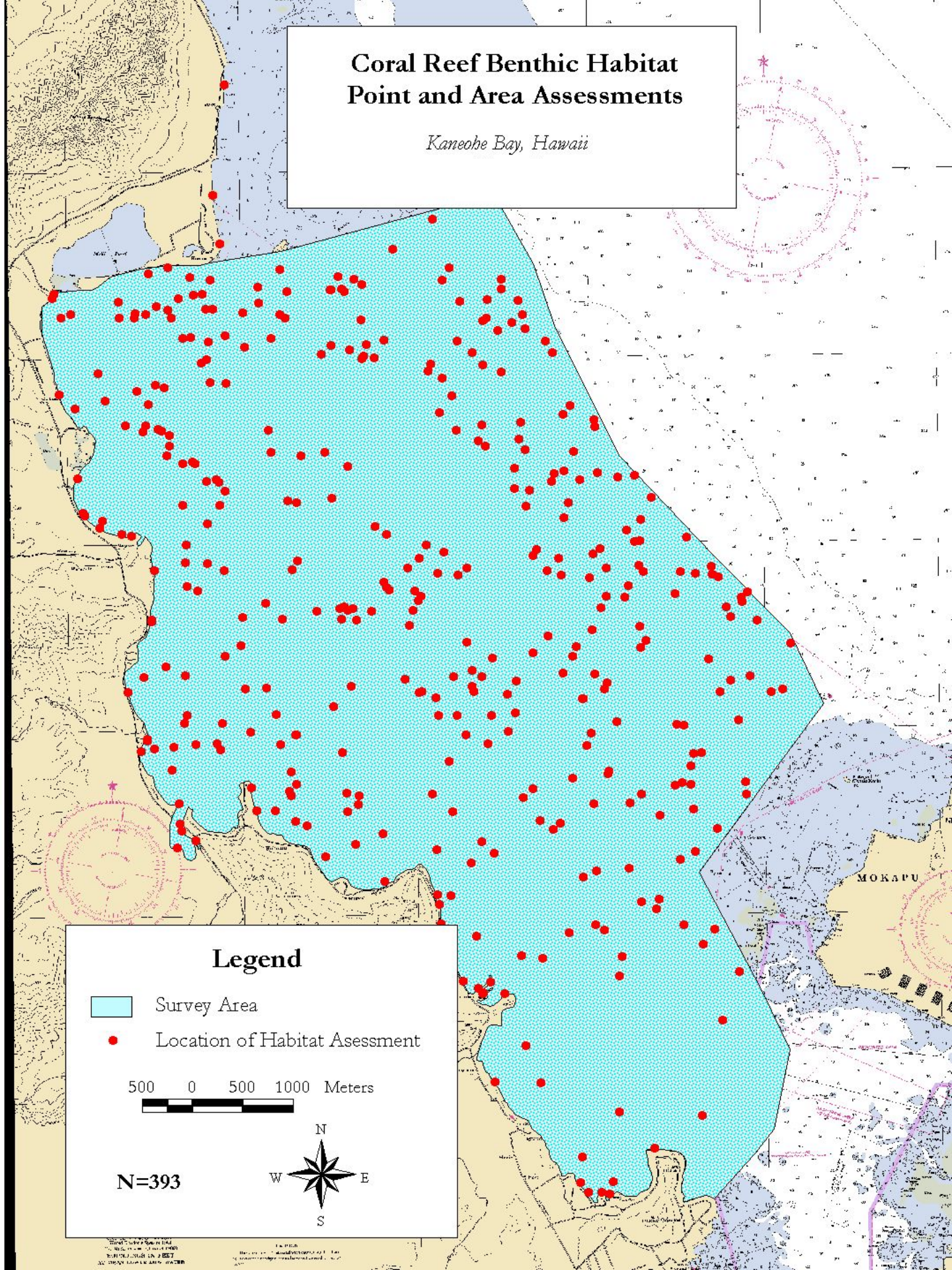
Island of Hawaii

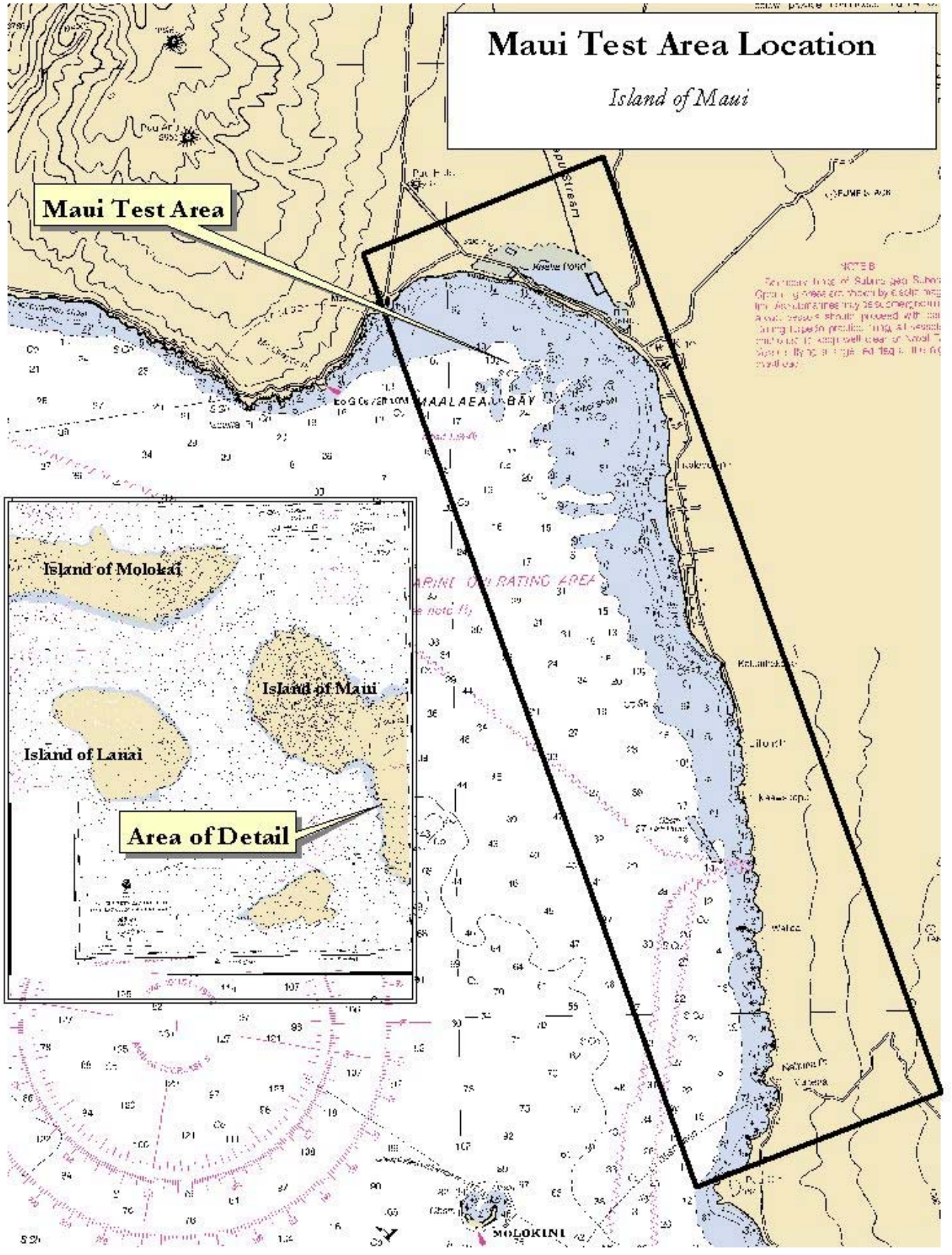
Coral Reef Benthic Habitat Point and Area Assessments

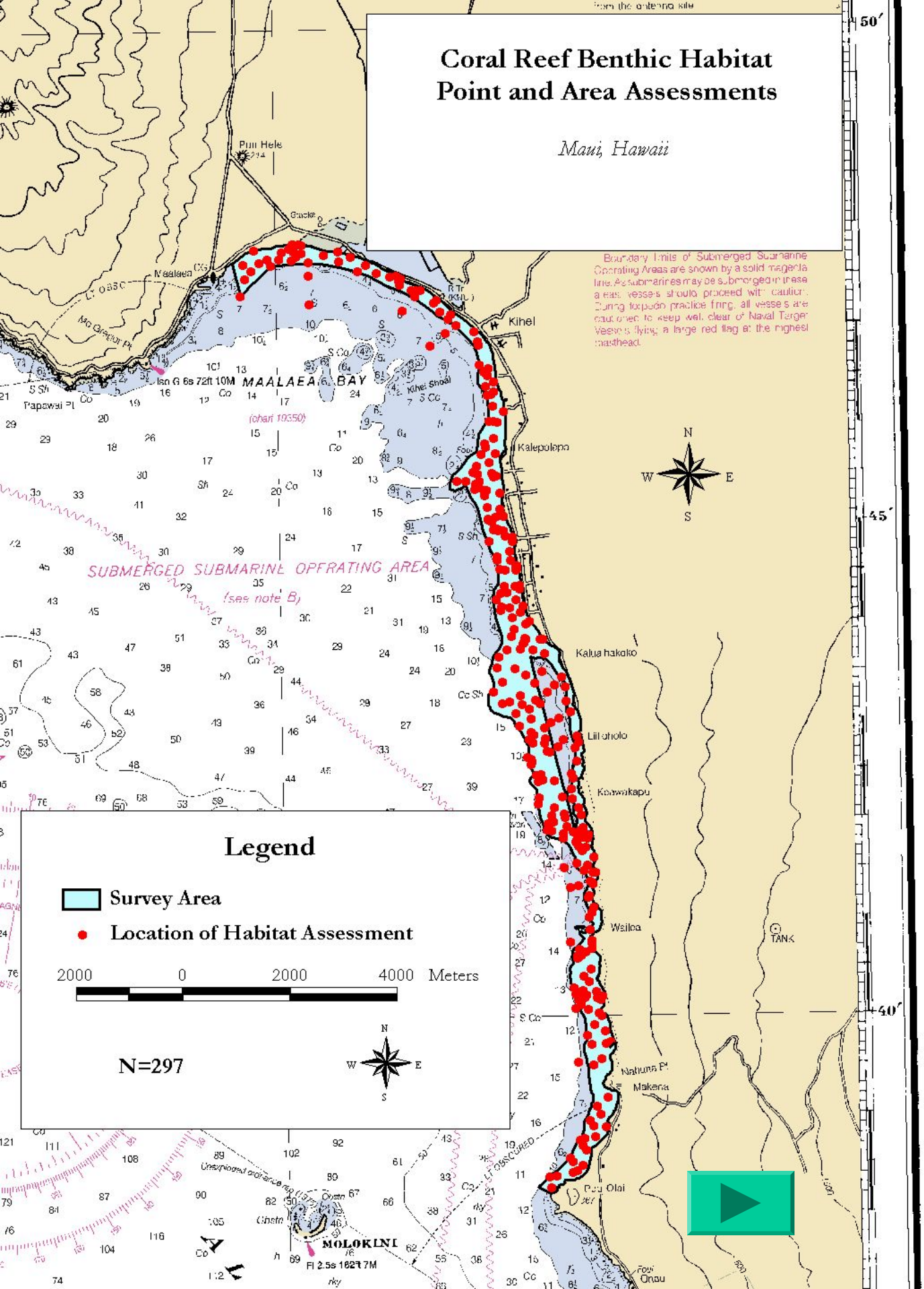
Kona Coast, Hawaii




Kaneohe Bay Test Area Location
Island of Oahu
Area of Detail
Kaneohe Bay Test Area
KANEOHE BAY
(use chart 19359)
DUMPING GROUND (Discontinued)
MOKAPU PT
Kailua Bay
HONOLULU
(chart 19357)
Puu Kanehoalani
Kualoa Pt
Mokolii I
Kapapa I
Waikane
Waiahole
Puu Ohulehule
Puu Kaumakua
Puu Lanihuli
Olomana Pk.
Puu Konahuanui
Puu Lanipo
Puu o Kona
Moanalua
Pearl City
Mt Olympus
Tantalus
S.E. RADOME
DANGER ZONE
Mokolea Rk
Alala Pt
Mokulua

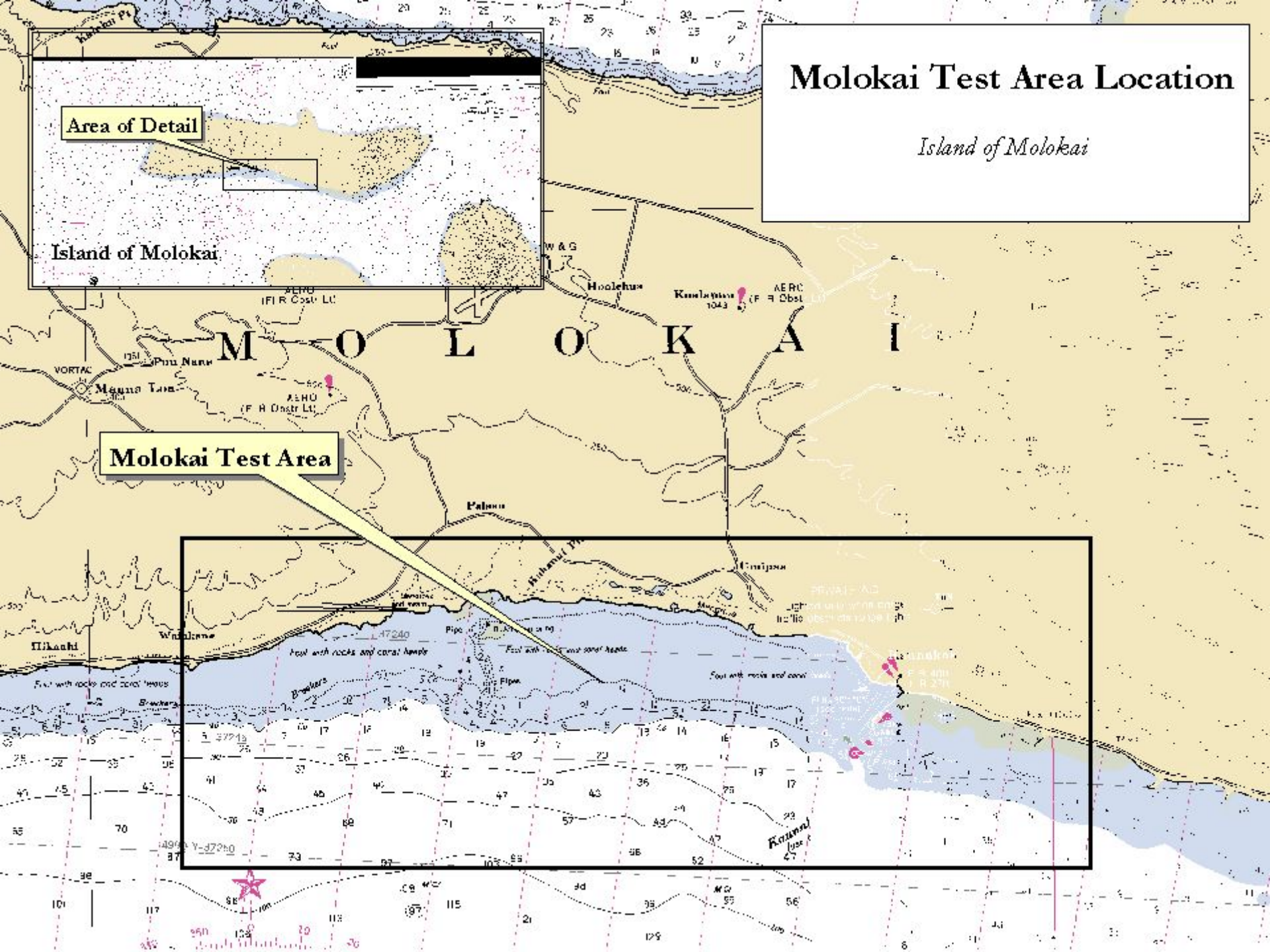

Coral Reef Benthic Habitat
Point and Area Assessments
Kaneohe Bay, Hawaii
MOKAPU
Legend
Survey Area
Location of Habitat Asessment
500 0 500 1000 Meters
N
W
E
S
N=393

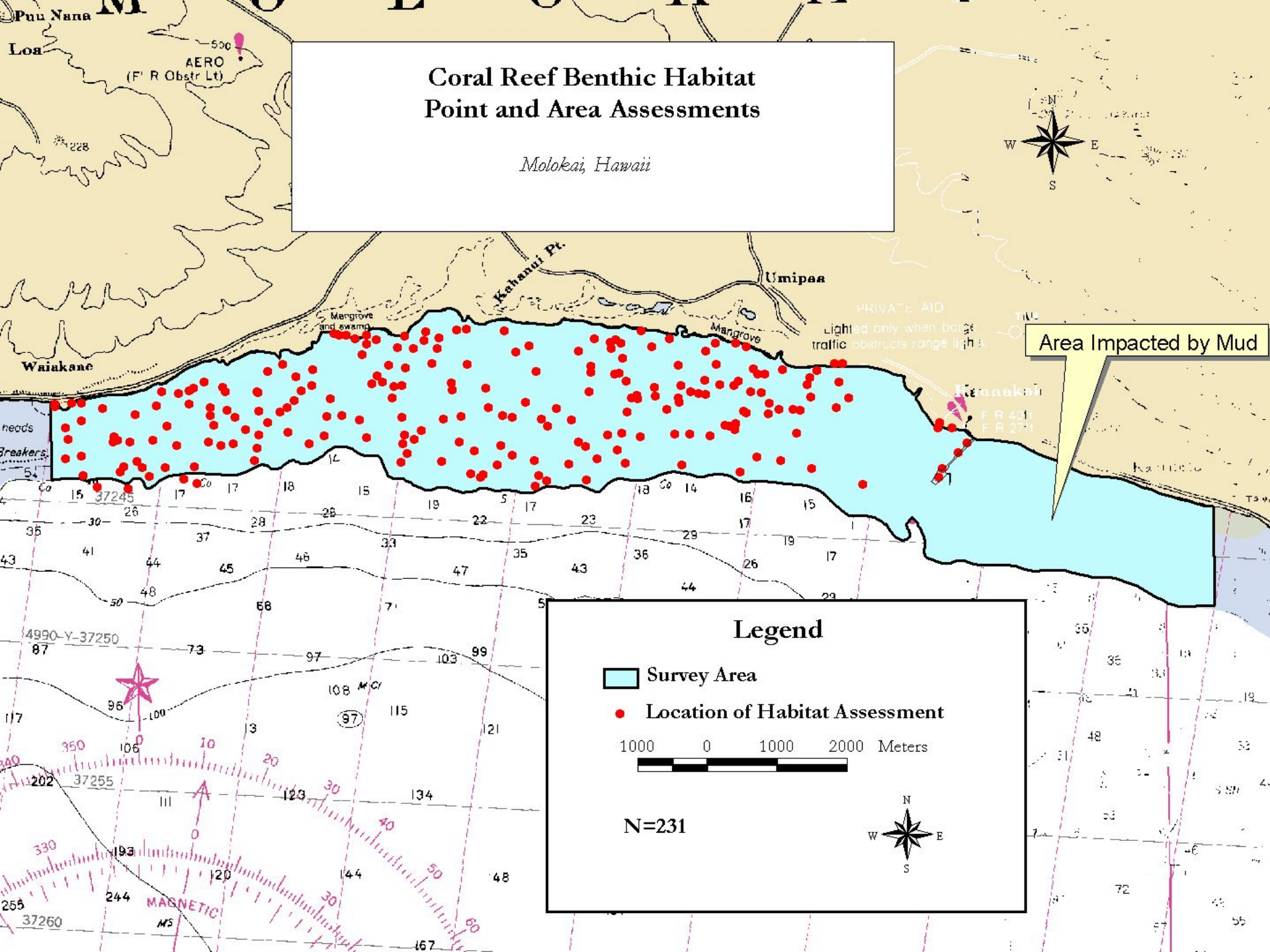

Maui Test Area Location
Island of Maui
Maui Test Area
Island of Molokai
Island of Maui
Island of Lanai
Area of Detail
MAALAEA BAY
MOLOKINI


Coral Reef Benthic Habitat
Point and Area Assessments
Maui, Hawaii
Boundary limits of Submerged Submarine Operating Areas are shown by a solid magenta line. As submarines may be submerged in these areas, vessels should proceed with caution. During torpedo practice firing, all vessels are cautioned to keep well clear of Naval Target Vessels flying a large red flag at the highest masthead.
MAALAEA BAY
SUBMERGED SUBMARINE OPERATING AREA
(see note B)
Kihei
Kalepolepo
Kalua hakoko
Lilioholo
Kaiwakapu
Wailea
Makena
Nahuna Pt
Puu Olai
MOLOKINI
Legend
Survey Area
Location of Habitat Assessment
2000 0 2000 4000 Meters
N=297

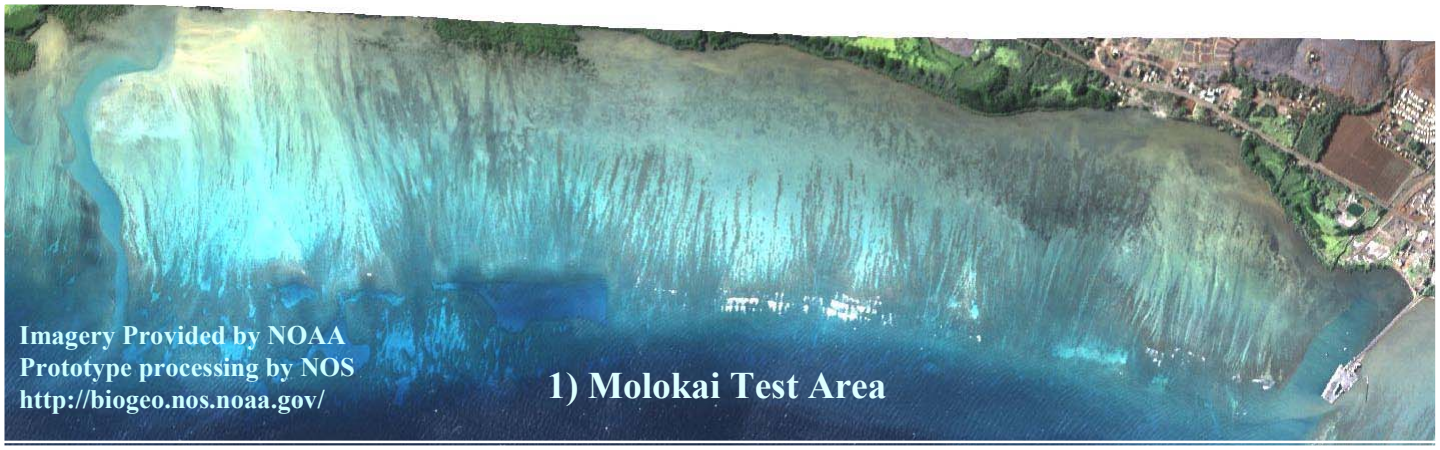
Molokai Test Area Location

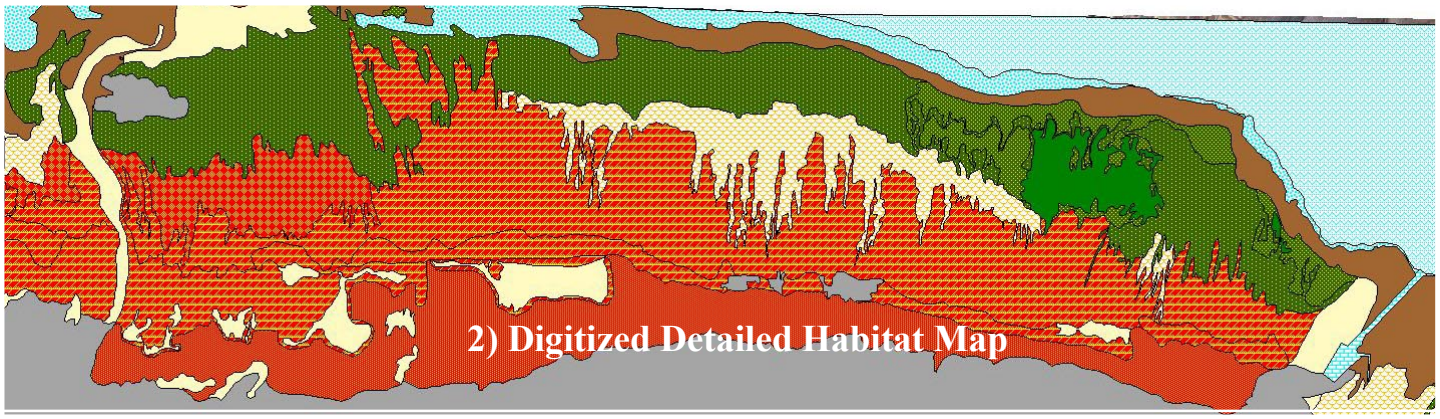
Island of Molokai

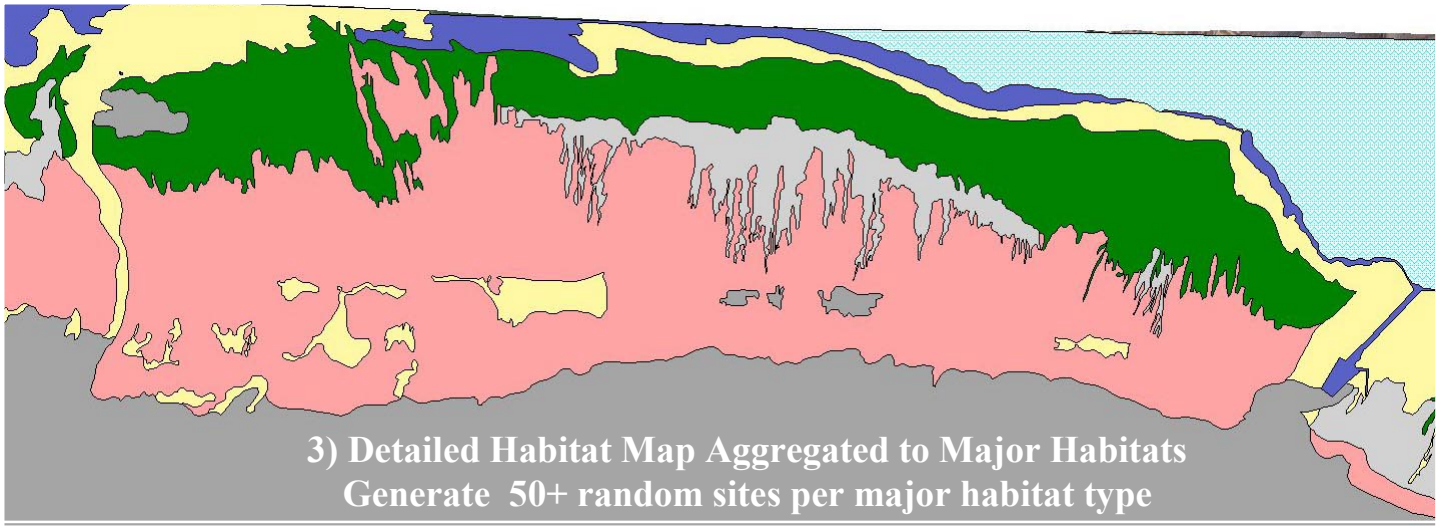


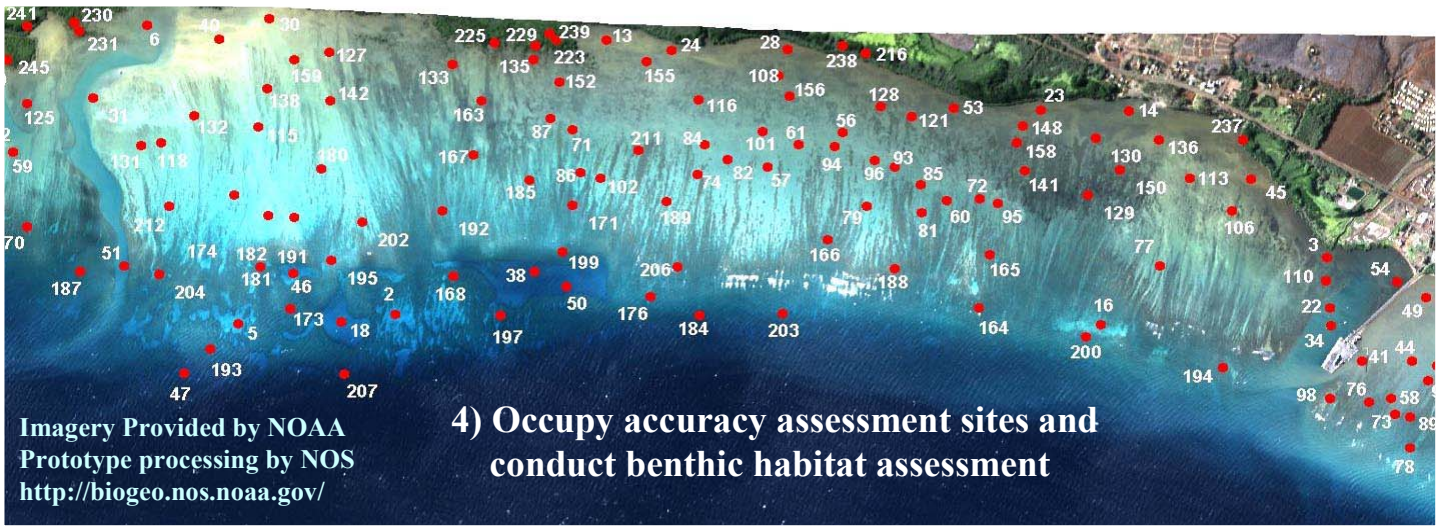

Coral Reef Benthic Habitat
Point and Area Assessments
Molokai, Hawaii
Area Impacted by Mud
Legend
Survey Area
Location of Habitat Assessment
1000 0 1000 2000 Meters
N=231
Kahanui Pt.
Umipaa
Waiakane
Mangrove
Mangrove and swamp
AERO
(F' R Obstr Lt)
Puu Nana
Lua
MAGNETIC


WEST
450


Imagery Provided by NOAA
Prototype processing by NOS
http://biogeo.nos.noaa.gov/
1) Molokai Test Area


2) Digitized Detailed Habitat Map


3) Detailed Habitat Map Aggregated to Major Habitats
Generate 50+ random sites per major habitat type


Imagery Provided by NOAA
Prototype processing by NOS
http://biogeo.nos.noaa.gov/
4) Occupy accuracy assessment sites and
conduct benthic habitat assessment

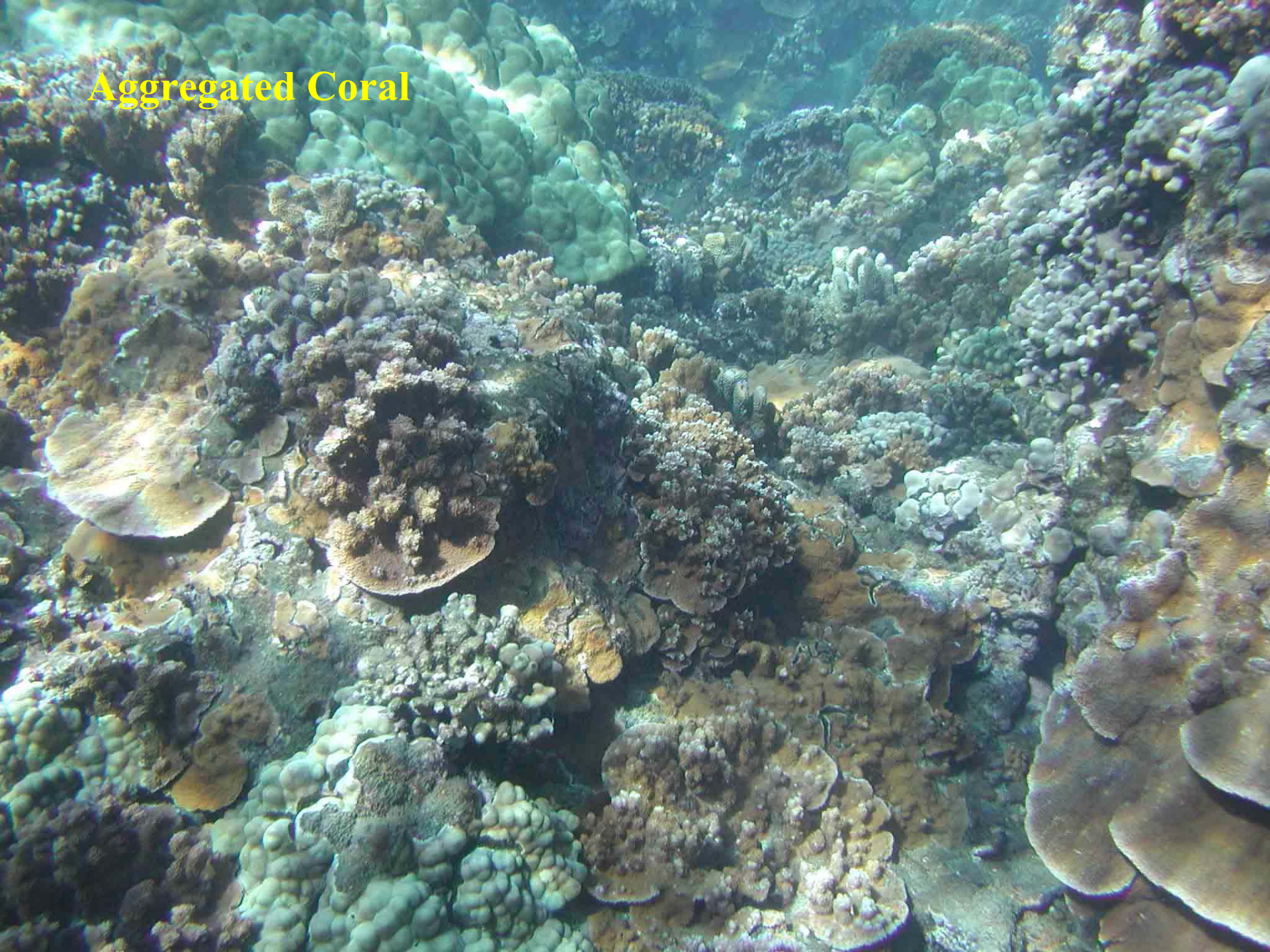
Boats used Ranged from 36 foot Radon to Ocean Kayak

Field Data Collected at Each Habitat Assessment Site

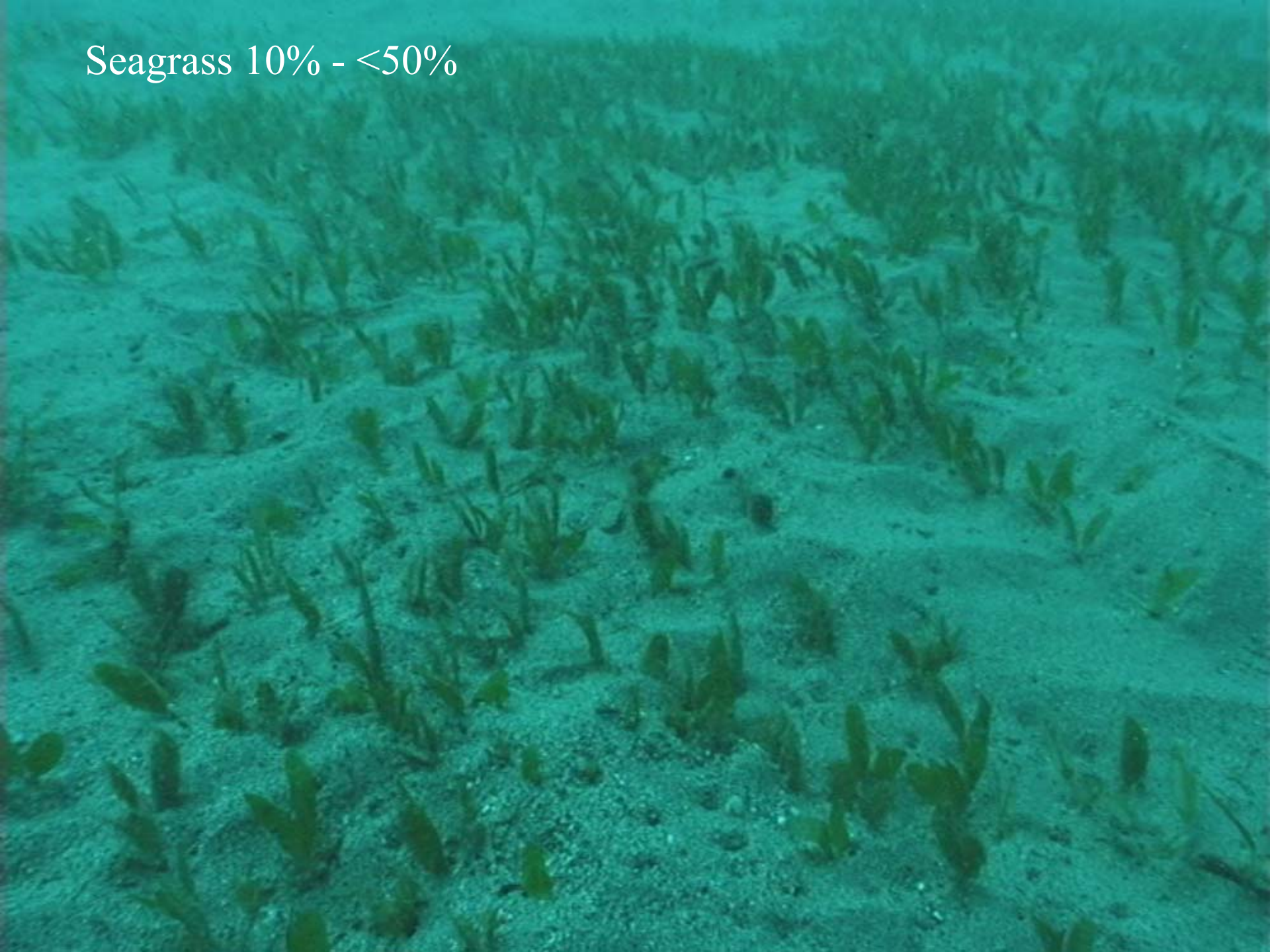
Site Data	Habitat Data
• Site ID • Study Area • GPS Date • GPS Time • GPS Position • GPS Statistics • Depth • Photo Information • Assessment Method	• Point Habitat Type • Area 1 Habitat Type • Area 2 Habitat Type • Dominant Coral Species • Dominant SAV Species • Estimated Coral Cover • Estimated SAV Cover • Area Description


Aggregated Coral

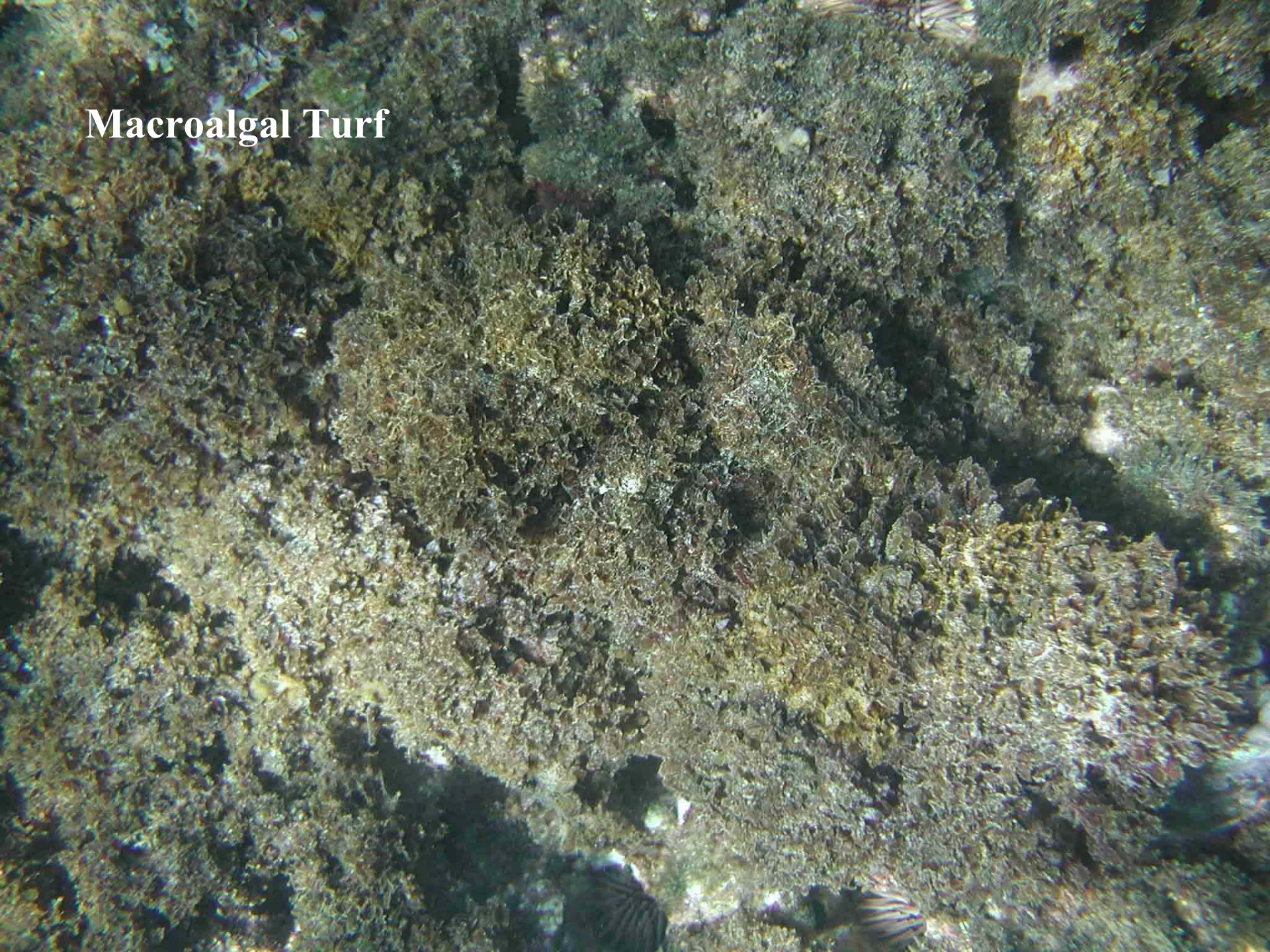

Aggregated Coral


Aggregated Coral


Sand
Patch Reef


Seagrass 10% - <50%


Fleshy **Macroalgae**


Macroalgal Turf


Fleshy Macroalgae and
Filamentous Turf

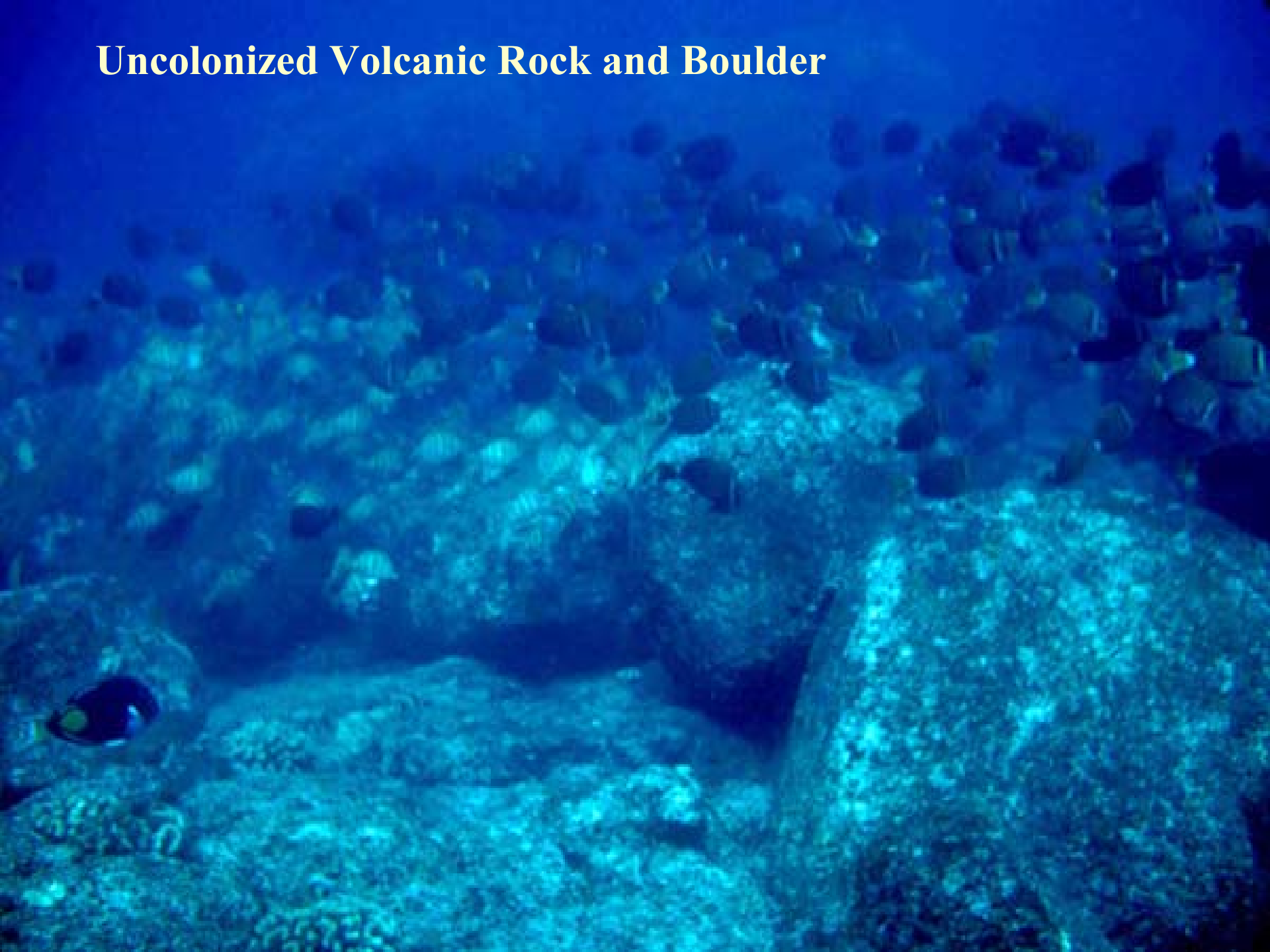

Fleshy Macroalgae
Covered with Sediment


Fleshy Macroalgae in the Upper Intertidal and
Encrusting Coralline Algae in the Mid Intertidal

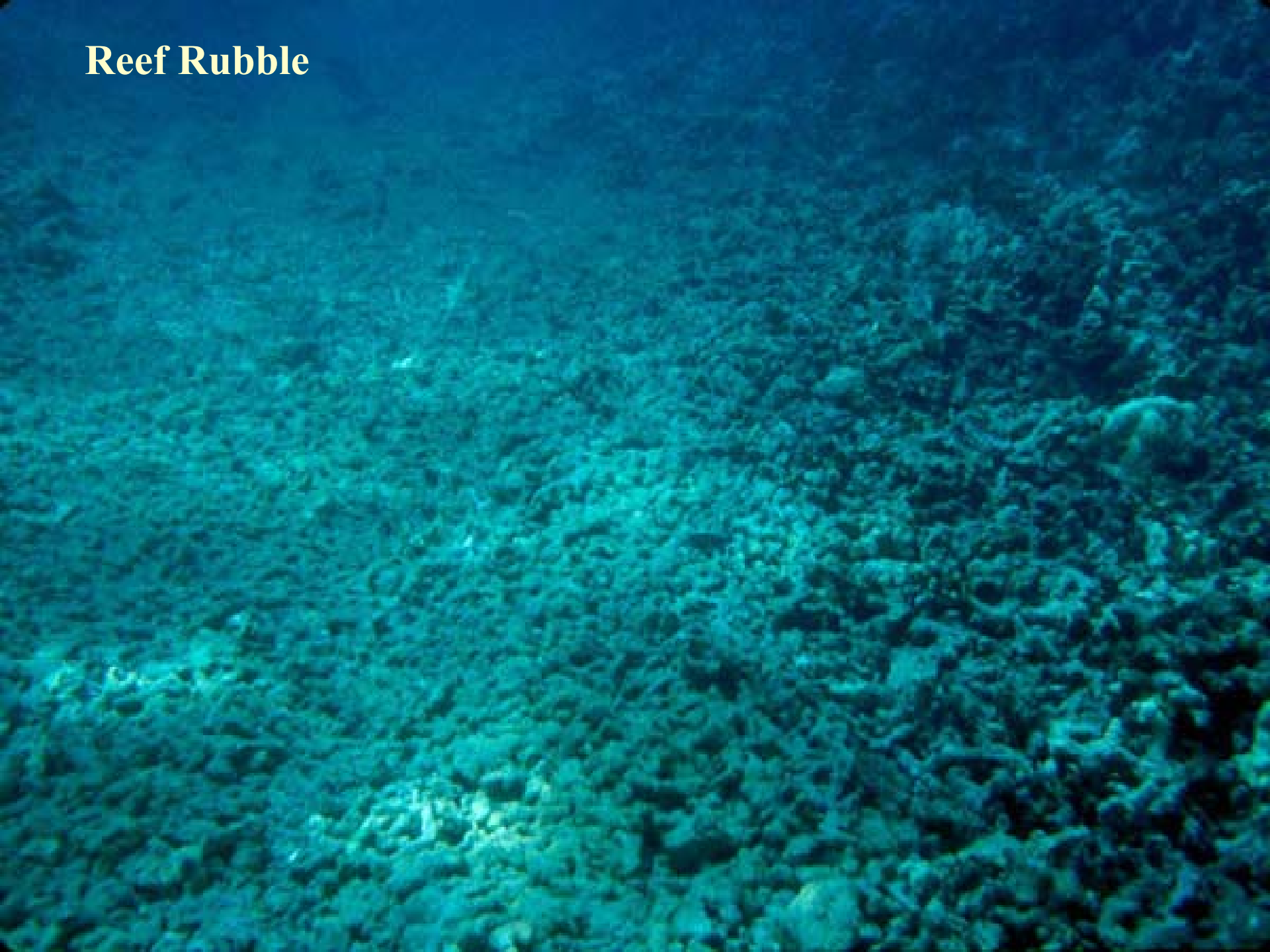

Encrusting Coralline Algae
on Relic Coral Reef

Colonized Volcanic Rock and Boulders

Uncolonized Volcanic Rock and Boulder



Reef Rubble




Emergent Vegetation


Emergent Vegetation

Summary of Habitat Types Encountered During Accuracy Assessment
Field Data Collection for all Test Sites

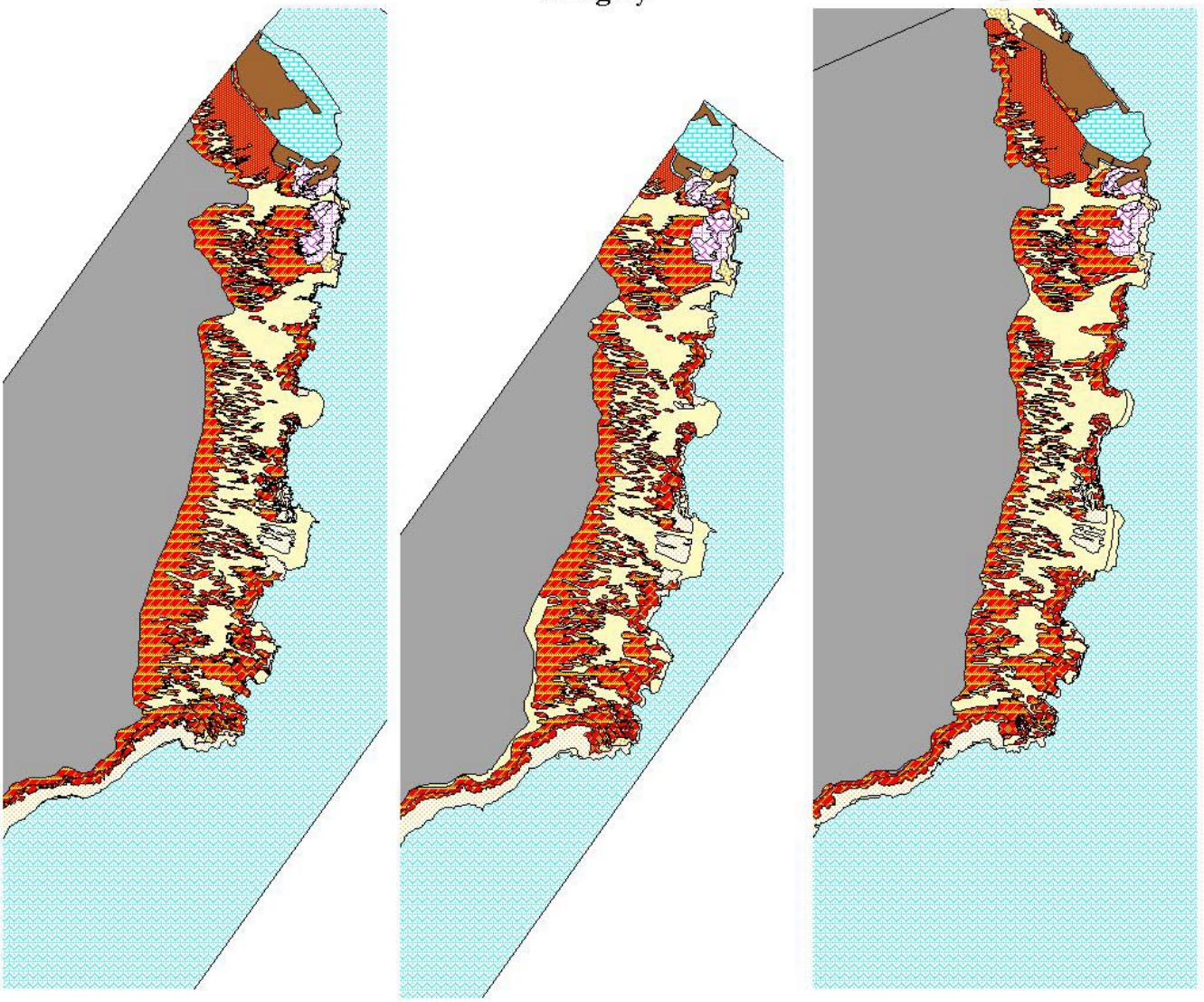
Habitat Type (Major Habitats in Bold Face Type)	Survey Area Kona	KBay	Maui	Molokai
Unconsolidated Sediment	**102**	**97**	**136**	**54**
Sand	99	45	136	51
Mud	3	52		3
Submerged Aquatic Vegetation	**4**	**81**	**55**	**52**
Continuous Seagrass (90%-100%)				
Patchy Seagrass (50%-<90%)	1			
Patchy Seagrass (10%-<50%)	3	4		
Continuous Macroalgae (90%-100%)		3	2	
Patchy Macroalgae (50%-<90%)		9	18	9
Patchy Macroalgae (10%-<50%)		65	35	43
Coral Reef and Hardbottom	**181**	**191**	**106**	**99**
Linear Reef				
Spur and Groove	4			1
Patch Reef (Individual)		1		
Patch Reef (Aggregated)				
Scattered C/R in Unconsol. Sed.	5	11		12
Aggregated Coral	68	17	49	48
Colonized Pavement	11	30	12	12
Col. Volcanic Rock/Boulder	56		20	
Col. Pav. With Sand Chan.	1	39		
Reef Rubble	5	10	1	3
Uncol. Pavement		62	18	19
Uncol. Volcanic Rock/Boulder	14	5	6	
Uncol. Pavement w/Sand Chan.		3		
Patchy Coralline Algae (10%-<50%)	7	13		4
Patchy Coralline Algae (50%-<90%)	8			
Continuous Coralline Algae (90%-100%)	2			
Other Delineations	**14**	**25**	**0**	**28**
Emergent Vegetation		8		22
Artificial	14	17		6

North End of Kona Coral Reef Benthic Habitat Map
Prepared from Photointerpretation Remotely Sensed Data

Color Aerial Photography

AURORA Hyperspectral Imagery

IKONOS Satellite Imagery



Legend

- Sand
- Mud
- Encrusting Coralline Algae (Cont)
- Encrusting Coralline Algae(50%-90%)
- Encrusting Coralline Algae(10%-50%)
- Spur and Groove Reef
- Colonized Volcanic Rock/Boulder
- Reef Rubble
- Uncolonized Volcanic Rock/Boulders
- Land
- Hardened Shoreline
- Other Man Made Structures
- Unknown

Detailed Habitat Class Accuracy of Coral Reef Habitat Map of Kaneohe Bay Prepared from Color Aerial Photography

Color - Kaneohe Bay Detailed Habitats

		FIELD ASSESSMENT															Row Totals	User's Accuracy
		AgCr	Artf	ColPv	ColPvSC	HMacAl	InPtRf	LCorAl	LMacAl	LSeaGr	MMacAl	Mud	RR	SAND	UnColPv	UnColPvSC		
POLYGON ATTRIBUTES	AgCr	**5**															**5**	**100%**
	Artf		**9**														**9**	**100%**
	ColPv			**11**							1				8		**20**	**55%**
	ColPvSC			13	**51**										1	3	**68**	**75%**
	HMacAl					**1**											**1**	**100%**
	InPtRf						**14**										**14**	**100%**
	LCorAl							**5**									**5**	**100%**
	LMacAl								**37**		1			1	10		**49**	**76%**
	LSeaGr									**0**							**0**	**NA**
	MMacAl					1			19		**6**				3		**29**	**21%**
	Mud	1	1			1		1		1		**62**		1			**68**	**91%**
	RR								1				**0**	1			**2**	**0%**
	SAND							1	1	2		1		**24**	1		**30**	**80%**
	UnColPv	3			1				4				1		**18**		**27**	**67%**
	UnColPvSC															**2**	**2**	**100%**
Column Totals		**9**	**10**	**24**	**52**	**3**	**14**	**7**	**62**	**3**	**8**	**63**	**1**	**27**	**41**	**5**	**329**	
Producer's Accuracy		**56%**	**90%**	**46%**	**98%**	**33%**	**100%**	**71%**	**60%**	**0%**	**75%**	**98%**	**0%**	**89%**	**44%**	**40%**		

Overall Accuracy of Detailed Habitats: 75%

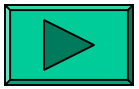
Major Habitat Class Accuracy of Coral Reef Habitat Map of Kaneohe Bay Prepared from Color Aerial Photography

Color - Kaneohe Bay Major Habitats

POLYGON ATTRIBUTES	FIELD ASSESSMENT: Unconsolidated Sediment	Submerged Vegetation	Coral Reef and Hard Bottom	Other	Row Totals	User's Accuracy
Unconsolidated Sediment	**88**	5	4	1	**98**	**90%**
Submerged Vegetation	1	**66**	13	0	**80**	**83%**
Coral Reef and Hard Bottom	1	5	**136**	0	**142**	**96%**
Other	0	0	0	**9**	**9**	**100%**
Column Totals	**90**	**76**	**153**	**10**	**329**	
Producer's Accuracy	**98%**	**87%**	**89%**	**90%**		

Overall Accuracy: 90.8%

TEST AREA	IMAGERY TYPE	ACCURACY STATISTICS			
		Major Habaitats	Kappa	Tau	Detailed Habitats
Kona	Color	93.9%	0.89	0.89	83.5%
	Hyperspectral	92.4%	0.86	0.87	81.4%
	IKONOS	90.2%	0.82	0.83	80.0%
Kbay	Color	86.2%	0.81	0.82	74.5%
	Hyperspectral	87.0%	0.83	0.83	75.8%
	IKONOS	81.5%	0.76	0.77	63.4%
Maui	Color	90.5%	0.86	0.87	80.1%
	Hyperspectral	88.4%	0.83	0.86	78.9%
	IKONOS	88.1%	0.83	0.84	77.4%
Molokai	Color	94.0%	0.92	0.95	88.5%
	Hyperspectral	88.0%	0.84	0.85	77.4%
	IKONOS	86.9%	0.83	0.84	79.6%
All Areas Combined	Color	90.7%	0.87	0.87	80.8%
	Hyperspectral	89.0%	0.85	0.85	78.1%
	IKONOS	86.5%	0.82	0.83	74.1%



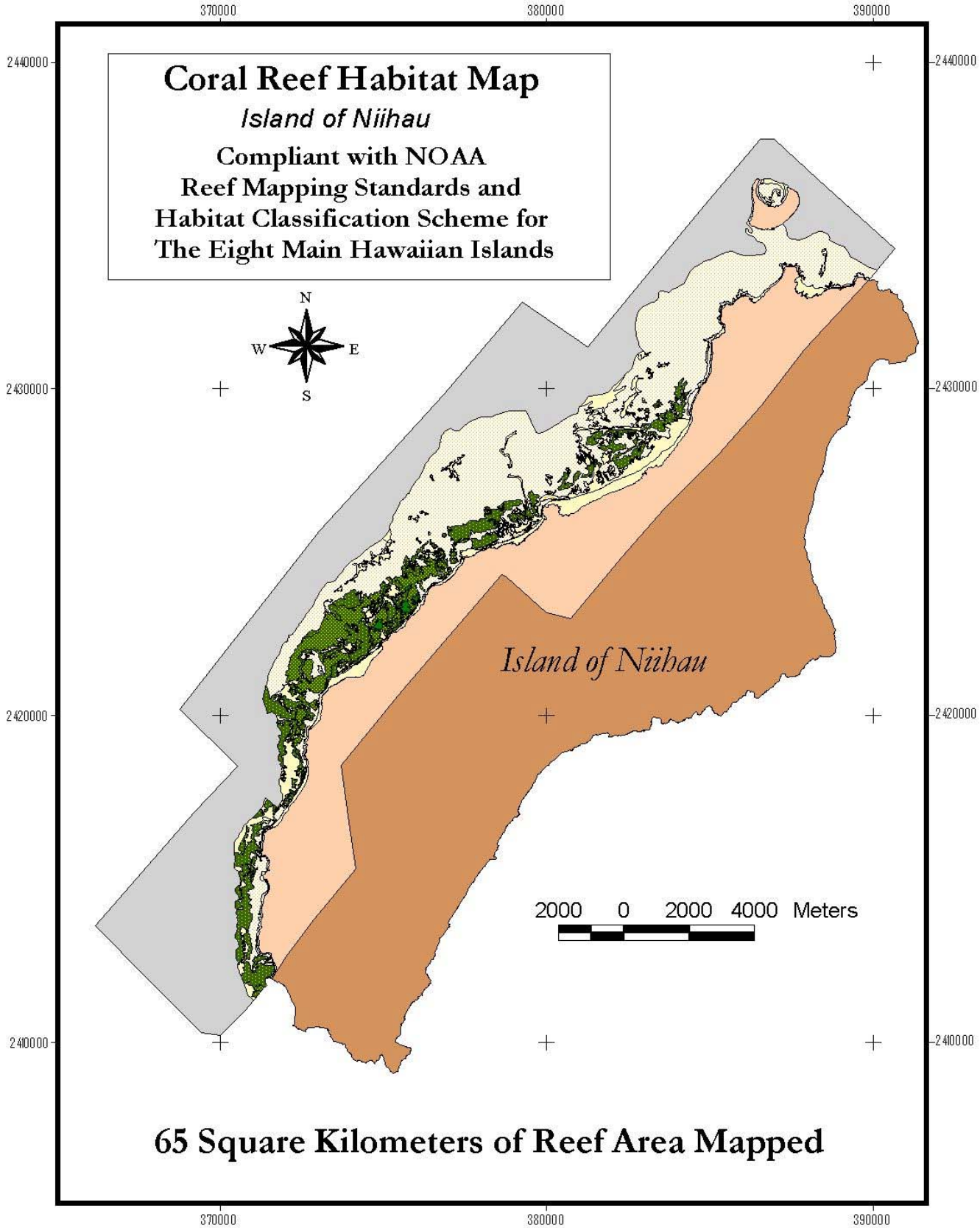
Comparison of Accuracy of Coral Reef Habitat Maps Prepared from Color Aerial Photography, Hyperspectral IKONOS Satellite Imagery

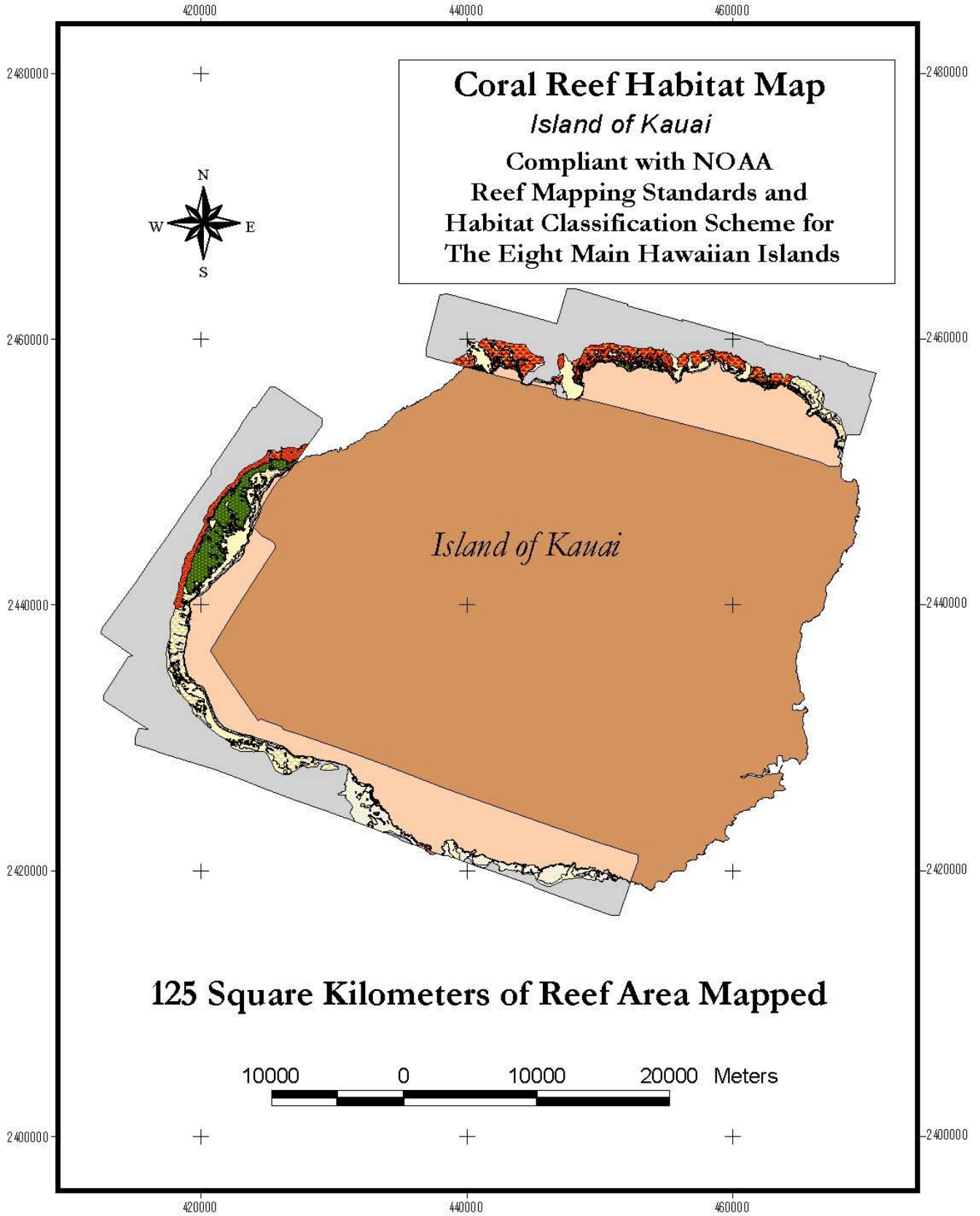
	Image Type	Color	IKONOS	HSI
MAUI	**Color**		0.999012	-0.61662
	IKONOS			-0.08237
	HSI			
MOLOKAI	**Color**		2.621557	-2.37355
	IKONOS			-0.29216
	HSI			
OAHU	**Color**		1.567347	-0.3975
	IKONOS			-1.89231
	HSI			
HAWAII	**Color**		2.012551	0.80843
	IKONOS			-1.17298
	HSI			
OVERALL	**COLOR**		-3.07086	1.42364
	IKONOS			-1.59611
	HSI			

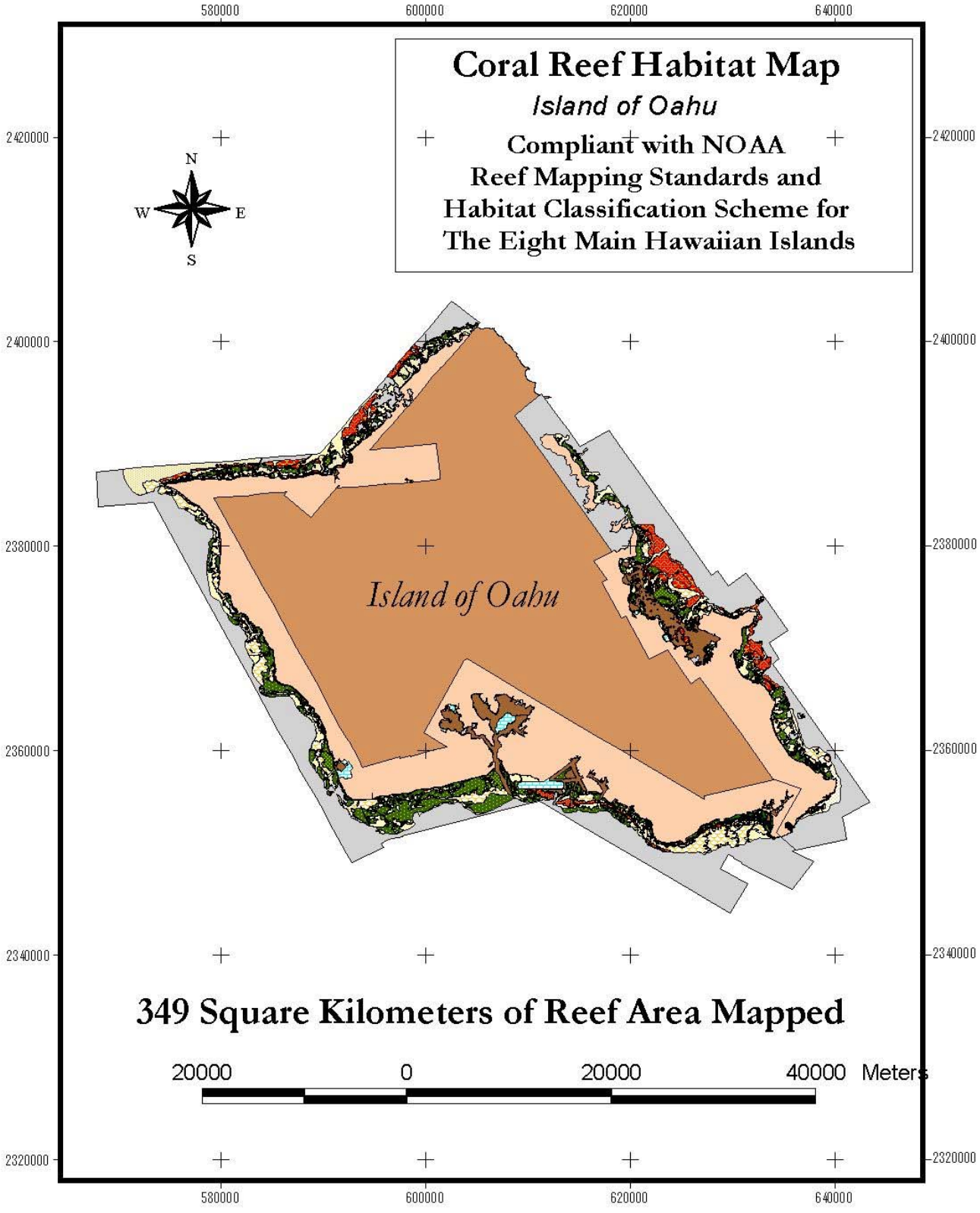
Difference Significant, $p<0.05$

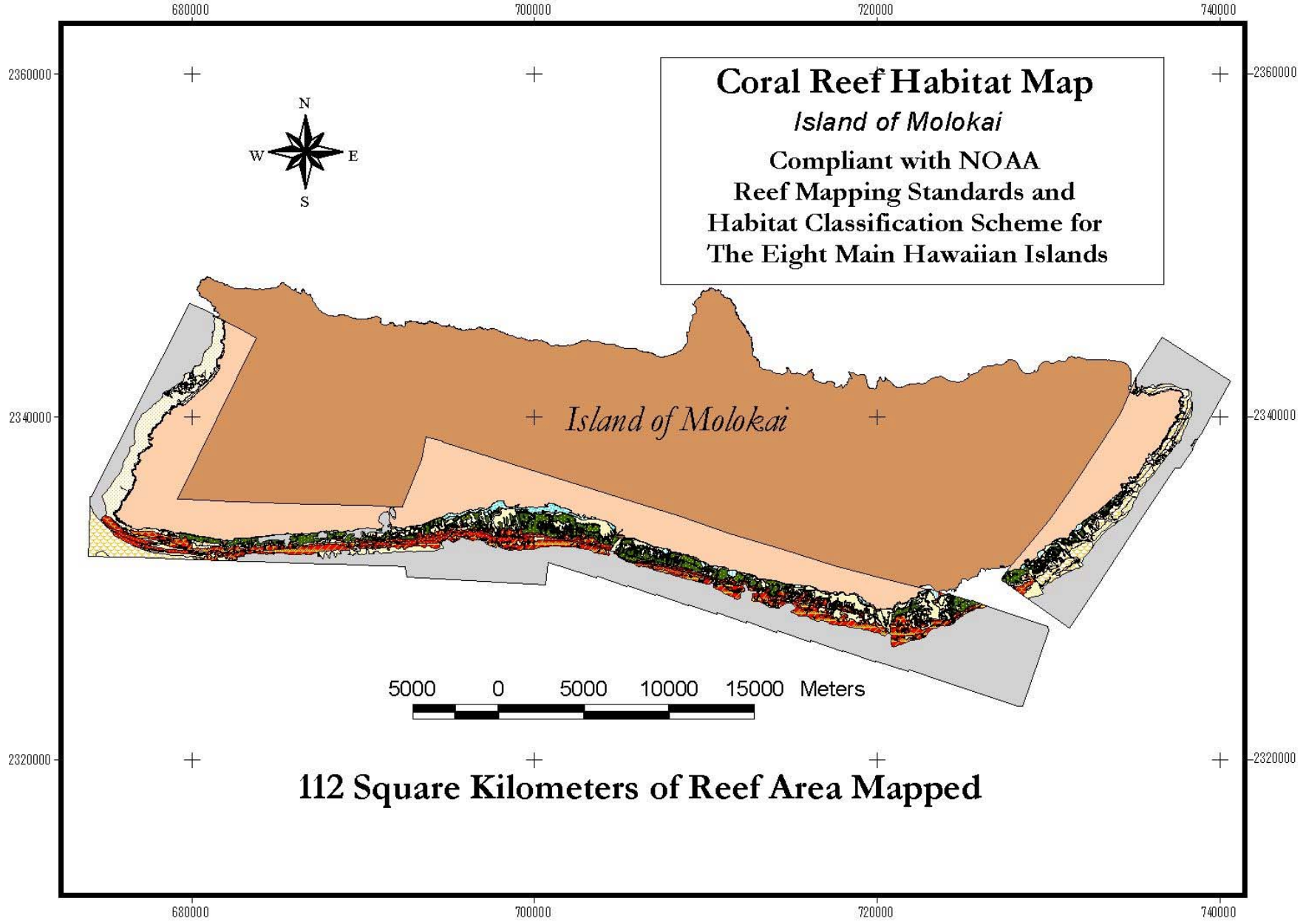
Summary of Spatial Accuracy of GPS Field Data

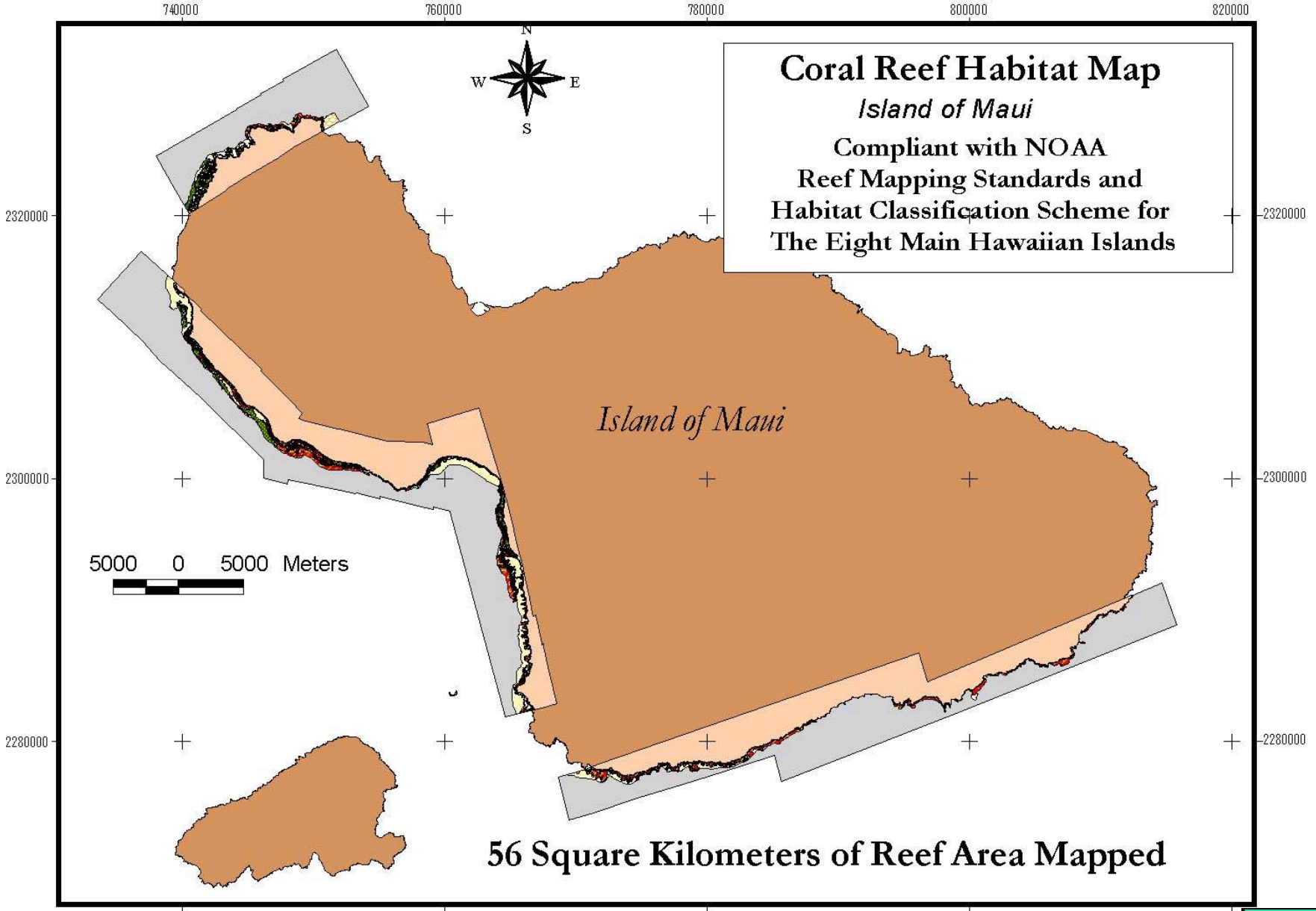
Control Type	RMS Value (meters)	N
Digitizing RMS	0.86	32
Benchmarks Vertical RMS	1.67	30
Benchmarks Horizontal RMS	0.66	30
Occupation of a Waypoint From a Boat	2.1	10
Occupation of a Waypoint on Land	3.4	34


370000
380000
390000
2440000
2430000
2420000
2410000
Coral Reef Habitat Map
Island of Niihau
Compliant with NOAA
Reef Mapping Standards and
Habitat Classification Scheme for
The Eight Main Hawaiian Islands
N
W
E
S
Island of Niihau
2000 0 2000 4000 Meters
65 Square Kilometers of Reef Area Mapped


420000
440000
460000
2480000
2460000
2440000
2420000
2400000
Coral Reef Habitat Map
Island of Kauai
Compliant with NOAA
Reef Mapping Standards and
Habitat Classification Scheme for
The Eight Main Hawaiian Islands
N
W
E
S
Island of Kauai
125 Square Kilometers of Reef Area Mapped
10000
0
10000
20000
Meters


580000
600000
620000
640000
Coral Reef Habitat Map
Island of Oahu
Compliant with NOAA
Reef Mapping Standards and
Habitat Classification Scheme for
The Eight Main Hawaiian Islands
N
W
E
S
2420000
2400000
2380000
2360000
2340000
2320000
Island of Oahu
349 Square Kilometers of Reef Area Mapped
20000
0
20000
40000
Meters

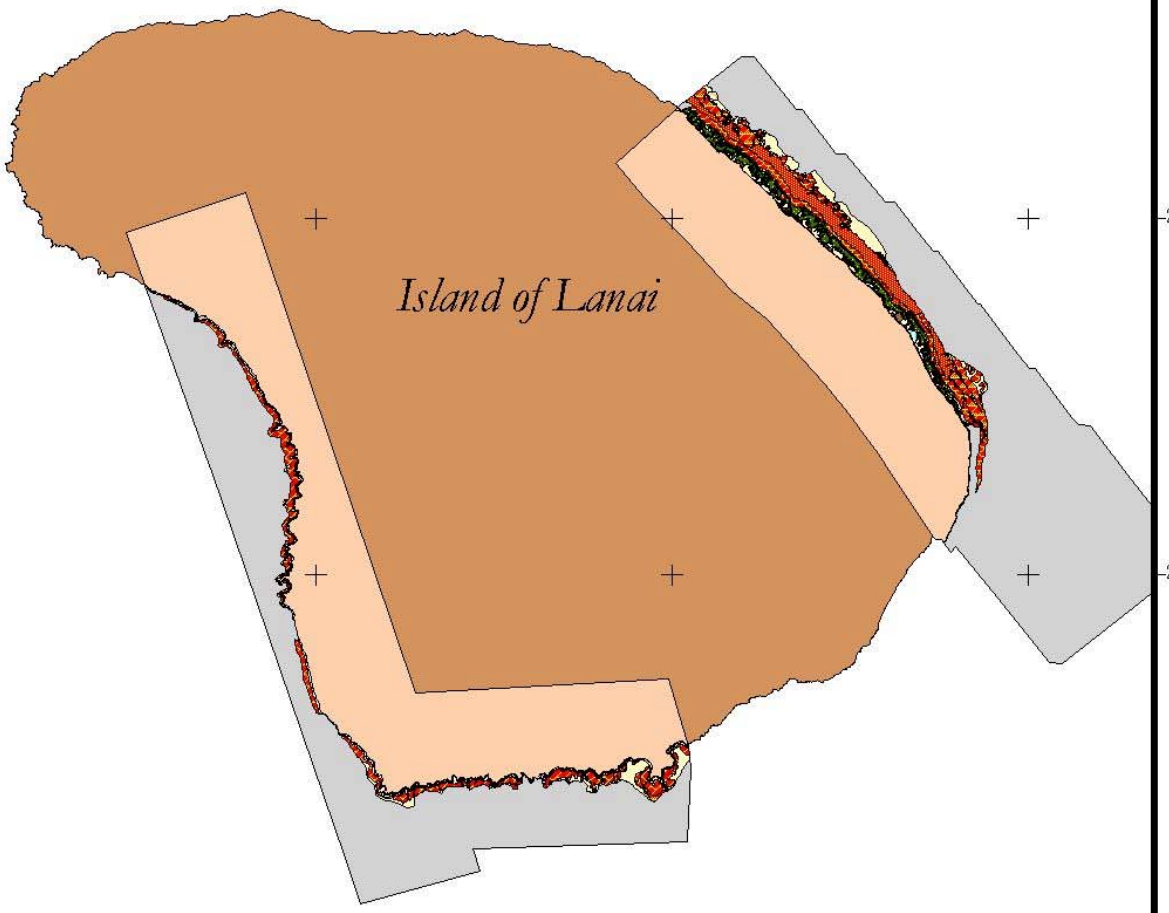

680000
700000
720000
740000
2360000
2340000
2320000
Coral Reef Habitat Map
Island of Molokai
Compliant with NOAA
Reef Mapping Standards and
Habitat Classification Scheme for
The Eight Main Hawaiian Islands
N
W
E
S
Island of Molokai
5000 0 5000 10000 15000 Meters
112 Square Kilometers of Reef Area Mapped


740000
760000
780000
800000
820000
N
W
E
S
Coral Reef Habitat Map
Island of Maui
Compliant with NOAA
Reef Mapping Standards and
Habitat Classification Scheme for
The Eight Main Hawaiian Islands
2320000
2300000
2280000
Island of Maui
5000 0 5000 Meters
56 Square Kilometers of Reef Area Mapped

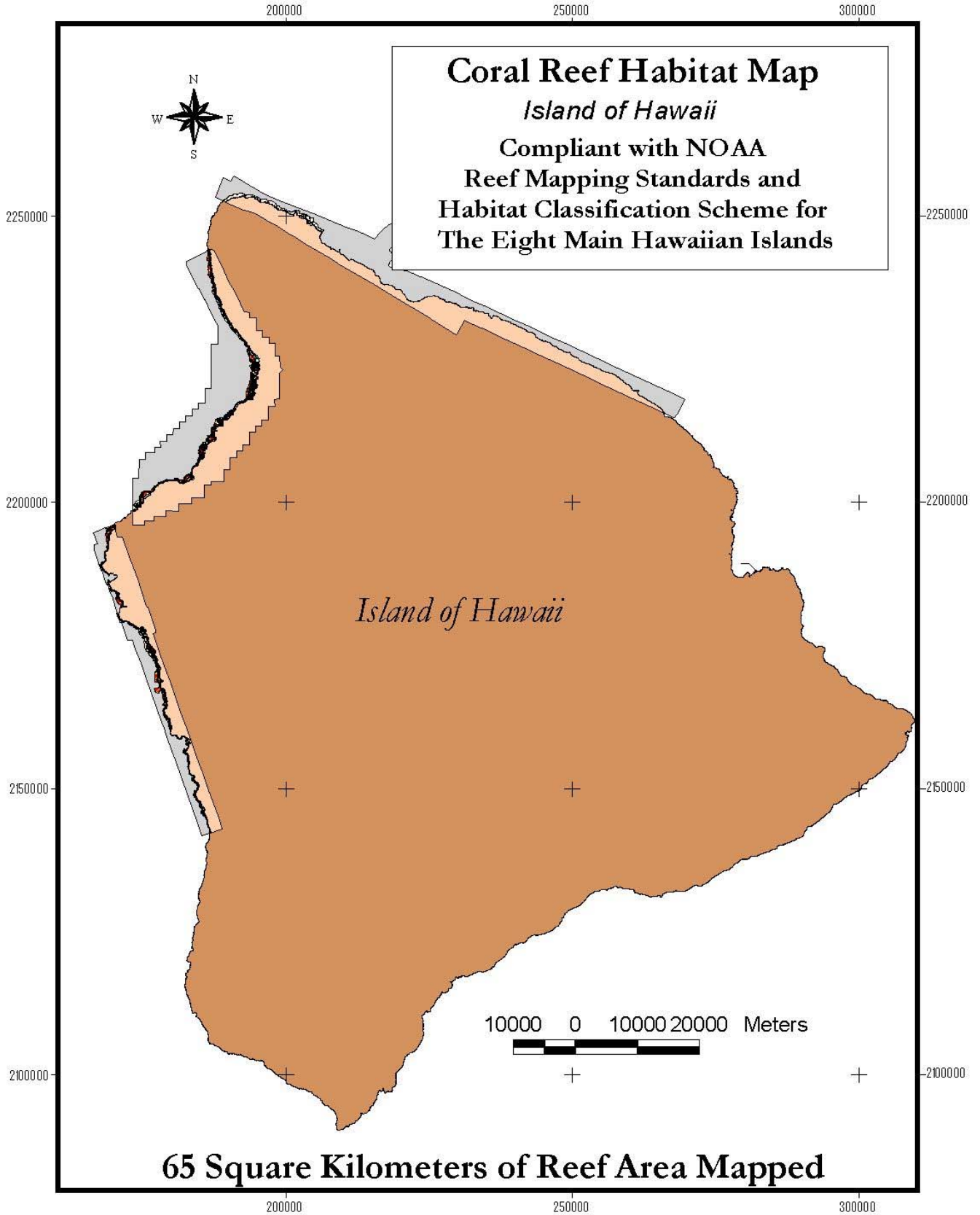
Coral Reef Habitat Map

Island of Lanai

Compliant with NOAA Reef Mapping Standards and Habitat Classification Scheme for The Eight Main Hawaiian Islands



18 Square Kilometers of Reef Area Mapped


Coral Reef Habitat Map
Island of Hawaii
Compliant with NOAA
Reef Mapping Standards and
Habitat Classification Scheme for
The Eight Main Hawaiian Islands
N
W
E
S
200000
250000
300000
2250000
2200000
2150000
2100000
Island of Hawaii
10000 0 10000 20000 Meters
65 Square Kilometers of Reef Area Mapped

Area of each Major Habitat Class Mapped for each Test and Production Area (Sq. Km.)

Map Type	Map Title	Coral Reef and Hard Bottom	Submerged Aquatic Vegetation	Unconsolidated Sediment	Total Area Per Map	Total Per Map Type
TEST AREA MAPS	Kbay color	19.46	9.50	24.09	53.05	
	Kbay HSI	9.25	8.29	14.12	31.66	
	Kbay IKONOS	13.62	13.23	24.71	51.56	
	Total Mapped for Kbay	42.33	31.02	62.92	**136.27**	
	Kona color	13.24	6.66	0.00	19.90	
	Kona HSI	17.60	7.11	0.00	24.71	
	Kona IKONOS	12.85	6.55	0.00	19.40	
	Total Mapped for Kona	43.69	20.32	0.00	**64.01**	
	Maui color	4.69	1.70	9.07	15.46	
	Maui HSI	5.68	1.92	6.24	13.84	
	Maui IKONOS	4.45	1.59	5.05	11.09	
	Total Mapped for Maui	14.82	5.21	20.36	**40.39**	
	Molokai color	10.33	9.05	7.71	27.09	
	Molokai HSI	9.30	9.07	7.73	26.10	
	Molokai IKONOS	10.22	8.72	7.22	26.16	
	Total Mapped for Molok	29.85	26.84	22.66	**79.35**	
	Total Mapped in Test Areas	**130.69**	**83.39**	**105.94**		**320.02**
PRODUCTION MAPS	Niihau Production	40.70	14.04	9.88	64.62	
	Kauai	71.76	17.68	35.81	125.25	
	Oahu 1	50.46	24.28	36.51	111.25	
	Oahu 2	102.47	67.76	68.08	238.31	
	Molokai	65.17	19.60	27.45	112.22	
	Maui	24.87	9.43	22.42	56.72	
	Lanai	12.35	2.53	4.10	18.98	
	Hawaii	47.76	15.72	0.00	63.48	
	Total Mapped in Production	**415.54**	**171.04**	**204.25**		**790.83**
Total Area Mapped During Contract						**1110.85**

Products Generated During this Work

Ground Control Points	350
Accuracy Assessment Points	1225
Ground Validation Points	553
Test Area Maps with Metadata	12
Production Maps with Metadata	8
Reports	
Monthly Reports	9
IKONOS Interpretive Rules	1
Accuracy Assessment Report	1
Project Completion Report	1