

A Review of Issues Pertaining to the Integration of Florida Reef Tract Benthic Maps

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Prepared by Renee Duffey and René Baumstark

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Abstract

The Unified Reef Map project seeks to integrate different benthic mapping efforts into a single continuous and seamless map. The data integration effort introduced the need to resolve discrepancies between maps in overlap areas and seams where maps meet. This work focused on integration issues in two areas within Biscayne National Park (BNP) where the National Park Service (NPS) mapping efforts overlap the mapping extents of both National Oceanic and Atmospheric Administration (NOAA) and the National Coral Reef Institute at Nova Southeastern University (NCRI). FWRI conducted ground truth surveys in 2014 to investigate areas where discrepancies between maps frequently occurred. In addition to comparison with ground truth data, discrepancies were evaluated by quantitatively comparing overlapping maps. Results of the map comparison analysis and ground truth observations revealed three primary factors which contributed to discrepancies and comparability between maps; 1) resolution of source imagery, 2) scale and minimum mapping unit (MMU), and 3) confusion between similar habitat types. As expected, there was higher disagreement between the NPS map and the NOAA map which delineated features using coarser Ikonos imagery. In general, higher resolution imagery enabled more detailed discrimination between habitats in the NPS and NCRI maps compared to NOAA. Discrepancies tended to be class specific, with frequent confusion between seagrass and pavement and also between certain hard bottom classes including pavement, aggregate reef, scattered coral rock and different types of patch reef habitat. Consistency in benthic mapping efforts would best be improved by adhering to an agreed upon methodology including consistent MMU, mapping scale and also consistent interpretation of classification schema between map sources.

1.0 Introduction

The Florida Reef Tract (FRT) covers an expansive area, spanning numerous managed areas and crossing the boundaries of several local, state, and federal jurisdictions. Habitat mapping and monitoring efforts support the information needs of resource management. Mapping and monitoring of the FRT is currently conducted by several entities resulting in an array of datasets. Funded by the Coastal Zone Management Section 309 Program, the *Coordinated Coral and Hardbottom Ecosystem Mapping, Monitoring and Management* project seeks to address the need for a single coordinated perspective on the mapping and monitoring of the FRT. This report will focus on the mapping components of said project, the Unified Reef Map.

When mapping natural systems, map classification schemes are developed to accommodate project objectives, the nature of the ecological landscape, data availability, and mapping method limitations. Mapping methods become disparate out of mapping necessity and project needs. Primary differences in mapping methods include: mapping scale, minimum mapping unit (MMU), and classification scheme. Table 1 summarizes scale differences between mapping methods throughout the FRT. Differences in map scale are partially the result of differences in the quality and availability of source imagery and ancillary data such as high resolution bathymetric data used for photo-interpretation.

The Unified Reef Map integrates various mapping efforts into a single, continuous habitat map for the Florida Reef Tract (Baumstark 2014). As part of the data integration process, spatial and thematic discrepancies caused by mapping method differences were found. Discrepancies include differences in line-work delineating benthic types and benthic classification differences. The discrepancies were found along seams between adjoining maps from different sources and in areas where there is overlap between either adjacent or historic maps. An example of these discrepancies is in Biscayne National Park where the National Park Service (NPS) mapping efforts overlap the mapping extents of both National Oceanic and Atmospheric Administration (NOAA) and the National Coral Reef Institute at Nova Southeastern University (NCRI). These areas where there is overlap between map sources provide a unique opportunity for investigating how differences in mapping methods cause discrepancies between maps and ultimately influence the region-wide Unified Reef Map.

The primary objectives of this report are to 1) summarize spatial and thematic discrepancies between mapping methods in areas where map data overlap; 2) provide insight as to why discrepancies exist; and 3) evaluate how these discrepancies may affect the region-wide Unified Reef Map product. The intention of this effort was not to assess map accuracy or evaluate which data source or mapping methodology performed best. Rather, this report aims at describing how and to what extent the Unified Reef Map is affected by differences in mapping data source and methods including varying imagery data sources, mapping scales, and classification schemes. This evaluation will also recommend actions and standards to improve comparability and compatibility of future mapping efforts.

Table 1. Mapping scale and MMU for each of the map sources in the Biscayne National Park.

Source	Source Imagery	Scale and MMU
NOAA	Ikonos (2006, 4m)	Map scale = 1:6,000 MMU = 0.4ha (4046m ²) and 625m ² for patch reefs
NPS	LiDAR (2008, 3m) & DOQ (2005, 30cm)	MMU = 0.5ha (5000m ²) and all discernible patch reefs were identified
NCRI	LiDAR (2002, 4m) & DOQ (2005, 30cm)	Map scale = 1:6,000 MMU = 1 acre (4046m ²)

Metadata for each of the following datasets are available via FWRI's Unified Reef Map database (FWRI, 2014).

2.0 Data and Methods

Analysis presented here will focus on comparison of NPS, NOAA, and NCRI maps in Biscayne National Park. The NPS map is overlapped by the NOAA map in the south and by the NCRI map in the north extent of the NPS boundary. Figure 1 shows the NOAA/NPS and NCRI/NPS overlapping areas used for the comparison analysis in this report. The NOAA/NPS overlap consisted of almost 10,000 ha, approximately 15% of the total NPS map area. The NCRI/NPS map overlap was smaller, with a little over 5064 ha (7.6%) of the NPS map overlapped by the NCRI map.

The Comparison analysis included a summary of differences in mapping methods, a visual assessment of differences between maps and a detailed quantitative map comparison analysis. The map comparison analysis was conducted to assess the extent of discrepancies between maps and determine where discrepancies occurred most often. Results of ground truth verification and map comparison analysis were organized based on the six major habitat type discrepancies that were encountered. The final portion of this report includes a detailed discussion of the implications of these discrepancies with recommendations for improving consistency in benthic mapping efforts.

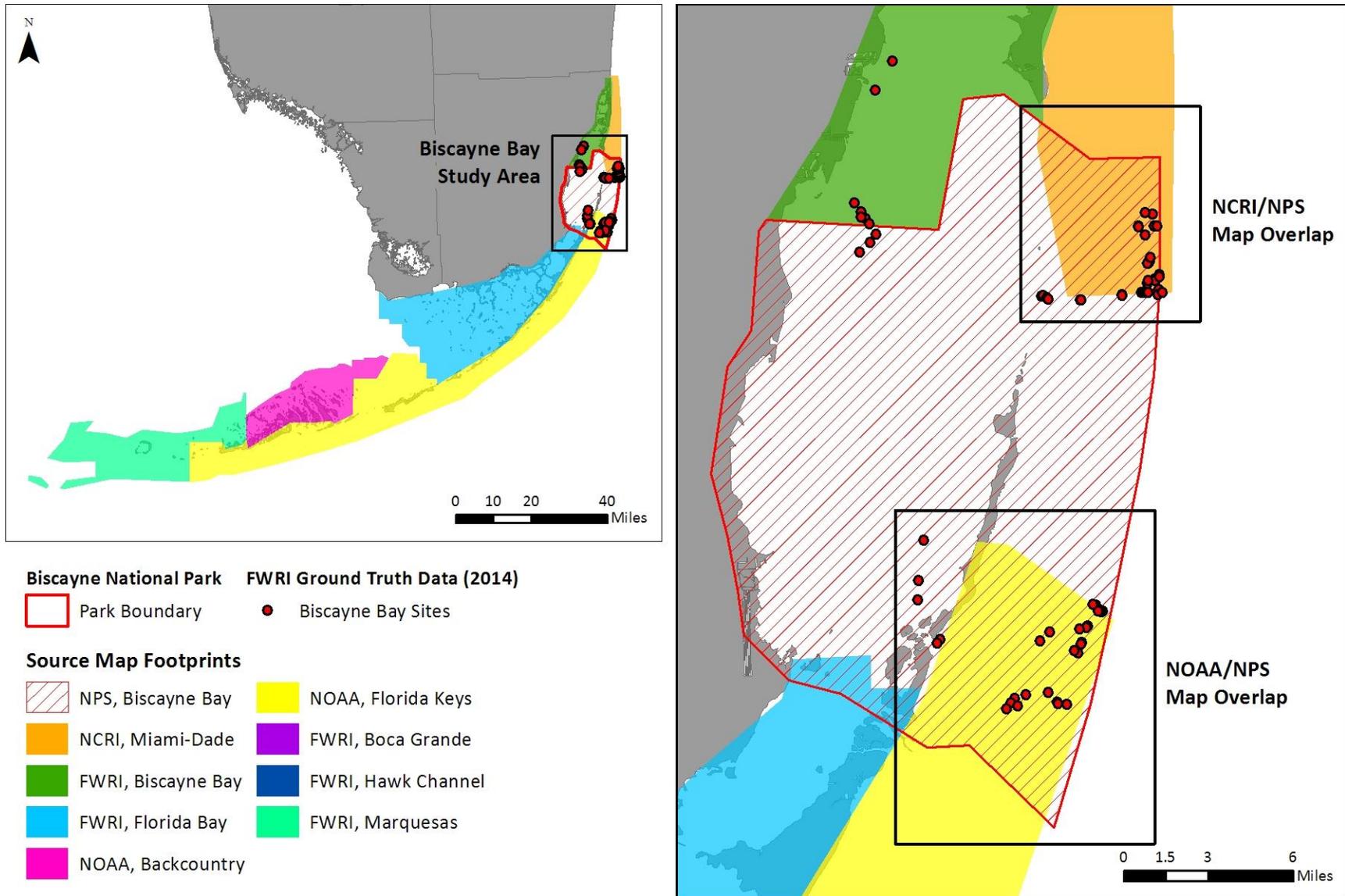


Figure 1. Overview of map source footprints in the Florida Keys with focus on FWRI 2014 ground truth sites the two map comparison areas in Biscayne National Park.

2.1 2014 FWRI Field Sampling

The Florida Fish and Wildlife Research Institute (FWRI) conducted a preliminary assessment of overlapping maps that identified several areas in Biscayne National Park where there were discrepancies between mapped habitat boundaries and types. Upon evaluating the frequency and pattern of these discrepancies, priority locations were identified for collecting additional ground truth data with the intention to resolve map discrepancies. Within these priority areas, 76 sites were visited by FWRI in Biscayne National Park (Figure 1).

Ground truth data were collected at each site via underwater photos and video acquired using a 12 megapixel GoPro Hero3 camera with an underwater housing (Woodman Labs, Inc., San Mateo, CA, USA). Fixed frame photos were collected at 5 second intervals from the GoPro camera mounted to a weighted PVC frame and lowered to the seafloor. Photos collected during ascent and descent provided an overview of the bottom type. While at the bottom of the seafloor, the PVC frame provided a photo approximately 0.5 meters from the substrate. Video transect sampling was conducted at shallower sites with higher visibility using the GoPro camera mounted to the end of a 5ft boom. The video boom was lowered into the water and allowed to scan the habitat type as close to the bottom as possible to identify more detailed seafloor bottom characteristics. The length of each transect varied based on the size of the targeted bottom type, visual observations at the site, and also the type of discrepancy being evaluated. The duration of video transects was between one to three minutes and covered an average ground distance of 50-60 meters. Total observer area varied between sites based on depth and visibility conditions but typically ranged from 250 to 600 m². Fixed frame photos were taken at offshore, deeper sites in which low visibility prohibited video sampling. Visual observations at sites where the bottom type coverage could be determined from the boat were noted to help discriminate between discontinuous and continuous habitat classes. Visual observations also indicated whether photos and video transect information were representative of the larger area. Field photography and videos were interpreted and classified based on the Unified Reef Map scheme.

2.2 Map Comparison Analysis

Original classification nomenclature used by NPS, NOAA, and NCRI differed. Application of the Unified Reef Map Class Levels allowed for direct comparison of map classes between different schema. A map comparison analysis was conducted in the overlapping map areas of Biscayne National Park to evaluate thematic differences between the NPS map and the NOAA and NCRI maps (Figure 1). Input datasets for the map comparison analysis were generated by converting the intersecting vector map coverages into 1 meter raster grids.

The Map Comparison Kit (Research Institute for Knowledge Systems, Maastricht, The Netherlands) software package was used to generate a comparison matrix for the NOAA/NPS overlap and also for the NCRI/NPS overlap. Maps were clipped to include only the overlapping area. Comparisons were made by converting maps to raster format and conducting a cell by cell comparison using the Map Comparison Kit. The Kappa statistic was calculated from each comparison matrix to provide a quantitative estimate

of the degree of agreement ($Kappa = 1$) or disagreement ($Kappa = 0$) between overlapping maps (Visser 2004). Kappa statistics were calculated for ten habitat classes within the areas where maps overlapped: unconsolidated sediment, discontinuous seagrass, continuous seagrass, spur and groove, scattered coral/rock in consolidated sediment, reef rubble, pavement, aggregate reef, and two subclasses of patch reefs, individual and aggregated. Kappa statistics were also calculated at a coarser thematic scale for all hard bottom classes, both seagrass classes, and also unconsolidated sediment.

A separate analysis of patch reef habitats was performed using ArcGIS software to compare the number and size of patch reefs in the NOAA/NPS and NCRI/NPS overlapping areas. The goal of this analysis was to explore how differences in digitizing scale influence patch reef mapping. To achieve this, individual patch reefs were intersected to estimate the extent of agreement between overlapping maps. Agreement was concluded when the centerpoint of an individual patch reef intersected an individual patch reef in the overlying map. For example, an NPS patch reef was considered correctly identified by NOAA if the centerpoint was located within an individual patch reef area identified in the NOAA map.

3.0 Results

3.1 Summary of Source Map Differences

Mapping methods including classification scheme, mapping scale and MMU varied between each of the three map sources compared (Table 1). The NOAA map was based on 2006 4-meter IKONOS imagery. NOAA mapped using a MMU of 0.4ha combined with a smaller MMU of 625 m² for patch reefs. NPS and NCRI mapped features using MMUs of 1-acre and interpreted features from the same 30cm 2005 aerial imagery and ancillary LiDAR data. While NPS cites a 1-acre MMU in their most recent 2013 update, visual assessment of the map indicates a smaller MMU and digitizing scale. Similarly, NCRI appears to map at a finer scale which is more consistent with the higher resolution 30cm imagery used for photo-interpretation. A single MMU was not reported for NPS and NCRI maps, rather any patch reef that was discernible from imagery was mapped.

In addition to differences in mapping scale, the classification schemes varied between NPS, NOAA, and NCRI. The NPS mapped 14 benthic cover classes using a modified version of the SCHEME classification system developed by Madley et al. (2002). The NOAA map was classified into 13 classes based on the classification scheme outlined by Zitello et al. (2009). NCRI used a modified classification scheme based on Zitello et al. (2009) which replaced aggregate reef with three linear reef classes, include additional seagrass categories, depth components, and the grouping of Reef Rubble into the Colonized Pavement class. While these schemes vary hierarchically in the organization of major classes and subclasses, descriptions of each habitat class are very similar and can be translated without much loss of information at a general level. To enable comparisons between classification schemes, each of the three map sources were attributed with the Unified Classification (UC) system used in the Unified Reef Map. The flexibility of the Unified Class system enables consistency between varying classification schemes while retaining the original detailed information specific to different source maps. The UC system classifies habitats based on level of detail starting with Class 0 representing the coarsest level of detail to Class 4 which is the highest level of detail provided by the source map. For this report, eight UC Level 1

habitat classes were compared as well as the two subclasses of patch reef; individual and aggregated. Pavement with sand channels was merged with the pavement class because it occurred infrequently throughout the Biscayne Bay study area.

3.2 Overview of the Map Comparison Analysis Results

Kappa statistics and comparison matrices were generated for the NOAA/NPS overlap and NCRI/NPS overlap. Habitat-specific discrepancies including map examples and field observation photos are discussed in detail in the Appendix. For both the NOAA and NCRI comparisons, similarity between maps was generally higher when comparing the three generalized Unified Classes (UC, Level 0) than the more detailed subclasses (UC Level 1). In the NOAA/NPS comparison, there was only 65.6% agreement in UC Level 1 cover types between maps. Compared to NOAA, NPS mapped considerably more seagrass in the areas where the maps overlapped. Conversely, NOAA mapped more hard bottom and unconsolidated sediment compared to NPS. Agreement was higher for the NCRI/NPS comparison, with almost 80% agreement in UC Level 1 cover types between maps. Unlike the NOAA comparison, the total area of seagrass, hard bottom, and sediment were similar between the NCRI and NPS maps.

Disagreement between both overlapping map comparisons varied between habitat classes. For both the NOAA and NCRI comparisons, agreement with the NPS map was generally lower for subclasses of hard bottom with frequent confusion between pavement and aggregate or patch reef habitat (Table 3 and 4).

Individual and aggregated patch reefs were also mapped inconsistently between map sources (Table 3-4). It was expected the total number of patch reefs and average patch reef size would vary between maps generated from different MMUs such that a larger MMU would correspond with fewer, albeit, larger patch reefs. While patch reefs were generally smaller in the NPS map, the total number of patch reefs was very similar between the NPS and NOAA maps which was unexpected given NOAA's much larger MMU. Conversely, patch reef agreement was expected to be much higher in the NCRI/NPS comparison due to similar mapping scales and source imagery. However, NCRI mapped considerably more individual patch reefs compared to NPS in the areas where the maps overlapped.

While not contributing significantly to the overall disagreement between maps, identification of less common hard bottom classes including scattered coral rock, spur and groove, and reef rubble also varied between map sources (Table 3-4). Scattered coral rock was only mapped by NPS, and was not identified at all by either NOAA or NCRI within the areas where there was overlap with the NPS map. Scattered coral rock in the NPS map was most often classified by either NOAA or NCRI as sediment or aggregated patch reef. For spur and groove habitat, there was less than 1% agreement in both the NOAA/NPS and NCRI/NPS comparisons. Spur and groove was most often confused with pavement or aggregate reef. Reef rubble was identified more frequently by NOAA compared to the NPS map which typically identified those areas as pavement. Reef rubble was not identified at all by NCRI in area overlapping the NPS map.

Table 2. Kappa values for comparison between NPS and NOAA maps.

Class Level	Class Type	Kappa Statistic	
		NOAA/NPS Comparison	NCRI/NPS Comparison
Level 0	Hard Bottom	0.59	0.84
	Seagrass	0.53	0.85
	Unconsolidated Sediment	0.47	0.84
	Kappa, all classes (Level 0)	0.54	0.85
Level 1	Aggregate Reef	0.41	0.67
	Aggregated Patch Reef	0.21	0.00
	Individual Patch Reef	0.47	0.26
	Pavement	0.40	0.38
	Reef Rubble	0.02	NA*
	Scattered Coral Rock	NA*	NA*
	Seagrass (Continuous)	0.48	0.79
	Seagrass (Discontinuous)	0.21	0.65
	Spur and Groove	<0.00	<0.00
	Unconsolidated Sediment	0.47	0.84
Kappa, all classes (Level 1)	0.40	0.72	

*Class was not mapped in at least one of the overlapping maps

Table 3. Results of the Map Comparison Analysis between the NOAA and NPS overlapping maps.

Map 1 \ Map 2		Map 1: NPS (ha)										NOAA Total Area (ha)	NOAA Agreement (%)
		Aggregate Reef	Aggregated Patch Reef	Individual Patch Reef	Pavement	Reef Rubble	Scattered Coral Rock	Seagrass (Continuous)	Seagrass (Discontinuous)	Spur and Groove	Unconsolidated Sediment		
Map 2: NOAA (ha)	Aggregate Reef	106.0	35.8	19.5	53.5	1.6	0.7	29.4	7.2	3.3	1.6	258.6	41.0
	Aggregated Patch Reef	17.7	63.6	25.3	22.3	0.6	0.1	162.9	50.3	0.0	4.0	346.9	18.3
	Individual Patch Reef	5.5	45.1	113.6	7.2	0.2	0.1	109.4	3.6	0.0	2.0	286.6	39.6
	Pavement	82.0	40.2	11.5	422.2	2.4	1.5	629.4	30.1	13.1	15.0	1247.5	33.8
	Reef Rubble	5.6	0.0	0.0	26.4	0.6	0.0	1.8	1.1	0.0	1.7	37.1	1.6
	Scattered Coral Rock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Seagrass (Cont.)	4.1	14.6	12.2	3.0	0.0	0.2	5051.2	101.6	0.0	32.1	5219.0	96.8
	Seagrass (Discont.)	4.9	1.2	1.3	7.0	0.3	0.4	826.7	232.8	0.0	16.1	1090.8	21.3
	Spur and Groove	5.9	0.0	0.0	11.3	0.0	1.1	0.0	0.0	0.0	0.2	18.6	0.0
	Uncons. Sediment	6.5	1.6	1.5	63.0	4.2	7.5	616.9	208.1	0.1	530.2	1439.6	36.8
NPS Total Area (ha)		238.2	202.2	184.8	615.8	9.9	11.7	7431.8	634.7	16.6	603.1	Total Agreement = 65.6 %	
NPS Agreement (%)		44.5	31.5	61.4	68.6	5.8	0.0	68.0	36.7	0.0	87.9		

Table 4. Results of the Map Comparison Analysis between the NCRI and NPS overlapping maps.

Map 1 \ Map 2		Map 1: NPS (ha)										NCRI Total Area (ha)	NCRI Agreement (%)
		Aggregate Reef	Aggregated Patch Reef	Individual Patch Reef	Pavement	Reef Rubble	Scattered Coral Rock	Seagrass (Continuous)	Seagrass (Discontinuous)	Spur and Groove	Unconsolidated Sediment		
Map 2: NCRI (ha)	Aggregate Reef	155.7	0.0	0.6	104.2	1.8	8.2	0.0	0.4	3.6	6.4	281.1	55.4
	Aggregated Patch Reef	0.2	0.0	0.0	4.9	0.2	36.8	0.1	7.0	0.0	10.2	59.5	0.1
	Individual Patch Reef	0.4	3.1	3.5	4.6	0.0	0.8	2.8	3.7	0.0	1.3	20.3	17.2
	Pavement	12.7	0.0	1.4	72.6	2.9	6.8	42.4	9.7	0.0	5.6	154.3	47.1
	Reef Rubble	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Scattered Coral Rock	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Seagrass (Cont.)	0.0	0.0	0.2	0.0	0.0	0.1	1700.4	31.7	0.0	7.1	1739.6	97.7
	Seagrass (Discont.)	1.1	2.0	1.0	9.9	0.8	5.5	402.3	974.3	0.0	139.7	1536.7	63.4
	Spur and Groove	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Uncons. Sediment	2.6	0.2	0.1	7.4	0.3	19.9	24.2	80.2	0.0	1137.8	1272.7	89.4
NPS Total Area (ha)		172.7	5.5	6.9	203.7	6.1	78.2	2172.2	1107.2	3.6	1308.2	Total Agreement = 79.9%	
NPS Agreement (%)		90.1	0.9	50.5	35.6	0.0	0.0	78.3	88.0	0.0	87.0		

4.0 Discussion

The objective of this report was to illuminate how differences in the methods and source data between map sources throughout the Florida Reef Tract (FRT) influence the consistency and comparability between benthic mapping efforts. The overlap of the NPS map with neighboring NOAA and NCRI maps in Biscayne National Park provided a unique opportunity for quantitatively comparing differences between mapping methods. Mapping methods varied in scale, MMU, source imagery used for photointerpretation, and classification scheme.

The intention of this effort was not to assess the accuracy of the NPS, NCRI, or NOAA maps. In fact, each of the map providers have conducted extensive quality assurance measures to identify and address map accuracy. All maps met and exceeded the 85-95% accuracy standard recommended for the Florida Keys in the Southern Florida Shallow-water Coral Ecosystem Mapping Implementation Plan (Rohmann and Monaco 2005). In the Biscayne National Park study area, there was an extensive amount of ground truth information collected, particularly by NPS and NCRI.

Despite high accuracy and rigorous ground truth observations reported by each of the individual maps, there was low agreement in the areas where the maps overlapped. Agreement was generally lower in the NOAA/NPS comparison than the NCRI/NPS comparison. Disagreement tended to be class specific, including discrepancies between presence of seagrass and also frequent discrepancies between hard bottom classes, particularly for less frequent hard bottom classes.

Disagreement between maps is not an indication that one map is more accurate than the other. Rather, results of this study suggest that both maps are often correct according to their respective mapping methods. In the Biscayne National Park comparison, there were two primary sources of disagreement between maps; 1) differences in the spatial resolution of source imagery and availability of ancillary data which ultimately influence the scale and MMU at which features are mapped, and 2) thematic differences in how classification scheme and methods were applied. Also influencing the comparability of different maps is the photo-interpretation process itself, which is inherently subjective. The consistency of photo-interpretation results relies largely on the interpreter's experience and ability to integrate the elements of image interpretation (Drake 1996). The statistical exactness of photo-interpretation results is difficult to determine (Reinhold and Wolff 1970, Bie and Beckett 1973). Benthic cover typically transitions over gradual spatial gradients whereas standard map representations require discrete boundaries. For this work, it was assumed that photo-interpretation inconsistencies were consistent among mapping efforts.

4.1 Factor 1: Differences in Source Imagery

Differences in the spectral and spatial resolution of source imagery was a major contributor of discrepancies in the NOAA/NPS and NCRI/NPS comparisons. In both comparisons, the spatial resolution of source imagery was a better predictor of scale-dependent discrepancies than the mapping scale reported in the source metadata, as the mapping scale was roughly equivalent between the three map sources. In general, the spatial resolution of source imagery influenced the precision and detail of

boundaries (i.e. linework) between mapped features. Coarser resolution IKONOS imagery (4m) corresponded with less spatial detail overall in the NOAA map compared to the much more detailed NPS map derived from higher resolution aerial imagery (30cm, Figure 2). Differences in imagery resolution explain lower overall agreement in the NOAA/NPS comparison and the relatively higher agreement between NCRI and NPS which were generated from the same imagery and LiDAR data. Fine-scaled delineation in the NPS map enabled more precise discrimination of seagrass from hard bottom. This ultimately resulted in a greater area of mapped seagrass, smaller size of individual patch reefs and less area of hard bottom overall in the NPS map compared to the coarser NOAA map.

In addition to overall differences in the detail between overlapping maps, the resolution of source imagery also influenced classification between visually similar habitat types. Higher resolution imagery may have improved discrimination between certain hard bottom classes which share similar visual signatures and often lack visually distinct boundaries. The subtle or finer scale feature detail used to distinguish these classes is often unavailable in the lower resolution imagery which likely explains higher disagreement between hard bottom classes in the NOAA/NPS comparison. This occurred frequently for patch reefs, where NPS was able to discern smaller, aggregated patch reefs from higher resolution imagery within an area appearing in NOAA's IKONOS imagery as a single individual patch reef (Figure 2). Similarly, NOAA frequently mapped unconsolidated sediment in areas identified by NPS as scattered coral rock or reef rubble, likely because fine scale detail signifying these bottom types was visible in the 30cm resolution imagery but not discernible in NOAA's 4m IKONOS imagery. The NPS also cited difficulty discriminating classes with transitional or gradational boundaries including aggregate reef, spur and groove and pavement compared to habitats with more explicit ecotonal boundaries such as patch reefs, sediment, and seagrass (Estep et al. 2014).

Consistent mapping of seagrass within Biscayne National Park also appeared to be sensitive to the spatial resolution of source imagery. Field observations collected by FWC indicate that in some areas of the NPS map, seagrass extent may be overestimated most likely due to misclassification of algae and/or colonized pavement as seagrass (Figure 3). In addition to confusion with another biological cover type, the ephemeral nature of seagrass may have also led to discrepancies between maps. It's possible that seasonal and temporal changes in seagrass and algae occurred between acquisition of NOAA's 2006 IKONOS imagery and NPS's 2005 aerial imagery. Field mapping verification data were collected over varying time periods which may have influenced map results. The visible extent of low relief pavement, particularly in shallow areas within Biscayne Bay, may also change over time as these habitat are susceptible to sediment erosion and deposition during storm events.

4.2 Factor 2: Differences in Mapping Scale and MMU

In addition to the spatial resolution of source imagery, mapping methods including MMU and mapping scale can also influence how features are mapped. There were several habitat-specific discrepancies that were related to MMU and mapping scale differences in both the NOAA/NPS and NCRI/NPS comparisons. Patch reefs tended to be particularly sensitive to map scale and MMU. The most notable example of this is the disparity in patch reef size between NOAA and NPS. While the total number of individual patch reefs were similar in the NOAA/NPS comparison, reefs in the NPS map were

considerably smaller, the majority of which were smaller than NOAA's MMU of 625m². It is interesting to note that NOAA's inclusion of patch reef halos enabled identification of patch reefs smaller than the MMU which resulted in higher than expected agreement with the NPS map generated at a much smaller scale and MMU (Figure 2).

How classification schemes are applied can also vary between mapping scales. Certain habitat types which are defined based on habitat size (individual v. aggregated patch reefs) or spatial distribution (continuous v. discontinuous seagrass) were particularly sensitive to map scale and MMU within the study area. Differences in MMU and map scale likely explain high disagreement between patch reef classes in the NOAA/NPS comparison. In the NPS map, which mapped at a much smaller MMU than NOAA, a group of small patch reefs would be delineated separately and classified as individual patch reefs (Figure 4). The same group of patch reefs in the NOAA map would be grouped together and classified as aggregated patch reefs if reef size was less than NOAA's larger MMU. For seagrass, disagreement between continuous, discontinuous and sediment between overlapping maps appeared to be sensitive to map scale and MMU. Most often, in an area identified by NOAA or NCRI as discontinuous seagrass, NPS would subdivide that area into smaller patches of continuous seagrass surrounded by either sediment or discontinuous seagrass.

4.3 Factor 3: Different Classifications of Similar Habitats

There were discrepancies between certain benthic classes that were somewhat independent of imagery resolution, mapping scale and MMU. While differences in map scale most often affected how features were *digitized*, differences in thematic interpretation influenced how similar habitats were *classified*. In fact, for these thematic-type discrepancies, linework was often similar between overlapping maps despite differences in classification. Thematic discrepancies occurred within the study area due to either 1) differences in how similar benthic features were photo-interpreted, or 2) differences in how classification schemes were interpreted or applied between map sources.

Pavement and other reef habitats were often classified differently between overlapping maps. Difficulties resolving between aggregate reef and pavement habitats was also documented by NPS in Biscayne Bay (Estep et al. 2014) and the Dry Tortugas (Waara et al. 2011). NCRI also noted issues with distinguishing between small patches of colonized pavement and patch reefs (Walker et al. 2008, Walker 2009). FWRI visited several sites where there was disagreement between pavement and reef habitat in an effort to resolve discrepancies between overlapping maps. Even with field observations and additional sources of imagery, distinguishing between these two habitat classes remained difficult (Figure 4). NPS also reported confusion between aggregate reef and pavement from field photos and videos in the Dry Tortugas (Waara et al. 2011).

Most classification schemes in the FRT distinguish pavement from other reef habitats by the lack of seafloor relief or rugosity, information that is often not available from even the highest resolution imagery. Additional bathymetric information may improve consistent discrimination of pavement from reef habitats. However, some bathymetric data such as LiDAR are often not collected at the horizontal or vertical scale necessary for distinguishing pavement from higher relief reef habitats (Estep et al.

2014). This may explain high disagreement between pavement and reef habitats in the NCRI/NPS comparison even though both maps were generated from similar LiDAR and imagery datasets. It is possible that differentiation between these visually similar habitat types could be improved by clearer thematic distinctions such as a numeric rugosity thresholds for classifying a bottom type as either pavement or reef. Brock et al. (2006) identified the need for quantifying average reef relief to develop a numerical threshold between certain habitat types.

Issues related to classification criteria may have also explained seagrass disagreement between the NPS map and FWRI field observations within Biscayne National Park. Seagrass classification criteria may have been particularly problematic in areas where total cover was near the 10% threshold used by most classification systems for identifying seagrass presence or absence (Madley et al. 2002, Madden and Goodin 2007, Estep et al. 2014). Discrepancies may have occurred because of difficulties consistently determining the extent of seagrass at the 10% level at either the ground truth or photointerpretation levels. Furthermore, the ability to accurately and consistently quantify the extent of any type at the 10% threshold will be influenced by map scale, MMU, and the quality of source imagery.

Thematic discrepancies may have also occurred as a result of information lost when translating between classification schemes. Habitat types which could not directly be converted to one of the Unified Classes (UC) used for the comparison in this report tended to have higher disagreement between overlapping maps, particularly for certain hard bottom types including reef rubble, pavement, spur and groove and aggregate reef. An example of this is the reclassification of NPS's Remnant (Low Profile) Reef to the UC Aggregate Reef class. While aggregate reef is likely the most appropriate translation, the definition for Remnant (Low Profile) Reef shares many of the same characteristics of pavement which may have led to higher confusion between these classes (e.g. *"relief less than 2m that lack distinctive spur and groove characteristics, reefs consist of coral and hard bottom features; often support soft corals, sponges, seagrass, Estep et al. 2008"*).

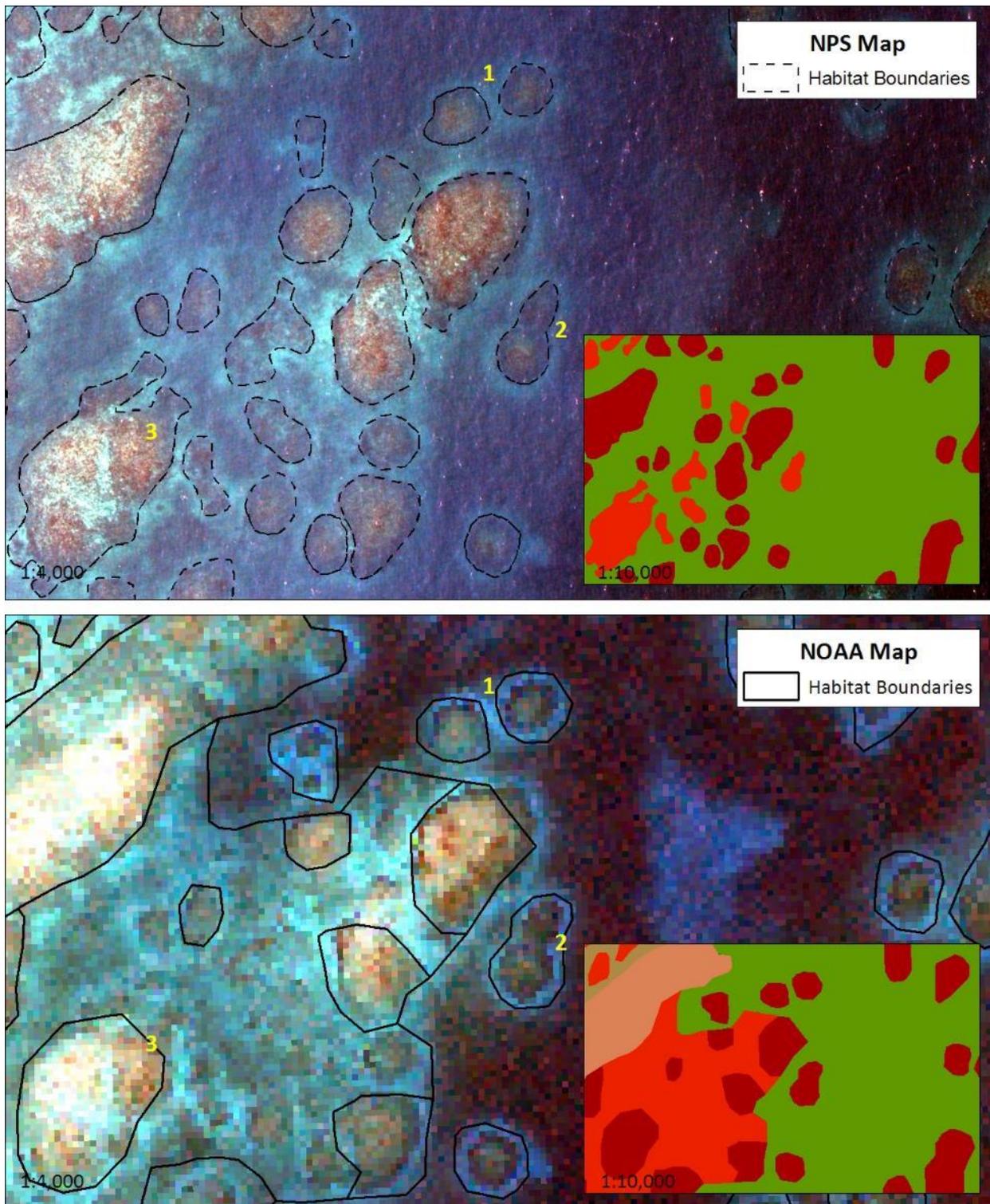


Figure 2. Example of discrepancies related to differences in imagery resolution between NPS (30cm aerial) and NOAA (4m Ikonos). In general, the NPS delineated between seagrass and hard bottom at a much finer scale than NOAA. The map also shows inclusion of individual patch reef halos in the NOAA map (Area 1) and aggregated patch reef detail in the NPS map not discernible in NOAA's imagery (Areas 2 and 3). ■ Aggregate Reef ■ Aggregated Patch Reef ■ Individual Patch Reef ■ Continuous Seagrass.

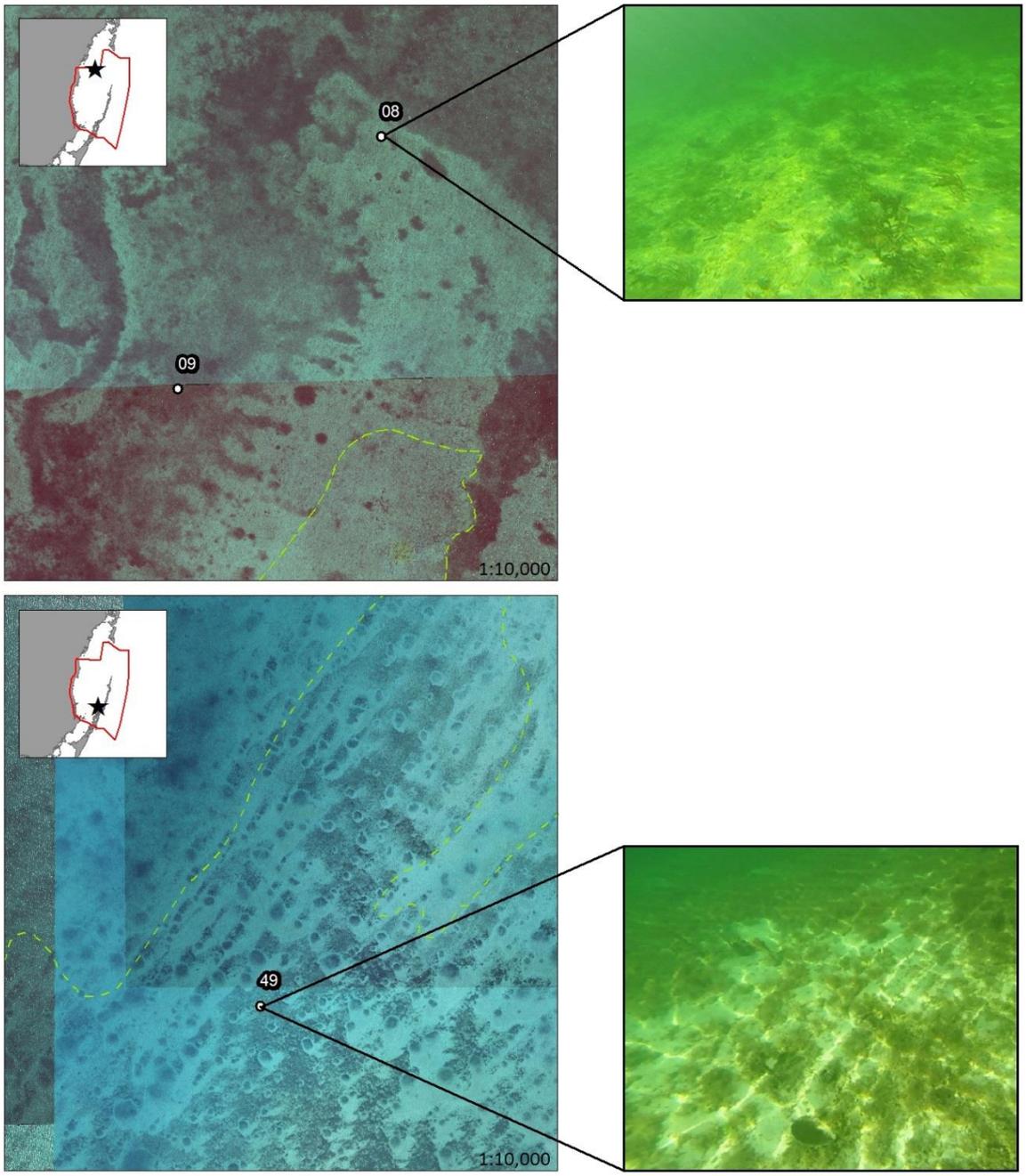


Figure 3. Example of seagrass discrepancies in the NPS map. Field data indicated that seagrass was overestimated in the NPS map due to confusion with algae or colonized pavement. These areas may require reclassification to discontinuous seagrass where seagrass was present but limited to small dense patches surrounded by sediment colonized by algae or other sessile fauna associate with hard bottom (Site 08). In other areas where seagrass was entirely absent (Site 49), reclassification to sediment or pavement may be necessary. - - - Discontinuous Seagrass (NPS)

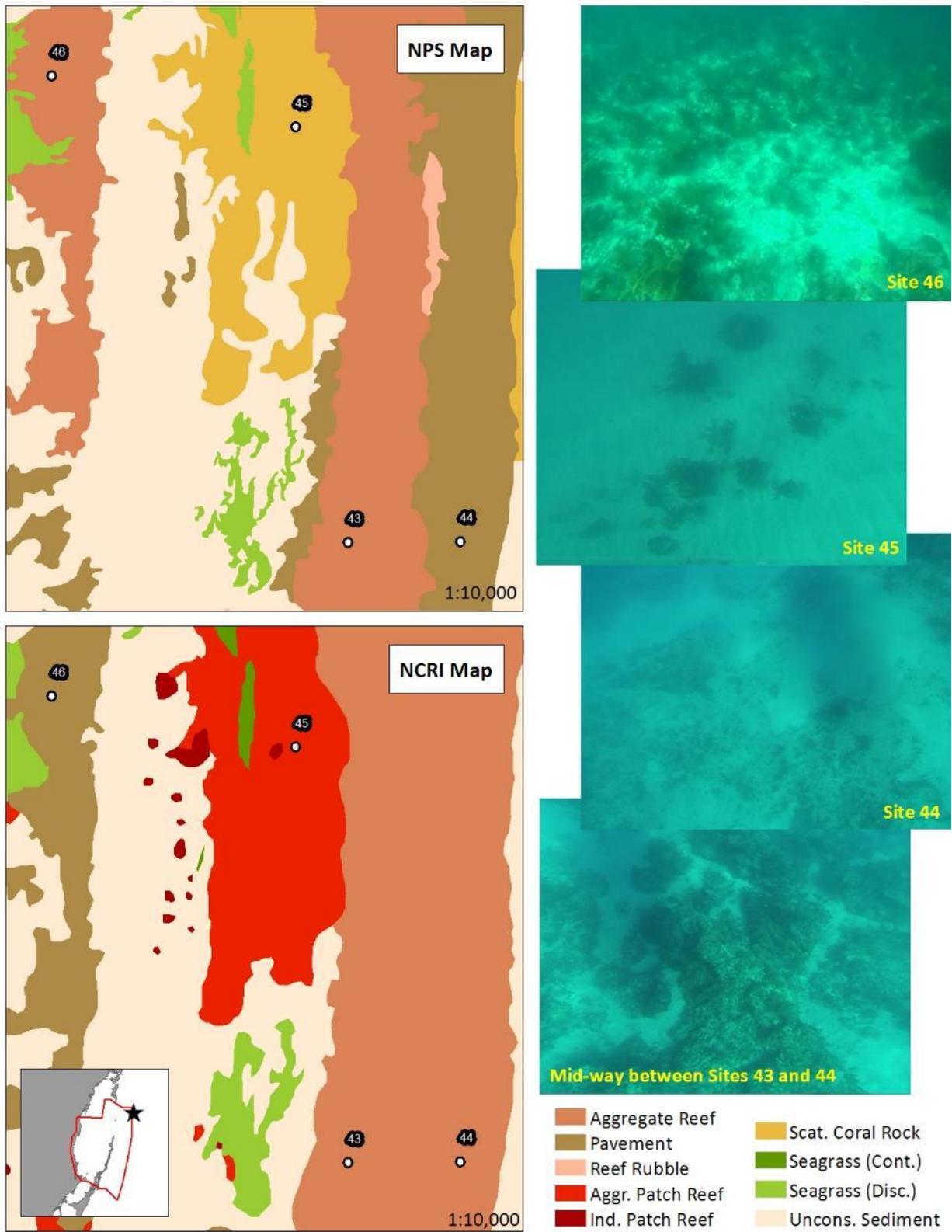


Figure 4. Example of discrepancies between similar types of hard bottom and FWC field observation photos including pavement (Site 44 and 46), aggregate reef (Site 43) and scattered coral rock (Site 45).

4.5 Relevance to Marine Resource Management

Results of the Biscayne National Park comparison, can be applied to identify possible consequences of different mapping methods on the overall Unified Reef Map. Based on the Biscayne National Park comparison, differences in mapping methods can influence the consistency and comparability of different benthic mapping efforts. These consistency and comparability issues affect regional (FRT wide) scale management and research in the following ways:

1) *Differences in the level of spatial and thematic detail/precision*: Differences in the spatial and thematic detail between maps can limit spatial comparisons between neighboring maps. For example, a comparison of patch reefs between maps generated at different scales and MMUs would produce considerably different results. In general, a larger MMU and mapping scale would indicate fewer, albeit larger patch reefs, whereas, a smaller MMU would generate a higher frequency of smaller patch reefs. In addition to the distribution of certain cover types, mapping scale can also influence other landscape-scale metrics such as the extent and complexity of edge habitat. For example, NPS mapped seagrass with much more spatial detail resulting in both a greater area of seagrass as well as a greater amount of edge habitat.

Comparability of maps generated at different spatial scales may be reduced or eliminated when compared at a less detailed thematic level (e.g. sediment, seagrass, hard bottom) which tend to be mapped more consistently between map sources compared to detailed habitat classes (e.g. discontinuous vs. continuous seagrass, aggregate reef vs. patch reef).

2) *Topology inconsistencies along seams between neighboring maps*: Merging independent maps of varying footprints and methodologies can also result in topological inconsistencies including gaps, overlap, and dissimilar geometry between neighboring maps. These topological disparities are usually easier to correct than other discrepancies discussed. Topology inconsistencies are corrected by FWRI during updates of the Unified Reef Map.

3) *Varying degrees of map accuracy*: Accuracy can vary between maps due to a variety of factors including photointerpretation preferences, differences in mapping scale and MMU, resolution of source imagery and availability of ancillary data. Differences in accuracy between maps can be addressed to some extent by development and adherence to accuracy standards such as the accuracy standard recommended in the Southern Florida Shallow-water Coral Ecosystem Mapping Implementation Plan (Rohmann and Monaco 2005). Map accuracy can be improved with the availability of ancillary imagery or bathymetric information, however, these supporting datasets are often not consistently collected throughout the FRT. Collection of additional ground truth data can significantly improve accuracy within a single map as well as resolve disagreement between neighboring or overlapping maps. However, there is often a disparity between mapping scale and observer scale. For example, the observer scale for both FWRI's 2014 effort and NPS's ground truth efforts was 0.2ha, which is considerably smaller than the 0.5ha MMU used to generate the NPS map. Efforts should be made to collect field data at a spatial scale closer to the mapping scale when possible to provide information relevant to habitat features mapped at larger spatial scales.

4) *Loss of thematic information between classification schemes:* The consistency of the Unified Reef Map may also be influenced by information lost in the reclassification between maps generated using different classification schemes. Descriptions of most habitat classes are generally similar and can be translated without much loss of information. For other habitats which cannot easily be translated between classification schemes have the potential to influence comparability between maps, such as the aggregate reef example in Biscayne Bay. The CMECS efforts as well as the Unified Class System attempt to accommodate classification scheme disparities through a hierarchical framework, however, information loss in translation between schemes throughout the FRT still remains an issue.

5) *Temporal discrepancies due to gaps in acquisition of source data:* Maps generated over different time periods have the potential to limit the comparability and consistency between maps particularly for habitats which exhibit seasonal or annual variability such as seagrass, macroalgae or other ephemeral type communities. Annual changes in seagrass cover have been cited by Walker (2009) as a source of potential map error in NCRl's map within the Biscayne National Park area. The consistency of mapping low relief habitats such as pavement in shallow areas may also be affected by shifts in sediment deposition over time.

5.0 Conclusion

Consistency in benthic mapping efforts would best be improved by adhering to an agreed upon classification scheme, photo-interpretation key, MMU and mapping scale. While all of these factors are dependent upon imagery type, quality and resolution, a common denominator could be found among imagery sources currently in use while still accommodating the mapping information needs of most research and resource management applications. Under a common mapping standard, the Unified Reef Map would provide a repository for integration of mapping datasets. For maps where common mapping standards are not met, the Unified Class Level system addresses thematic discrepancies by grouping similar habitat types into larger, more general, groups. Currently no method has been identified to rescale benthic mapping line-work to a consistent scale. Data in the Unified Reef Map has however been edited to address overlap and create consistency between datasets at seams where maps meet.

Issues related to discrepancies between classification of similar benthic types can be addressed by leveraging ancillary data. For example, ancillary bathymetric data can improve delineation between habitat types defined by different degrees of vertical relief not detectable from optical imagery. High resolution bathymetric information (e.g. Lidar, side-scan, or multibeam surveys) could improve the reliability and accuracy of resolving between pavement and aggregate reef. As part of the Coordinated Coral Reef and Hard Bottom Mapping and Monitoring program, patch reefs will be reworked using high resolution imagery and ancillary data to create consistent representation of patch reefs across the FRT.

The large swath width and synoptic nature of satellite imagery is well suited for image processing routines such as pixel classification. Image processing routines have been shown to provide more quantitative and cost effective results for mapping benthic habitats (Baumstark et al. 2013). High temporal frequency satellite data also enables more frequent assessment of ephemeral habitats such as

seagrass and algae. Biological cover density is mapped differently between schemes. Seagrass for example, is mapped as continuous or discontinuous using SCHEME, while the NOAA classification records biological cover percentage in a separate field.

Pattern and process of landscape change depend on viewing scale (Wu et al. 2006). Density can be difficult to estimate as it is a function of scale and MMU. The spatial configuration of biological cover which tends to be patchy in nature, such as seagrass or patch reefs, is also ecologically relevant but is not considered in mapping schemes. Quantitative image processing methods can help quantify biological density and can be combined with landscape ecology metrics to provide representations of spatial configuration.

Additionally, results of this report indicate the need for refined class descriptions which identify clearer thresholds and numerical criteria to improve discrimination between very similar classes such as pavement and aggregate reef. The class description for delineation of patch reefs should be defined to either include or exclude halo. The inclusion of a secondary biological cover type (or a modifier as implemented with SCHEME) allows for the representation of areas with mixed biocover, such as seagrass intermixed with attached macroalgae, sponges or soft corals. As implemented in CMECS schema, the distinction between geological formation (or substrate) and biological cover would allow for the classification of hard bottom areas mixed with seagrass. Any efforts to develop mapping standards must consider a range of data sources and should be informed by technicians who are familiar with the limitations and nuances of photo-interpretation and mapping. Consistency would be further improved by coordinating and cross training technicians from different mapping entities through workshops and meetings.

Future work with classification schemes should also consider whether classifications are biologically distinct, i.e. represent true differences in community structure (Brock et al. 2008) and whether distinctions between classes are ecologically relevant. The inclusion of reef zone and region information also help to differentiate benthic classifications which are ecologically distinct based on their geographic location (Walker 2012).

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APPENDIX:

Habitat Specific Discrepancies between Overlapping Maps in Biscayne Bay

Contents

A.1	Seagrass Discrepancies within Biscayne Bay	A2
A.2	Delineation between Hard Bottom and Seagrass along the Reef Tract	A7
A.3	Confusion between Pavement, Reef, and other Hard Bottom Classes	A12
A.4	Patch Reef Discrepancies	A21

A.1 Seagrass Discrepancies within Biscayne Bay

Nearly all of Biscayne Bay, inshore of the reef tract, is mapped by NPS as seagrass most of which is classified as continuous seagrass. Seagrass was also predominantly mapped in the Biscayne Bay Aquatic Preserve, just north of the NPS boundary. This portion of the Biscayne Bay Aquatic Preserve was mapped by Avineon for the previous 2008 version of the NPS map. This area has since been revised by FWRI to improve consistency with NPS's 2013 updated map which excluded all areas outside of the NPS boundary.

Several areas within Biscayne Bay were visited in 2014 by FWRI to confirm seagrass cover and density and also explore the potential presence of other habitats, particularly pavement hard bottom (Figures A1-A4). Presence of pavement was suspected in some areas of the Bay based on preliminary review of the recent 2008 imagery as well as presence of hard bottom in earlier maps. Collection of additional field observations was also motivated by the potential for confusion between seagrass and macroalgae attached to hard bottom via photo-interpretation.

FWRI field surveys indicated that in some areas seagrass is likely overestimated in the NPS map. Disagreement between FWRI field observations with the NPS map occurred most frequently in areas where seagrass cover was sparse or patchy and/or when seagrass was co-located with attached macroalgae, sponges or soft corals typically associated with hard bottom (Figure A1 and A2). Misinterpretation of colonized pavement as seagrass may have contributed to overestimation of seagrass in the NPS map.

Estimating whether total cover or density met classification criteria in areas where seagrass was sparse or patchy may have also contributed to disagreement with FWRI field results. According to the SCHEME classification framework used by NPS, an area is mapped as seagrass if total coverage exceeds 10%. The 10% threshold can be problematic, primarily because reliably estimating the extent of any habitat type at the 10% scale is often difficult. For example, when seagrass is sparse and continuous, determining whether total cover exceeds 10% is difficult even with high resolution imagery and extensive field verification. Issues with the 10% threshold may also occur when seagrass occurs as scattered dense patches which are clearly visible from imagery but are far smaller than the MMU to enumerate consistently. While seagrass cover may be easier to estimate in situ, ground truth data is often collected at such a small spatial scale relative to the MMU that extrapolation to larger areas is limited.

While the extent of seagrass appeared overestimated in some areas, the presence of pavement appeared under-represented in other areas of the NPS map. Several sites mapped as seagrass by NPS were classified from in situ data as pavement with very little to no presence of seagrass (Figure A3 and Figure A4). Pavement was often obscured by a thin veneer of sand and colonized by macroalgae and sessile fauna including sponges and gorgonians which may have been misinterpreted as seagrass and sediment in the NPS map. Similar to seagrass, disagreement between the NPS map and FWRI field data may have been attributed to difficulties quantifying the extent of pavement relative to the 10% threshold, especially because pavement was patchy or infrequent and very close to 10% of total substrate.

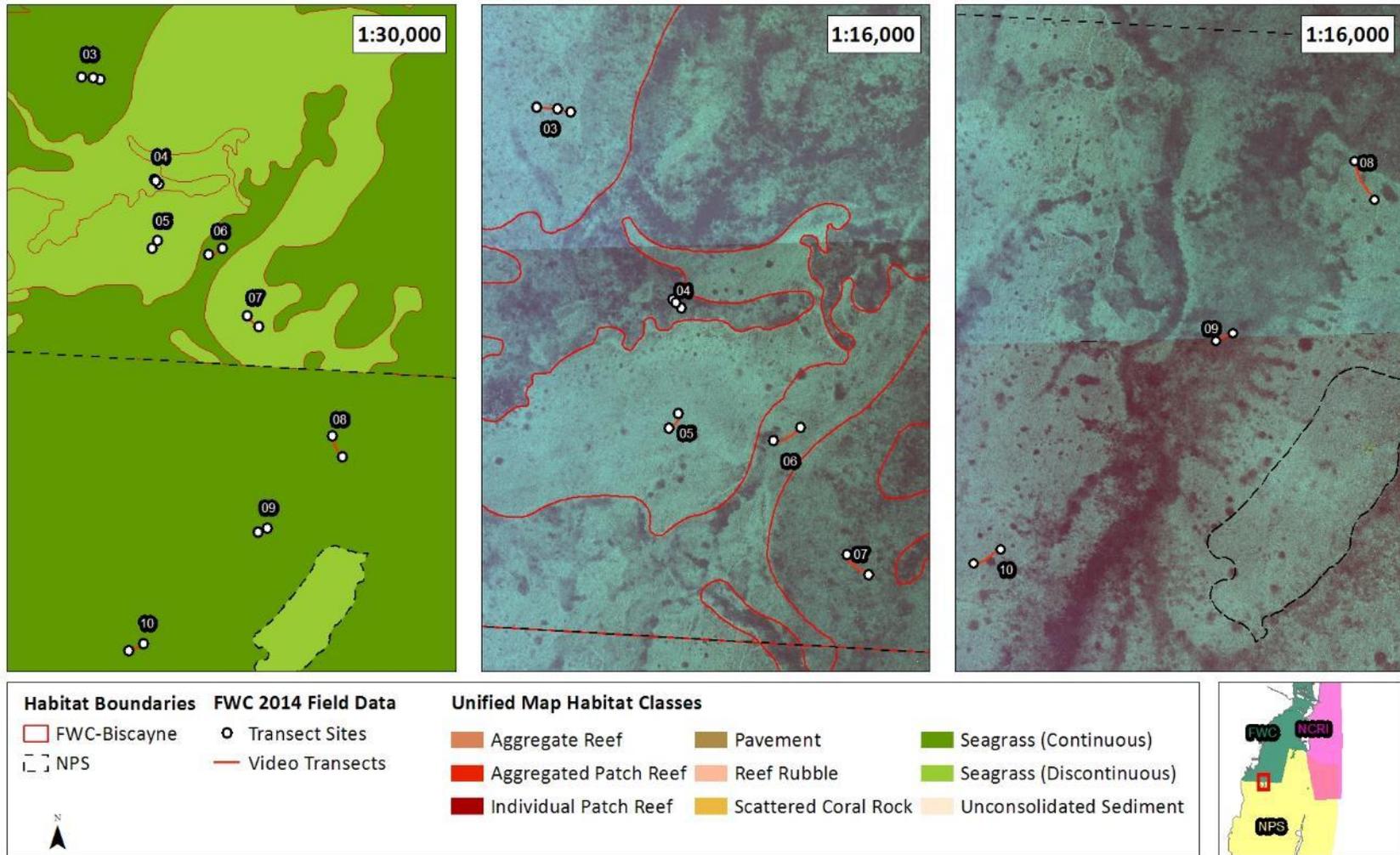


Figure A1. Example of seagrass discrepancies within Biscayne Bay. Seagrass was identified as the dominant cover type at Sites 4, 7, and 9. Darker areas in the 2005 imagery consistently corresponded with areas of dense seagrass observed during FWC surveys. At the remaining Sites 3, 5, 6, 8, and 10, habitat consisted of patchy seagrass surrounded by sediment dominated by macroalgae, sponges, and other fauna associated with hard bottom. This sediment-algae-hardbottom habitat is represented in the imagery above as lighter, speckled areas in between the darker patches of dense seagrass. Large portions of continuous seagrass area will likely require reclassification to discontinuous seagrass or possibly pavement.

Site 3



Site 8



Site 8



Site 6



Figure A2. Video transect snapshots showing dominance of algae and possible presence of hard bottom in areas mapped as seagrass.

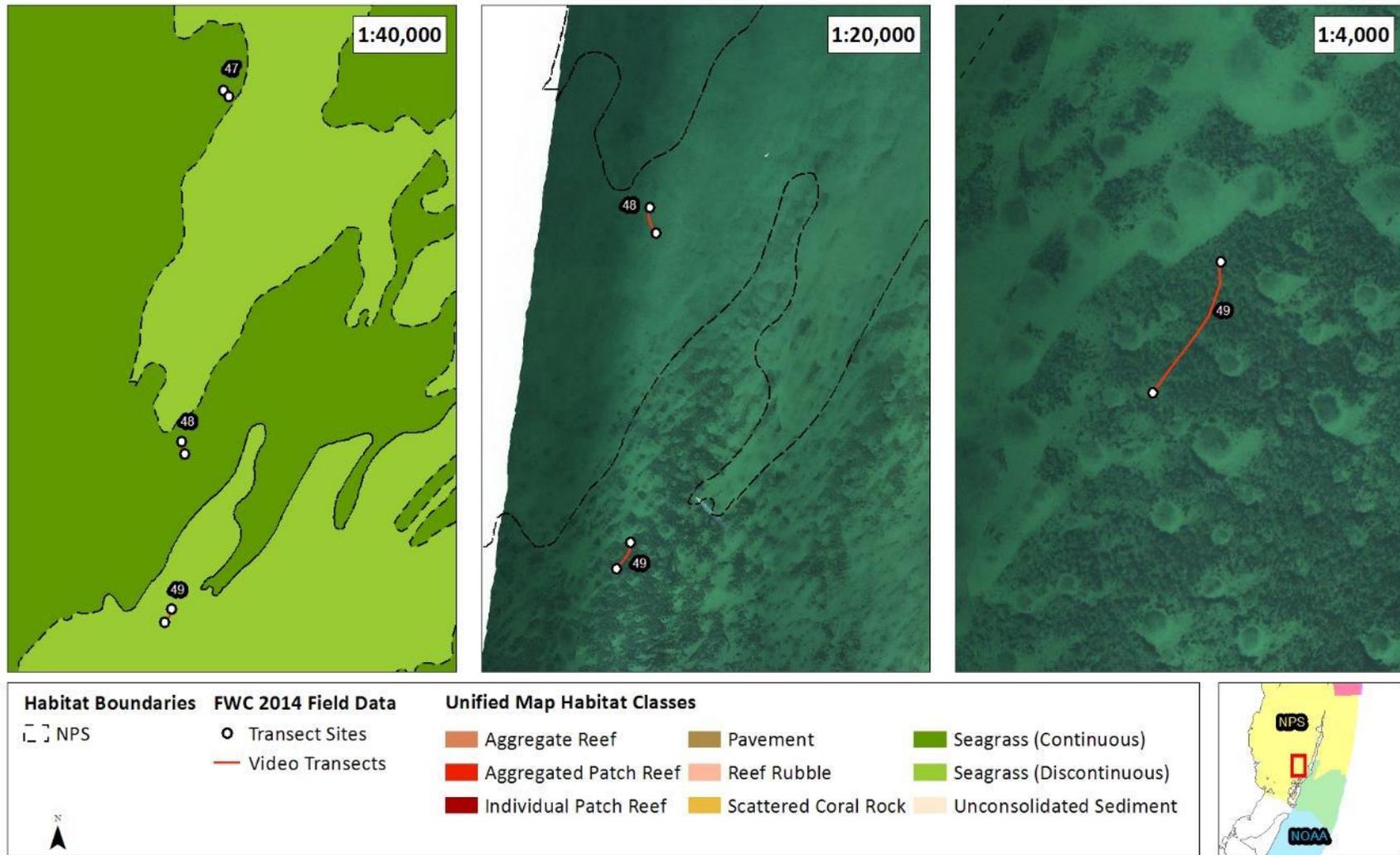


Figure A3. Ground truth sites within Biscayne Bay where presence pavement was observed in areas mapped by NPS as discontinuous seagrass. Imagery shown was acquired in 2005.

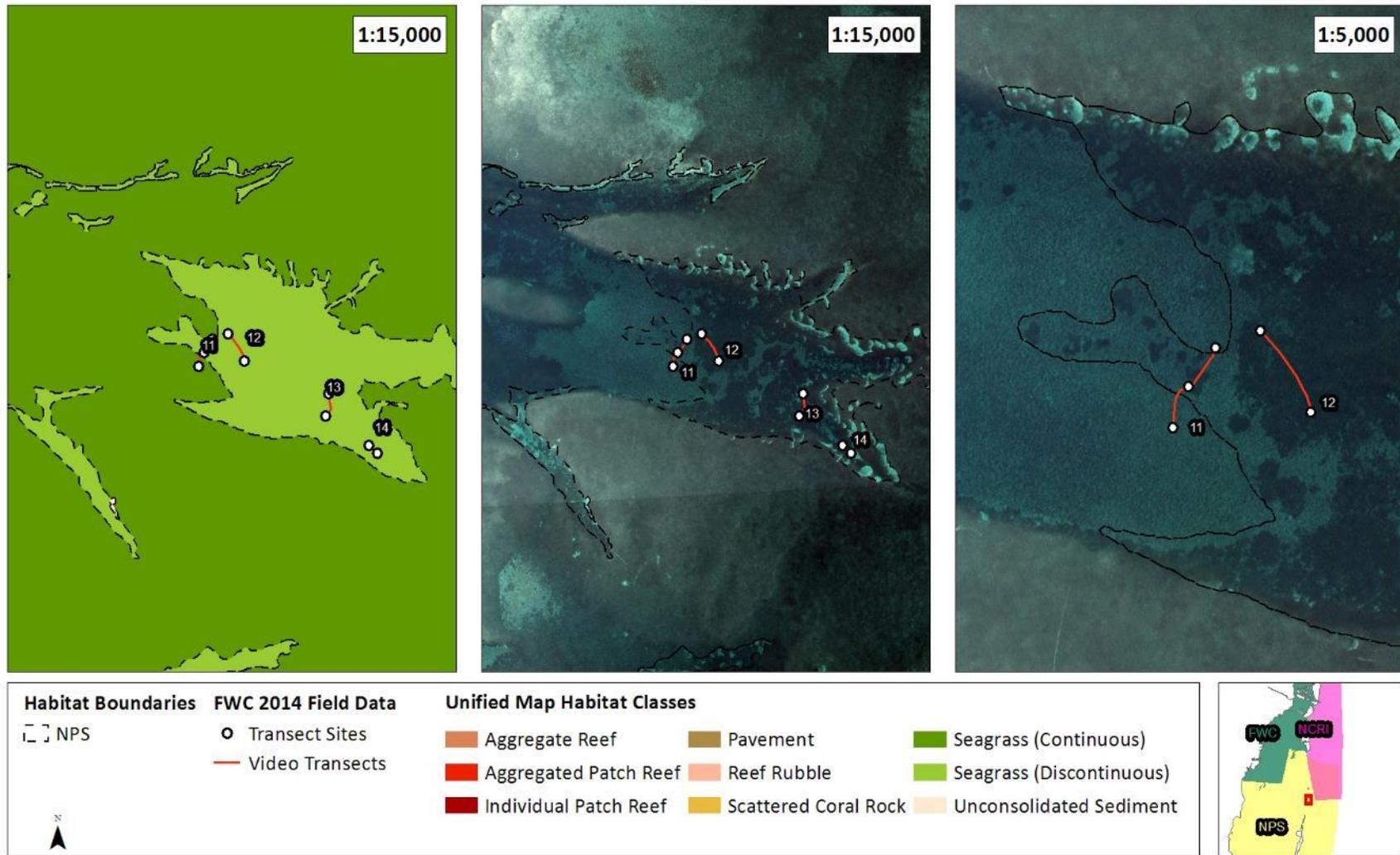


Figure A4. Example of seagrass-pavement discrepancies at Sites 11-14. Sites 12, 13, and 14 were classified as discontinuous seagrass and were characterized by dense, patchy seagrass surrounded by sediment. Habitat type along the Site 11 transect was classified as pavement, with the exception of a dense patch of seagrass mid-transect which corresponds with the 2005 aerial image above. Areas identified as pavement by FWC correspond with a distinctly lighter, slightly speckled signature in the 2005 aerial imagery compared to the surrounding darker seagrass habitat. Delineation of pavement in this area is recommended as well as assessing similar signatures in nearby area.

A.2 Delineation between Hard Bottom and Seagrass along the Reef Tract

Seagrass was also mapped frequently along the reef tract, offshore of Biscayne Bay. In these areas, NPS generally classified a much greater area of continuous seagrass than NOAA. Continuous seagrass in the NPS map was frequently classified by NOAA as discontinuous seagrass or pavement and most often in larger, contiguous areas between the reef tract and the barrier islands (Figure A5). Similar to issues within the Bay, NOAA/NPS disagreement are likely related to inconsistencies when mapping low density seagrass.

There was also disagreement between NPS's coverage of continuous seagrass in areas along the reef tract which were mapped by NOAA as hard bottom reef habitat (Figure A6 and A7). In these areas, seagrass-hard bottom discrepancies are likely the result of higher resolution imagery used by NPS which enabled better discrimination of seagrass from hard bottom habitats. Seagrass mapped by NPS in these small gap areas were grouped in with larger aggregate and patch reefs in the less detailed, coarser resolution NOAA map (Figure A6 and Figure A7).

In the NCRI/NPS comparison, although seagrass agreement was higher than the NOAA comparison, discontinuous and continuous seagrass were frequently confused between maps (Figure A8). These discrepancies appear to be mostly scale related, despite both the NPS and NCRI maps being generated at comparable MMUs from the same 30cm imagery. In general, NPS identified continuous seagrass more frequently and with more spatial detail than NCRI. This occurred in larger areas identified as discontinuous seagrass in the NCRI map that were subdivided into smaller continuous seagrass polygons surrounded by either discontinuous seagrass or sediment in the NPS maps (Figure A8).

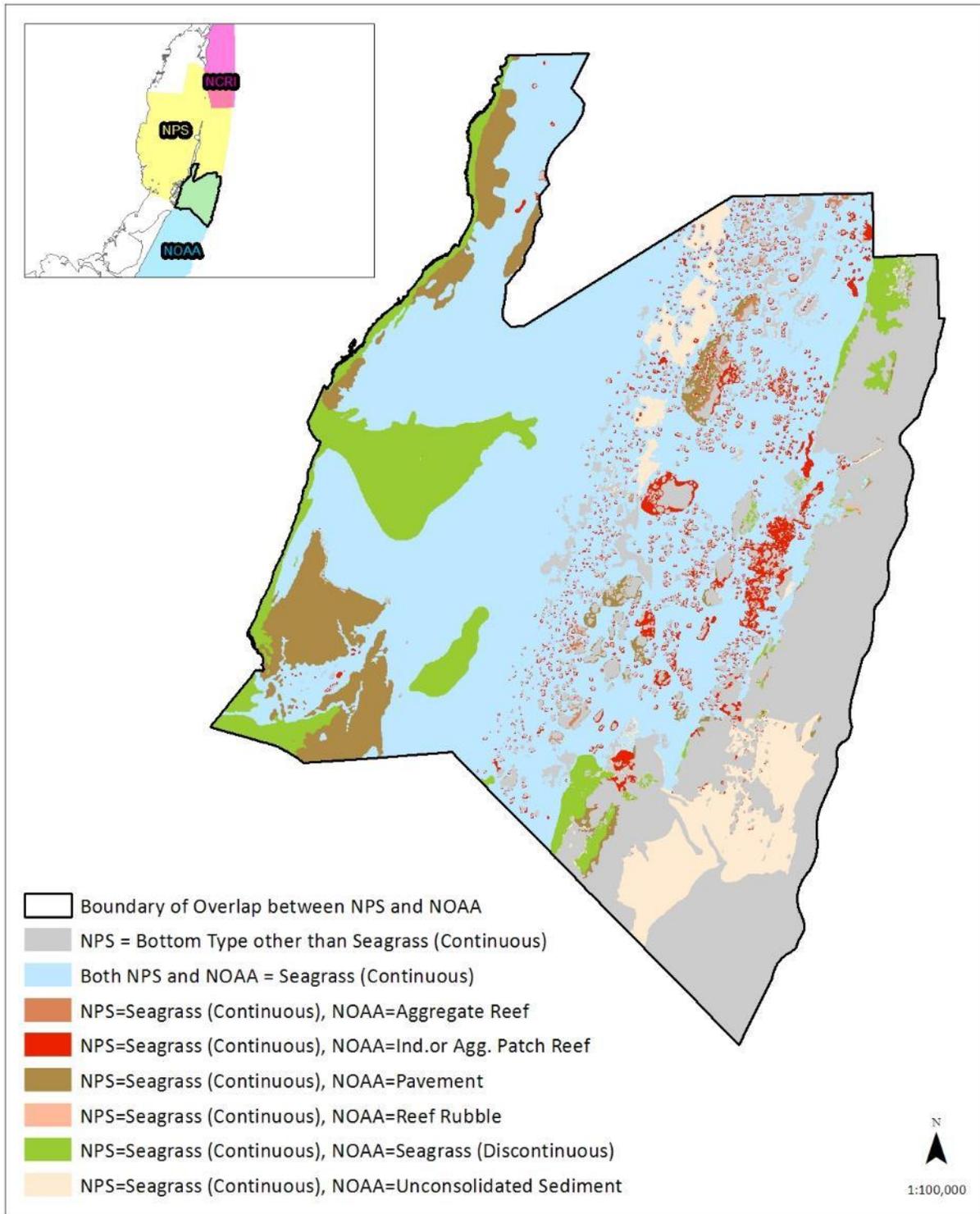


Figure A5. Example of continuous seagrass discrepancies between NPS and NOAA. Colored areas represent the habitats classified by NOAA classification results in areas identified by NPS as continuous seagrass.

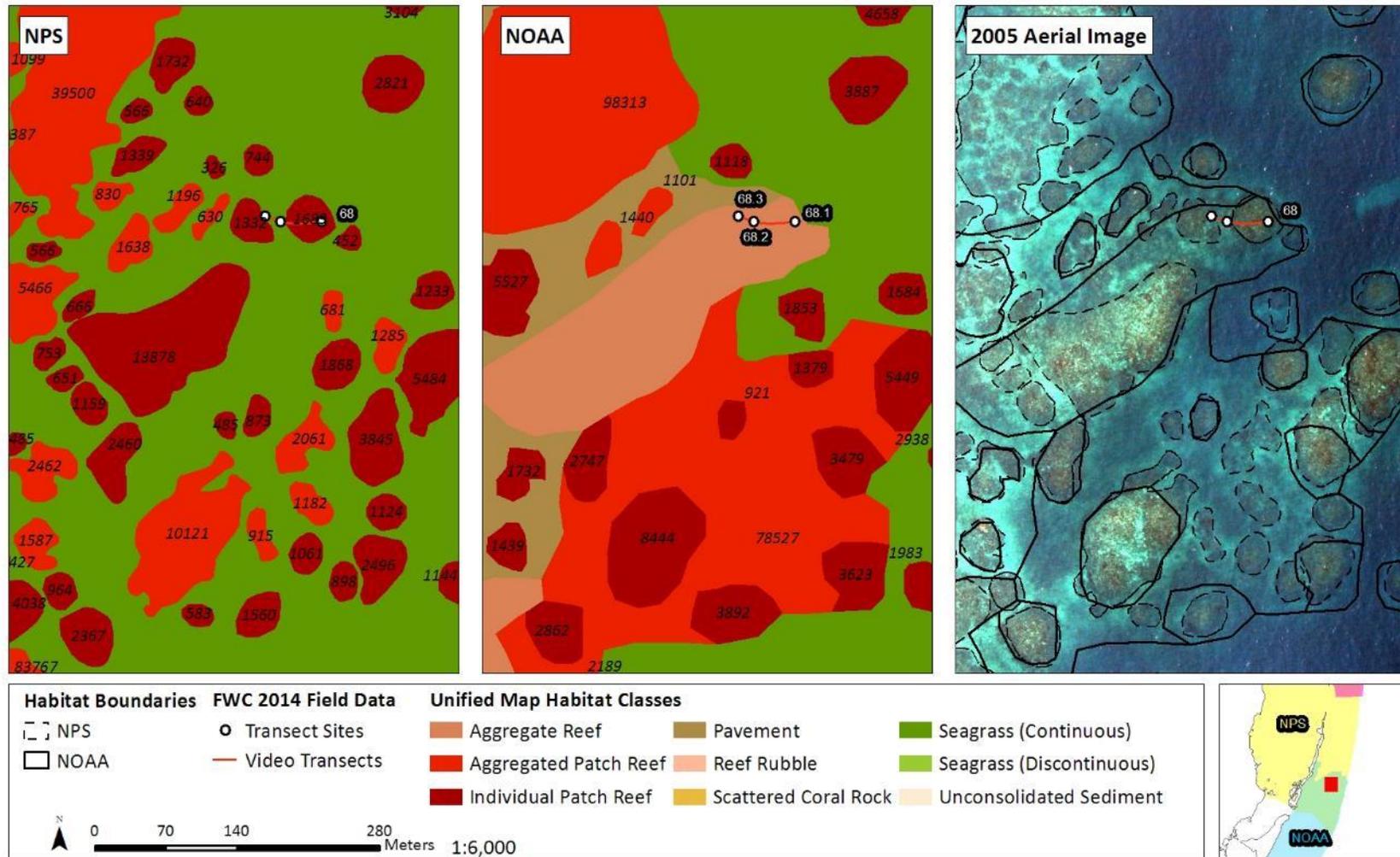


Figure A6. Example of 1) NPS classification of continuous seagrass in hard bottom areas identified by NOAA, and 2) discrepancies between aggregate reef, aggregated patch reefs, and individual patch reefs. Italicized numbers represent polygon area (m^2). FWC field observations confirmed NPS's delineation of patch reef habitat at the start (68.1) and end (Site 68.3) of the video transect. Pavement was identified in between patches at Site 68.2, indicating that seagrass is likely overestimated in the NPS map.

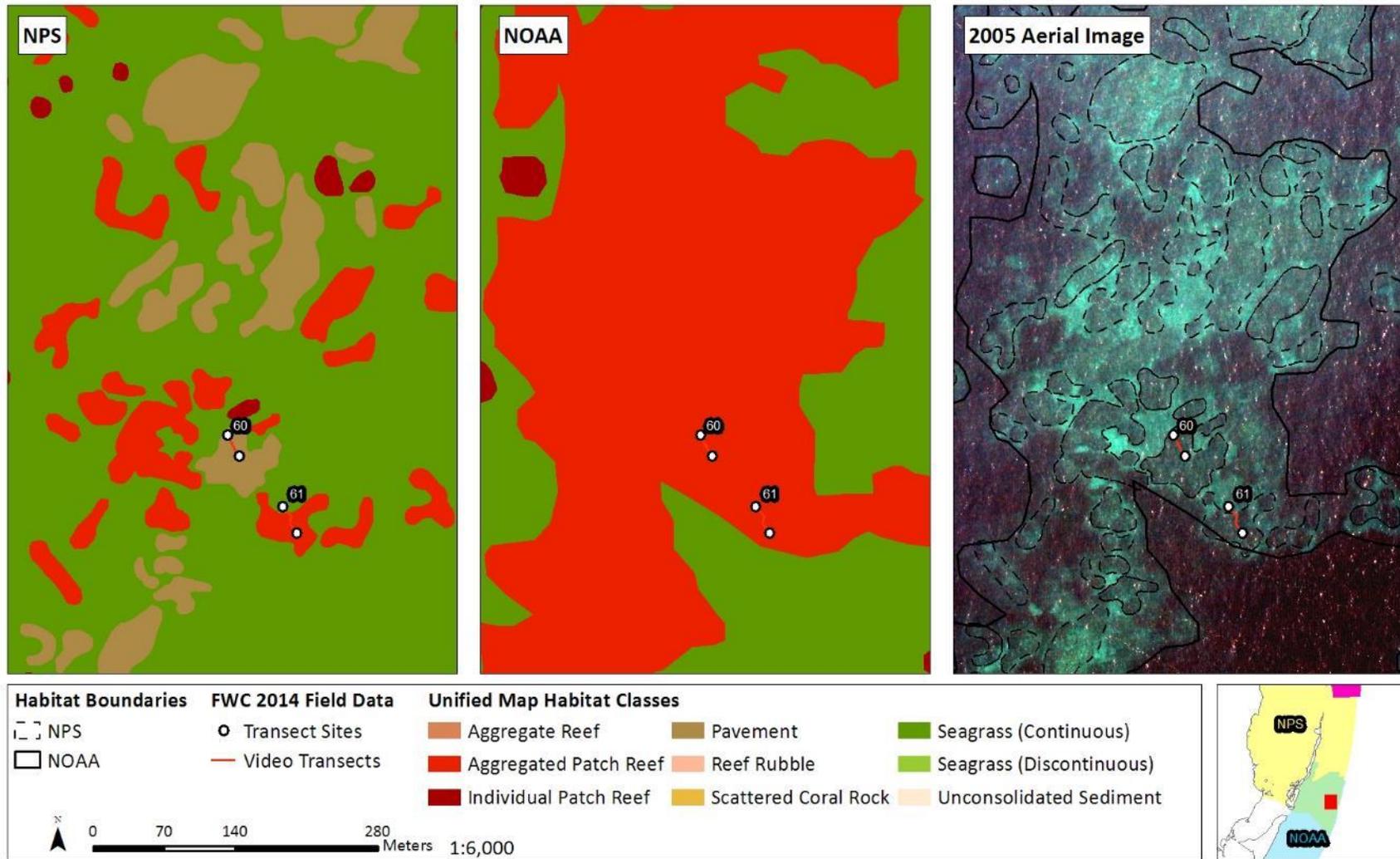


Figure A7. Example of patch reef and aggregate reef discrepancies. Both Sites 60 and 61 were classified as patches of colonized pavement due to lack of relief typical of patch reefs.

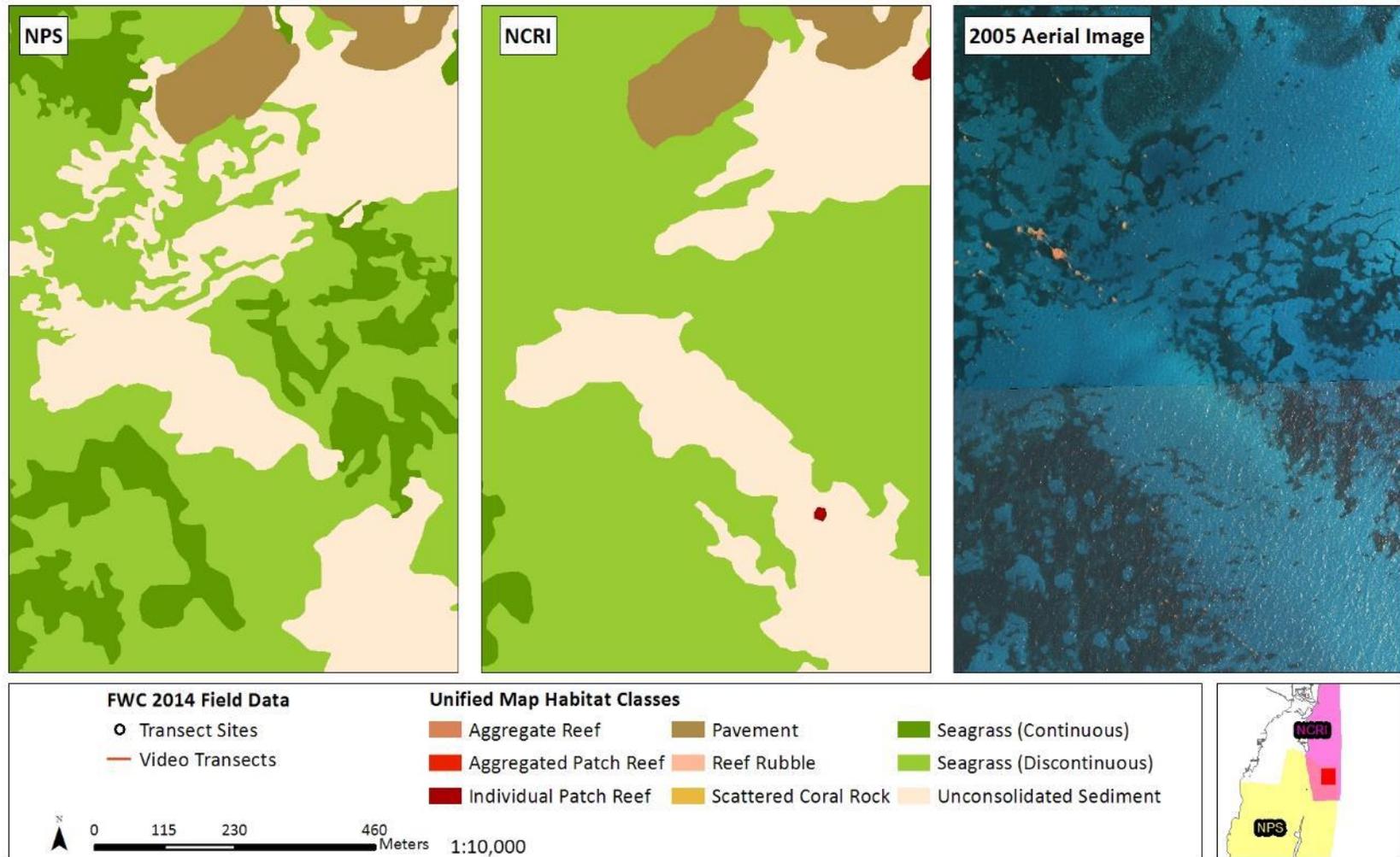


Figure A8. Example of continuous and discontinuous seagrass discrepancies between NPS and NCRI.

A.3 Confusion between Pavement, Reef, and other Hard Bottom Classes

Pavement was often confused with aggregate and patch reef in both the NOAA/NPS and NCRI/NPS comparisons. A considerable portion of aggregate reef mapped by NPS was identified by NOAA as pavement. Conversely, most aggregate reef identified by NOAA was mapped by NPS as pavement or patch reef.

In the NCRI/NPS overlap, although the total area of mapped hard bottom was similar, there was notable disagreement between hard bottom habitats. For example, approximately half of the pavement identified by NPS was classified by NCRI as aggregate reef.

In an effort to resolve discrepancies between pavement and reef classes, FWRI visited several sites where disagreement between overlapping maps occurred (Figure A9 through A16). Even with additional field observations and 2008 imagery, distinguishing between these two habitat classes remained difficult. Habitat at these sites generally consisted of low relief patchy carbonate rock which was densely colonized by macroalgae and other sessile fauna. Pavement was identified as the most appropriate class for most of these sites due to the absence of higher relief stony coral structure of aggregate or patch reefs.

While not as prevalent as with other habitats, scattered coral rock (aka Scattered Coral/Rock in Unconsolidated Sediment) was mapped inconsistently between maps. Scattered coral rock was not identified at all by either NOAA or NCRI in the areas where the maps overlapped with the NPS boundary. Areas where scattered coral rock was mapped by NPS were most often classified by either NOAA or NCRI as sediment or aggregated patch reef.

Several areas that were mapped as scattered coral rock by NPS were visited by FWRI in 2014 to resolve discrepancies with the NCRI and NOAA maps. FWRI confirmed the presence of scattered coral rock at several sites most of which were classified by NOAA or NCRI as aggregated patch reef. FWRI field observations and map comparison results suggest that the scattered coral rock class may be underrepresented in the NOAA and NCRI maps. While scattered rock was identified in some areas from FWRI field data, at other sites it was often difficult to distinguish scattered coral rock from other habitat types including reef rubble and patchy, colonized pavement. These habitats not only share similar aerial signatures but also share many of the same characteristics when viewed from video transect and ground truth photos.

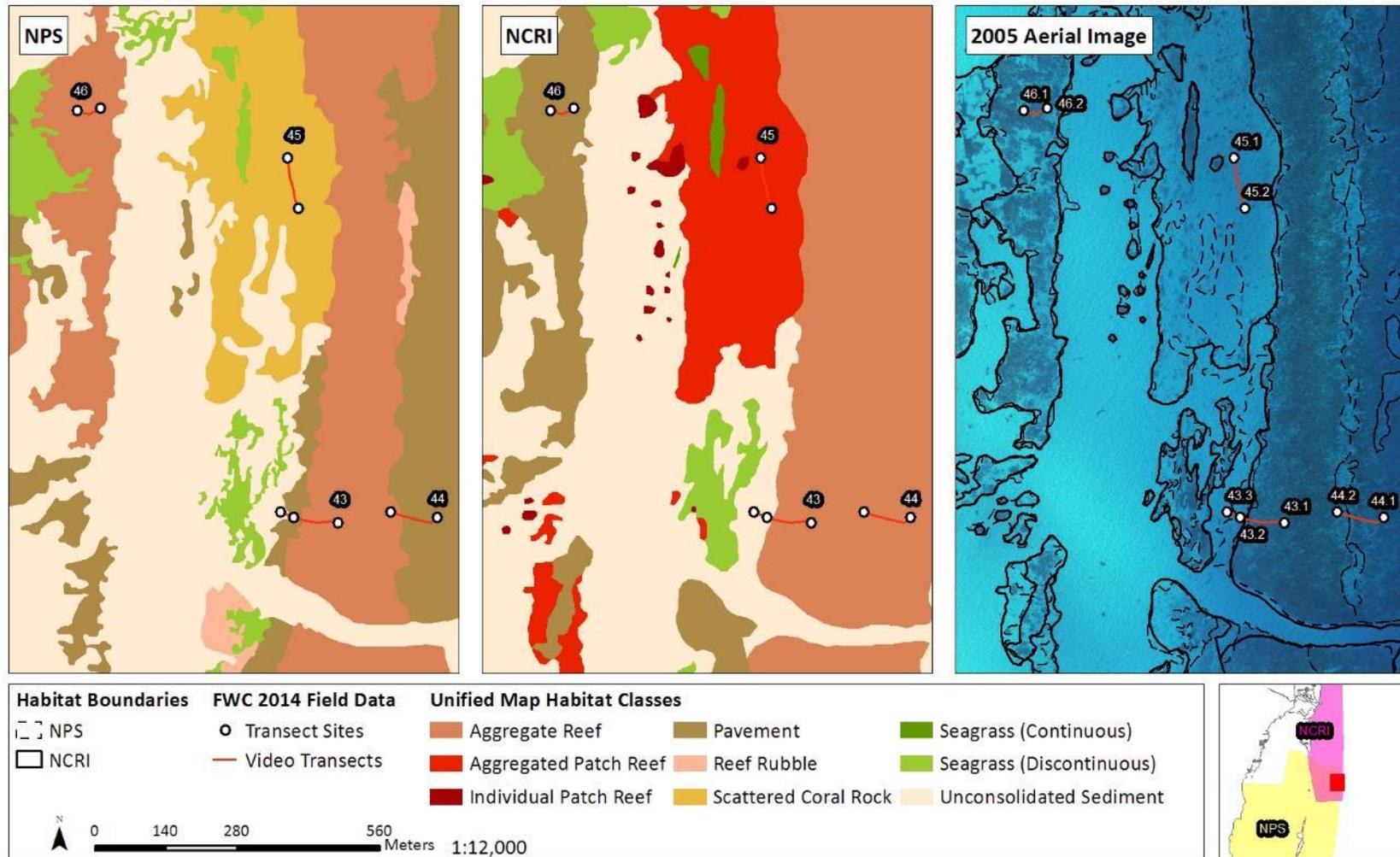


Figure A9. Example of pavement-aggregate reef discrepancies (Sites 43, 44, and 46) and scattered coral rock discrepancies (Site 45). Habitat type at Site 46 was identified by FWC as patchy colonized pavement. Site 45 was classified as scattered coral rock due to absence of larger coral heads/reef structure characteristic of aggregated patch reefs. Pavement was identified along most of the video transect at Sites 43 and 44 with the exception of the areas near Site 43.1 and 44.2 which were classified as aggregate reef.

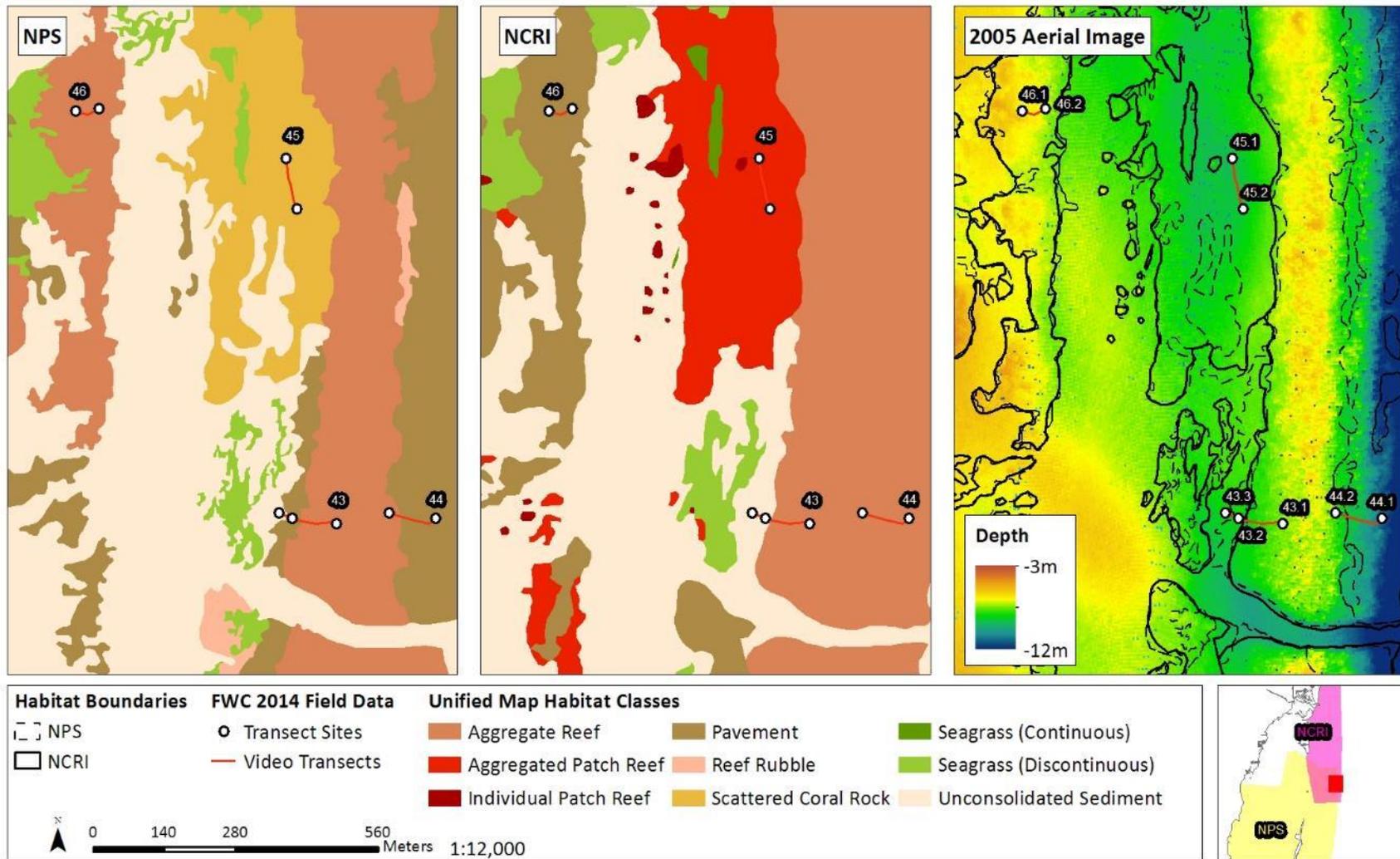


Figure A10. Bathymetric relief differences between pavement and aggregate reef at Sites 43-46. Site 46 was identified as pavement by FWC due to lack of bathymetric relief which corresponds with the LiDAR bathymetry. FWC observations of aggregate reef near Sites 43.1 and 44.2 corresponds with bathymetric differences in the LiDAR map, suggesting that aggregate reef will likely require re-delineation in this area.

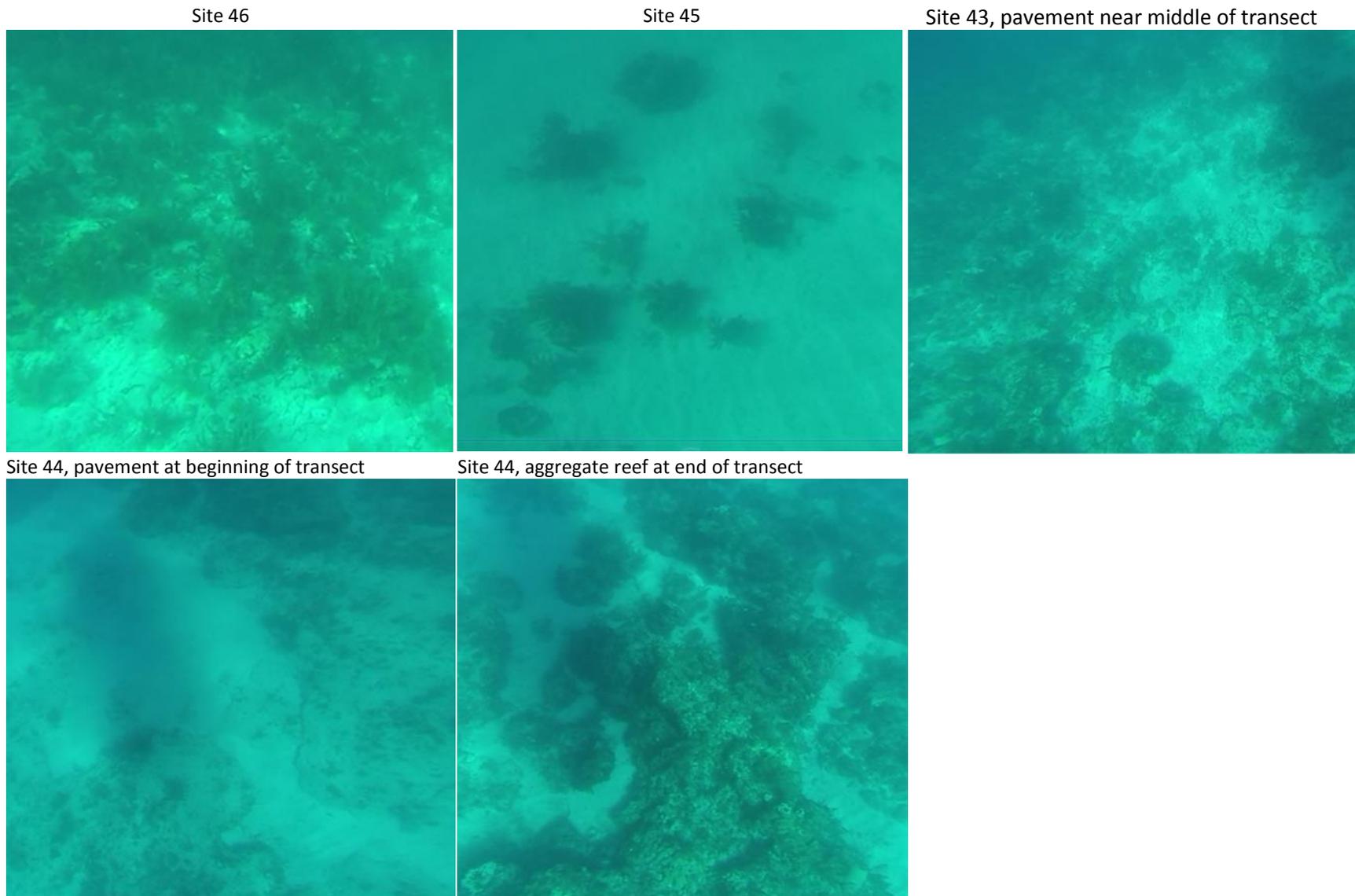


Figure A11. Video transect snapshots of Sites 46 and 45. FWC classified Sites 46 and 43 as patchy colonized pavement and Site 45 as scattered coral rock. Video transect snapshots at Site 44 showing example of differences between low relief, patchy pavement at the beginning of the transect (left) transitioning into aggregate reef at the end of the transect (right).

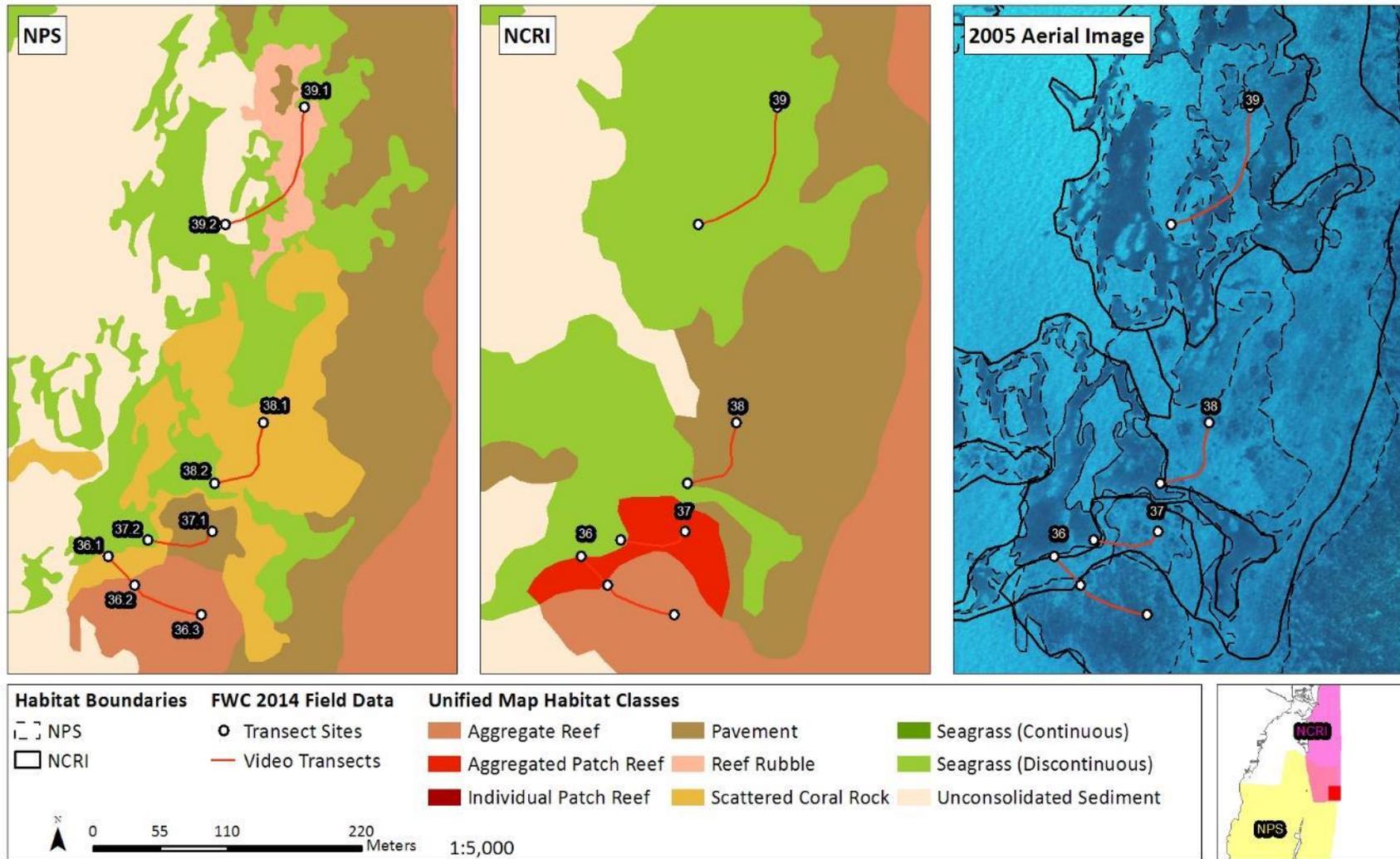


Figure A12. Example of scattered coral rock and reef rubble discrepancies. At Site 39, FWC observations confirmed NPS’s delineation of reef rubble. FWC observations at Site 38 and between Sites 36.1 and 36.2 agreed with NPS’s delineation of scattered coral rock. Habitat at Site 37 was also identified as scattered coral rock due to lack of continuous hard bottom characteristic of pavement habitat which was identified in the NPS map. Coral rock patches were too small to meet the definition of aggregated patch reef habitat which was identified in the NCRI map. Aggregate reef was confirmed between Sites 36.2 and 36.3.

Site 37



Site 38



Site 38



Site 39, beginning of transect



Figure A13. Video transect snapshots of Sites 37, 38, and 39. Sites 37 and 38 were classified as scattered coral rock and were characterized by small patches of coral rock surrounded by rubble mixed with unconsolidated sediment. Site 39 was classified as reef rubble, although rubble fragments were smaller and appeared very similar to unconsolidated sediment in the transect video.

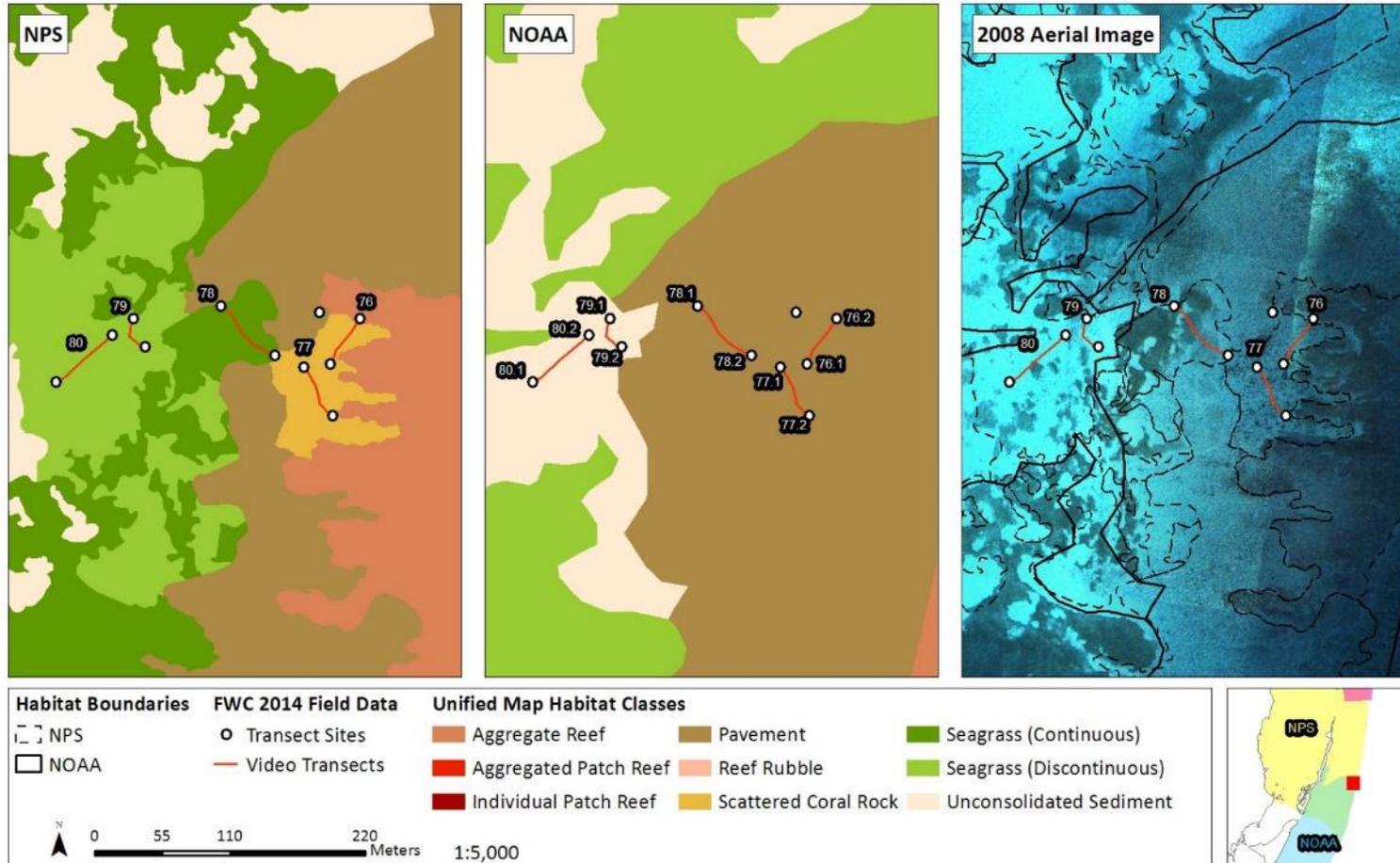


Figure A14. Example of scattered coral rock and pavement discrepancies. In general, pavement is overestimated in the NOAA map. Habitat at Sites 76 and 77 shared characteristics of both reef rubble and scattered coral rock. FWC observations agree with NPS delineation of aggregate reef at Sites 76.2 and 77.2. Patchy seagrass and reef rubble were observed at Sites 79 and 80 confirming discontinuous seagrass in the NPS map. Patchy seagrass was also observed at Site 78 suggesting that continuous seagrass mapped by NPS in these areas should be reclassified to discontinuous.

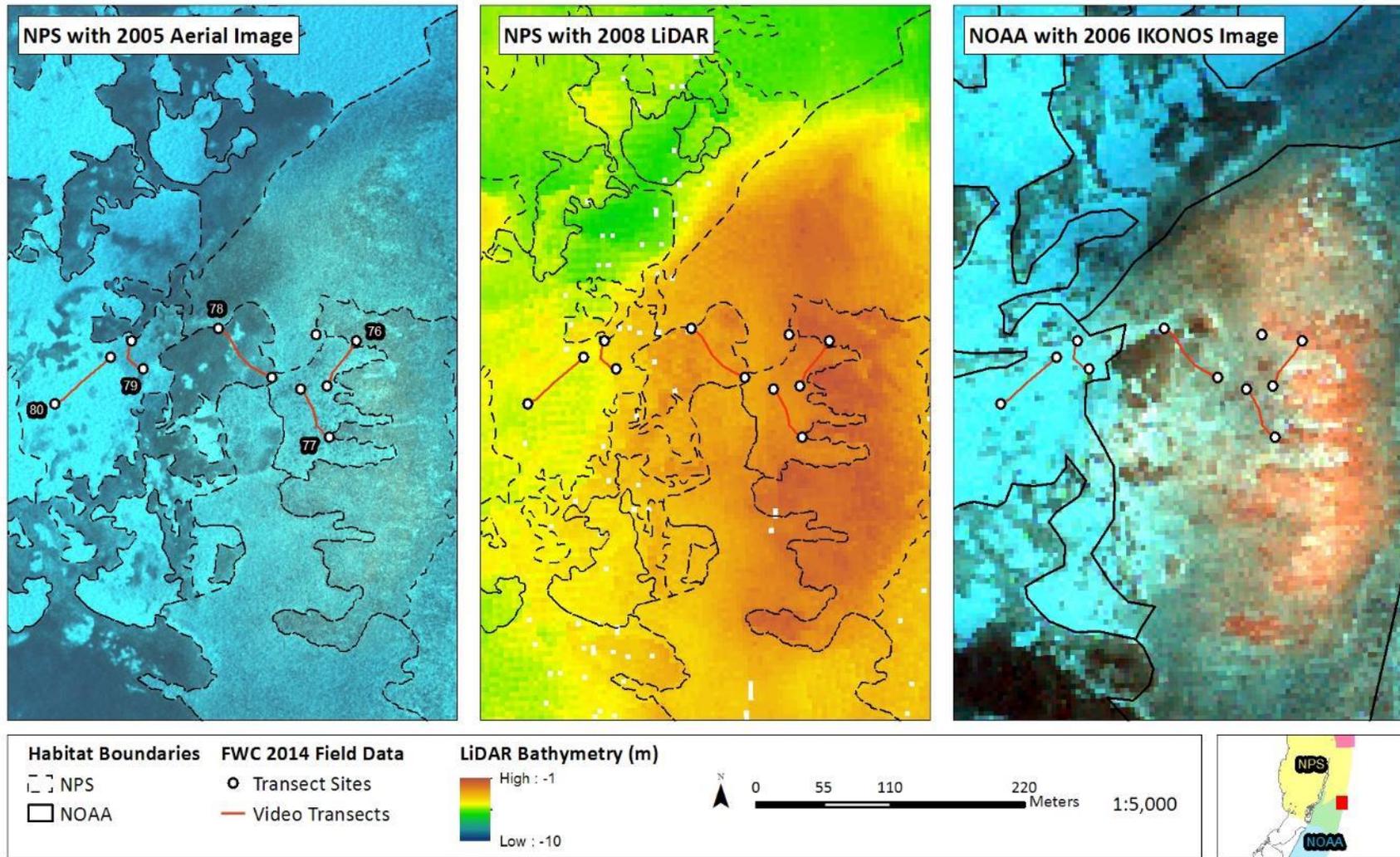


Figure A15. Differences in the spatial and spectral resolution between imagery sources used for the NPS map and the NOAA map at Sites 76-80. The 2005 aerial imagery and LiDAR used for the NPS map show bathymetric relief and subtle aerial signature differences between pavement and aggregate reef that are less discernible in NOAA's Ikonos image.

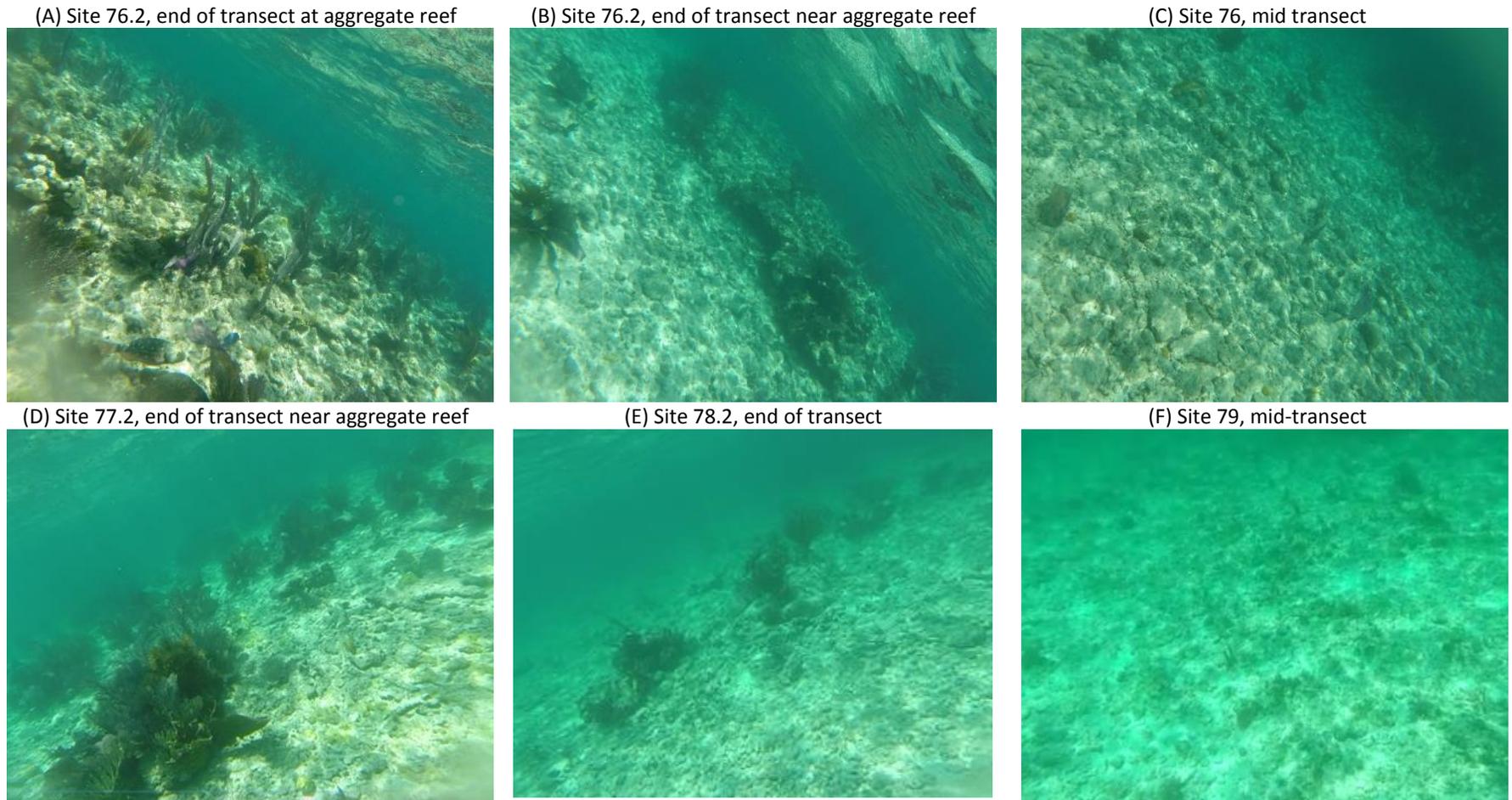


Figure A16. Video transect snapshots of Sites 76, 77, and 79. Habitat type as Sites 76 (Photo B and C) and 77 (Photo D) and at the very end of 78 (Photo E) consisted of reef rubble with scattered coral rock. Photos A and D show aggregate reef at the ends of Site 76 and 77 transects. Maps A and B show aggregate reef at end of Site 76 transect. Reef rubble mixed with unconsolidated sediment was observed at transects classified as discontinuous including Site 79 (Photo F), 78, and 80.

A.4 Patch Reef Discrepancies

In the NOAA/NPS comparison, there was an unexpectedly high similarity of individual patch reefs between maps. It was expected that higher resolution imagery and mapping scale would enable identification of more patch reefs in the NPS map, particularly smaller reefs that would be missed by NOAA's larger MMU of 625 m². This was not the case, however, as the total number of individual patch reefs was very similar between NPS (n=1460) and NOAA (n=1315). Agreement or disagreement between maps was also surprisingly independent of patch reef size (Figure A17). For example, almost half of the smallest reefs in the NPS map (i.e. <500 m²) were also identified by NOAA even though patch area was smaller than NOAA's MMU. Differences in how patch reefs were digitized can explain the unexpectedly high agreement of smaller individual patch reefs between NPS and NOAA. NOAA's coarser delineation of individual patch reefs often included grazing halos which enabled identification of smaller patch reefs that were less than the 625 m² MMU. NPS did not use a minimum size threshold for identification of patch reefs, rather, all reefs discernible from the 2005 imagery or LiDAR data were identified. Comparatively smaller individual patch reefs in the NPS map is likely the result of more precise delineation of patch reefs and exclusion of grazing halos. These results show that although map scale may influence *how* patch reefs are mapped (i.e. size), there was no noticeable difference in the *probability* of identifying an individual patch reef between the higher resolution NPS map and NOAA's map which was derived from coarser Ikonos imagery at a larger MMU.

Despite high individual patch reef agreement between NPS and NOAA, there were still a considerable number of NPS reefs that were unmapped by NOAA and vice versa. There was frequency confusion between individual patch and aggregated patch reefs in the NOAA/NPS comparison. This was likely a scale related issue that affected mapping of smaller clustered reefs. A group of smaller patch reefs was typically lumped together and classified by NOAA as aggregated patch reef, most likely because they could not be resolved separately from the coarser Ikonos imagery (Figure A19). In the NPS map, the same group of smaller patch reefs would be delineated separately and classified as individual patch reefs. Interestingly, individual patch reefs in the NOAA map were often classified by NPS as aggregated patch reef. This discrepancy can be attributed to NPS's ability to identify smaller patch reefs from higher resolution imagery within an area appearing in NOAA's Ikonos imagery as a single individual patch reef (Figure A19). In addition to confusion with aggregated patch reefs, individual patch reefs were also frequently classified as aggregate reef and pavement in the NOAA/NPS overlap.

In the NCRI/NPA comparison, agreement in patch reef habitats was low despite being digitized from similar imagery and seemingly comparable MMUs. NCRI mapped considerably more individual patch reefs than NPS. Agreement between maps was generally independent of patch size (Figure A18). Most individual patch reefs in the NCRI map were often classified by NPS as pavement or aggregated patch reef. The remaining unmapped NCRI individual reefs were simply missed by NPS; occurring in large areas of sediment or seagrass in the NPS map. Unlike the scale-related NOAA discrepancies, NCRI-NPS disagreement between individual patch reefs is likely a photo-interpretation issue.

For aggregated patch reefs, there was less than 1% overlap between the NCRI and NPS maps. Similar to individual patch reefs, NCRI mapped a significantly greater number of aggregated patch reefs than NPS. Most (over 60%) of NCRI's aggregated patch reefs were identified by NPS as scattered coral rock. This consistent discrepancy between aggregated patch reef (NCRI) and scattered coral rock (NPS) suggests differences in thematically interpreting these two classes rather than a scale or photo-interpretation issue.

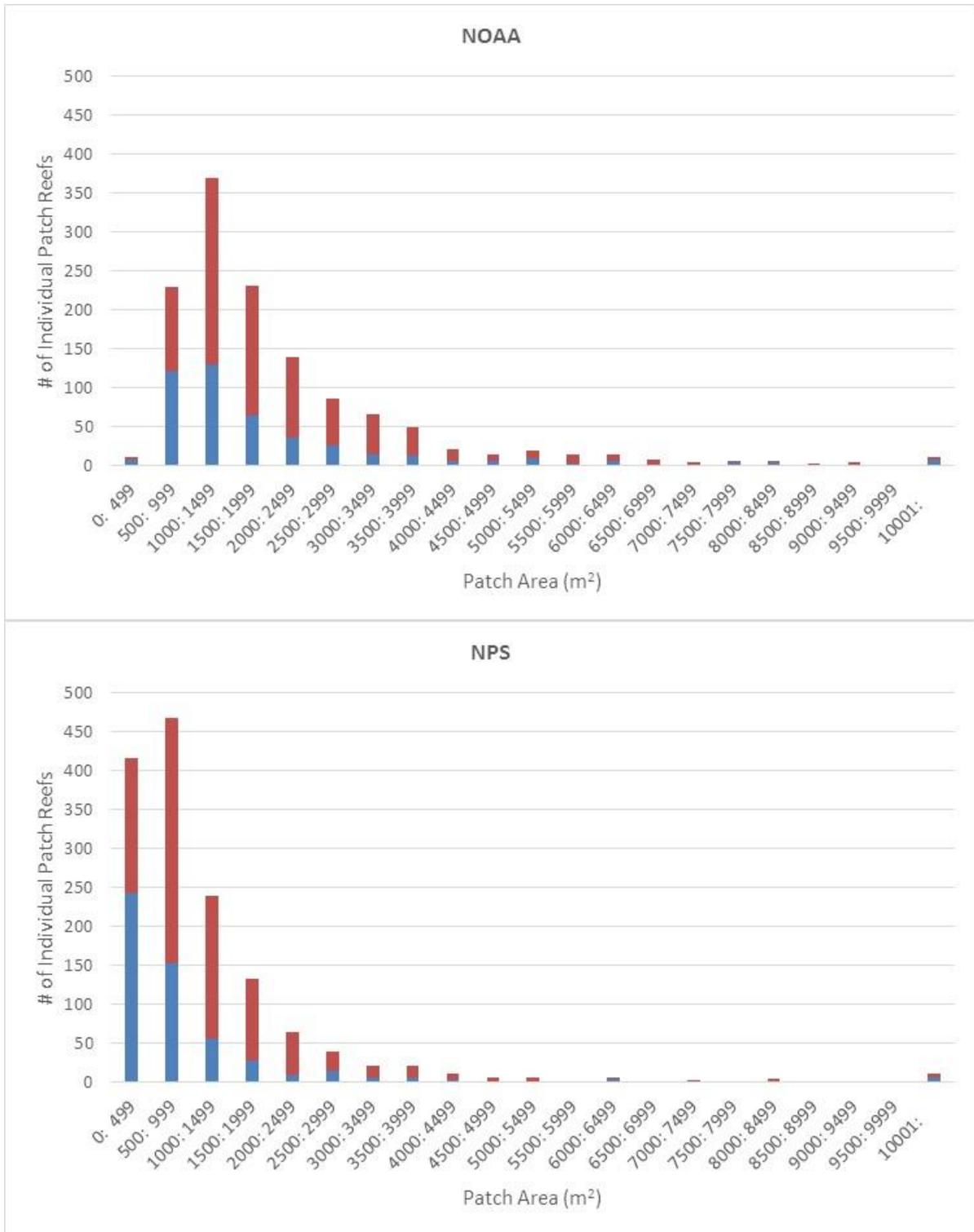


Figure A17. Size distribution of individual patch reefs in the overlap between NOAA (top) and NPS (bottom) maps.
 ■ Agree = # of individual patch reefs identified in both the NOAA and NPS map
 ■ Disagree = # of individual patch reefs identified by NOAA but not NPS (top) or identified by NPS but not NOAA (bottom)

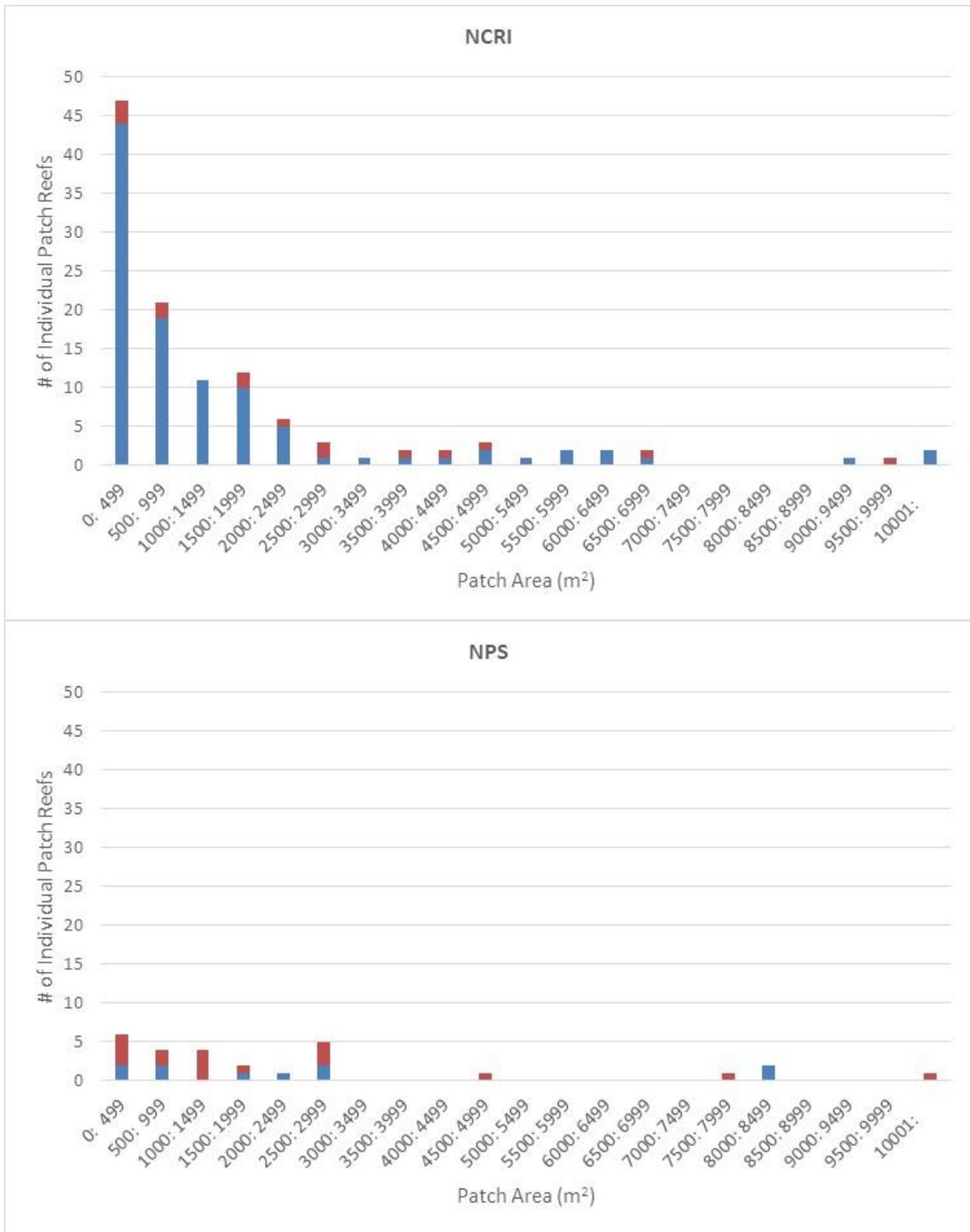


Figure A18. Size distribution of individual patch reefs in the overlap between NCRI (top) and NPS (bottom) maps
 ■ Agree = # of individual patch reefs identified in both the NCRI and NPS map
 ■ Disagree = # of individual patch reefs identified by NCRI but not NPS (top) or identified by NPS but not NCRI (bottom)

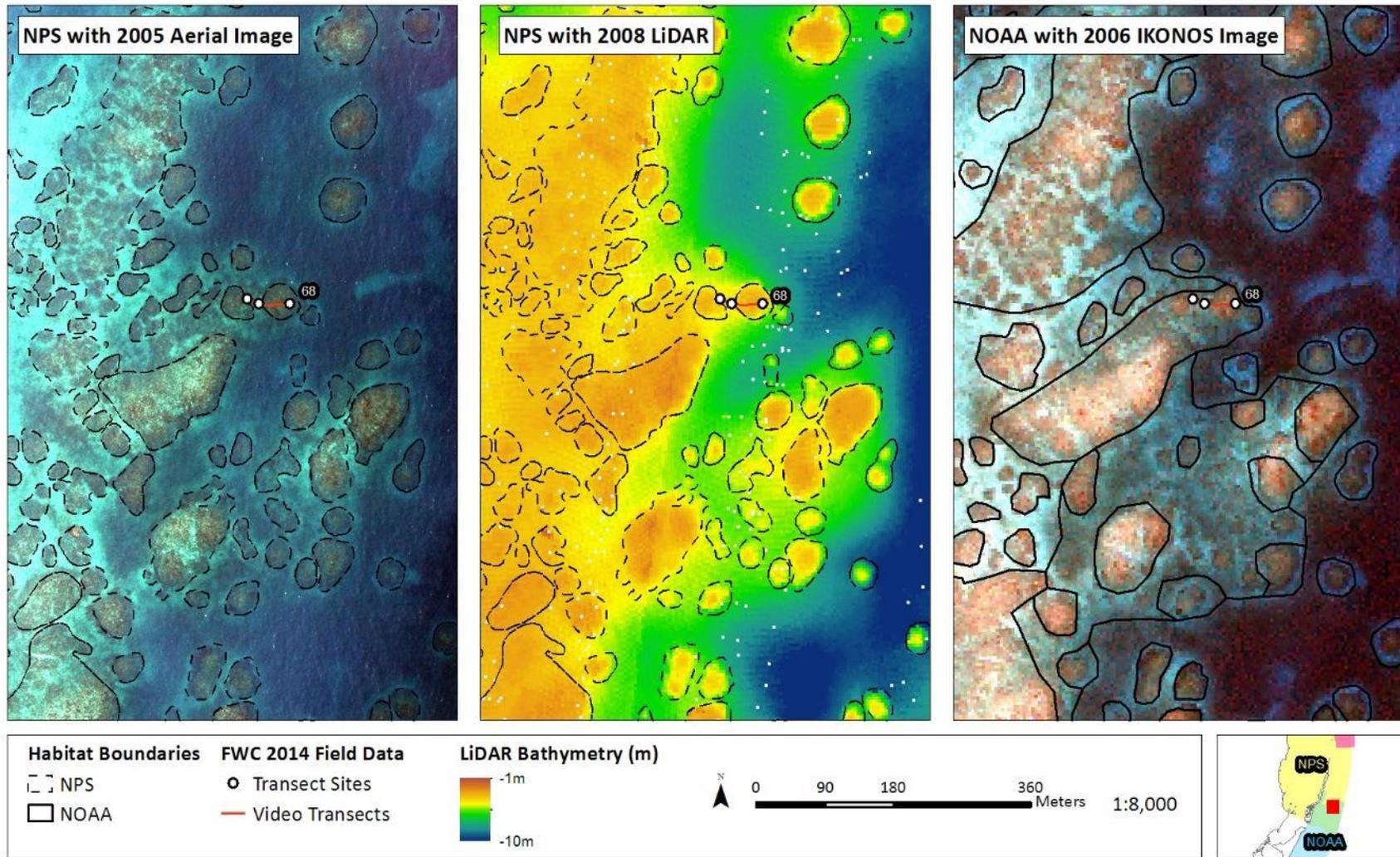


Figure A19. Aggregate reef and patch reef discrepancies between NOAA and NPS showing the differences in resolution between source imagery. The NPS map was derived in part from the 2005 aerial image (30cm) and LiDAR bathymetry. The 2006 IKONOS imagery (4m) was used to create the NOAA map.