Project: Regional Board 9 - Development of a Monitoring and Assessment Framework for Submerged Aquatic Vegetation (SAV)

Technical Report #1 – Monitoring and Assessment Framework (9.2.a,b)

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Introduction

Submerged aquatic vegetation (SAV) is an ecologically, economically, and societally important component of estuarine and coastal systems across Southern California, as well as the World (Nordlund et al., 2016; Dewsbury et al., 2016; Ruiz-Frau et al., 2017; Cullen-Unsworth et al., 2014). SAV plays an important role in the ecology of coastal systems, as it provides unique structure and enhancement of biogeochemical processes. The physical structure of SAV can function as temporary refuge from environmental threats, substratum as a permanent point of attachment and a direct or indirect mechanism for food acquisition (Boström et al. 2006; Hemminga and Duarte 2000; Orth et al. 1984). Within many Southern California estuarine environments, SAV forms expansive beds in shallow, soft-bottom sediments, comprising an important functional component of the mosaic of shallow subtidal and intertidal habitats, interspersed among emergent wetlands, biotic reefs, mudflats, and other intertidal habitats (e.g., Heck et al. 2008; Polis et al. 1997). SAV beds, like many other "habitat engineering" flora and fauna (e.g., Wright and Jones 2006; Jones et al. 1994), have a dual nature, both as semi-permanent biological resources, whose condition can be indicative of ecosystem health and integrity, as well as a unique habitat that facilitates or enhances unique foodwebs and biogeochemical cycling that are absent from adjacent habitats in shallow coastal waters. Constructing a monitoring framework that addresses both the resource and the habitat nature, poses a unique challenge that will differ from traditional bioassessment efforts.

Southern California's coastal embayments are host to a variety of SAV species, including *Ruppia maritima*, *Zostera pacifica* (wide-leaved eelgrass) and *Zostera marina* (narrow-leaved eelgrass), but *Z. marina* is the dominant species present in these habitats (Green & Short, 2003; Olsen et al., 2014). Given its dominance in the region and high ecological value (Moore & Short, 2006), most efforts at monitoring, restoration, and mitigation of SAV habitat in Southern California coastal waters have focused on *Z. marina,* with more than 50 different eelgrass mitigation projects conducted in Southern California over the last 30 years (NMFS, 2014). These eelgrass beds, natural and constructed, represent greater secondary production than *R. maritima* (Heck et al. 1995) or bare subtidal sediment (Wong 2018) and higher rates of biogeochemical cycling compared to bare subtidal sediment (Jankowska et al., 2014; McGlathery et al. 2012).

Most present-day *Z. marina* monitoring programs in Southern California focus on the seagrass as a natural resource (as opposed to a habitat); monitoring the location and extent of the eelgrass beds across the region (e.g., Coastal Resources Management 2017; Merkel and Associates 2014; Merkel and Associates 2011). Under this type of assessment framework, the primary concern is where and how much of the resource there is across the region, as well as the how those values are changing through time. The goal is to establish a bench mark so that trends in areal extent can be tracked through time and used as a proxy for the condition of the habitat (Bernstein et al.

2011). Underpinning this approach is the implicit assumption that the presence and structure of the beds conveys that they are functioning as they should. A wide variety of studies have sought to investigate the linkage between eelgrass presence, structure, and function (e.g. Potouroglou et al. 2017; Boström et al. 2014; Hansen & Reidenbach 2012; McGlathery et al. 2012; Hovel 2003; Attrill et al. 2000), but were limited in spatial or temporal scale (i.e., not applied at a regional scale or in a regular monitoring context).

Despite the variety of ecological roles it serves in the coastal ocean and the high value it has to those who use the ecosystem, there is no robust framework for monitoring and assessing the resource and habitat function (or condition) aspects of SAV in Southern California. To that end, we propose a new assessment framework for assessing SAV structure and function in the region. Our initial work will focus on *Z. marina* as it is the dominant estuarine seagrass in Southern California, but it is our philosophy that the assessment framework should be broadly applicable to all species of SAV in the region. However, we would expect the spatial scale and complexity of the different monitoring elements to vary among species. Furthermore, we would expect the thresholds of desirable structure and function measures to vary from species to species.

Proposed Framework

We are proposing a three-tiered assessment approach that focuses on SAV Extent, SAV Condition/Health, and SAV Ecological Function to better capture the multiple aspects of SAV meadows (i.e., a living natural resource and a biologically-based habitat for other flora and fauna). The three elements or tiers of the framework can be seen to operate in a sequence of ecological completeness (*sensu* Haines-Young and Potschin 2009; Vlachopoulou et al. 2013) for the habitat:

1. If the landscape is ecologically suitable, is SAV present?;
2. If present, what is the condition of the SAV bed (health, structural integrity, etc.) and the waterbody where it is located?; and
3. Given the condition of the bed, how well is it functioning in the habitat mosaic of the coastal zone?

The tiers of this proposed extent-condition-function framework will operate at different spatial, ecological, and analytical scales of complexity given how each focuses on a different aspect of SAV (Table 1). That said, it is our hope that all three pieces of the framework should be conceptually applicable at both the regional and statewide scales, with the appropriate amount of monitoring effort to produce data of enough spatial and temporal density to be evaluated within the framework.

Table 1. A summary of the three tiers of the proposed SAV assessment framework, including the likely scale of interpretation and the potential components of each tier

Assessment Tier	Core Question	Spatial Scale of Interpretation	Potential Components
Tier 1 - SAV Extent	Is SAV present in those locations where it should be?	Statewide to Waterbody	Habitat Suitability Model Causal Assessment Tools
Tier 2 - SAV Condition	What is the condition of the vegetated parts of the coastal zone?	Statewide to Waterbody	Reference Habitat Definition Quantitative Condition Assessment Tool Causal Assessment Tools
Tier 3 - SAV Ecosystem Function	Are SAV beds functioning as a normal part of the coastal zone?	Regional to Individual Beds	Reference Habitat Definition Functional Assessment Tools

Tier 1 - SAV Extent

The first tier of the proposed assessment framework is designed to address the questions of "where should SAV beds be present in coastal waters of Southern California, based on physiological limitations in the absence of anthropogenic disturbance?", and "Is any SAV present in these suitable habitats?". This tier has three primary components corresponding to those questions: 1. Identifying the natural, abiotic characteristics that affect SAV distribution – its theoretical niche (e.g., Hutchinson 1959); 2. Mapping that niche space across Southern California; and 3. Determining the presence or absence of SAV in those locations.

Under the assumption that most SAV beds in Southern California are largely mono-cultures (e.g., Johnson et al. 2003), the process of identifying theoretical niche space and mapping it to the region will most likely be modularized into species-specific, habitat occupancy models; either statistical (e.g., Detenbeck and Rego 2015; Kemp et al. 2004) or mechanistic (Koch 2001; Wetzel and Neckles 1986). Site-specific landscape characteristics derived from remote sensing and or GIS databases can then be used to parameterize the models for sites across the region (Table 2). Model output, as a likelihood of SAV presence, can then be used to create an expectation of SAV bed presence or absence over a given area. This expectation would in turn be tested with observational data collected as part of a routine monitoring program (e.g., Christiaen et al. 2016; NMFS 2014; Morro Bay National Estuary Program 2013). Absence of SAV in locations where it would be expected could lead to focused monitoring efforts to confirm its absence. Furthermore, a causal assessment would be conducted to investigate presence or absence in the past and analyze anthropogenic and natural factors that could inhibit SAV bed growth and persistence. If SAV are present, the assessment would progress into the second tier.

Table 2 Potential types of data needed to construct a mechanistic habitat occupancy model to predict where SAV beds should occur in Southern California. The Limiting Rate indicates physiological rates or physical aspects of SAV plants that constrain their growth and survival. Forcing Factors are aspects of the environment that act upon the Limiting Rates of SAV plants. State Variables are some of the potential ways to measure the Forcing Factors and parameterize the model(s).

Limiting Rate	Forcing Factor	State Variables
Min/Max light for photosynthesis	Light Penetration	Water Depth Latitude Bottom Shear Stress
Recruitment	Connectivity to Other Beds	Distance to Nearest Bed
Sediment Setting	Permeability	Sediment Composition
	Available Nutrients	Sediment TN Sediment OM content
	Toxic Reduced Chemicals	Ammonia Concentration Sulfide Concentration
Growth Rate	Temperature	Water Temperature Tidal Range
	Osmotic Balance	Salinity
Physical Disturbance	Wave Exposure	Fetch Degree of Shelter Water Depth

Tier 2 – SAV Condition

The second tier of the proposed assessment framework is designed to address the questions of "How healthy is the SAV bed?" and "What is the ecological integrity of the waterbody in which the bed is found?". There are a variety of assessment tools available to evaluate the condition of unvegetated parts of Southern California's embayments and coastal ocean (e.g., Pelletier et al. 2018; Ranasinghe et al. 2009; Smith et al. 2001), but there is no formal approach for the SAV beds in these waterbodies (Bay et al. 2014). As such, this tier of the framework will focus on evaluating the integrity of the bed as a whole and evaluate if the local environmental conditions are supportive of plant growth and persistence. There has been reasonable amount of research in this area, most frequently using the presence/extent of SAV bed growth as an assessment of eutrophication impacts in a waterbody (e.g., Corbett et al. 2005; Kraus-Jensen et al. 2005; Dennison et al. 1993). The pre-existing work in the literature will provide a good knowledge base for this part of our framework, however, there are only limited examples (mostly from Europe) where these patterns have been codified into a proper assessment tool (Garcia-Marin et al. 2013; Neto et al. 2013; Montefalcone 2009).

This tier of the framework will ultimately consist of an assessment scoring tool that uses various aspects of SAV bed health and vigor to infer the conditions of the locale in which the bed is located. This type of tool will be contingent on producing a sufficiently robust data set, and could take a variety of different forms – predictive vs. non-predictive, Multi-Metric Index vs. Stressor-Tolerance Index, bed-scale measures vs. individual plant-scale measures. Regardless of its form, an index will allow for quantitative estimates of SAV parameters that are demonstrated to be responsive to the different types of anthropogenic stressors the benthic zone of the coastal ocean is exposed to (i.e., eutrophication, habitat alteration, toxic chemicals, altered hydrology, sea level rise, climate change, ocean acidification). As part of this process, it will be important to identify the appropriate reference conditions (Stoddard et al. 2006) given the extensive alterations and degradation of Southern California's coastal zone (Stein et al. 2014; Ahn et al. 2005). It will also be important to determine if there is differential response to stressors among the different bed-scale and individual plant-scale aspects of SAV condition, as this will help to inform stressor diagnostics and causal assessment interpretation of any observed impacts to SAV condition. Completion of a tier 2 assessment will allow for a reasonable evaluation of waterbody health and provide insight into any potential disturbances that may be degrading the condition of the vegetated parts of the coastal ecosystem. If one's concerns extend beyond an evaluation of structural integrity and into the most integrative assessment of potential alteration to an ecosystem, then progressing onto the third tier of proposed framework would be required.

Tier 3 – SAV Ecosystem Function

The third tier of the proposed assessment framework is designed to address the question, "Are SAV beds providing the ecosystem functions they would be expected to?". This tier of the framework will focus on the extrinsic aspects of SAV beds; emphasizing how they are part of the mosaic of habitats in the coastal landscape and how they contribute to a healthy and fully functioning coastal ecosystem (e.g., Ruiz-Frau et al. 2017; Dewsbury et al. 2016; Nordlund et al. 2016; Cullen-Unsworth et al. 2014). Whereas tier 2 is focused around using structural aspects of SAV beds to infer the health and condition of their host waterbody, tier 3 is explicitly focused on evaluating if an SAV bed – natural or created – is providing the ecological functions it should. The presence and rate of a habitat's functions (e.g. productivity, hydrological buffering, biogeochemical cycling) speak to the most wholistic and direct assessment of anthropogenic impacts to a system (Strong et al. 2015; Cortina et al. 2006). Most studies covering ecosystem functions of SAV beds provide direct estimates of a function(s) through relatively intensive, local-scale measurements that provide insight into the magnitude of a function or how it may change under different abiotic or biotic scenarios (e.g., Lamb et al. 2017; Potouroglou et al. 2017; Thorhaug et al. 2017; Zarnoch et al. 2017). Much of this work however, is not conducive to implementation in a regional-scale, regular monitoring program. As such, much of the work associated with developing this tier will entail identifying key functions, easily measurable proxies for the functions, and understanding how they respond to different stressors in the coastal ocean.

This tier of the assessment framework will most likely consist of a series of assessment tools designed to evaluate the expression – and possibly magnitude/rate of flux – of different ecological functions in a given SAV bed. The initial tools will focus on suite of ecological functions determined to be of primary importance to local management agencies and experts in SAV ecology (Table 3). Given the difficulty of directly measuring all of the ecosystem functions described in Table 3, we will endeavor develop a series of SAV structural metrics (e.g., shoot density, above ground biomass, plant C:N ratio) that can be demonstrated to be predictive of function, responsive to stressor exposure, and relatively easy to incorporate into a regular regional monitoring program.

Table 3 Priority list of ecosystem functions that SAV beds are known to provide, as concluded by SAV ecological experts and resource managers from across Southern California. These functions will be the focal point of Tier 3 assessment tools.

Function	Definition
Substrate Stabilization	Stabilization of soft bottomed sediments within and adjacent to SAV beds by sediment/organic matter retention and wave attenuation
Carbon Sequestration	Uptake and long-term retention of carbon
Improving Water Quality	Enhancing local water quality by a variety of mechanisms, including uptake of nutrients, settlement of sediment particles, production of oxygen, and increases in pH due to photosynthesis
Primary Production	Increased diversity and rates of primary production related to the above and below ground structural complexity of SAV beds
Secondary Production	Increased productivity of infauna and epifauna due to higher structural complexity and organic mater production in SAV beds
Fish Habitat	Enhanced survival and greater food availability for fish and other nekton within and adjacent to SAV beds
Waterfowl Habitat	High productivity of SAV estuarine habitat make attractive feeding grounds for many species of water fowl

Incorporation of the three tiers into a single framework

As noted above, it is our vison that the framework presented here should be applicable across different species of SAV, but that the components of each tier are most likely species-specific in their construction and interpretation. While there are multiple paths forward, we advocate an approach of building out all three tiers for a single species – *Zostera marina*, given its importance and prevalence in the region – to help evaluate the scientific utility of the framework. Having a complete framework to deploy will also allow time for development of an understanding for how the framework can be used by interested parties and incorporated into regional monitoring programs like the Bight Regional Monitoring Program.

The three tiers of the framework are meant to be implemented sequentially, building upon the information from the previous tier while simultaneously increasing the ecological meaning of the results and drawing closer the beneficial uses they are meant to represent. In their application towards achieving natural resource management goals, each tier will probably have its own threshold for meeting management targets. These thresholds could be applied to a bed or waterbody independently (e.g., “X% of this estuary has desirable extent, Y% is in reference condition, and Z% is functioning at natural levels”) or they could be applied and interpreted in an aggregated fashion (e.g., “X% of this estuary meets the goal of desirable extent, condition, and function, but Z% is only meeting goals for extent”). Alternatively, an expectation of meeting extent and condition goals may be sufficient for SAV in all waterbodies, but evaluation of meeting the ecological function goals cold be applied to habitats undergoing restoration, mitigation, or some other priority designations, as these types of SAV beds are the more likely to have a breakdown of the “structure implying function” paradigm than naturally occurring beds and would need to have their functioning directly assessed.

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