Improving Monitoring and Management of the Saipan Lagoon through the Integration of Ground Surveys with Detailed Habitat Mapping

Final Project Report

September 2006

Peter Houk [1,2,3] and Dr. Rob Van Woesik [3], Co-PI's

[1] Pacific Marine Resources Institute, Inc.
P.O. Box 10003, PMB 1156
Saipan, MP. 96950

[2] CNMI Division of Environmental Quality
P.O. Box 501304
Saipan, MP. 96950

[3] Department of Biological Sciences
Florida Institute of Technology
150 West University Blvd
Melbourne, Florida. USA
32901-6988

Pacific Marine Resources Institute, Inc. in Cooperation with the CNMI Division of Environmental Quality and Florida Institute of Technology

Project Summary:

The Saipan Lagoon comprises an ecological resource beneficial to the economy and livelihood of the Commonwealth of the Northern Mariana Islands (CNMI) and its residents. Here we have used a novel habitat mapping approach to examine this ecological system at a larger spatial scale, not available before. We show that our approach successfully demarcated 16 ecologically unique habitats with a 77% accuracy. Habitat mapping involved the following steps: 1) *a priori* identification of 'habitats' in the Saipan lagoon using Moving Window Analysis (MWA); 2) testing identifications with two, independent datasets, 3) digitizing habitats by spatially integrating statistically similar habitats into a Geographic Information System (GIS), and 4) assessing the accuracy of product map by ground truthing 348 validation points. These results represent a 35% improvement in classification accuracy when compared with a traditional supervised classification procedure, representative of resources that are available to monitoring programs. Multiple regressions found that preeminent controls to *Enhalus* habitat development are adjacent watershed size and lagoon width, while *Halodule* habitat development is limited by surface current velocities but grows with watershed development. Notably, the two seagrass habitats have differing controls of growth, and should not be grouped together when making general statements regarding the impacts of pollution on these systems. Increases in watershed development had a positive relationship with *Halodule* habitat size but a negative relationship with a (*Halodule* / macroalgae) ratio, suggesting *Halodule* actually decreases in response to pollution despite the proliferation of the seagrass/macroalgae habitat. Habitats were also digitized from a 1959 map and compared with contemporary MWA classifications of IKONOS satellite images. The most notable changes since 1959 include considerable reductions in seagrass, staghorn *Acropora*, and *Acropora palifera* (*Isopora)* and *Porites* habitats (-3.72 km^2, -1.26 km^2, and -1.37 km^2 respectively). These vacancies have been replaced by sand, which increased by 6.16 km^2. This project advances habitat mapping by increasing habitat resolution and accuracy, which in turn improves the texture at which reef ecology is used by management.

Project Results:

All milestones (Table 1) have been completed in accordance with our project timeline. Our final manuscript, GIS layers, and website have been submitted along with this document.

The Moving Window Analysis (MWA) successfully detected habitat transitions along the 8 transect lines extending from the shoreline to the barrier reef (Figure 1 and 2). Habitat characterizations were tested using multivariate benthic data assemblages collected along each MWA line. Significant findings revealed ecologically relevant habitats found within throughout the Saipan Lagoon. Pair-wise comparisons based upon benthic and diversity data provide confidence measures for the MWA characterized habitat classes. All MWA defined transitions were incorporated into a GIS layer that was projected over an IKONOS satellite image for digitization (Figure 3). An accuracy assessment protocol, which used 348 ground validation points stratified by habitat-size showed an overall accuracy of 77%.

Supervised classification for regions I, II, III, IV and V, accurately distinguished between 8, 11, 8, 11, and 9 habitat classes, respectively, for a total of 14 unique classes (Figure 4). All classifications had high internal accuracies (Kappa = .92, .95, .85, .91, and .93 respectively). The 302 ground validation points that were stratified by habitat-size, but were *not* MWA derived, showed a low overall accuracy of 41%.

Cloud (1959) identified and mapped 9 "biotypes" (or major habitat types) in the Saipan lagoon in 1959 (Figure 5). In order to evaluate change over time, and compare the present study with Cloud's, it was necessary to combine several habitat classes. The most notable changes since 1959 include considerable reductions in seagrass, staghorn *Acropora*, and *Acropora palifera* (*Isopora)* and *Porites* habitats (-3.72 km^2, -1.26 km^2, and -1.37 km^2 respectively) (Table 2). These vacancies have been replaced by sand, which increased by 6.16 km^2.

Multiple regressions were employed to search for causal relations between environmental variables and habitat sizes. Watershed size explained 91% of the variance in the size of *Enhalus* beds (habitat 12 and 16, $\beta = .16$, $R^2 = 0.91$, $p<.001$, Table 3). Including additional variables in the stepwise process did not substantially enhance the amount of variance explained. Surface current velocity explained the largest amount of variance in the size of habitat 14 (*Halodule* and macroaglae) ($\beta = -.15$, $R^2 = .63$, $p<.001$), however, including watershed development in the stepwise regression provided the best fit ($\beta = .06$, $R^2 = .74$, $p<.001$). A three variable model best described the *Halodule*/macroalgae ratio, with negative relationships between watershed development and current velocity, and a positive response to watershed size.

Project Discussion:

This study represents a novel, *a priori* approach for the ecological characterizations of habitats with confidence measures. Ecologically derived maps are desirable because few habitats are defined by single species that have strong spectral signals favorable to their detection with remote sensing.. MWA based maps create an opportunity to define influential environmental variables, or gradients, that can explain habitat occurrences in the Saipan lagoon.

The multiple regression models facilitate a predictive knowledge base. Predictive habitat models are desirable tools for permitting agencies and managers to consider cost/benefit analyses upon which they can base sound, ecologically-based decisions. Currently, the generated maps are being used to: 1) base a long-term lagoon monitoring program from, 2) generate a scientifically-desirable MPA network design, and 3) generate quantitative relationships to infer processes responsible for ecological change over time. Additionally, their continued attention will provide much needed insight into causative relationships in ecology, specifically between abiotic factors and biological measures that are relevant to niche quantification. Finally, their publication will expand the use of this novel habitat mapping approach, and forward our ecological understanding of how natural and human disturbances interact to cause ecological change.

Project Timeline (Months Following Funding Award)	**Milestone**	**Expected Product**
0 - 2	Purchase equipment, supplies, and set up accounts	Equipment, supplies, and accounts available for project
2 - 3	Conduct MWA transects	Initial habitat delineations, GPS coordinates for benthic and diversity data
3 - 5	Conduct benthic video and diversity surveys	Baseline datasets in each habitat, initiation of long-term monitoring
5 - 7	Data analyses and incorporation into GIS layers	Database establishment, GIS layers
7 - 8	Digitize all habitat maps, create comparision tables and figures	GIS maps with metadata tables
7 - 8	Create supervised classification of lagoon	GIS maps with metadata tables
8 - 10	Ground validation of maps	~600 ground truthed points throughout the lagoon
10 - 12	Create web site, final report, submit work to peer reviewed journal	Web site, technical report, submission to journal

Table 1. Milestone chart.

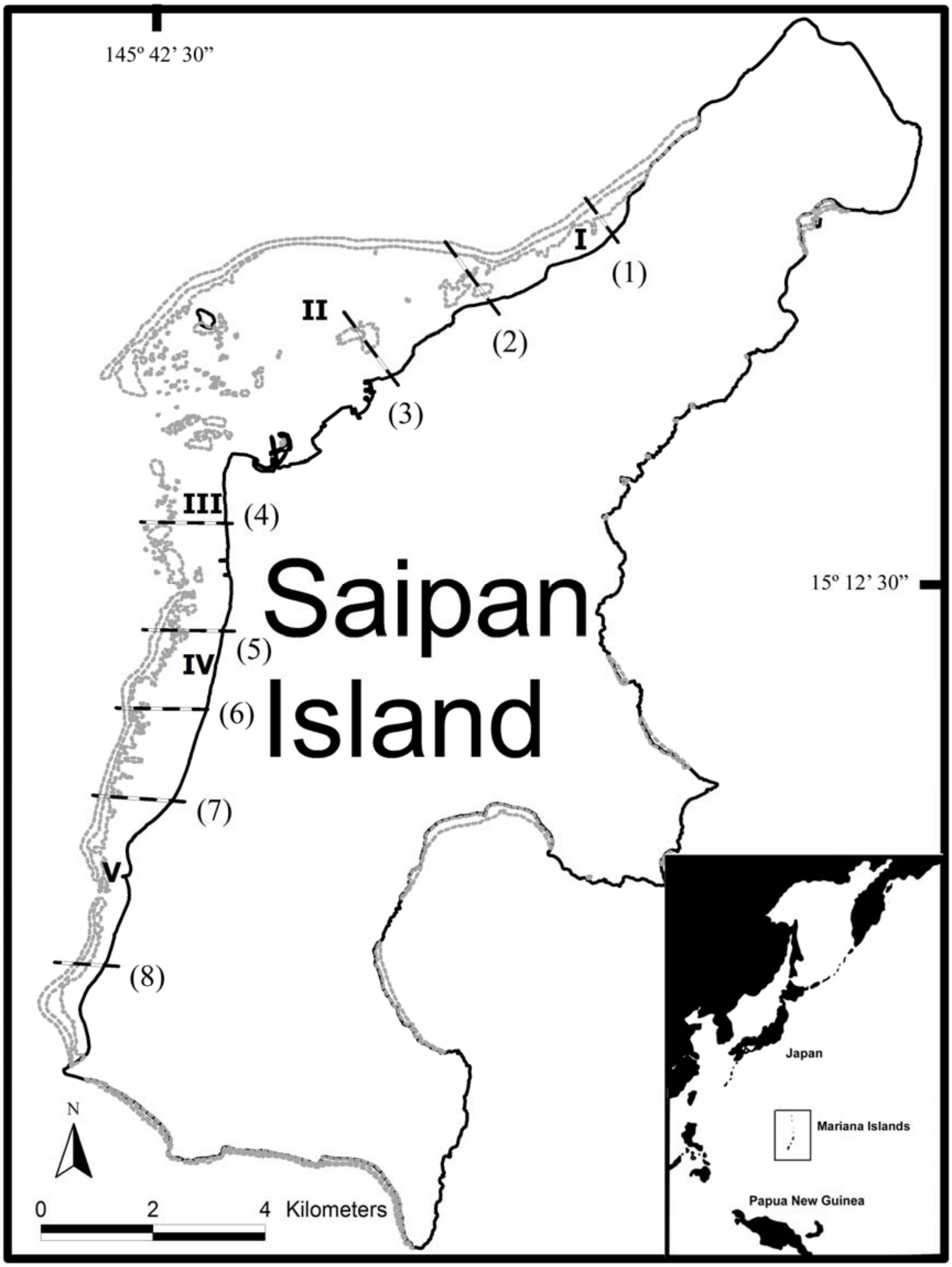
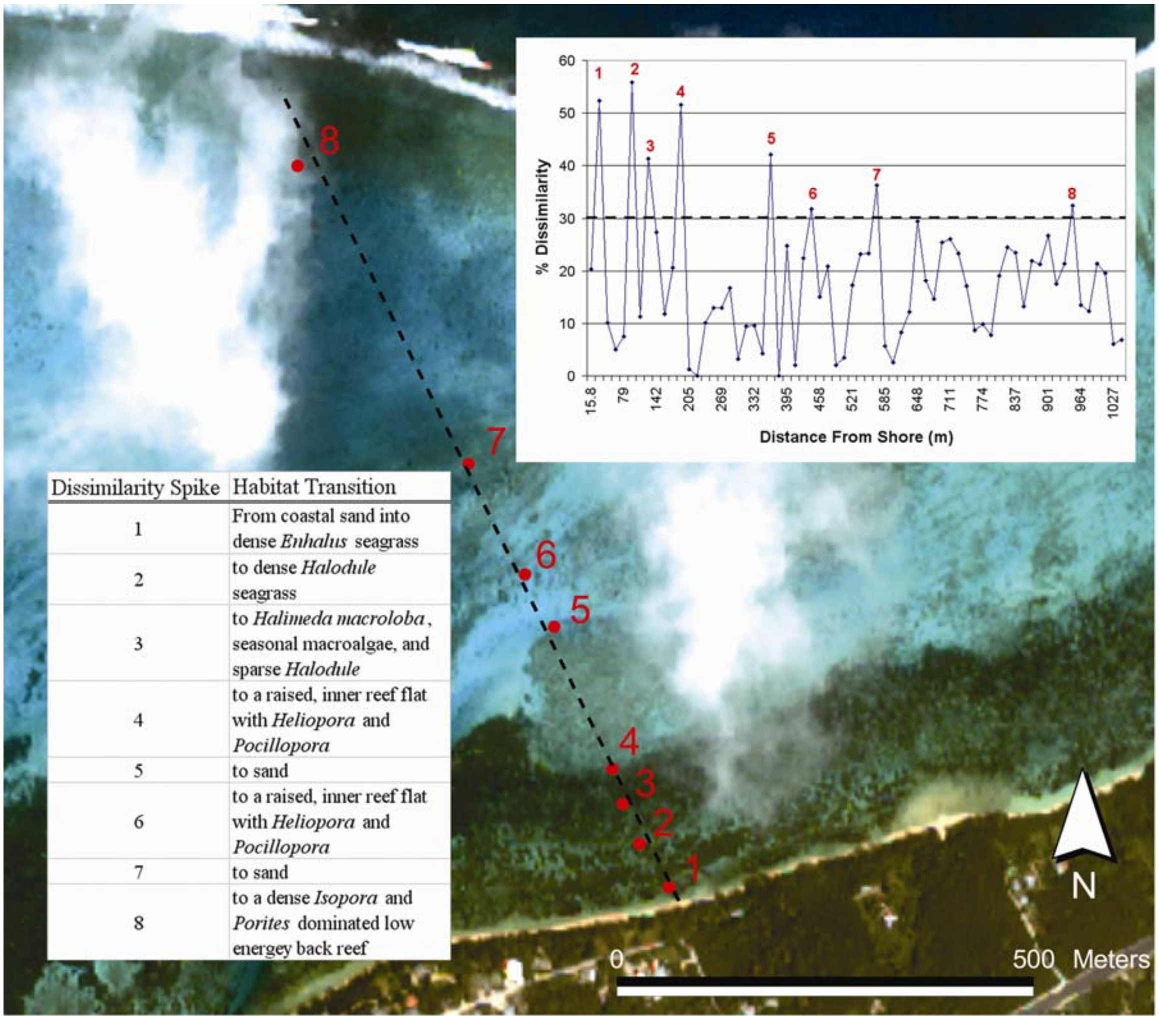


Figure 1. A map showing the location of the Mariana Islands (inset) and the Saipan lagoon. Eight Moving Window Analyses (MWA) lines were established throughout the lagoon (1-8). Ikonos imagery was spliced to create five regions in which remotely sensed, supervised classifications are being carried out (I-V).



Dissimilarity Spike	Habitat Transition
1	From coastal sand into dense *Enhalus* seagrass
2	to dense *Halodule* seagrass
3	to *Halimeda macroloba*, seasonal macroalgae, and sparse *Halodule*
4	to a raised, inner reef flat with *Heliopora* and *Pocillopora*
5	to sand
6	to a raised, inner reef flat with *Heliopora* and *Pocillopora*
7	to sand
8	to a dense *Isopora* and *Porites* dominated low energey back reef

Figure 2. An example of the results attained by MWA analyses, line # 2. Habitat transitions were identified by high dissimilarity (spikes on graph) between adjacent analyses windows. Transitions were mapped using a GIS and surveyed for benthic and diversity data as described in our proposal.

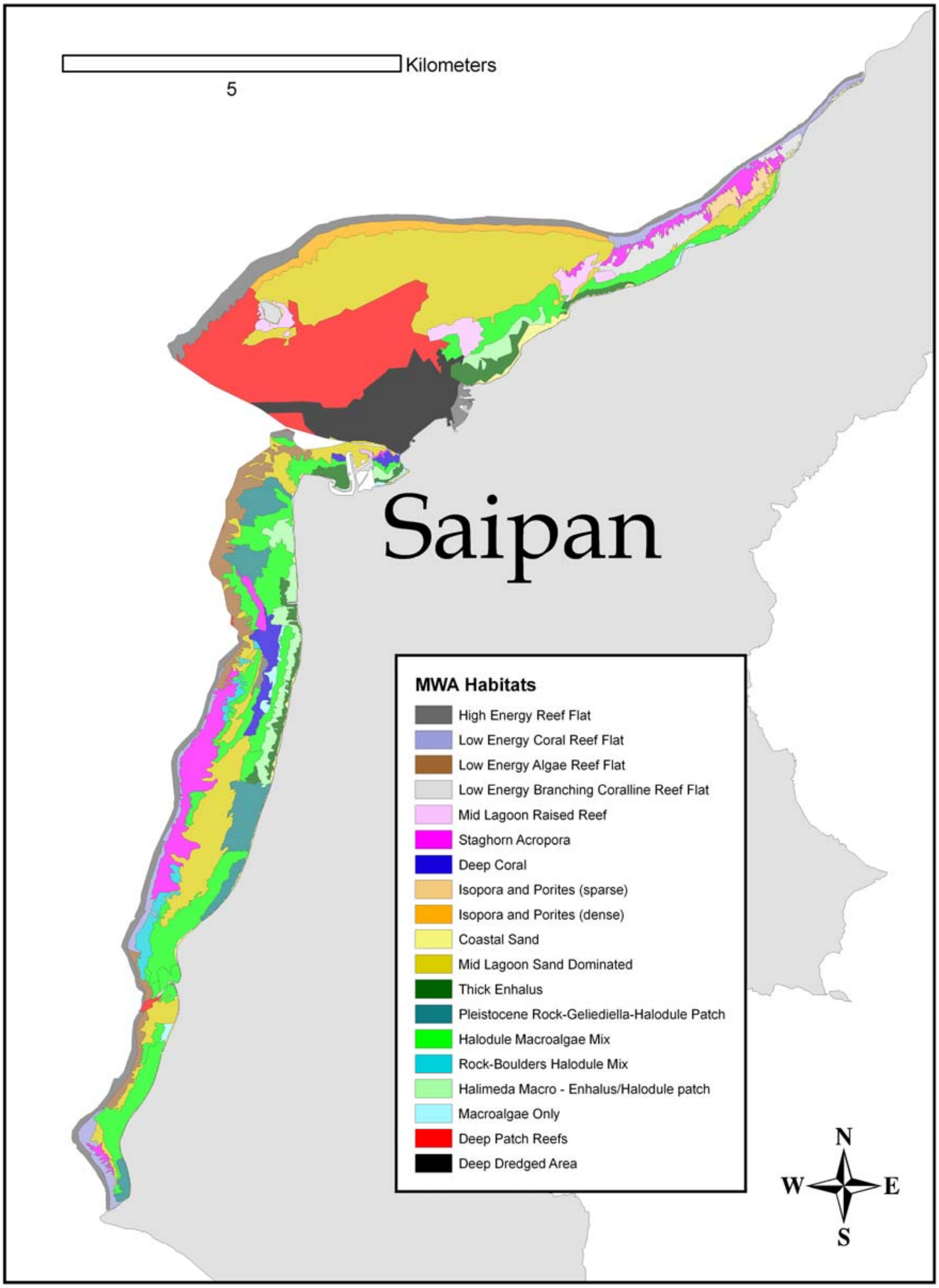


Figure 3. Habitat map resultant from MWA process.

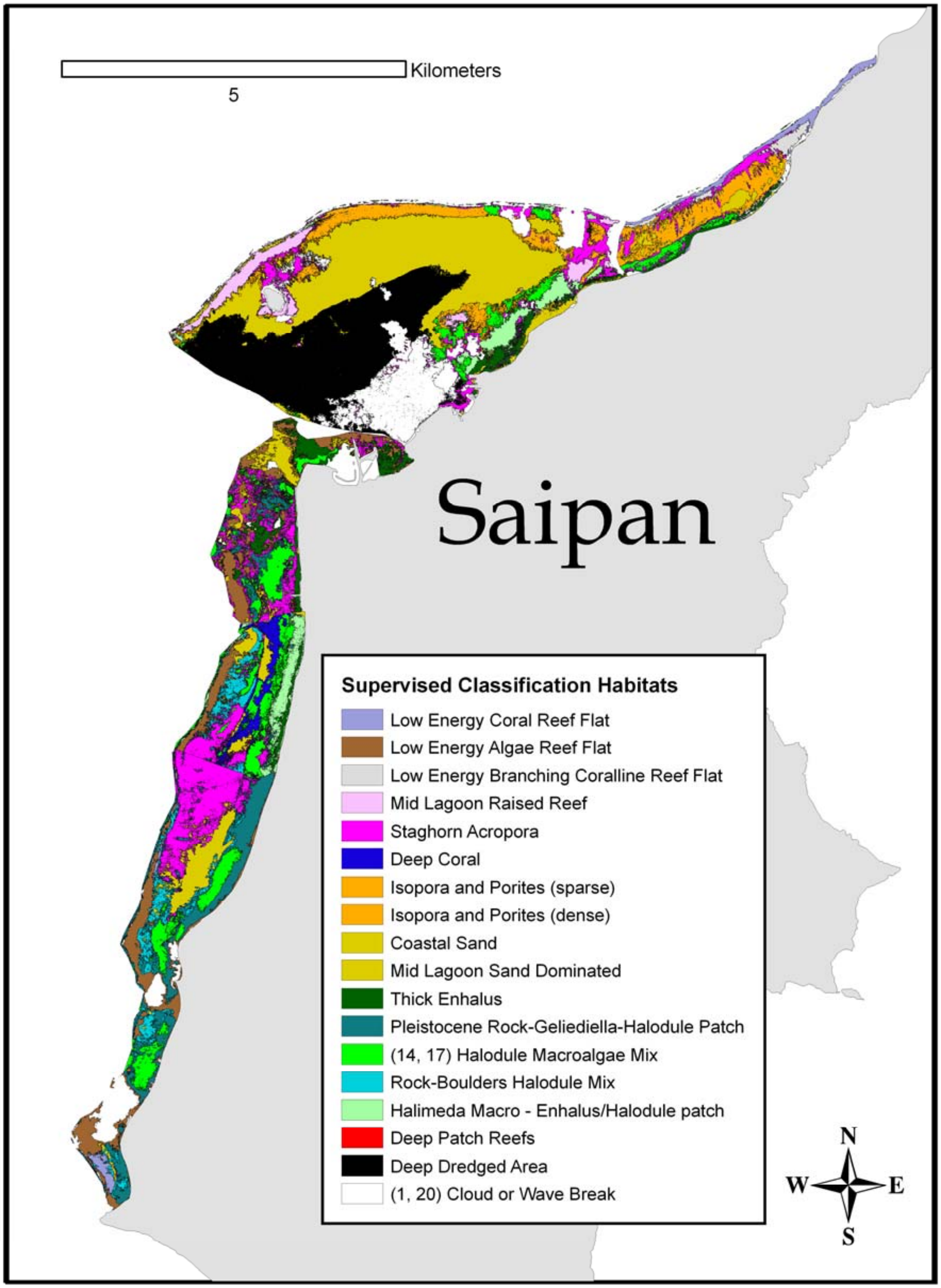


Figure 4. Habitat map resultant from supervised classification process.

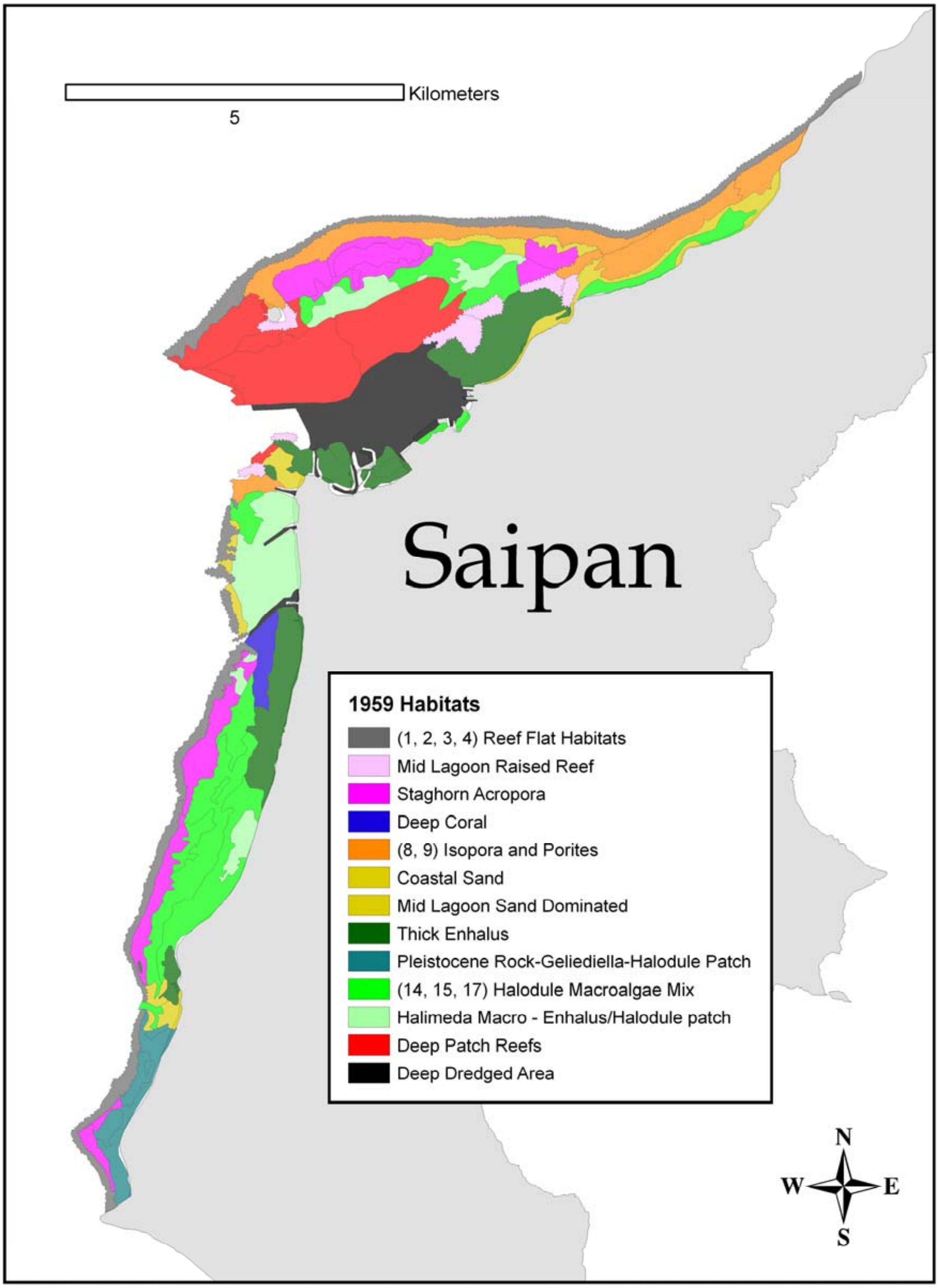


Figure 5. Habitat map digitized from Cloud (1959).

Habitat Number	Habitat Description	Total Area in 2004 MWA Delineated (km2)	Total Area in 1959 Historical Map (km2)	Change In Area (2004 - 1959) (km2)
1	Outer reef flat, high energy zone, exposed to waves	2.18	N/A	N/A
2	Outer reef flat, lower energy, dominated by live coral growth	0.76	2.84	-0.93
3	Outer reef flat, lower energy, dominated by macroalgae (mainly *Geliediella acerosa*) growth	1.06		
4	Outer reef flat, lower energy, dominated by branching coralline growth	0.09		
5	Mid-lagoon raised reefs covered with sparse growth of *Heliopora coerulea* and *Pocillopra damicornis,* coralline, and turf algae	0.59	0.80	-0.21
6	Staghorn *Acropora aspera* and *A. formosa* dominate (mixture of live and dead coral due to 2001 bleaching event)	1.47	2.73	-1.26
7	Mid-depth (2-3m) massive *Porites* and macroalgae zone	0.38	0.36	0.02
8	Sparse *Acropora palifera* and *Porites lutea* providing structure for other corals and reef organisms (sand and raised carbonate rock are the dominant benthos)	0.65	2.74	-1.37
9	Similar to habitat #8 except dense growth of *Acropora palifera* and *Porites lutea*	0.72		
10	Coastal sand adjacent to shore	0.42	0.30	0.12
11	Sand dominated, little seagrass, macroalgae, and coral	7.37	1.21	6.16
12	Thick *Enhalus acoroides* beds with little sand (varying amounts of seasonal macroalgae within seagrass)	0.76	10.92	-3.72
13	Pleistocene rock and macroalgae (mainly *Gelidiella acerosa*) growth mixed with sparse patches of sand and *Halodule* growth	1.19		
14	Thick *Halodule uninervis* beds, varying amounts of seasonal macroalgae	3.88		
15	Outer lagoon sparse *Halodule uninervis* beds, reef boulders with limited coral growth, limited macroalgae growth	0.33		
16	Sand and *Halimeda macroloba* dominated, sparse *Halodule uninervis* and/or *Enhalus acoroides* patches, varying amounts of seasonal macroalgae	0.94		
17	Macroalgae dominated zone, with or without sand, little to no seagrass	0.10		
18	Deep patch reefs and sand associated with a channel	4.20	4.23	-0.03
19	Deep dredged harbor, fine sand bottom	1.95	2.66	-0.71
20	Cloud or wave break	2.01	N/A	N/A
	Total (km^2)	*31.05*	*28.79*	

Table 2. Description of ecological change over time in the Saipan Lagoon.

	Watershed Size			Watershed Development			Surface Current Velocity			Lagoon Width		
	Step #	Beta (SE)	R^2 (P-Value)	Step #	Beta (SE)	R^2 (P-Value)	Step #	Beta (SE)	R^2 (P-Value)	Step #	Beta (SE)	R^2 (P-Value)
Enhalus (n=7)	1	.16 (.03)	***.91 (<.001***)***		----			----		2	.05 (.03)	***.96 (.001**)***
Halodule (n=14)		----		2	.06 (.03)	***.74 (<.001***)***	1	-.15 (.03)	***.63 (<.001***)***		----	
Seagrass Total (n=14)		----		2	.15 (.03)	***.82 (<.001***)***	1	-.19 (.05)	***.51 (.004**)***		----	
Halodule / Macroalgae Ratio (n=10)	3	.35 (.23)	***.8 (.016*)***	1	-.36 (.16)	***.43 (.039*)***	2	-.38 (.19)	***.69 (.017*)***		----	

Table 3. Results from stepwise, multiple regressions between environmental variables (horizontal axis) and dependent variables (vertical axis). Each significant step is presented in bold, while the grey box highlights the best fit regression. A "----" indicates that either the standard error of β was much greater than the mean, or that no substantial improvement to the model (e.g. R^2 value) resulted from the inclusion of additional variables.