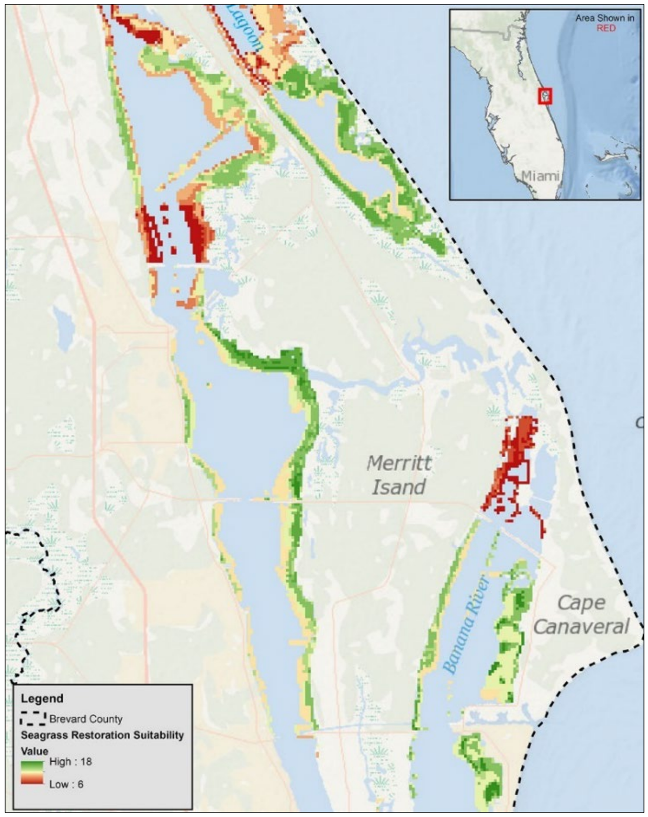
Brevard County Seagrass Restoration Protocol

November 2022



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01	05/31/2022	Client deliverable	J. Pennell
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Executive Summary

ES-1 PROGRAMMATIC BACKGROUND

The Indian River Lagoon, Florida (I.R.L.) is one of 28 estuaries of national significance, authorized as part of the United States Environmental Protection Agency's National Estuary Program. This shallow, microtidal estuary supports seven seagrass species: *Halodule wrightii* (shoal grass), *Syringodium filiforme* (manatee grass), *Thalassia testudinum* (turtle grass), *Halophila johnsonii* (Johnson's seagrass), *Halophila engelmannii* (star grass), *Halophila decipiens* (paddle grass), and *Ruppia maritima* (widgeon grass). Seagrasses are keystone species of this lagoon, with historic areal extent between approximately 20,000 and 30,000 hectares (Morris et al. 2022). Since 2011, the lagoon has experienced catastrophic loss of seagrass coverage with 58% of seagrass area lost and percent cover reduced to 4% from 20% by 2019 (Morris et al. 2022). The I.R.L. National Estuary Program (I.R.L.N.E.P.) Comprehensive Conservation and Management Plan (C.C.M.P) lists seagrass as one of its critical "vital signs" needing immediate, aggressive intervention with related goals of removing seagrass stressors and restoring seagrass habitats. The I.R.L.N.E.P. and most I.R.L. scientists agree that water quality improvements are urgently needed to restore seagrass coverage. Available estimates suggest seagrass recovery could take at least 12 to 17 years (Morris et al. 2022). While planting will not correct losses, as conditions in the I.R.L. improve, seagrass restoration through planting may help to support recovery in some areas by augmenting and enhancing recolonization and natural recovery (I.R.L.N.E.P. C.C.M.P.).

As planning for seagrass restoration planting projects begins, it is important to note that early projects will be largely experimental. While water quality conditions continue to need additional improvement, any planting will have a high risk of potential failure to survive and persist. However, by taking a methodical approach to planting design, execution, and monitoring, important questions can be addressed and lessons learned from successes while relative failures can inform future restoration efforts. The seagrass restoration protocol tool presented here aims to guide efforts to maximize what can be learned by offering guidance on initial site selection, design, and monitoring to understand what factors impact planting success. Variables known to influence seagrass growth and persistence were weighed in the presented model to identify the relative risk of planting in regions of the Brevard County portion of the I.R.L. at the segment level. This model does not predict outcomes, but rather aims to identify current conditions that pose differing risk levels to seagrass survival. Even highest-suitability/lowest-risk locations will have inherent risk; and low-suitability/high-risk locations do not necessarily guarantee failure. Rather, as risk increases, the need for well-designed, question-driven planting also increases. With this, the degree of monitoring necessary will also result in higher project complexity, labor, time, and thus cost. This protocol aims to provide a framework to start addressing current questions and leverage this effort to minimize risk where possible, while maximizing the investment in areas that test the current understanding of limitations to seagrass restoration success.

Early planting efforts funded through the I.R.L.N.E.P. have resulted in some important lessons learned. In a study led by Florida Oceanographic Society, the importance of genetic diversity to survival success was investigated. Though genetic diversity did not result in significant differences to shoot counts or density, impacts of water quality and siltation to survival success were observed. A seagrass restoration pilot conducted by Florida Atlantic University – Harbor Branch Oceanographic determined that herbivory can be a major challenge to planted sites. In Brevard County, both sedimentation and herbivory were noted challenges to a restoration planting conducted by the City of Satellite Beach. From additional projects led by Sea and Shoreline, LLC in the I.R.L., survival at one-year post-planting ranged from about 20 to 40%. From these and additional projects, having appropriate water quality, site selection, and design are key to success. When choosing locations, understanding historic persistence of seagrass, sediment type and stability, water depth, wave action, proximity to a major freshwater discharge, and adjacent land use are critical components. Projects are likely to face challenges related to herbivory, biofouling, bioturbation, and storms. Standardizing terms, a set of planting techniques, and monitoring protocols will be necessary to compare overall success between methods and locations and may also streamline future permitting.

ES-1 THIS REPORT

Section 1 and its antecedents provide term definitions, list local agencies and seagrass experts, and outlines the project objectives. **Section 2** describes the GIS based risk assessment model (Esri ArcGIS Pro 2.9.2, suitability modeler widget through ArcGIS web AppBuilder) and how input variables were chosen, and suitability values assigned. Water quality data were evaluated for their probability distribution and risk bins (suitability values) were subjectively assigned to major percentile levels but guided by the literature. However, recent research (Morris et al. 2022) provided invaluable, locally relevant suggested limits and percentile values were replaced by recommendations from that publication where appropriate. **Section 3** presents model outputs with links to the online map tool. **Section 4** details how to utilize relative risk scores to plan question driven restoration designs and poses some initial priority questions. Critical variables and suggestions for monitoring type and frequency are also proposed. The appendices provide a step-by-step plan for choosing a location and suggested directions for designing a project. There is also a sample data sheet, and suggested monitoring protocols available upon request (SeagrassProjects@brevardfl.gov).

At this point in time, the risk assessment model revealed only limited low-risk areas for seagrass restoration located primarily in the northern extent of the IRL in Brevard County. Notably, seagrass persistence is a very strong indicator of restoration suitability but can be misleading in areas of widespread seagrass loss where the absence of seagrass propagules due to past die-backs can mask suitable habitat emerging with any improved water clarity. Otherwise, it is important to recognize that these are risk assessments only and do not indicate where seagrass can and cannot survive. Rather, when multiple factors combine to indicate increased risk (above the inherent risk of seagrass restoration) then expectations of success should be tempered. Finally, a key objective of this effort was to facilitate useful question asking using seagrass transplants as experimental units and to capture that information systematically to feedback into subsequent decisions on restoration under a Plan-Act-Monitor-Learn cycle of management.

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List of Acronyms and Abbreviations

Chl a	water column chlorophyll a (may be as a concentration)
County	Brevard County
CSA	CSA Ocean Sciences Inc.
DEM	digital elevation model
DO	dissolved oxygen
EAI	Ecological Associates, Inc.
IRL	Indian River Lagoon
MWL	mean water level
PAML	plan, act, monitor, and learn
PU	planting unit
SAV	submerged aquatic vegetation
SJRWMD	St. Johns River Water Management District
SMW	suitability modeler widget
SV	suitability value

Presentation of Draft Guidelines for Seagrass Restoration Tool Participants (April 28, 2022). Input from the participants greatly improved the project. Participants with * are co-authors of this report:

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1 Study Background and Objective

In 2022, CSA Ocean Sciences Inc. (CSA) was contracted by Brevard County (County) through Ecological Associates, Inc. (EAI) to collaborate with scientists at the County and the St. Johns River Water Management District (SJRWMD) and create a protocol to guide restoration of seagrass. The protocol focused on guidance for selecting sites for restoration, with the objective being to restore seagrasses, primarily in the County's portion of the Indian River Lagoon (IRL) ecosystem. One of the overriding considerations in developing this protocol was to create a process of knowledge accumulation that would guide future restoration efforts.

Selecting a site for planting seagrass is a critical step in the process of seagrass restoration (Fonseca et al. 1998, Short et al. 2002, Eddings 2012, Novak and Short 2012, Santos and Lirman 2012, Thom et al. 2014, Flindt et al. 2016, Hu et al. 2021). Yet too often, seagrass restoration is performed without examination of the risk at a given site. Consequently, when a planting fails it may be assumed that "transplanting does not work", an unfortunate confusion of method and success while in fact, most methods work if applied in the appropriate environmental setting (Fonseca 2011). Relocation methods are almost exclusively vegetative stock and, currently, not seeds for the species in the IRL. Intact rhizomes with rhizome apicals and several shoots on the rhizome are required for successful colonization and subsequent vegetative expansion. Two methods are the most widely used; small sods of seagrass and anchored bare root units (e.g., landscape erosion staple) (see Fonseca et al. 1998).

Often, verification of the suitability of a site ultimately requires at least a pilot study to begin to understand limiting factors at the spatial scale of an individual site. The act of transplanting seagrass itself also offers an important opportunity to test those limiting factors and find what works best in each area. With only minimal additional effort, planting arrangements can become hypothesis-driven "experimental agriculture", organized under straightforward statistical designs whose results sort fact from supposition. Iterations of transplanting efforts, each subsequently informed by prior knowledge, will quickly focus efforts on successful approaches (which may include a recognition that restoration of seagrass is not yet an option for a given geographic location, pending larger scale environmental remediation). The protocol developed for this project emphasizes this experimental approach as part of the effort to restore seagrasses in the IRL.

Here, in a collaborative effort among scientists from CSA, SJRWMD, Applied Ecology[1], and the County, a data-based process of selecting sites for restoration of seagrass was created. Local IRL data were leveraged, and a risk modeling technique was applied, informed by seagrass growth limits from the literature on similar efforts worldwide as well as opinions of subject matter experts with decades of experience in seagrass ecology and restoration to select qualitative, relative risk values. The intent of the collaboration was to offer to those considering seagrass transplanting and restoration in the IRL simple, but effective, protocols for selecting sites, arranging planting, and monitoring. Practitioners of seagrass restoration using this guidance can then participate in the iterative process of knowledge building through the site selection process, informed project design, monitoring, analysis, and application of that new knowledge to the next round of seagrass restoration efforts. The protocol has four key elements:

1. Creation of a GIS-based risk assessment widget/program;
2. Linkage of the GIS-based risk assessment with a decision tree guiding utilization of the widget and its data;

[1] Applied Ecology produced the chlorophyll data layer through the development of calibration curves to apply in the analysis of satellite imagery and statistical analysis of chlorophyll trends geospatially over time under a separate contract with Brevard County.

3. Recommendations for design of plantings to address risk of failure at a given site; and
4. Guidance on information capture (monitoring and provision of data) and knowledge building (analysis and interpretation).

The combination of these four elements forms the totality of the protocol. The protocol starts with the selection of sites for restoration of seagrasses supported by chart products delineating levels of seagrass planting suitability throughout the IRL. Importantly, the suitability levels (i.e., the inverse of risk) of the site selection process are organized to allow those performing seagrass restoration not only to choose sites, but to also provide guidance as to what questions they could answer with their project design and monitoring based on the area's level of risk. Planting design guidance is integrated into the decision tree to build a larger knowledge-building framework so that otherwise disparate projects occurring within the County will have the opportunity to "fill in the blanks" and collectively accumulate knowledge in a pre-organized rather than post-hoc fashion. As questions regarding limitations to seagrass restoration are addressed through the various seagrass planting projects, "blanks" are filled in, and those questions will then be revised or de-emphasized and different, and remaining questions can be emphasized for subsequent projects. In this manner, the process minimizes redundancy of efforts and maximizes building a cumulative knowledge base.

The protocol is summarized in seven steps for users in **Appendix A** and follows a path of Plan, Act, Monitor, and Learn (PAML) where a seagrass restoration is planned with goals of learning ways in which to refine successful restoration efforts and promote seagrass recovery. After careful planning, the seagrass planting is then performed (the Act) and subsequently monitored (supporting learning). Those monitoring data should be provided to the County for analysis to learn about factors limiting seagrass survival and growth in the IRL and in turn, guide the next round of seagrass restoration. The protocol emphasizes the importance of planning including utilization of the site selection process using the GIS-based risk assessment described in this report. Also provided in **Appendix A** is a sample data sheet and reference to the monitoring protocol used by the SJRWMD which can be adapted to guide sampling of seagrass performance under transplanting.

2 Methods: Creation of a GIS-Based Risk Assessment

2.1 MODEL BASIS

The first step in building the model was assembly of spatially articulated parameters of environmental data across the IRL. Parameters were selected for relevance to seagrass survival and growth and assessed for their influence on seagrass restoration success to rank locations by risk of planting failure. The rank of each environmental data parameter was assigned across geographic locations, creating a suitability raster dataset covering the geography of the IRL for each parameter. The highest valued cells in each suitability raster represent the most suitable (lowest risk) areas for seagrass transplanting. The lowest valued cells in each suitability raster represent the least suitable areas for seagrass to thrive and should be considered high risk. The risk layers of the individual environmental parameters were summed to create a spatially articulated heat map of relative seagrass restoration site suitability across the IRL.

Water quality data were provided by the SJRWMD, Applied Ecology Inc., and the County. Water Quality data for water temperature, salinity, and dissolved oxygen (DO) were downloaded from online sources[2] and their locations shown in **Figure 1**. Locations of permanent monitoring transects surveyed from 2018 to 2020 (Morris et al. 2021, 2022) are also provided in **Figure 1**. Any seagrass restoration project should avoid these transect locations by at least 100 m to avoid biasing the seagrass health data collection. Bathymetry points with depths relative to Mean Water Level (MWL) were obtained from St. John's River Water Management District.

[2] The collection of data on the long-term health of seagrass: https://www.sjrwmd.com/data/water-quality/#status-trends , https://apps.sfwmd.gov/WAB/EnvironmentalMonitoring/index.html

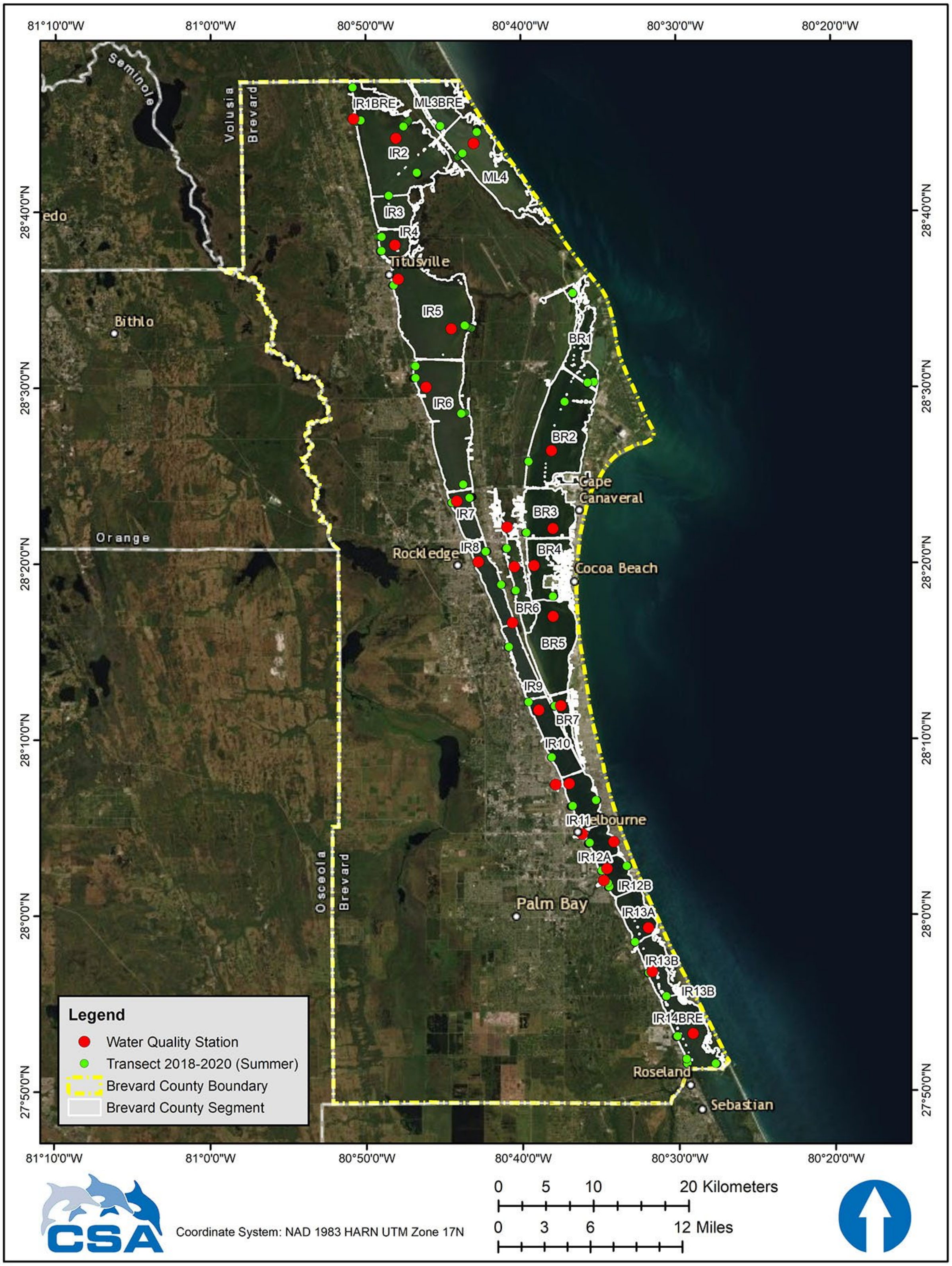

Figure 1. Map showing Indian River Lagoon segment delineation within Brevard County, Florida, along with locations of monthly water quality stations used in developing thresholds for risk assessment. The locations of permanent seagrass monitoring transects are also noted.

Data were compiled in an Esri (ArcGIS Pro 2.9.2) project and utilized in a suitability modeler widget (SMW) through ArcGIS web AppBuilder. The SMW allowed combination and if necessary, weighting of data layers to evaluate risk to the success of seagrass restoration. The SMW used a ranked raster overlay process to provide a spatial representation of risk by geographic location. A description of the steps followed in applying the SMW are given in **Appendix B**.

After review of the data provided in collaboration with the SJRWMD and the County, environmental parameters with a capacity to have a direct effect on seagrass physiology were selected to define risk. Additional parameters suggested in a feedback session with IRL stakeholders included sediment type and wave energy at the seafloor as these parameters can be incorporated into the model as they become available. Water column chlorophyll a (Chl a) data were available through an ongoing contracted project between Applied Ecology, Inc., and the County (Applied Ecology 2022), and were included to identify areas of recurrent algal blooms which consistently limit the light available to seagrass even in shallow water where seagrasses are normally found in the IRL. A final parameter, seagrass persistence was also added making six total parameters that were combined to create an overall risk assessment:

- Direct:
    - Water depth (as a surrogate for light availability);
    - Water temperature;
    - Salinity;
    - DO,
- Indirect:
    - Chl a;
    - Seagrass persistence.

These data were independently ranked for risk to seagrass growth and survival using literature guidance and combined to create overall risk zones of low, moderate, high, and extreme (no seagrass restoration recommended) risk.

Using values from the literature, assignation of risk was informed by creating thresholds within each data type based on trends in each parameter towards limited availability. Water depth was used as a surrogate for light availability based on suggested limits by Morris et al. (2022). Water temperature was also selected as it has been recognized as a factor limiting seagrass growth as early as Setchell (1929) as has salinity (Thayer et al. 1984 and references therein) although ranges are broad and species specific in their effects on productivity and survival (Fong and Harwell 1994, Merino et al. 2009). Dissolved oxygen was also selected as it directly affects the ability of seagrasses to prevent sulfide intrusion into their rhizomes and meristem (Carlson et al. 1994, Borum et al. 2005) and has been demonstrated to co-vary in its effect on seagrass as a function of temperature (Greve et al. 2003).Consequently, the simultaneous and sometimes co-varying effect of light, temperature, salinity, and DO on seagrass growth and survival is complex and a definitive model to predict the interactions, to our knowledge, does not yet exist. Hence, contributions of these parameters towards physiologically stressful conditions are approached simply as an additive process contributing to risk of planting failure or success. It should be noted that water quality and seagrass presence had begun to decline prior to this sampling period and the data utilized reflect relatively poor conditions, providing a conservative estimate of risk. As conditions improve, the risk at a given site may also decrease; however, site-specific conditions that are supportive to seagrass success should still be assessed.

The focus for the development of this model was to utilize recent environmental data including that for seagrass persistence, Chl a and water quality parameters. An emphasis on recent years' data was decided because, aside from turtlegrass (*Thalassia testudinum*), individual shoots of the other seagrass species in the IRL typically live no longer than two years (personal observation), ensuring that all the present-day seagrasses will have experienced and responded to these most recent environmental conditions (which are most likely to be most like conditions that may be experienced by any transplants).

While it remains possible for some seagrass species (e.g., *Ruppia maritima*, *Halophila* spp.) to grow in lower suitability (high-risk) areas and including areas of extreme risk, those areas may also represent conditions where extreme events may manifest more frequently and lead to greater fluctuation in cover (and seagrass planting success) in unpredictable ways. Nonetheless, while planting into high-risk sites may not generate persistent seagrass habitat, when combined with a statistically valid experimental design, these high-risk plantings can sometimes yield important information about limiting factors that will in turn guide upcoming restoration efforts. Nonetheless, a decision to undertake high-risk plantings is not recommended except in a strictly experimental investigation under the direction of experienced researchers. Here, the data are summarized and initial decisions regarding assigning suitability/risk to the range of each environmental parameter are discussed. All data were provided either by the SJRWMD or the County and their contractors. Data were compiled in ArcGIS Pro and were limited to Segments of the IRL falling within the boundaries of the County (**Figure 1**). Based on discussions by the project team, and in recognition of the spatial and temporal structure of the available data, it was decided that generalizations regarding seagrass site selection would be at the spatial extent of an IRL segment[3]. Those segments and the total number of water quality records along with means, standard error, median, minimum, and maximum values are shown in **Table 1**. Only 20 of the 25 IRL segments falling within the County contained water quality monitoring stations; however, the five segments that did not have a water quality monitoring stations (IR1BRE, IR9, IR3, ML3BRE, and BR1) did have seagrass persistence. Consequently, for those five segments water quality parameter values for temperature, salinity and DO were assigned a risk value for low suitability. This was done because in the SMW, absence of data for any parameter from a segment would prevent inclusion of that segment in the overall risk model process. Several data types were utilized in the tool; spatial distribution of seagrass persistence, bathymetry, and monthly measures of environmental parameters (water depth [m], water temperature [$^{\circ}$C], dissolved oxygen [DO ppm], salinity [ppt]) and the spatial distribution of Chl a over time. It should be noted however, that the persistence data provided by the SJRWMD are for the years 2015-2019, every two years. An updated seagrass persistence database should be utilized when available.

For environmental parameters, the emphasis was on parameters with the capacity to directly affect seagrass physiology. Parameters that for the most part indirectly affect seagrass physiology such as water column total suspended solids, colored dissolved organic matter, and other water column constituents such as nutrients that could cascade to affect light attenuation (e.g., facilitate algal abundance) were not selected. The water depth band (-0.5 to -0.9 m) recommended by Morris et al. (2022) was utilized as a screening factor that represents light availability, hence other parameters associated with light attenuation such as diffuse attenuation coefficient and Secchi depth were not selected. However, Chl a has been mapped as an indicator of algal bloom conditions and has the capacity to shade seagrass even within the recommended depth range, thus was included as a risk factor.

Risk levels were assigned using a combination of information including a numeric process based on available raw data subjected to cumulative frequency distribution analysis, limits as described in Morris et al. (2022) and information from Applied Ecology Inc working under a separate contract for the County. For the numeric process, the data for water temperature, DO, and salinity from water quality stations in the IRL in Brevard County were each analyzed (SAS Proc Univariate, SAS 2016, version 9.4) using values from all IRL segments combined to obtain an IRL-wide probability distribution of those data. The locations of the water quality stations were plotted in relation to the IRL segments and mean values were computed for each segment. Initial risk levels were assigned to each segment by comparing

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[3] (9) (PDF) Decadal Changes in Seagrass Distribution and Abundance in Florida Bay (researchgate.net)

the segment mean values to the 25th and 75th percentile values from the overall IRL probability distribution (see **Section 2.2**, below for the actual risk level cut-off values). Information from Morris et al. (2002) and the Applied Ecology (2022) study was used to populate risk levels for other parameters and sometimes were used to override and modify the quartile-based risk levels for water temperature, DO, and salinity; those alterations to risk levels are described in **Section 2.2**, for each parameter below.

All parameters were ranked in a 3-value suitability/risk framework with 1 being the lowest suitability (highest risk) and 3 being a better condition and hence more suitable (lowest risk). This was done to accommodate some parameters that were best represented across a gradient (e.g., seagrass persistence, Chl a) and to allow future addition of graduated risk scoring for those currently ranked under a single threshold that creates only two risk categories. Consequently, the two-value risk categories for water temperature, DO, and salinity where an initial suitability value of just 1 or 2 was assigned were converted in the ArcGIS widget into a three-class framework. Scores of 1 stayed 1 and scores of 2 became 3, skipping over a suitability value of 2 in such a case. Using the 3-value suitability framework with six parameters (seagrass persistence, water depth range, water temperature, salinity, DO, and Chl a), the highest (most suitable) possible total score was 18 and the lowest total suitability score was 6 (least suitable) and are presented in a heat map format. In geographic portions of the IRL where there was no overlap of data for all six parameters, these areas are not presented in the final summation of suitability (i.e., the color ramp for the heat map ranges from 6 to 18). Risk for seagrass restoration in those areas would be yet more extreme and should not be considered as restoration sites.

Weighting can also be applied to each parameter in the SMW. For example, if more parameters with indirect effects on seagrass were added to the model, then those might be weighted less than those with the capacity for direct, physiological effects. In this version with its emphasis on parameters with direct effects, all parameters remain unweighted. The assignation of suitability values (SV) for the seagrass and environmental parameters are discussed below.

Table 1. Summary of monthly water quality data for salinity (ppt), temperature (˚C) and dissolved oxygen ([O_2] mg l^{-1}) by segment from 3/1/2019 to 3/1/2022, by Indian River Lagoon segment. Colored bars scaled to all the cell values with that color were added for visual comparability. N = number of observations.

Salinity (ppt)	N	Mean	Std Error	Median	Minimum	Maximum
BR2	32	20.4	0.33	20.0	17.9	24.8
BR3	119	20.2	0.14	19.9	17.9	24.0
BR4	30	20.0	0.25	19.7	17.9	22.6
BR5	31	20.0	0.19	20.3	18.2	22.2
BR6	66	18.9	0.17	18.6	15.8	22.9
BR7	31	20.1	0.32	20.2	17.0	24.5
IR10	31	19.7	0.36	19.8	16.4	24.8
IR11	237	17.8	0.28	18.0	0.2	29.4
IR12A	197	17.4	0.50	18.1	0.7	31.9
IR12B	194	17.0	0.61	18.3	0.2	33.8
IR13A	31	23.9	1.07	21.6	17.0	35.7
IR13B	31	25.6	1.13	25.2	16.7	35.6
IR14BRE	31	28.1	1.05	28.3	17.1	36.1
IR2	62	22.7	1.00	23.7	2.9	34.9
IR4	123	23.5	0.38	23.6	16.1	31.2
IR5	64	22.7	0.49	22.7	16.5	29.8
IR6	31	21.8	0.58	21.6	16.4	27.5
IR7	119	20.3	0.20	19.9	16.6	25.7
IR8	62	19.7	0.23	19.6	16.3	24.2
ML4	124	28.7	0.37	29.4	20.0	37.5
IR1BRE	no data					
ML3BRE	no data					
IR3	no data					
BR1	no data					
IR9	no data					

Table 1. (Continued).

Water Temperature (°C)	N	Mean	Std Error	Median	Minimum	Maximum
BR2	32	23.8	0.91	25.3	12.6	29.7
BR3	119	24.8	0.48	26.9	12.1	31.2
BR4	30	24.7	0.94	26.8	12.7	30.6
BR5	31	24.8	0.87	26.1	14.4	30.5
BR6	66	24.9	0.55	26.1	13.5	30.8
BR7	31	24.7	0.93	26.0	13.7	31.2
IR10	31	25.4	0.86	27.3	14.9	31.6
IR11	237	26.3	0.27	27.3	15.2	33.1
IR12A	197	26.1	0.30	27.3	13.6	32.6
IR12B	194	26.3	0.30	27.5	14.3	32.1
IR13A	31	24.7	0.89	26.9	14.1	30.5
IR13B	31	25.0	0.89	27.0	14.0	30.7
IR14BRE	31	24.6	0.85	26.8	13.9	30.1
IR2	62	24.3	0.60	25.7	12.9	30.7
IR4	123	25.5	0.42	27.1	13.5	31.8
IR5	64	25.2	0.62	27.4	14.0	32.2
IR6	31	24.9	0.87	26.7	14.6	30.4
IR7	119	25.4	0.44	27.2	14.5	31.6
IR8	62	25.3	0.61	27.0	14.5	31.0
ML4	124	24.9	0.42	26.8	11.6	31.2
IR1BRE	no data					
ML3BRE	no data					
IR3	no data					
BR1	no data					
IR9	no data					

Table 1. (Continued).

Dissolved O_2 (mg l^{-1})	N	Mean	Std Error	Median	Minimum	Maximum
BR2	32	6.7	0.26	6.7	4.1	9.5
BR3	119	7.0	0.14	7.2	4.3	12.9
BR4	30	7.5	0.22	7.2	5.6	9.6
BR5	31	7.4	0.28	7.1	5.1	11.6
BR6	66	7.1	0.18	7.1	3.8	11.7
BR7	31	7.3	0.39	7.0	1.6	13.1
IR10	31	7.4	0.28	7.1	3.8	11.0
IR11	237	6.7	0.14	6.8	0.7	12.0
IR12A	197	5.7	0.20	5.6	0.5	20.9
IR12B	194	5.4	0.20	5.9	0.3	11.8
IR13A	31	6.9	0.24	6.7	4.8	11.9
IR13B	31	6.7	0.24	6.2	4.2	9.9
IR14BRE	31	6.9	0.21	6.4	4.9	9.2
IR2	62	4.9	0.33	5.6	0.5	10.4
IR4	123	6.6	0.15	6.5	2.8	12.3
IR5	64	7.6	0.18	7.4	4.7	11.7
IR6	31	6.7	0.23	6.8	3.6	9.3
IR7	119	6.5	0.15	6.5	1.9	10.7
IR8	62	7.1	0.15	7.0	4.3	10.1
ML4	124	6.5	0.11	6.5	3.3	9.8
IR1BRE	no data					
ML3BRE	no data					
IR3	no data					
BR1	no data					
IR9	no data					

2.2 INPUT DATA

Seagrass Persistence: Persistent presence of natural seagrass is a strong and highly integrative indication of the ability of a segment to support seagrass transplanting. The resolution of these data was 10 × 10 m and they provide the granularity observed in the heat map products. Seagrass persistence has spatial resolution within the individual IRL segments whereas the water quality data, except for Chl a (resolution of 300 × 300 m) were averaged at the IRL segment level. Areas where no seagrass had ever occurred during the years 2015-2019 were excluded from the scoring (effectively setting those areas to a SV of 0). SV scoring was as follows:

- If present all three survey years, SV = 3 (low risk)
- If present two of the three survey years, SV = 2 (moderate risk)
- If present for only one of the three survey years, SV = 1 (high risk)
- All other values: excluded.

Except for water depth and Chl a, both of which had spatial resolution within the individual IRL segments, the other environmental parameters were evaluated at the segment level for their quartile distribution using PROC Univariate in SAS (9.4) after averaging each parameter. Cut-off values in the quartile distribution were made to assign an SV (e.g., above and below a cumulative percentage of the observed environmental data) to create SV bins for each parameter. The environmental data represent monthly measurements of a variety of water quality information from 03/01/2019 to 03/01/2022. The cut-off values were informed by review of literature values especially those provided in Fong and Harwell 1994, Merino et al. 2009, Morris et al. 2021, and Morris et al. 2022.

The values at which seagrass may die off fall outside the quartile range of the segment-averaged data. Consequently, the quartile cut-offs are indicative of a trend towards poor quality conditions rather than the cut-off being a representation of a mortality threshold. There is no definitive model to forecast how all these parameters interact to influence seagrass growth and survival, given the combinations and permutations of how extreme, how long, and how frequent any given parameter may be at a level stressful to seagrass. In the absence of predictability of these interactions on seagrass growth, the additive approach to combine trends toward stressful conditions for the various parameters is a conservative approach to assessing combined risk of all the environmental parameters.

Other strategies may be developed for ranking risk and the SMW model is flexible and readily allows incorporation of different risk-binning[4]. In the suitability model being developed, higher SV score indicates a better overall environment.

Water Depth (m): The bathymetry transects from the downloaded data were used to create a digital elevation model (DEM) by using the "Topo To Raster" tool. The bathymetry DEM was then reclassified using the "Reclass" tool to represent scores based on a literature review to reflect suitability for seagrass survival. Water depth (MWL) was set by water depths recommended by Morris et al. (2022). As noted above, use of a fixed water depth range obviated the need to utilize any parameters related to light transmission through the water column (e.g., diffuse attenuation coefficient, Secchi depth, etc.) that would otherwise be utilized to predict seagrass depth limits. The 0.5 to 0.9 m depth range received an SV score of 3 representing the lowest risk (highest suitability) depths for seagrass. A shallower >0.1 m and <0.5 m "buffer zone" received an SV score of 2 (moderate risk) to accommodate potential shallow water colonization by *Halodule wrightii* but was also less suitable because of potential emersion. A >0.9 m and ≤2.0 m depth range received an SV of 1 to represent a high-risk depth range for seagrass that could become available with only an improvement with water clarity. All other values were excluded from the scoring, consistent with methods applied to areas of no seagrass persistence, setting those areas to an SV of 0. SV scoring after transformation to the 3-value framework followed the initial classification:

- Shallow water depths of, ≥0.1 m and <0.5 m, SV = 2 (moderate risk)
- Mid water depths of ≥0.5 m and ≤0.9 m, SV = 3 (low risk)
- Deep depths of >0.9 m and ≤2.0 m, SV = 1 (high risk)
- All other values: excluded.

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[4] More information on the ArcGIS Pro tool can be found here: https://pro.arcgis.com/en/pro-app/2.7/help/analysis/spatial-analyst/suitability-modeler/the-general-suitability-modeling-workflow.htm

Water Temperature (˚C): Water temperature data are shown in **Table 1**. Data were largely invariant with a grand mean of 25.1 (± 0.095 standard error [SE]). For the suitability model, we used the 75th percentile (25.42˚C) as an upper threshold and an SV = 2 (moderate risk) cut-off. Also, if the segment water temperature 25th percentile was lower than 20 °C then per Morris et al. (2022) it was scored as SV = 1 (high risk). SV scoring after transformation to the 3-value framework was as follows:

- If 25th percentile of the segment's water temperature is <20 °C then SV = 1, (high risk)
- If the segment means water temperature >75th percentile of the lagoon (25.42 °C), then SV = 2 (moderate risk)
- Otherwise, SV=3 (low risk).

Dissolved Oxygen (mg l^{-1}): DO data are shown in **Table 1**. The grand mean value (mean of 20 segments) was 6.72 mg l^{-1} (± 0.104 standard error [SE]). For the suitability model, we used the 25th percentile (6.55 mg l^{-1}) as the lower threshold cut-off. SV scoring after transformation to the 3-value framework was as follows:

- if DO was <25th percentile then SV = 1 (high risk)
- otherwise, SV = 3 (low risk).

Salinity (ppt): Salinity data are shown in **Table 1**. The grand mean value (mean of 20 segments) was 21.4 ppt (± 0.104 standard error [SE]). For the suitability model values from Morris et al. (2022) were used as guidance; if the segment mean salinity was <25th percentile (19.75) it was scored as SV=1 (high risk). If the 75th percentile of the segment salinity was <23ppt and the segment mean was >25th percentile (19.75ppt) then it was scored as SV = 2 (moderate risk). Otherwise, the risk was set to SV = 3 (low risk)). SV scoring after transformation to the 3-value framework was as follows:

- If the segment mean salinity is < 25th percentile (19.75), SV = 1 (high risk)
- If the 75th percentile of the segment salinity is <23ppt and the segment mean > 25th percentile (19.75ppt), SV = 2 (moderate risk)
- Otherwise, SV = 3 (low risk).

Chlorophyll a (Chl a): Estimated chlorophyll concentrations were provided by Applied Ecology, Inc under contract to the County (Applied Ecology 2022) and were calculated from reflectance data (2015-2019) obtained via satellite with equations calibrated to *in situ* measurement of chlorophyll. Data were ranked via Mann-Kendall statistics to identify trends in chlorophyll concentrations, assigning a classification based on the relative concentration of chlorophyll, its trend over time, and the frequency of high chlorophyll events. This resulted in 10 categories ranked based on more stable and clear trends versus categories with higher variability due to the presence of submerged aquatic vegetation (SAV) or more random bloom activity. SV scoring after transformation to a 3-value framework was as follows:

- If chlorophyll concentration was significantly decreasing over time, chlorophyll concentrations were generally low, and there were infrequent high concentration events, then SV = 3 (low risk)
- If chlorophyll concentration was significantly increasing over time and chlorophyll concentrations were generally low, however there was a high frequency of high concentration events, then SV = 1 (high risk)
- Otherwise, SV = 2 (moderate risk) due to fluctuating chlorophyll values over time and the potential presence of SAV.

3 Results

The individual parameters and their spatial contribution to the overall, final heat map of seagrass planting suitability is summarized starting with **Figure 2** which shows the spatial distribution of SV for water depth. Water depth and the depth range used as the basis for risk binning crosses all segments with spatial resolution within the individual IRL segments. **Figure 3** shows the spatial distribution of SV for seagrass persistence which, like water depth, was a spatially continuous parameter that crossed all segments. **Figures 4, 5** and **6** show the spatial distribution of SV for water temperature, salinity and DO, respectively. Values for these parameters were averaged at the segment level and were derived from the water quality stations shown in **Figure 1** and so have discrete SV that occur by IRL segment. The segment-specific SV for these three parameters is shown in **Table 2**. **Figure 7** shows the spatial distribution of SV for Chl a which, like water depth and seagrass persistence, is a spatially continuous variable across IRL segments. **Figures 8** to **10** show the spatial distribution of overall SV, a sum of all SV (**Figures 2** to **7**)[5] as the final guide for seagrass planting site selection. **Figures 8** to **10** (the final guide was divided into three segments for readability for those not viewing in PDF format) indicate substantial spatial restriction to the areas of low, moderate, and high-suitability sites for seagrass restoration from recommendation for seagrass transplantation. A link to the online tool is provided in the footnote along with a QR code for readability.[6]

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[5] Again, geographic portions of the IRL which sum to suitability values less than 6 (i.e., data did not occur at that location for all six parameters) is not plotted because it has an even lower potential of seagrass restoration success.
[6] https://gis.brevardfl.gov/portal/apps/webappviewer/index.html?id=4732bdd5ed724f1391bd9d521a37d653

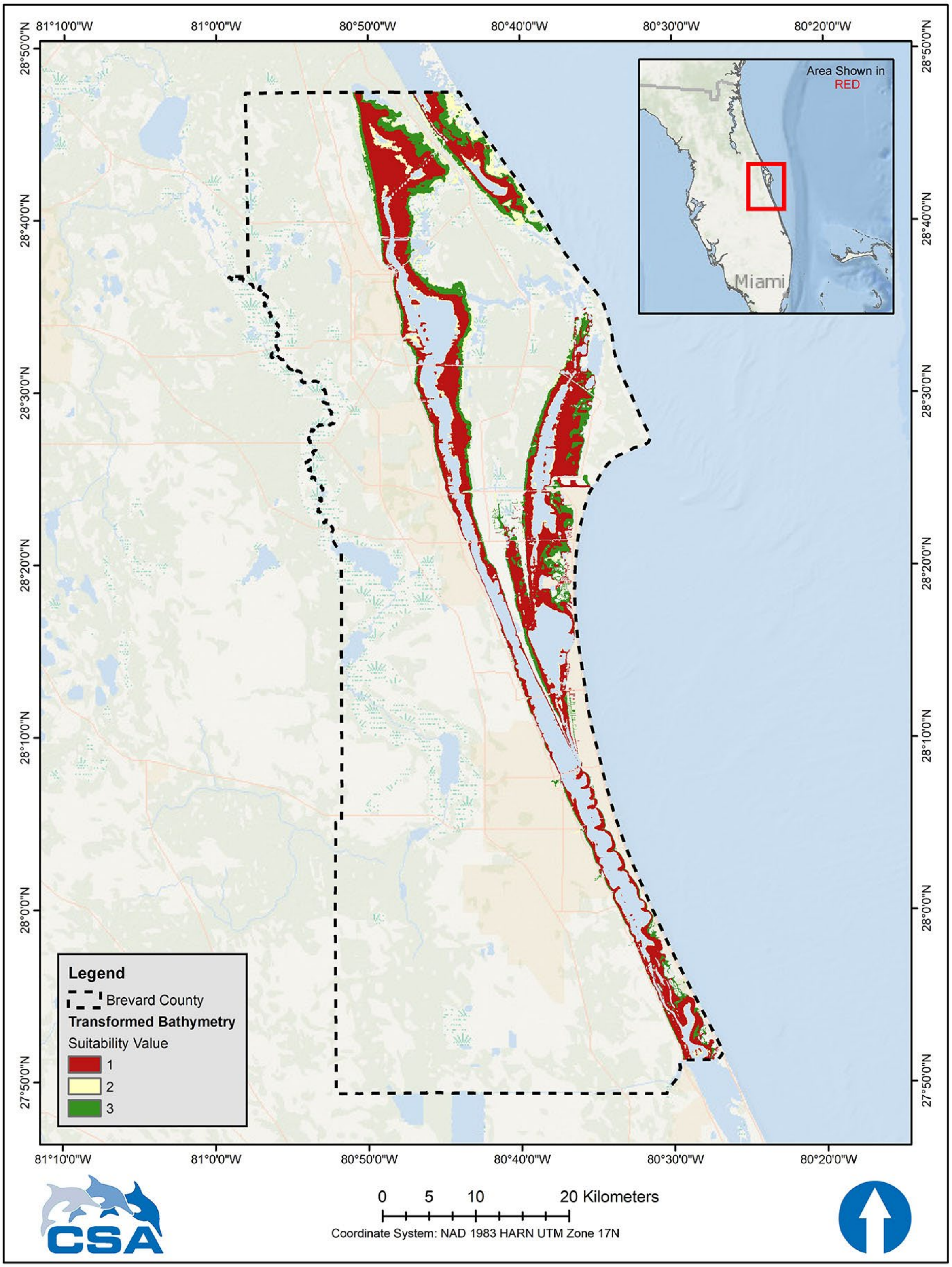

Figure 2. Map showing risk values for seagrass transplantation based on water depth (m) for the Indian River Lagoon segments within Brevard County, Florida. A suitability value of 1 = high risk, 2 = moderate risk, and 3 = low risk. Areas not within the selection range were excluded.

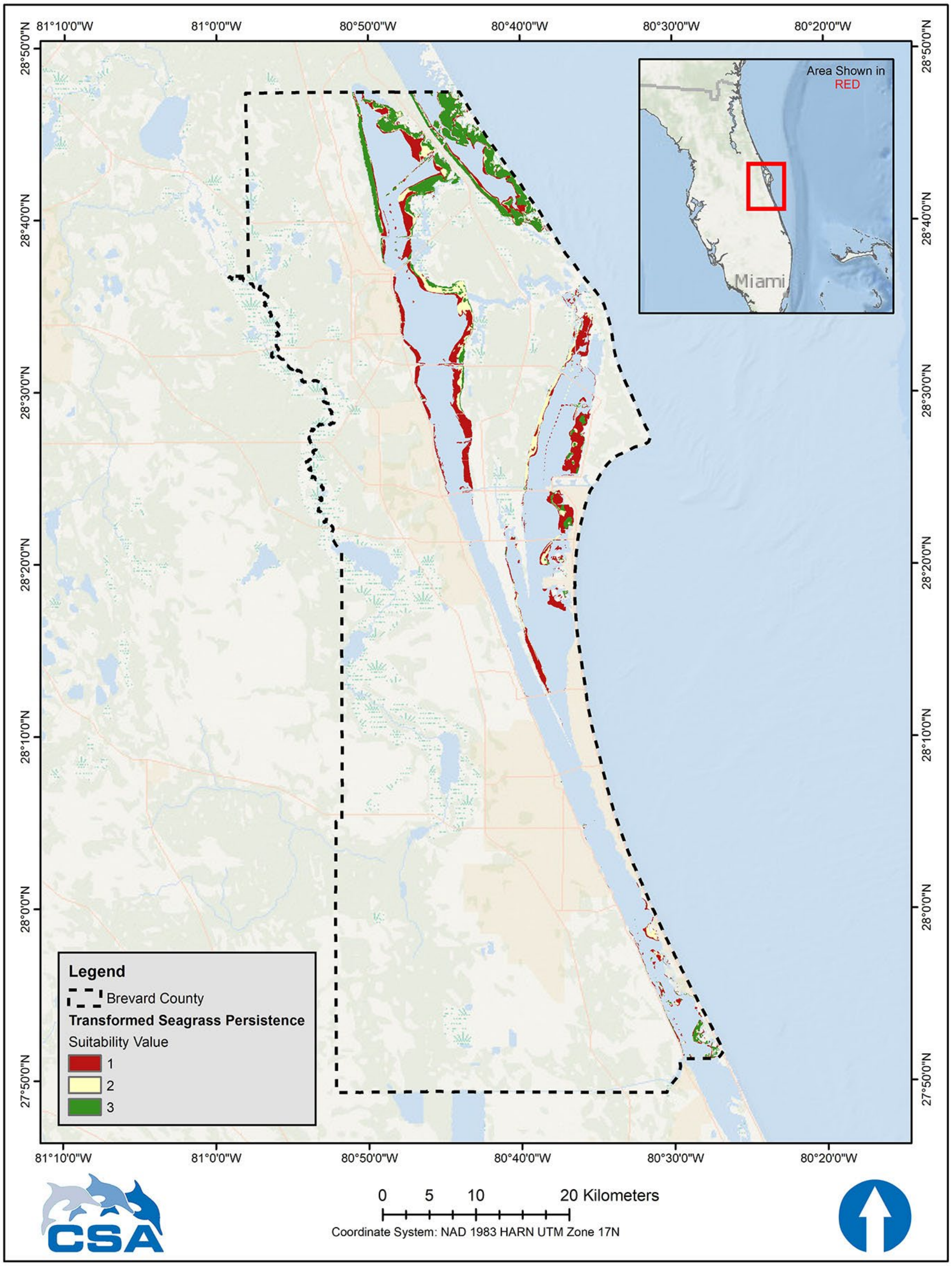

Figure 3. Map showing risk values for seagrass transplantation based on seagrass persistence across survey years 2015, 2017 and 2019 and across the Indian River Lagoon segments within Brevard County, Florida. A suitability value of 1 = high risk, 2 = moderate risk, and 3 = low risk. Areas not within the selection range were excluded.

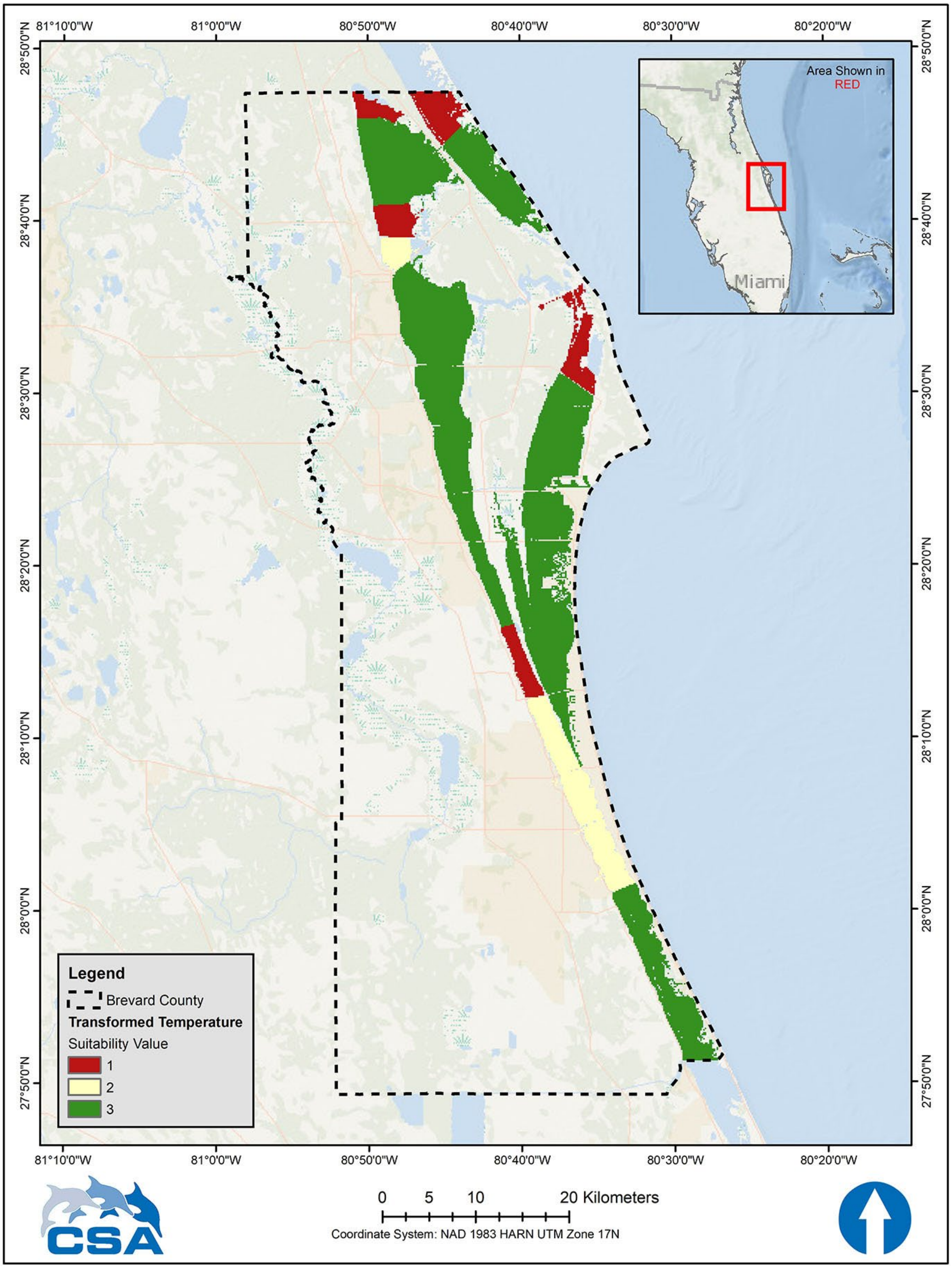

Figure 4. Map showing risk values for seagrass transplantation based on water temperature (°C) for the Indian River Lagoon segments within Brevard County, Florida. A suitability value of 1 = high risk and 3 = low risk. There was no risk value of 2.

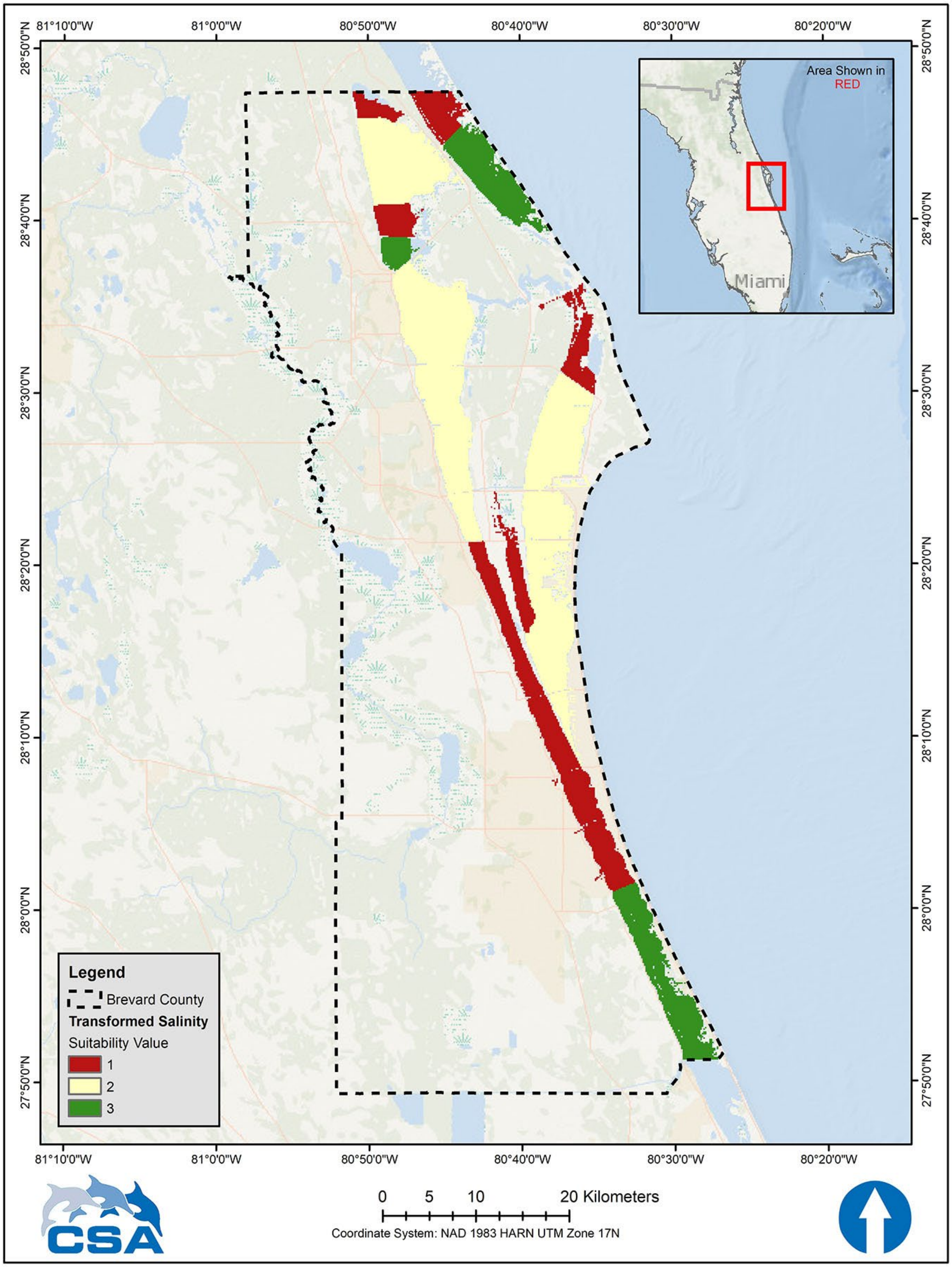

Figure 5. Map showing risk values for seagrass transplantation based on water salinity (ppt) for the Indian River Lagoon segments within Brevard County, Florida. A suitability value of 1 = high risk and 3 = low risk. There was no risk value of 2.

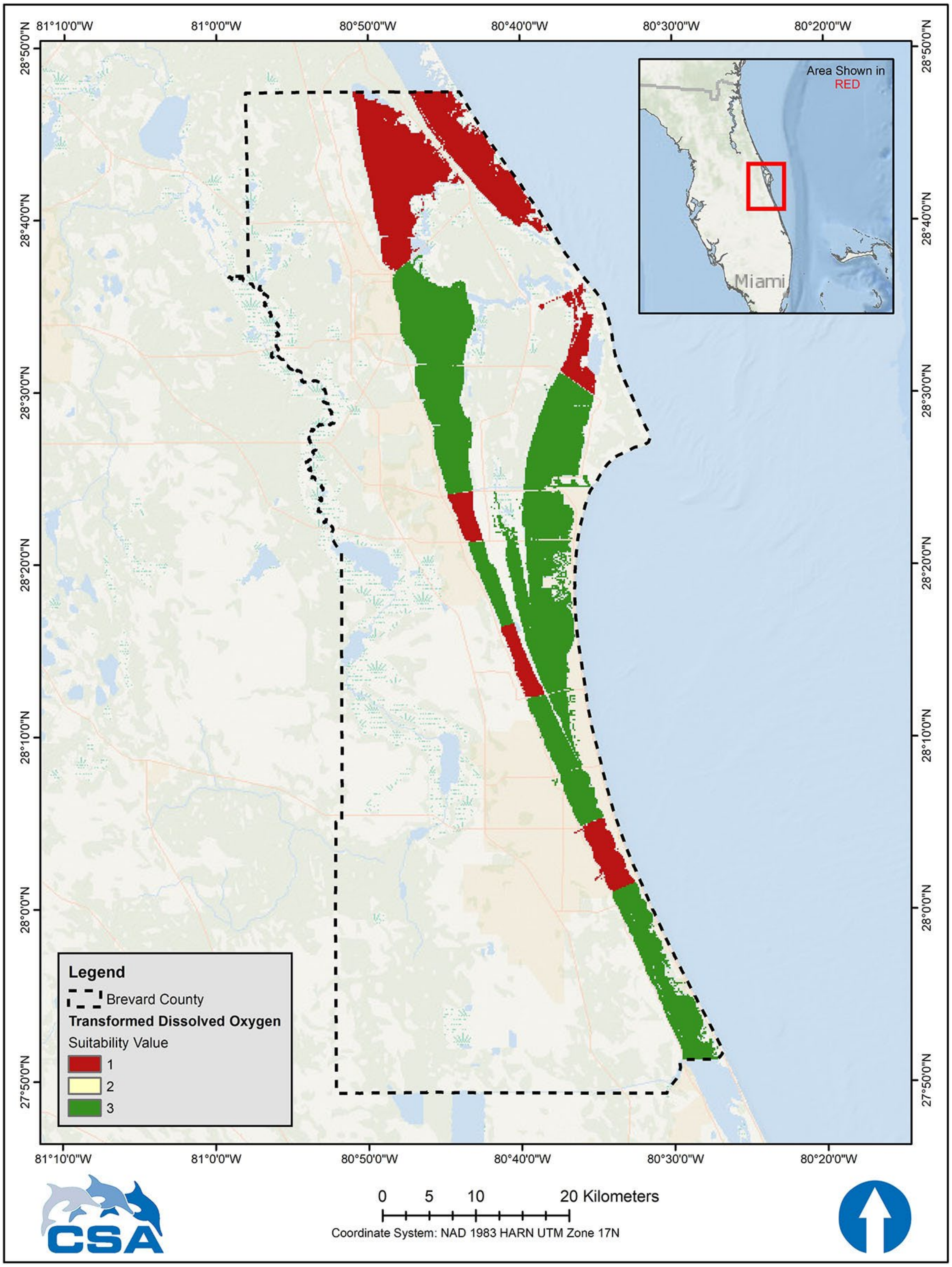

Figure 6. Map showing risk values for seagrass transplantation based on water dissolved oxygen (mg l^{-1}) for the Indian River Lagoon segments within Brevard County, Florida. A suitability value of 1 = high risk and 3 = low risk. There was no risk value of 2.

Table 2. Chart showing the transformed risk values, by segment for the three parameters that were averaged at the segment level. Colored bars scaled to all the cell values were added for visual comparability.

Segment	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg l^{-1})
BR1	**1**	**1**	**1**
IR12A	**2**	**1**	**1**
IR12B	**2**	**1**	**1**
IR1BRE	**1**	**1**	**1**
IR2	**3**	**2**	**1**
IR3	**1**	**1**	**1**
IR4	**2**	**3**	**1**
IR7	**3**	**2**	**1**
IR9	**1**	**1**	**1**
ML3BRE	**1**	**1**	**1**
ML4	**3**	**3**	**1**
BR2	**3**	**2**	**3**
BR3	**3**	**2**	**3**
BR4	**3**	**2**	**3**
BR5	**3**	**2**	**3**
BR6	**3**	**1**	**3**
BR7	**3**	**2**	**3**
IR10	**2**	**1**	**3**
IR11	**2**	**1**	**3**
IR13A	**3**	**3**	**3**
IR13B	**3**	**3**	**3**
IR14BRE	**3**	**3**	**3**
IR5	**3**	**2**	**3**
IR6	**3**	**2**	**3**
IR8	**3**	**1**	**3**

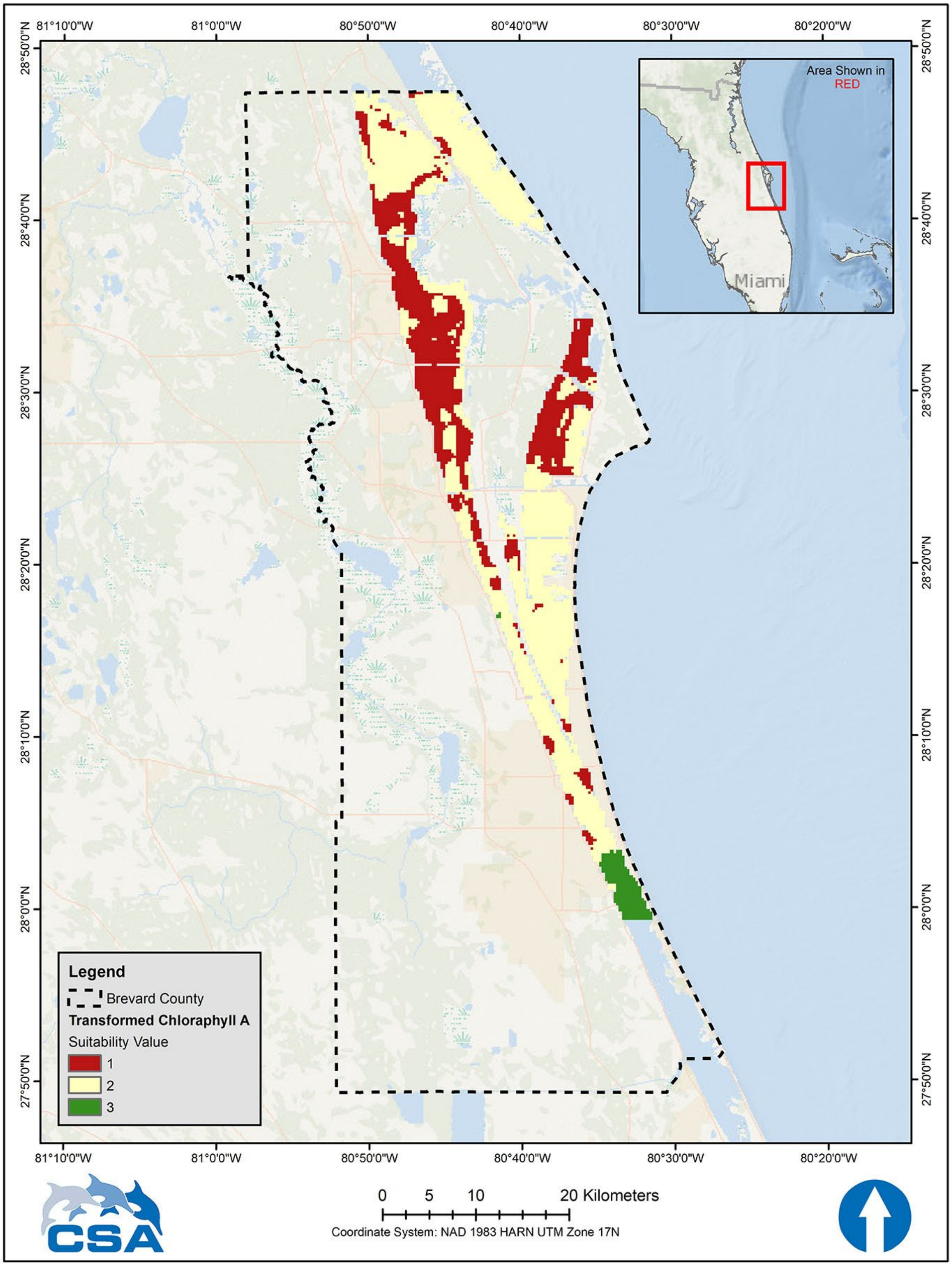

Figure 7. Map showing risk values for seagrass transplantation based on water column Chlorophyll a (Chl a) for the Indian River Lagoon segments within Brevard County, Florida. A suitability value of 1 = high risk, 2 = moderate risk, and 3 = low risk.

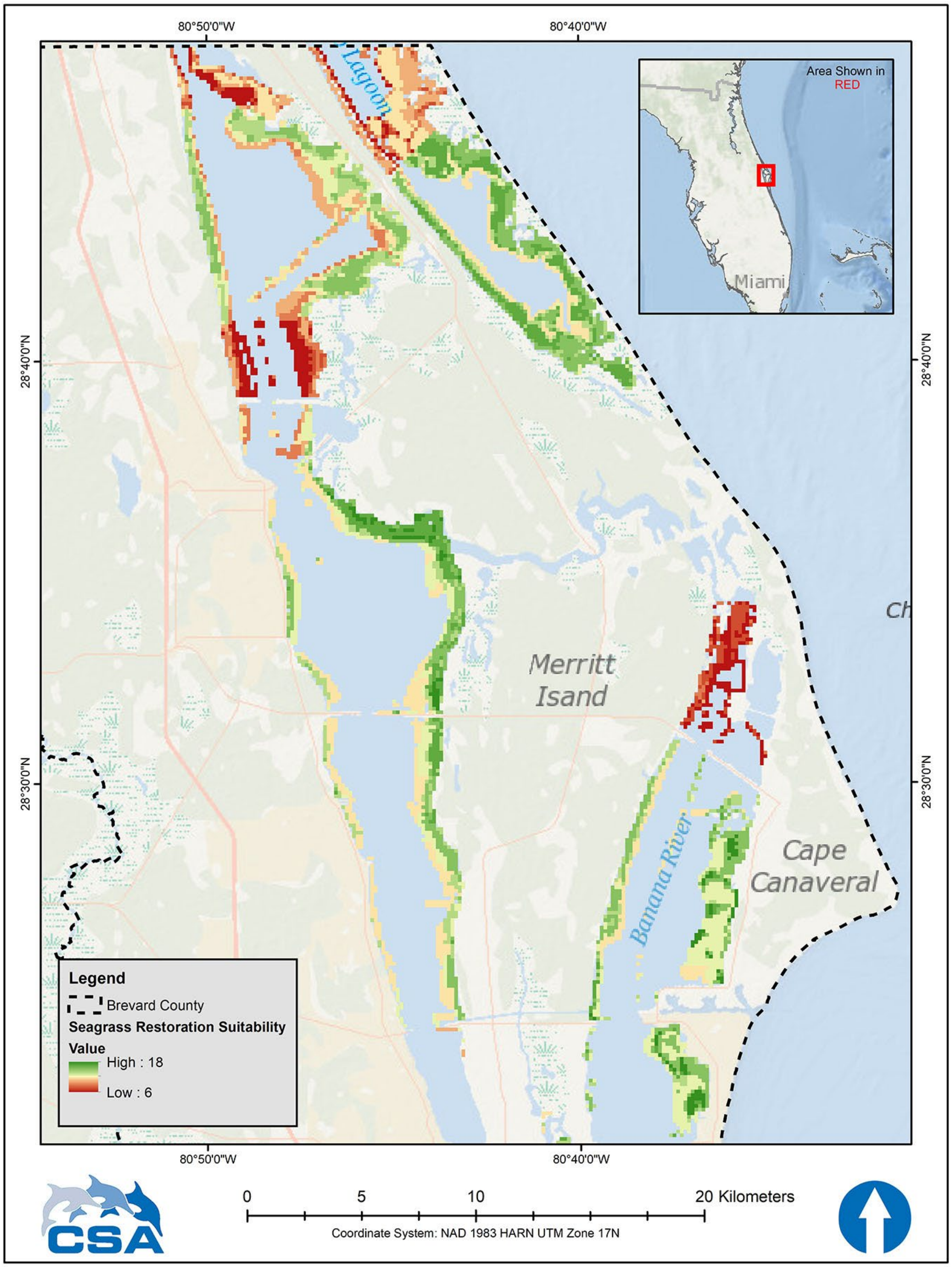

Figure 8. Heat map showing final total suitability values for seagrass transplantation site selection for the north range (from north to south) of the Indian River Lagoon segments within Brevard County, Florida. A suitability value score of 6 = lowest suitability (highest risk) environment ranging up to 18, indicating the most suitable (lowest risk) environment. Any geographic location without representation in the color ramp has a suitability value less than 6 and is excluded from recommendation for seagrass transplantation.

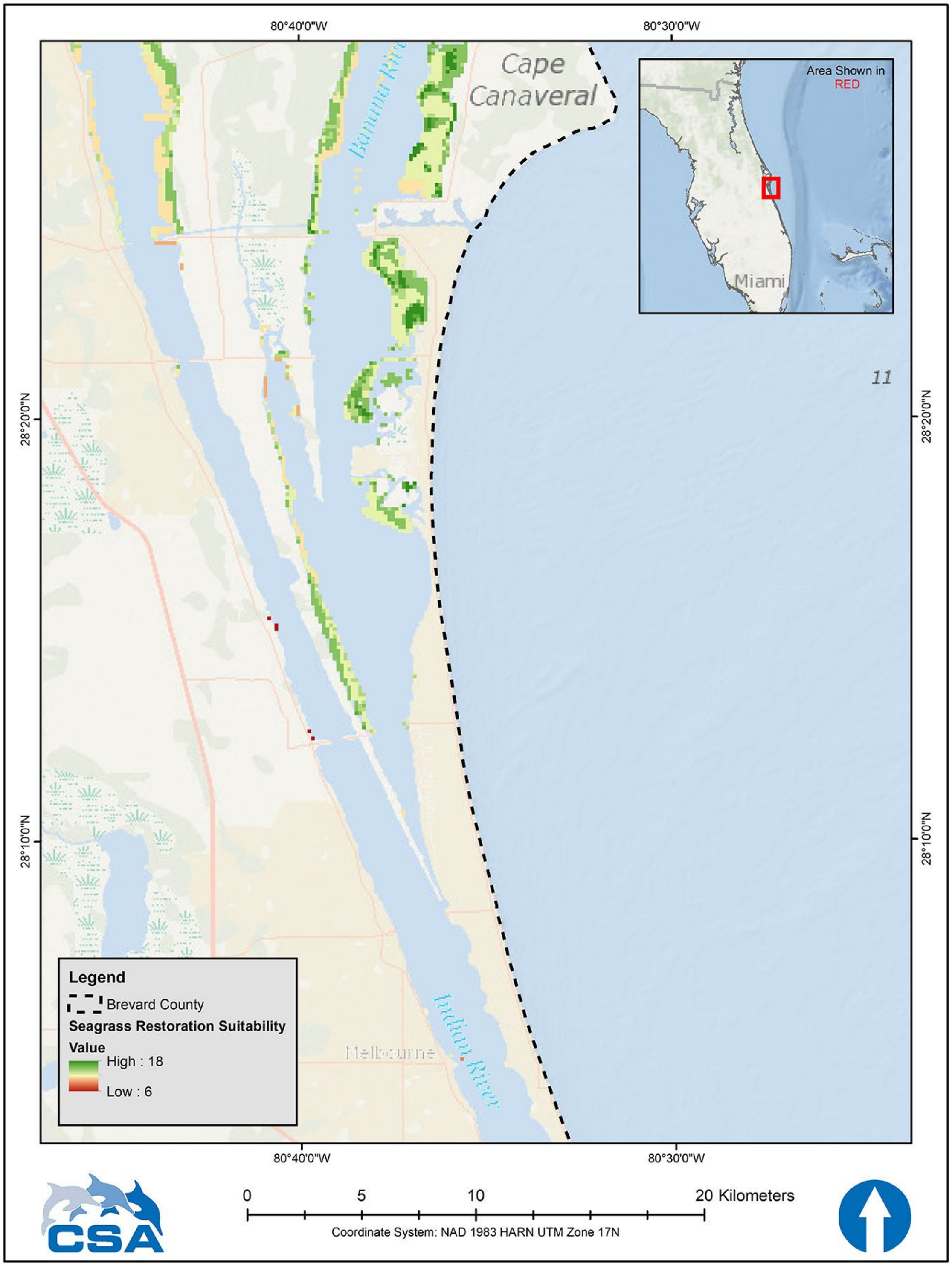

Figure 9. Heat map showing final total suitability values for seagrass transplantation site selection for the middle range (from north to south) of the Indian River Lagoon segments within Brevard County, Florida. A suitability value score of 6 = lowest suitability (highest risk) environment ranging up to 18, indicating the most suitable (lowest risk) environment. Any geographic location without representation in the color ramp has a suitability value less than 6 and is excluded from recommendation for seagrass transplantation.

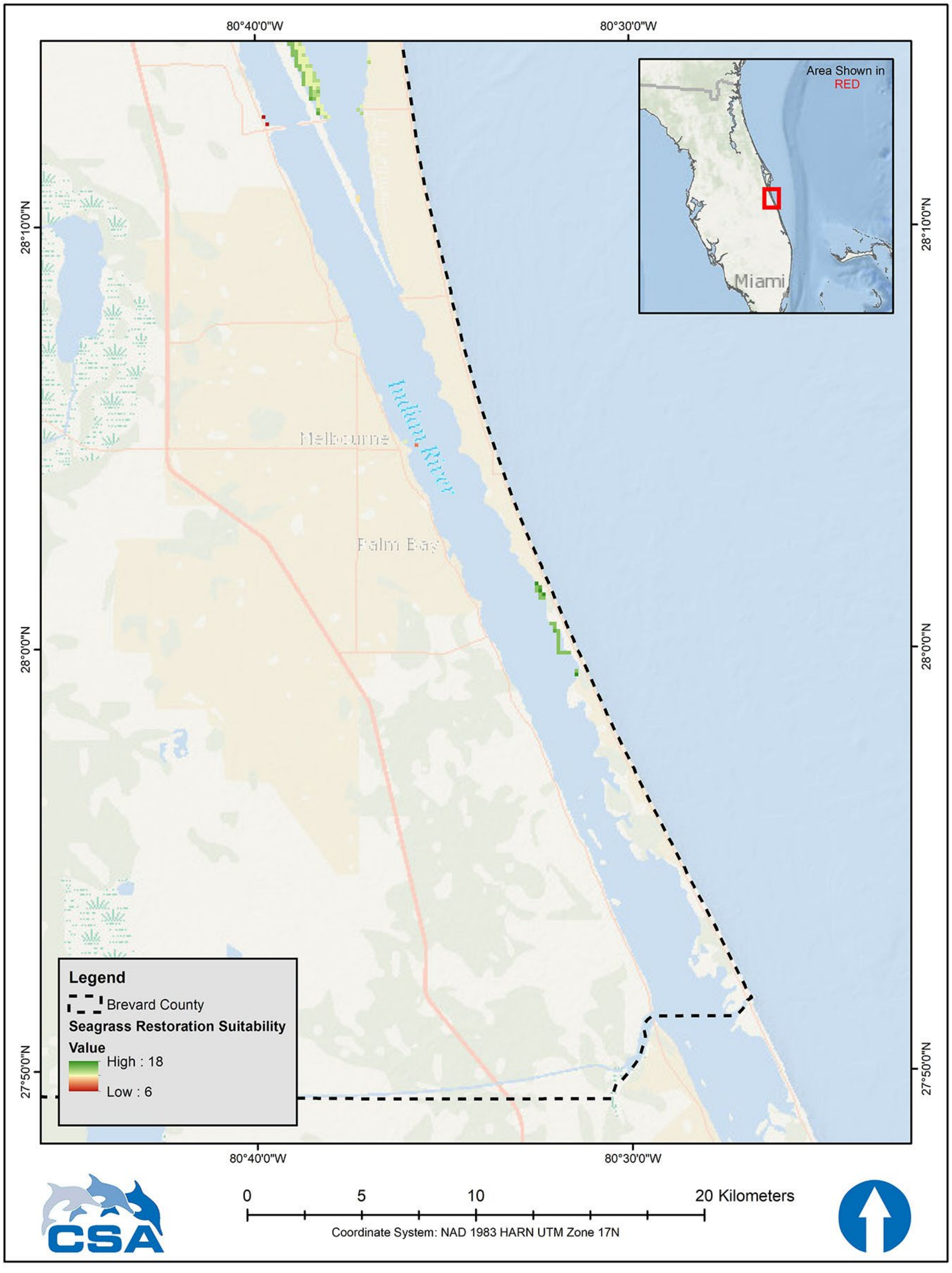

Figure 10. Heat map showing final total suitability values for seagrass transplantation site selection for the south range (from north to south) of the Indian River Lagoon segments within Brevard County, Florida. A suitability value score of 6 = lowest suitability (highest risk) environment ranging up to 18, indicating the most suitable (lowest risk) environment. Any geographic location without representation in the color ramp has a suitability value less than 6 and is excluded from recommendation for seagrass transplantation.

4 Designing a Seagrass Restoration to Ask Questions under a Plan, Act, Monitor, and Learn Sequence

The IRL planting season and planting methods are not high priority topics to investigate. Planting season is in the spring, particularly April and May. Planting may be done as early as March, but water temperatures may be uncomfortable especially if volunteer staff are used (R. Virnstein, personal communication). There are many planting methods and most of them are successful (Fonseca 2011), but here the methods are assumed to involve mature, vegetative seagrass plants; seeding methods are not considered in this protocol. The planting method may depend more on the source material. If planting vegetative material, then either staple units or sods are recommended (Fonseca et al. 1998). Other methods may be considered; however, unless a decision is made to further test different planting methods as experimental treatments, the planting method must be applied consistently across the entire planting campaign to facilitate asking questions within a given planting.

As planting risk increases, testing complexity also increases to address potential limiting factors to seagrass recovery. If seagrass is not present, the reason for its absence is not known, and there is no evidence of recovery (e.g., seeding or fragment colonization), then a restoration should be seen as highly experimental and potentially postponed until substantially more experimental results are obtained (*sensu* Fonseca et al. 1998).

The overall risk is the output of the SMW and after that, sites feed into one of three bins of planting designs. In **Figure 11** a flowchart shows four risk-associated (low, moderate, high, and extreme risk) decision paths to consider for beginning to design a seagrass transplant under the PAML cycle. Each path leads to a distinct set (tier) of recommended planting questions that become more complex as risk increases (except extreme risk where no planting experiments are recommended).

The entire seagrass restoration protocol is summarized in a simplified, step-by-step process described in **Appendix A**. Although the protocol is designed to stand alone, users of this protocol are strongly encouraged to engage with the County (SeagrassProjects@brevardfl.gov, see also information in **Appendix A**) for project coordination and to be connected to scientists to assist in application of the protocol.

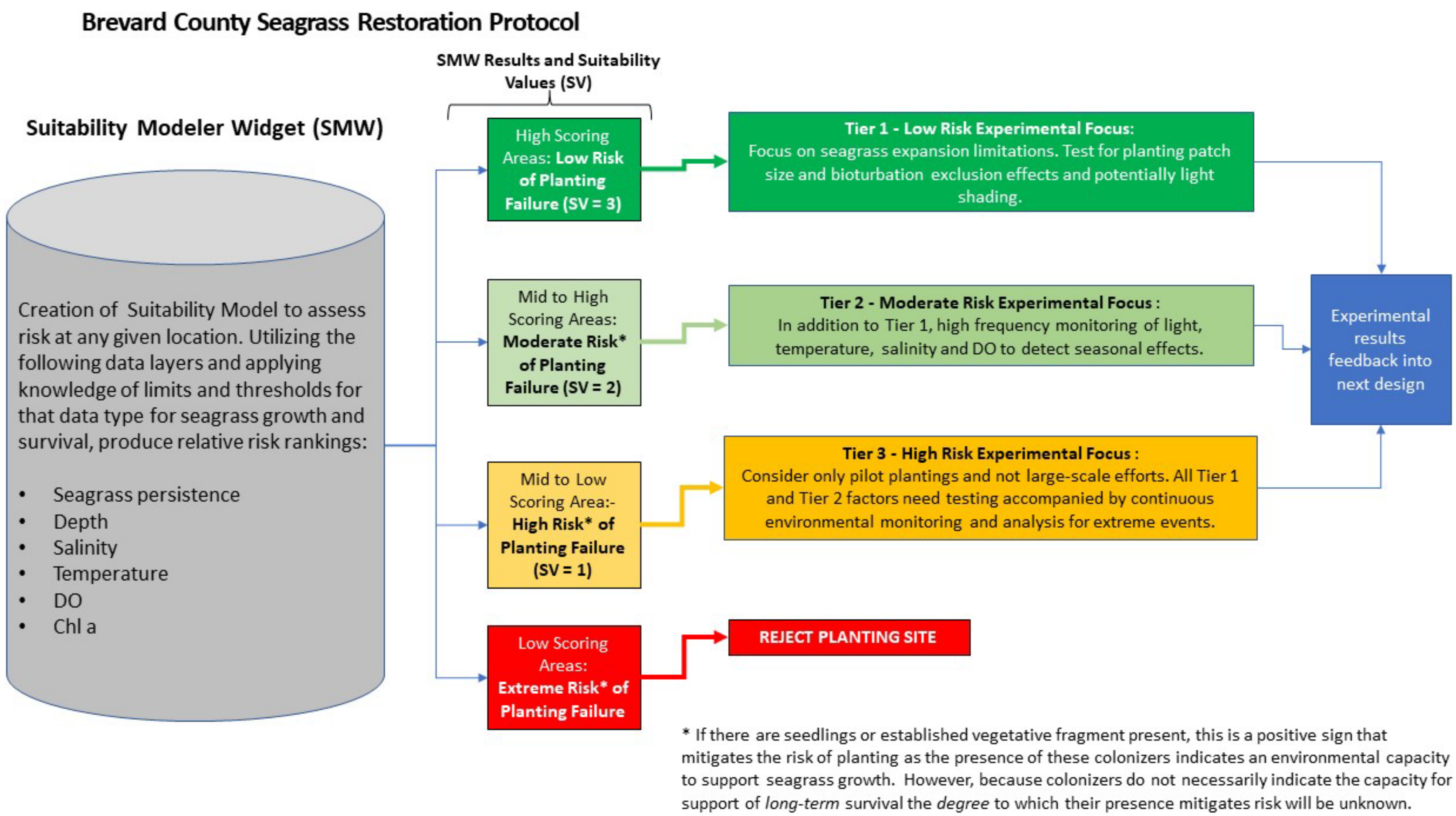

Figure 11. Flowchart describing the application of the risk environment designation from the total risk value at a given site to determine the question set (tiers 1-3, associated with low to high-risk experimentation) that should be addressed for a location with that level of risk. Chl a = chlorophyll a, DO = dissolved oxygen.

4.1 PLANTING QUESTIONS IN HIGH SUITABILITY (LOW-RISK) SETTINGS

High suitability (low-risk) settings (**Figure 11** and the dark green highlighted path) involve the proximity of existing seagrass (i.e., within approximately 100 m and at the same water depth as the existing seagrass). The presence of seagrass serves as the proverbial "canary in the coal mine". If seagrass is in proximity, then conditions are obviously suitable. Under conditions where seagrass is present, there are often gaps in seafloor cover[7] by seagrass. Uncolonized gaps may be used to perform transplanting experiments to understand what may be limiting further expansion of seagrass into those areas. For this protocol, gap formation in stable seagrass landscapes is considered to arise from some external driver holding the landscape pattern and amount of seafloor cover in equilibrium. Consequently, augmentation of colonized seafloor without some modification to the factor limiting its colonization is not recognized here as "restoration" as it may not produce a sustained local increase in seagrass acreage (*sensu* Fonseca et al. 1998). See **Section 1** and/or Fonseca et al. (1998) for comments on potential planting methods.

Recommended questions (i.e., treatments – bold faced emphasis of topic) to consider here are the effects of the following list. Combinations of treatments are encouraged, but every addition of a treatment means that it must be replicated in every block, creating a multiplier of planting effort. Also, every treatment selected must exist in every possible combination with every other treatment. So, adding treatments multiplies the size of the planting.

To address five priority questions identified as of 2022, five recommended experimental treatments to test in a high suitability (low-risk) setting were developed. For each treatment, seagrass change in cover over time is the recommended metric of success. See comments in **Section 1** and/or Fonseca et al. (1998) about methods. The recommended experimental treatments are:

- Treatment 1: Seagrass **species** and combinations thereof. This tests the role of mixed versus individual seagrass species in their ability to colonize space. Recommended combinations (treatments) include the following:
  - *H. wrightii* alone
  - *R. maritima* alone
  - *H. wrightii* plus *R. maritima* (if a combination is chosen then treatments with the species alone must also be selected)
  - *Halophila decipiens* alone (or potentially *Halophila johnsonii* for shallow environments)

[7] Seagrass cover is defined here as that portion of the seafloor where overlap of seagrass rhizomes occurs. While this may sometimes be difficult to visually discern, it is meant to differentiate portions of the seafloor where seagrass shoots are close together apart from small individual plants or long rhizome runners extending from visibly colonized seafloor.

- Treatment 2: Seagrass planting **patch size** tests for resilience of transplanted seagrass primarily to biological or physical disturbance. Recommended treatments include the following; if it is impractical to employ all these treatment levels, start with the individual planting unit (PU) and add as many patch size levels as manageable:
  - Individually spaced PU[8] usually 1 m apart
  - Clusters of PU placed conterminously forming a 0.25 × 0.25 m patch[9] usually 1 to 2 m apart
  - Clusters of PU placed conterminously forming a 0.5 × 0.5 m patch usually 1 to 2 m apart
  - Clusters of PU placed conterminously forming a 1.0 × 1.0 m patch usually 2 m apart

- Treatment 3: Seagrass planting **density** also tests for resilience to biological or physical disturbance. Within a patch, the number of PU per unit area and/or spacing of each PU can be tested. For this test, either a single density of PU with various heterogenous distributions or multiple densities of homogenous distribution can be chosen.

- Treatment 4: Utilization of **bioturbation/herbivory exclusion devices**, such as stakes, fences, cages, etc. Like patch size and density, this also tests for resilience of transplanted seagrass primarily to biological disturbance. While tests may include plots with and without exclusion devices, one type should be chosen and utilized consistently within a treatment. However, if aiming to directly test the exclusion device type, additional treatments will need to be added in a multi-factorial design.

- Treatment 5: Light **shading**. This test helps determine the degree to which seagrass plantings (and potentially, existing, established seagrass) may endure reduced light events. This question is more experimental and complex, and a design is not given here. Instead, engagement with the County (SeagrassProjects@brevardfl.gov) for coordination and to be connected to scientists that can provide guidance is advised.

- **Reference site**: monitoring of nearby natural beds during a transplanting project is a critical part of the knowledge accumulation process. This monitoring ensures that any trends, particularly negative, in a seagrass transplant can be understood to be a result of a treatment or whether the condition for supporting seagrass is in decline, making a negative response in the planting largely irrelevant.

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[8] A PU is here defined as an individual staple unit or a small sod (which may include peat-pot methods) all following Fonseca et al. (1998).

[9] While spacing among individual PU is recommended to be as described by Virnstein (2021), spacing among these larger patches can be large, recognizing how many PU are absorbed in creation of these patches. Note that any organized planting arrangement at a point as in Virnstein (2021), all PU must be counted and averaged as one replicate for statistical sampling purposes.

4.2 PLANTING QUESTIONS IN MODERATE SUITABILITY (MODERATE-RISK) SETTINGS

See **Figure 9** and the light green highlighted path. The recommended questions (treatments) for low-risk settings should be repeated here. Other recommended questions (treatments) in addition to those in low-risk settings (above) are high-frequency monitoring of water quality. This would preferably be a weekly or once every two-week monitoring event for water clarity (horizontal Secchi)[10], temperature, and if possible, salinity and DO. Engagement with the County for coordination and to be connected to scientist to provide guidance and procedures for selecting and employing monitoring equipment is recommended.

4.3 PLANTING QUESTIONS IN LOW SUITABILITY (HIGH-RISK) SETTINGS

See **Figure 9** and the orange highlighted path. Here, there may be less chance of being in proximity to existing seagrass and so transplanting may be attempting to overcome numerous limiting factors, some of which may occur only sporadically. In addition to repeating planting treatments (questions) in the low-risk setting, these sites should be accompanied by continuous, electronic monitoring of light, temperature, and salinity and DO, all sensors that may be found on commercially available sondes. This is because these settings likely have the greatest chance of being influenced by extreme, and sometimes comparatively short-term, excursions of light reduction, temperature, salinity, and DO that would not be detectable with monthly or even twice-monthly monitoring. Note that light data collection is especially challenging due to fouling of the sensor. Engage with the County for coordination and to be connected to scientist to provide guidance and procedures for selecting and deploying such equipment.

4.4 PLANTING QUESTIONS IN VERY LOW SUITABILITY (EXTREME-RISK) SETTINGS

See **Figure 9** and the red highlighted path. No seagrass restoration efforts are recommended in these settings until such time as widespread improvement in water quality occurs. However, if there are seedlings or established vegetative fragments present, this is a positive sign that mitigates the risk of planting as the presence of these colonizers indicates an environmental capacity to support seagrass growth, at least temporarily. However, because these colonizers do not necessarily indicate the capacity to support long-term survival, the degree to which their presence mitigates risk is generally unknown.

[10] A Secchi disk (https://en.wikipedia.org/wiki/Secchi_disk) value is a distance through the water column traditionally measured by looking down vertically from the water surface and recording the depth at which the disk disappears from view and averaging the depth at which it disappears upon lowering and the depth at which it reappears upon raising. Horizontal Secchi is the use of a Secchi disk held vertically on its edge and viewed underwater by a person wearing a mask at increasing distance horizontally across the seafloor, again averaging the distance between the disk and the distance at which it disappears from view underwater while moving away from it and the distance at which it reappears when approaching it. This measure should be taken just above the seagrass canopy and at an equivalent elevation above the seafloor at a control (natural seagrass) location.

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Appendices

Appendix A: Brevard County Seagrass Restoration Protocol

A1. Background

This protocol was developed to assist in the process of seagrass restoration in the Indian River Lagoon (IRL). It utilizes data and publications generated by many scientists in the IRL as well as similar efforts worldwide to guide restoration efforts and ultimately promote seagrass recovery. The following protocol steps are an abbreviated process built on a larger research effort which is described in the main report accompanying this Appendix. Readers are encouraged to familiarize themselves with that effort to better understand the decisions guiding the formulation of the protocol.

A2. Protocol

This protocol follows a path of **Plan, Act, Monitor and Learn (PAML**) where a seagrass restoration is planned with goals of learning ways in which to refine successful restoration efforts and promote seagrass recovery. The planting is then performed (the Act) and subsequently monitored. Those monitoring data may be provided to Brevard County for analysis to learn about factors limiting seagrass survival and growth in the IRL and in turn, guide the next round of seagrass restoration. To participate in the PAML process, follow these 7 steps to select a planting site and to create a Planting Design and Monitoring Plan. Note the heavy emphasis on planning!

Users are strongly encouraged to expand and improve this plan in concert with the Brevard County Natural Resources Management Department and share data with the County by contacting Brevard County (SeagrassProjects@brevardfl.gov).

A2.1 PLAN

Step 1: Review **Figure A-1** to avoid existing monitoring stations. If your site falls near these monitoring stations, please contact the persons listed in the legend of **Figure A-1**. Any seagrass restoration project should avoid these transect locations by at least 100 m to avoid biasing the seagrass health data collection. Once avoidance of the sites in **Figure A-1** is ascertained, then review **Figures A-2** through **A-4** to assess the value of risk for your preferred seagrass restoration site (or use this to pick a restoration site).

Step 2: If the value of risk is acceptable, proceed to Step 3. If not, use the maps in **Figures A-2** through **A-4** to select a site of higher suitability.

Step 3: Review **Figure A-5**. For the value of risk at your selected seagrass restoration site, follow the flowchart to the recommended tiers of planting questions to address. These questions are designed to help understand the factors limiting seagrass growth and survival (i.e., plant success).

Step 4: Using the question(s) you have selected to test, proceed to building a Planting Design. **It is strongly recommended that users engage with Brevard County Natural Resources Management Department in developing their design** (SeagrassProjects@brevardfl.gov).

Each question entails use of certain planting arrangements, such as size of the planted group, the seagrass species used, the method of planting, etc. Each planting arrangement to be tested is a “treatment”.

Step 5: Review **Figure A-6** to build your Planting Design:

- Choose either a Randomized Complete Block (RCB) or Latin Square design (LS).
- Note that a "block" is a grouping of the chosen treatments.
  - a constant depth should be maintained across the study area unless depth is being tested in which case a different design would be required
  - spacing between treatments in a block or among treatments in an LS design should be large enough to accommodate potential expansion of the plantings without encountering another treatment, typically 3-5 meters.
- Assign all treatments to a block without repeating them (randomly assigned to a location in a block for RCB or in an arbitrary but consistent order for LS[11]).
- Once the treatments are assigned to a block then one replicate has been achieved.
- Now, repeat the blocks per the design guidance to obtain replication of the treatment.
- Each treatment should be replicated 5 to 10 times (i.e., 5 to 10 blocks).

Step 6: Create a Monitoring Plan to address questions based on the risk category and Planting Design. In general, if plantings have NOT followed one of these recommended treatments, monitoring should at a minimum include initial survival of plantings and change in seagrass area covered over time. Percent survival of the plantings (discrete planting unit, PU) and area covered by PU should be monitored at least quarterly from at least 50, randomly selected, until the PU begin to overlap. At that point, monitoring of cover should shift to a percent cover approach using 1 m^2 quadrats randomly placed throughout the planting area (usually 50 to100 random locations are sufficient to attain a stable standard deviation and variance).

If one of the above treatments has been utilized, then monitoring should include measurement of all experimental units at each sampling time (preferably quarterly for at least 3 years), which calls for application of repeated measures statistics although simple plotting of data is always the first step to compare performance of treatments to one another. Survival of individual experimental units and their change in area covered of the seafloor should be measured.

[11]If you are unsure how to assign random values, contact Brevard County for assistance (SeagrassProjects@brevardfl.gov).

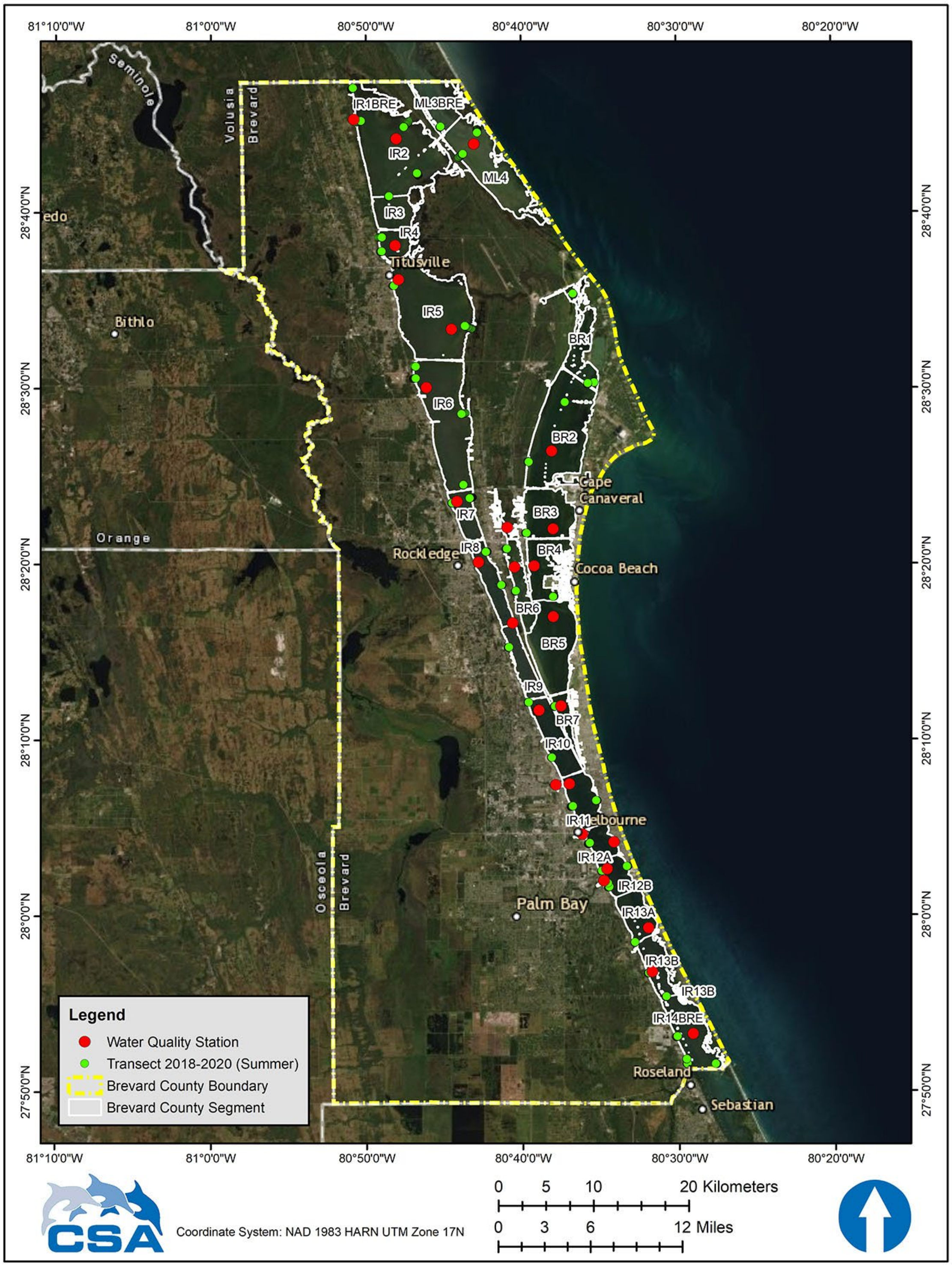

Figure A-1. Map of Brevard County showing both water quality stations and permanent seagrass monitoring transects. No seagrass restoration work should occur within 100 m of these locations to prevent disruption of long-term monitoring efforts. If your restoration site appears to lie anywhere close to these, please contact these persons immediately and they will assist in placement of your project on a not-to-interfere basis: Lauren Hall (lhall@sjrwmd.com) or Lori Morris (lmorris@sjrwmd.com).

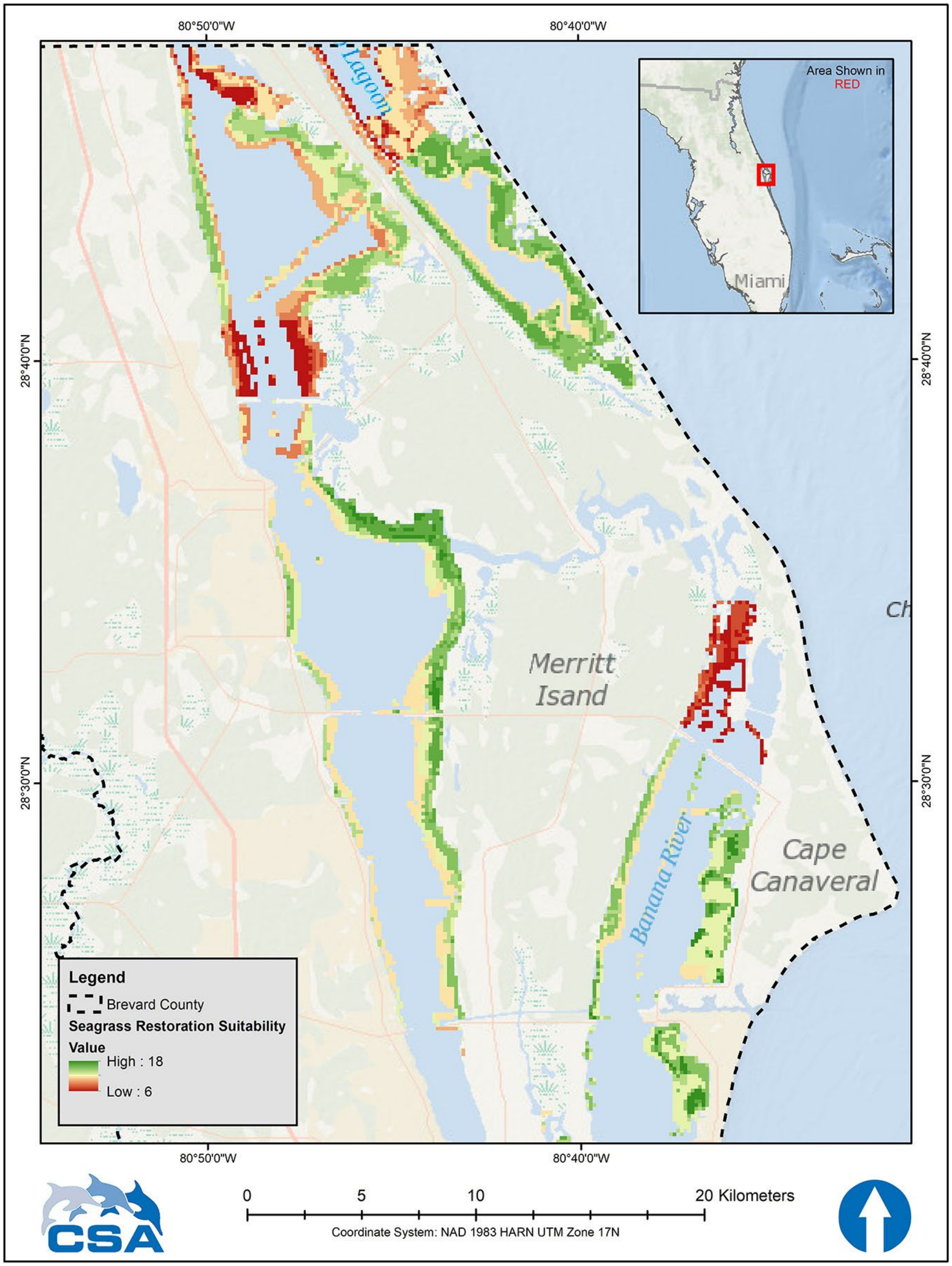

Figure A-2. Heat map showing final total suitability values for seagrass transplantation site selection for the north range (from north to south) of the Indian River Lagoon segments within Brevard County, Florida. A suitability value score of 6 = lowest suitability (highest risk) environment ranging up to 18, indicating the most suitable (lowest risk) environment. Any geographic location without representation in the color ramp has a suitability value less than 6 and is excluded from recommendation for seagrass transplantation.

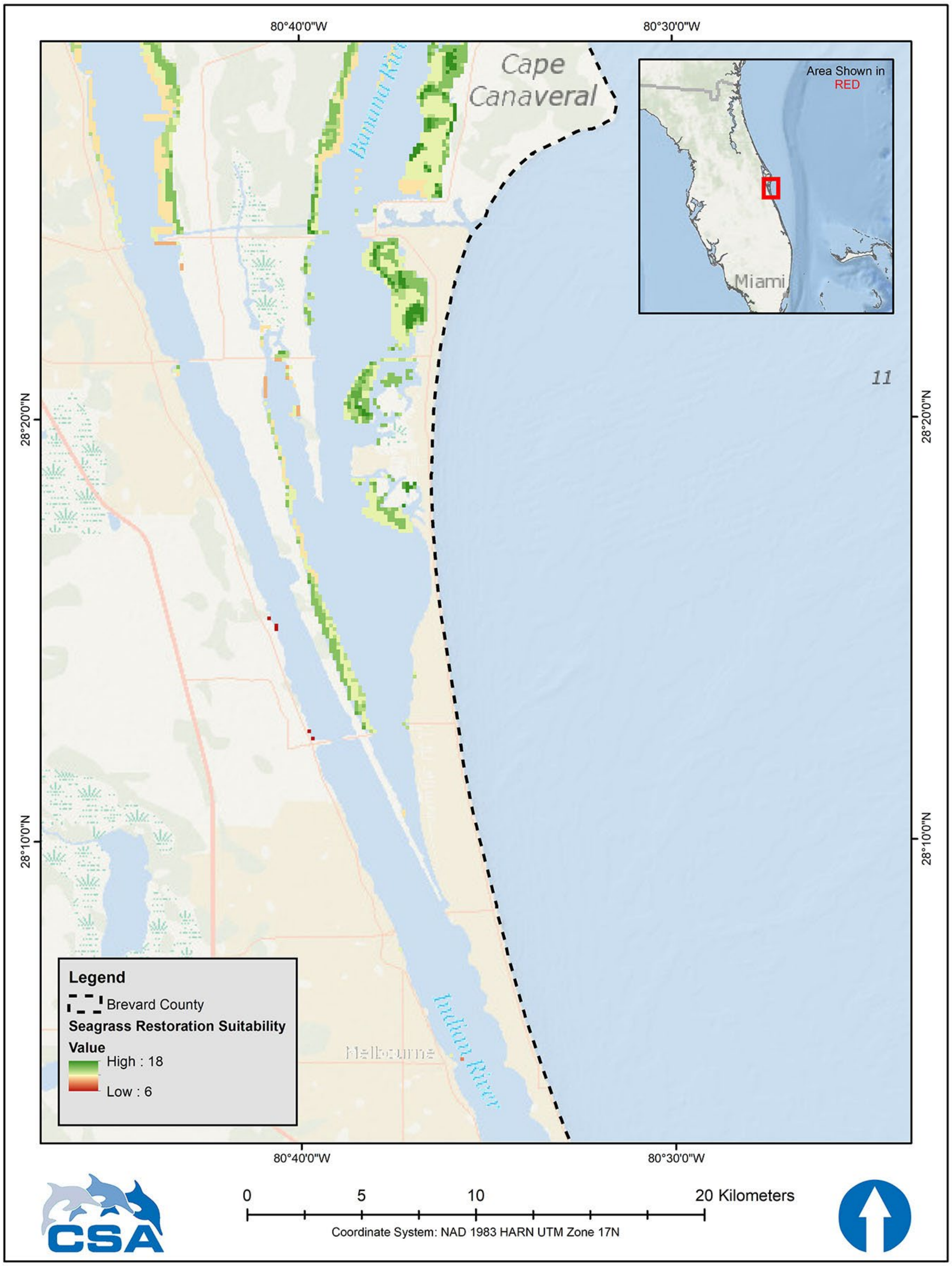

Figure A-3. Heat map showing final total suitability values for seagrass transplantation site selection for the middle range (from north to south) of the Indian River Lagoon segments within Brevard County, Florida. A suitability value score of 6 = lowest suitability (highest risk) environment ranging up to 18, indicating the most suitable (lowest risk) environment. Any geographic location without representation in the color ramp has a suitability value less than 6 and is excluded from recommendation for seagrass transplantation.

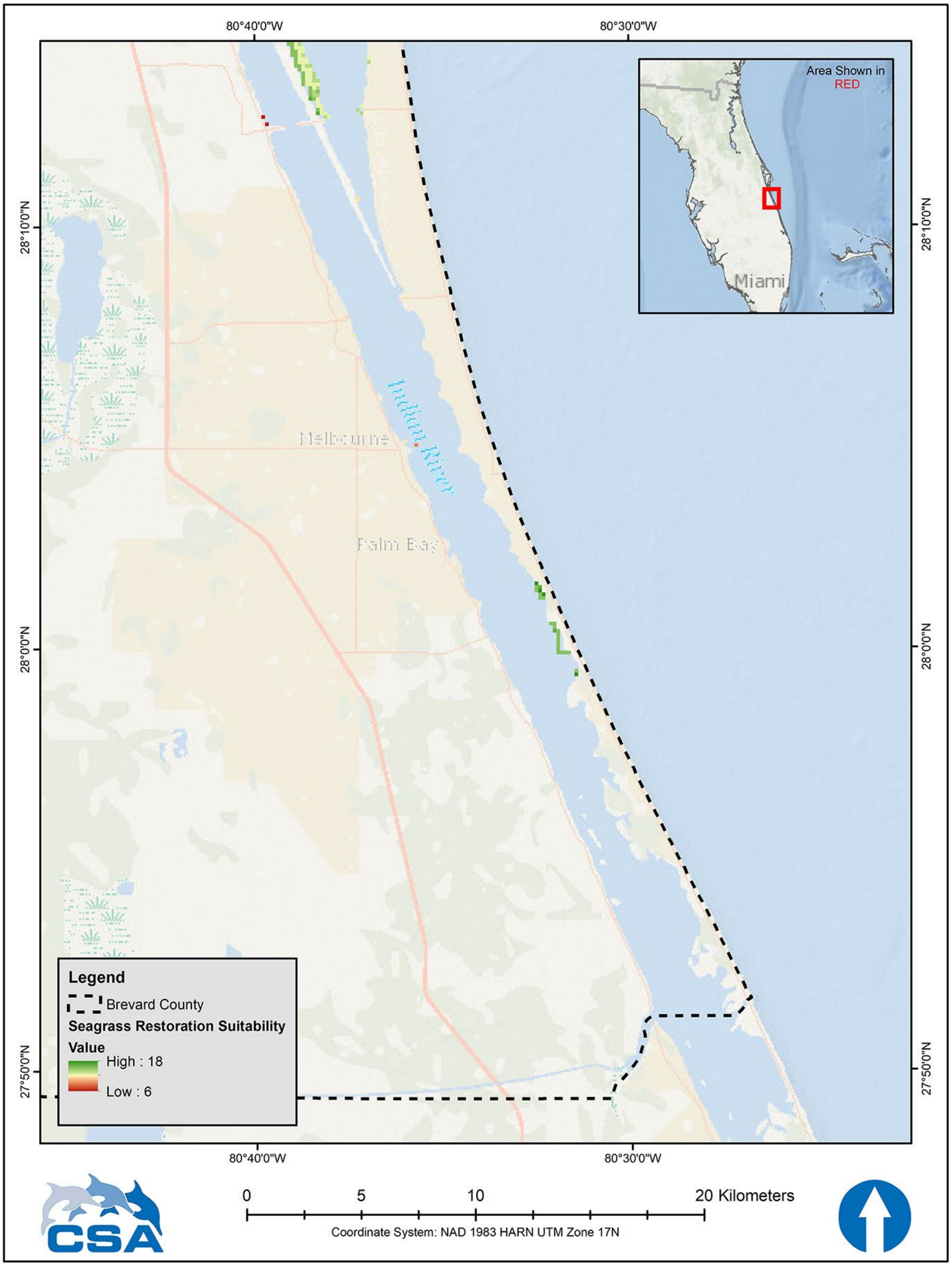

Figure A-4. Heat map showing final total suitability values for seagrass transplantation site selection for the south range (from north to south) of the Indian River Lagoon segments within Brevard County, Florida. A suitability value score of 6 = lowest suitability (highest risk) environment ranging up to 18, indicating the most suitable (lowest risk) environment. Any geographic location without representation in the color ramp has a suitability value less than 6 and is excluded from recommendation for seagrass transplantation.

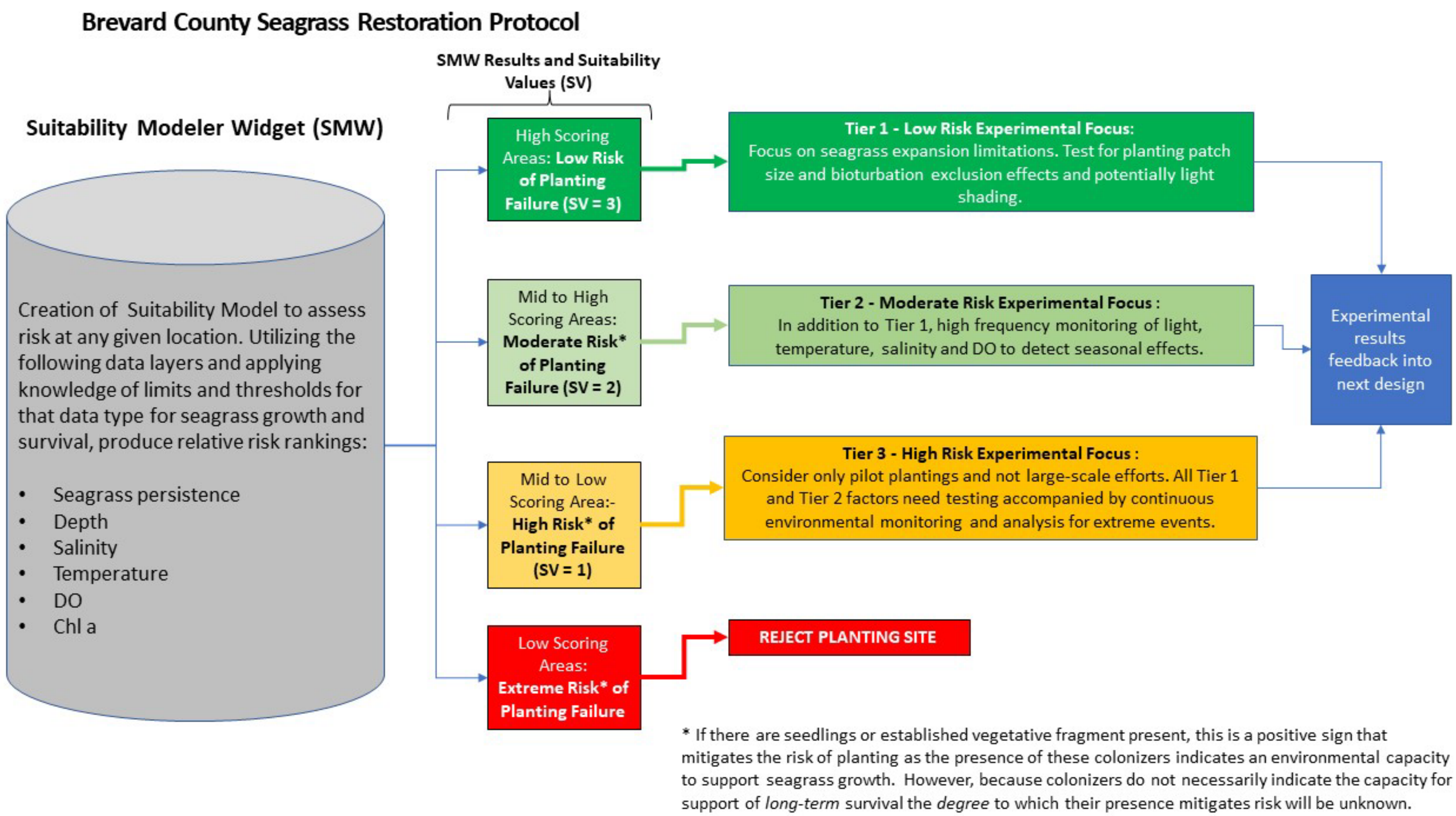

Figure A-5. Flowchart describing the application of the risk environment designation from the total risk value at a given site, to determine the question set (tiers 1-3, associated with low to high-risk experimentation) that should be addressed for a location with that level of risk. Chl a = chlorophyll a, DO = dissolved oxygen.

Figure A-6. Two options for designing a seagrass planting to allow application of questions in the planting process. Note that the number of blocks should equal the number of treatments.

A2.2 ACT

Step 7: Use this Planting Design in the field. Follow the Monitoring Plan described below.

A2.3 MONITOR

Step 8: Use this general Monitoring Plan in the field; monitoring should continue for a minimum of 3 years:

- Deployment: Establish a baseline of the predominant benthic community and note any presence of submerged aquatic vegetation (SAV). Map the deployment, spacing and number of PU, and total number of shoots deployed per treatment area.
- No more than 30 days after planting, survey the entire site to count the number of PU present in every treatment, recording and labeling the counts by each replicate treatment making sure that each treatment in each block is uniquely labeled so data analysis can proceed properly.
- Also monitor the status of nearby (preferably within approximately 100 m) natural beds (if they exist) at the same approximate water depth as a reference. Even if a reference bed is further away, it would be worth monitoring it using the method for when planting units run together, below. Take measurement of environmental variables (i.e., depth, light, salinity, temperature, DO, sediment type, stability, and quality, herbivory/bioturbation) at both locations, especially if greater than 100 m between locations.
- Every 6 months thereafter perform the following monitoring (try to take no more than a minute or two to do measurements in each treatment; these methods do not need precision, just accuracy):
    - While individual PU are still discernible as separate units (i.e., before they grow together), do the following in every treatment in every block:
        - For each treatment count the number of PU present.
        - Either measure all PU or randomly select 3 to measure their approximate size.
        - Measure the length of the area of the PU and the width (perpendicular to the longest length) in cm (accuracy to the nearest 5 cm is acceptable).
        - Again, record the data by labeling the counts by each replicate treatment making sure that each treatment in each block is uniquely labeled so data analysis can proceed properly.
    - Once individual planting units begin to run together, change your method, and do the following in every treatment in every block:
        - Obtain a 1-meter square quadrat gridded with strings on 10-cm increments (**Image A-1**).
        - Place a 1-meter square quadrat in the approximate center of the plot.
        - Count the number of 10 x 10 cm cells that contain seagrass emerging from the sediment.
        - If there is more than one species of seagrass present in a plot, count the number of cells with just one species, by species, as well as the number of cells with both species.
        - Again, record the data by labeling the counts by each replicate treatment making sure that each treatment in each block is uniquely labeled so data analysis can proceed properly.

Figure A-7 shows an example data sheet that may be utilized to collect data in general surveys or can be adapted for use in any experimental monitoring. Also available upon request (SeagrassProjects@brevardfl.gov) is a more detailed monitoring protocol: **Indian River Lagoon Seagrass Monitoring Standard Operating Procedures modified for Brevard County (September 2022) by the St. Johns River Water Management District.**

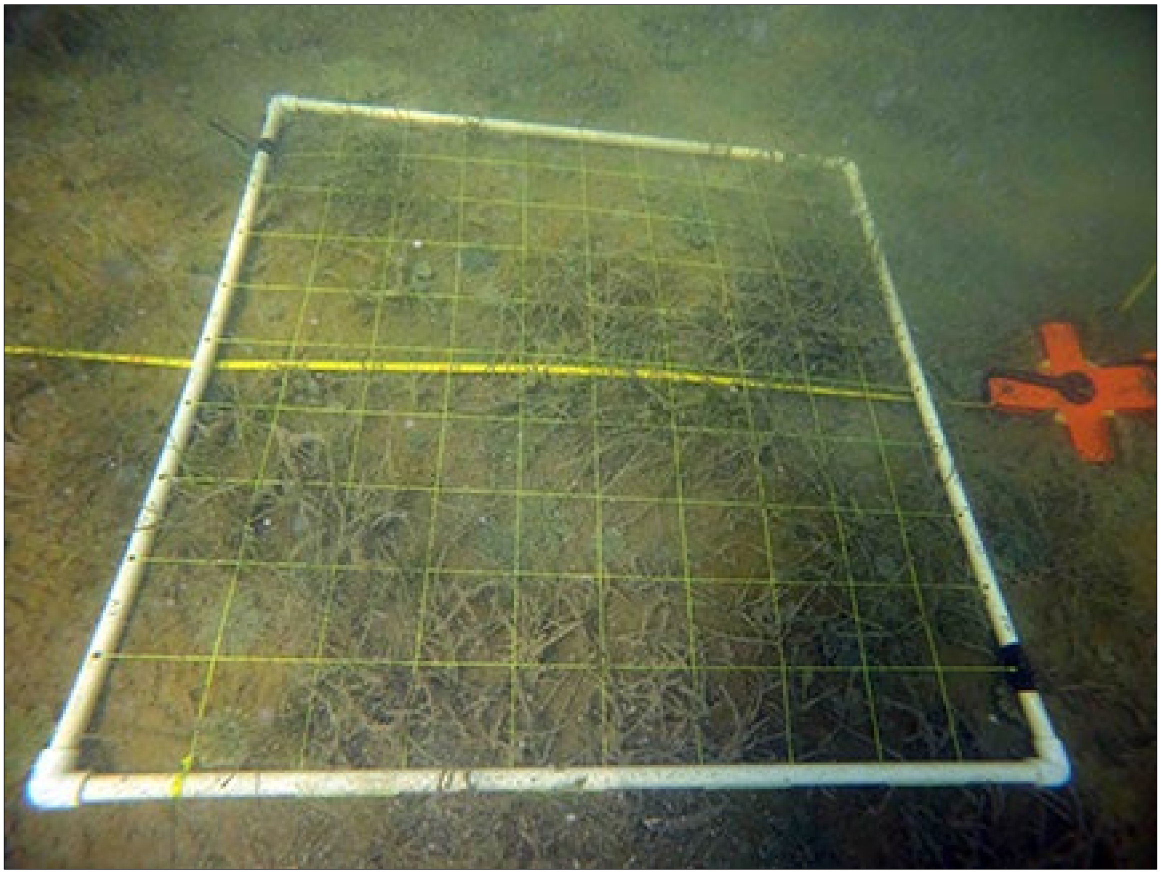

Image A-1. Underwater photograph of a typical 1m × 1 m quadrat gridded with strings on 10 cm increments.

Date: **Time:** **Location:** **Sampler Initials:**

Sampling Point (Distance/Plot#)	% Occurrence Drift Algae	Drift Algae Biomass (0-5)	Height of Drift Algae Canopy	% Occurrence *Caulerpa*	% *Caulerpa* Cover	*Caulerpa* spp.	% Occurrence Seagrass (all species)	Seagrass Species	% Cover Seagrass (each species)	Canopy height (each species)	Epiphyte Load	Shoot Counts (Each Species)							
												1	2	3	4	5	6	7	8

Seagrasses growing outside the quadrate (Y/N): **General Condition of Seagrass:**
Presence of depressions from digging (Y/N): **Seagrass Blade Color:**
Additional Notes:

Figure A-7. Example data sheet for monitoring submerged aquatic vegetation.

A2.4 LEARN

Report your data for analysis to the Brevard County Natural Resources Management Department by contacting Brevard County (SeagrassProjects@brevardfl.gov).

Appendix B: Summary of Suitability Modeler Widget Key Steps in ArcGIS Pro

Step 1: Load input rasters:

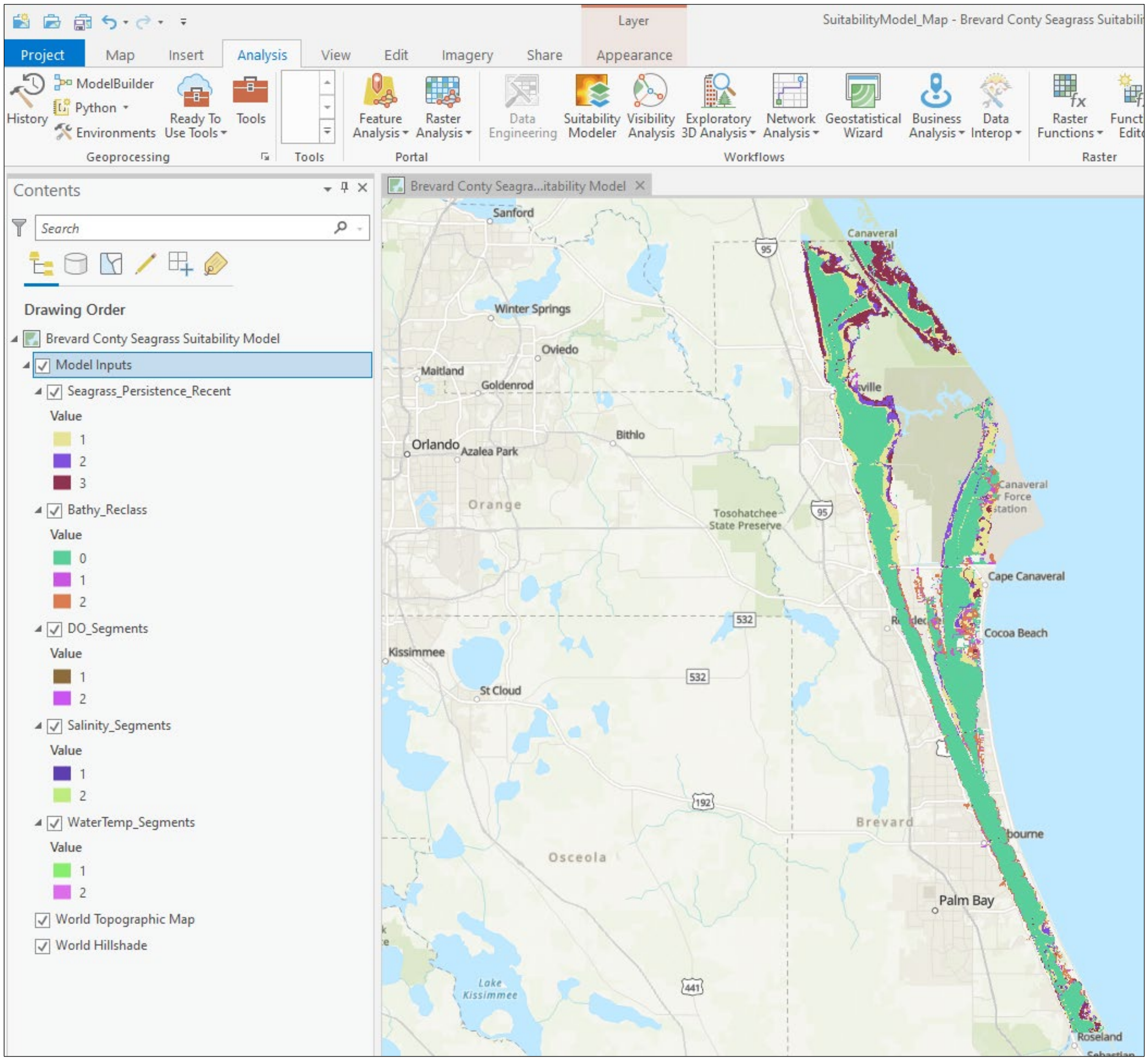

Figure B-1. Example of loading rasters.

Step 2: Set name, suitability scale and output raster:

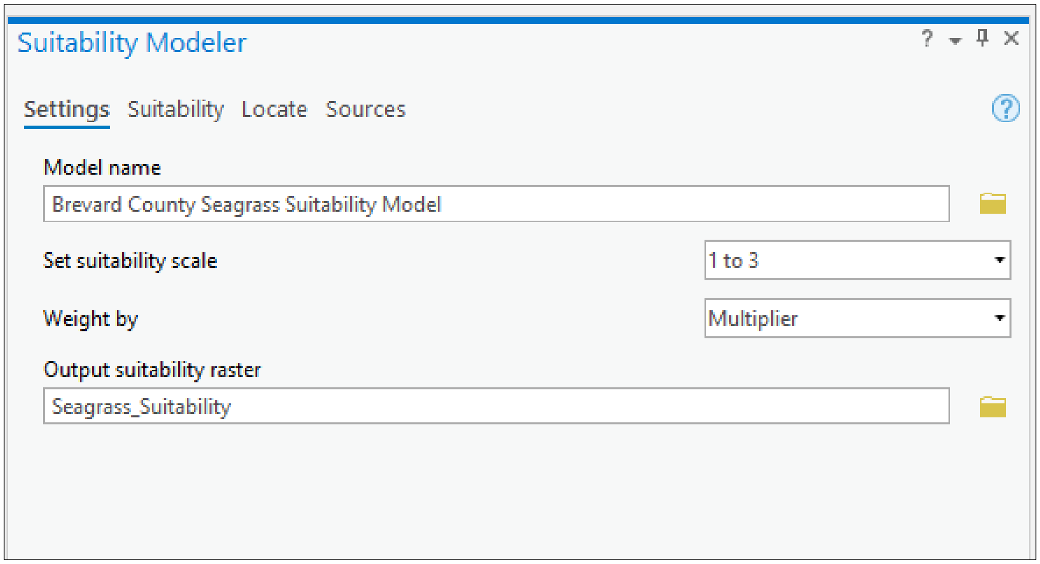

Figure B-2. Setting scales and naming output.

Step 3: Select all input rasters on the Suitabilty Tab. Each raster is transformed into the final form by clicking the circle next to them. After all rasters are tranformed, users select "Run" at the bottom of the tab to initiate the model.

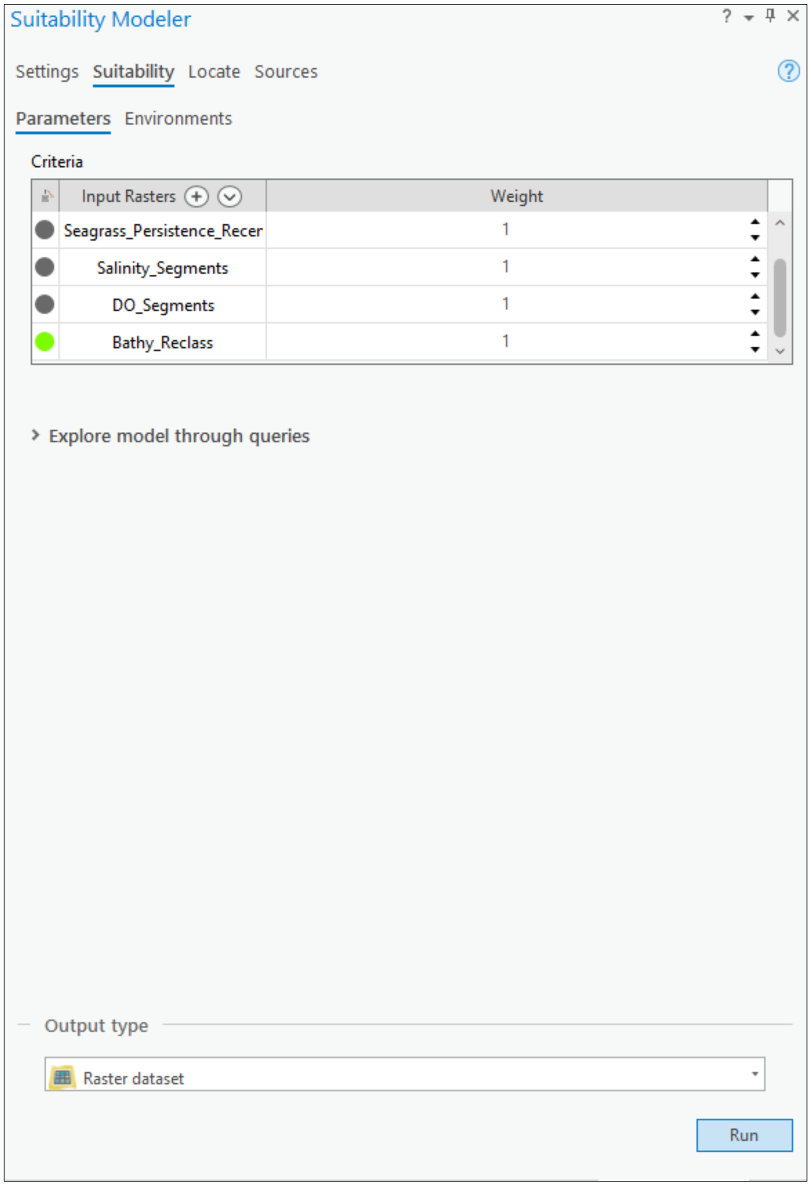

Figure B-3. Raster selection.

Step 4: The Locate Tab can be used to further refine siting by setting site parameters. This was not done in this analysis. More information can be found here: https://pro.arcgis.com/en/pro-app/2.7/help/analysis/spatial-analyst/suitability-modeler/locate-tab-in-suitability-modeler.htm#:~:text=IntheSuitabilityModelerCuse,subject'sspatialrequirementsaredetermined. The Sources Tab simply shows the input "transformed" data.

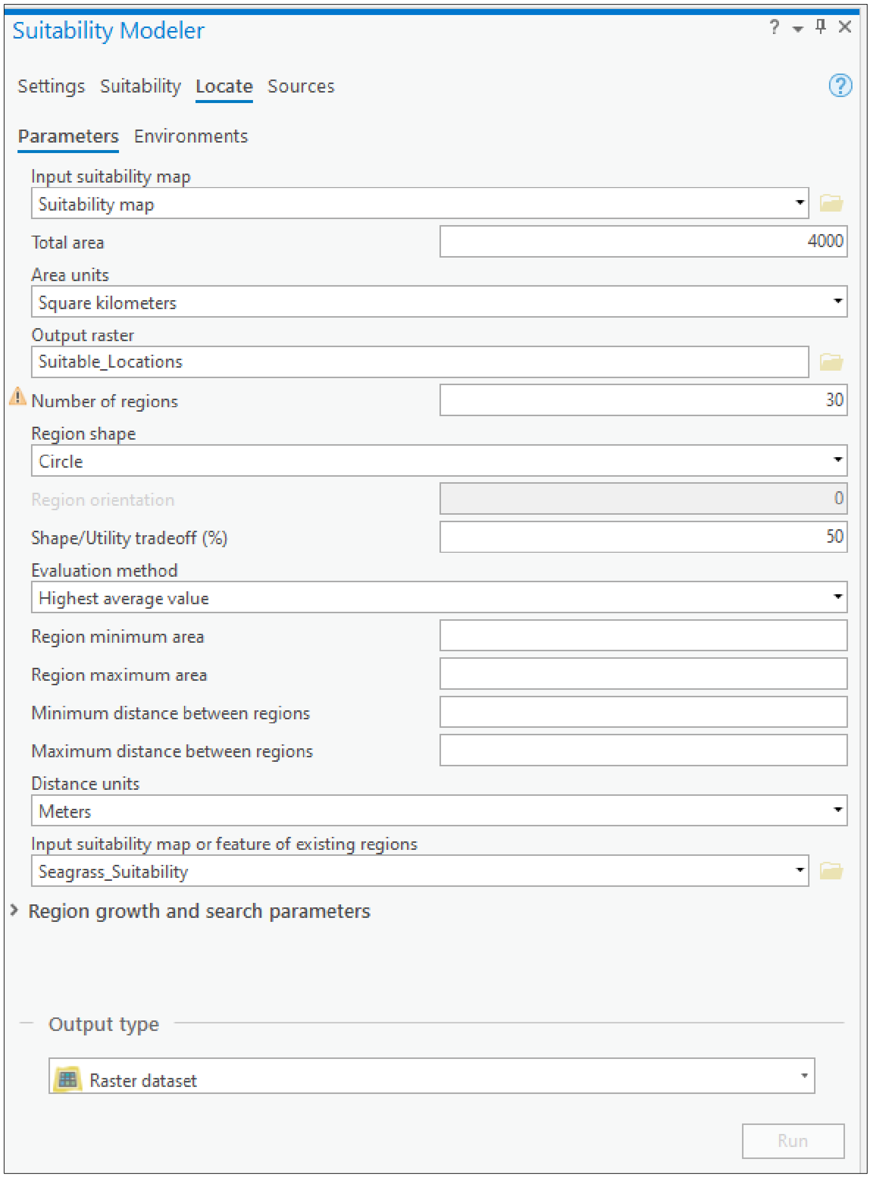

Figure B-4. Additional (unused in this model) settings refinement options.