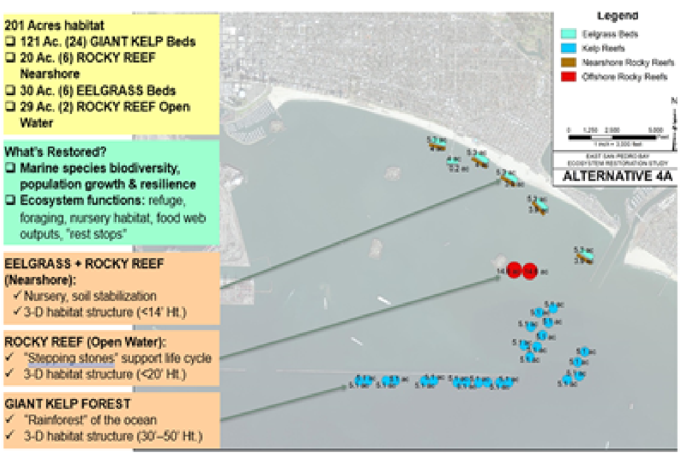
FINAL INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL IMPACT STATEMENT / ENVIRONMENTAL IMPACT REPORT (EIS/EIR)

APPENDIX D: HABITAT EVALUATION MODEL AND MODEL DOCUMENTATION

EAST SAN PEDRO BAY
ECOSYSTEM RESTORATION STUDY
Long Beach, California

January 2022



US Army Corps of Engineers ®

Table of Contents

SOUTHERN CALIFORNIA COASTAL BAY ECOSYSTEM MODEL

MODEL DOCUMENTATION

May 4, 2018

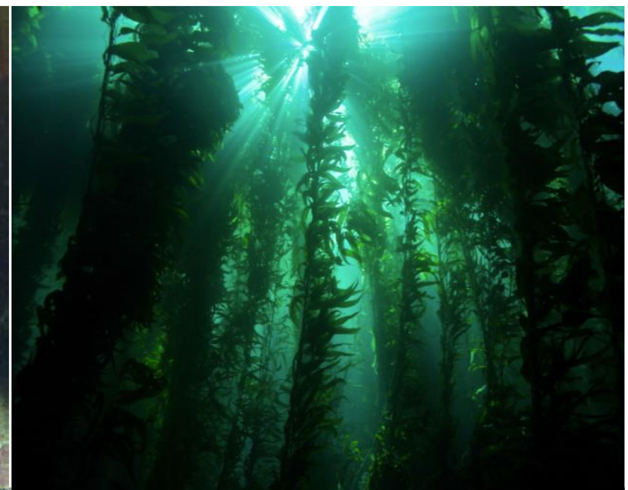


Table of Contents

Background

The East San Pedro Bay (Bay) is located along the Pacific coast within the city of Long Beach, California. The Bay, like many along the Southern California coast, has undergone extensive human modification as the result of development of navigation channels, installation of piers and breakwaters and other alterations for human use. These modifications have resulted in the loss of critical habitat types, such as estuary wetlands, decreased biodiversity and reduction of natural habitat that support a variety of wildlife and marine species. In response to the loss of ecosystem structure and function, a partnership between the U.S. Army Corps of Engineers (USACE) and the City of Long Beach (City) was formed to investigate potential restoration measures that could recover and restore lost ecosystem structure and function.

In 2015, the Los Angeles District (District) began a feasibility study to determine if there is a federal interest in restoring the ecosystem within the Bay. As part of the feasibility study, a quantitative ecological model is needed to quantify potential benefits of proposed restoration measures. Model outputs, combined with estimated costs per restoration measure, will then be used in the planning process along with the National Environmental Policy Act (NEPA) analysis and other considerations to recommend a tentatively selected plan (TSP) for the restoration of the Bay. Additionally, the model used in the calculation of benefits per restoration alternative needs to be approved or certified for use by the USACE. In February 2016, in pursuit of an ecosystem planning model, the District convened an initial model development workshop. The workshop was used to develop an early ecosystem conceptual model that refined the District's knowledge of the drivers, stressors and functions that interact to form the ecosystem of the Bay. The initial conceptual model was refined in November 2016 and serves as a template for a quantitative ecosystem model described in this report (Figure 1).

Model Background and Purpose

The Southern California Coastal Bay Ecosystem Model (Bay Model) was developed to assist in the planning process of the East San Pedro Bay Ecosystem Restoration Feasibility Study (Study). The study purpose was to recommend actions that will restore lost ecosystem structure and function and increase native biodiversity of the Bay. The Bay sits in the middle of the Southern California Bight, a coastal region from Point Conception by Santa Barbara to the Mexico border. This region has a rare Mediterranean climate only found in a few regions on earth. The Southern California Bight acts as a transition between multiple warm and cold-water masses from the Pacific subarctic, Pacific equatorial, to the North Pacific. As a transition zone, many native aquatic species from the different water masses move through the Southern California Bight.

In 2015, the Los Angeles District began the Study to determine if there is a federal interest in restoring the ecosystem within the Bay. During a USACE feasibility study, a quantitative ecological model is needed to quantify potential benefits of proposed restoration measures. Model outputs, combined with estimated costs per restoration measure, will then be used in the planning process along with the NEPA analysis and other considerations to recommend a tentatively selected plan (TSP) for the restoration of the study area. Additionally, the model used in the calculation of benefits per restoration alternative needs to be approved or certified for use by the USACE. Ecological models may be developed in a variety of ways, however, this type of study is considered a partnership between the USACE and the City of Long Beach with close collaboration of other agencies and organizations. This type of partnership requires the use of a model development strategy that allows for inputs from a variety of sources, encourages consensus on model parameters and ownership of model outputs. A mediated model development process was used to develop the East San Pedro Bay Habitat Evaluation Model.

In February of 2016 in pursuit of an ecosystem planning model the Los Angeles District convened an initial model development workshop. The workshop included members of the Los Angeles District's study team, engineers, biologists, hydrologist, economists and program managers. The workshop was used to develop an early ecosystem conceptual model that refined the Los Angeles District's knowledge of the drivers, stressors and functions that interact to form the ecosystem of the Bay (Figure 1). A second workshop, November 2016, was conducted to develop the conceptual model into a quantitative model. The second workshop included the study team and members of the study's Technical Advisory Council (TAC). The TAC is an organization that provides critical insight and advice to the study team and the City of Long Beach during the planning phases of the study. The TAC includes representatives from several state and federal resource agencies as well as marine biologists from local universities and local organizations (Table 1).

TABLE 1. TECHNICAL ADVISORY COUNCIL MEMBERS AND AFFILIATION.

Technical Advisory Council Participant	Affiliation
Adams, Loni	California Department of Fish and Wildlife
Avery, Jon	U.S. Fish and Wildlife Service
Chesney, Bryant	National Oceanic and Atmospheric Administration
Gillett, David	Southern California Coastal Water Research Project
Nye, LB	California State Water Resources Control Board
Paznokas, William	California Department of Fish and Wildlife
Pondella, Daniel	Occidental College
Simon, Larry	California Coastal Commission
Whitcraft, Christine	California State University Long Beach

The purpose of the Model is to assist in the planning phase of an ecosystem restoration project focused on restoring coastal ecosystems that are located within the Southern California Region in North America. The Model is able to capture the quality or suitability of habitat types associated with coastal ecosystems. For the purposes of the Model, habitat quality or suitability is defined as the ability of a particular habitat to support species of concern. As the suitability of a habitat increases, so does the likelihood that habitat will support a given suite of species. The model is able to capture the baseline conditions and predict increases in habitat quality under different future restoration scenarios in a given study area, given the study area is located in within the Southern California Region of North America. Application outside of the model domain would need additional scrutiny for appropriate applicability. It should be noted that the Model, though generically referred to as habitat evaluation model, is not meant to represent as or be tied to the formal Habitat Evaluation Procedures Process or Handbook developed by the U.S. Fish and Wildlife Service.

The Model is designed as a spatially-explicit, grid based model that uses a series of habitat specific linear equations to calculate habitat suitability for restoration of the following habitat types: rocky reef, kelp forest, eelgrass, oyster reef, tidal salt marsh and sandy islands. The model is composed of six habitat types, each with a series of 2-6 variables that are assigned a dimensionless Suitability Index (SI) value that represents the relationship between an environmental variable and habitat suitability for the habitat of interest. Each SI is represented quantitatively as a series of linear suitability curves, with a minimum value of 0 for unsuitable to 1.0 for optimal habitats. Suitability curves are formulated as step-functions with linear approximations between each step. A habitat specific HSI score is calculated as the geometric mean of the individual SI values and represents the overall suitability of a particular location for restoration (Pollack et al. 2012). Data and equations are imported into a GIS and applied to specific geo-referenced locations. The geospatial location of each habitat type is considered so that location specific data can be used to calculate SI values for each variable of interest. Spatial coverage of habitat (acreage) can then be used in combination with habitat HSI scores to calculate Habitat Units, as described in the "Calculating Habitat HIS" section of this document.

This document is intended to provide documentation of the Model's technical details, use and relevant information for USACE model certification (EC 1105-2-412, PB 2013-02).

Introduction

This report presents the results of steps taken to further the development of a quantitative ecosystem model that will be used to recommend a TSP for the restoration of the Bay for the USACE planning process. This report presents a refined conceptual model as well as the quantification process used in the model development process. Prior to these steps, model conceptualization was developed through workshops and meetings between the District planning branch, the Study's Technical Advisory Committee (TAC), the City of Long Beach and the Engineer Research and Development Center (ERDC). For purposes of this report here is a brief review of model objectives and limitation:

- to be able to distinguish between proposed restoration alternatives, including the Future without Project alternative;
- to be able to include input from other agencies and stakeholders once a conceptual model or model framework has been developed;
- to be relevant to habitats of interest and at the ecosystem level, not just the species; and
- to communicate benefits derived from a recommended restoration plan.

This model is not meant to project absolute system changes, but relative differences between proposed restoration alternative actions.

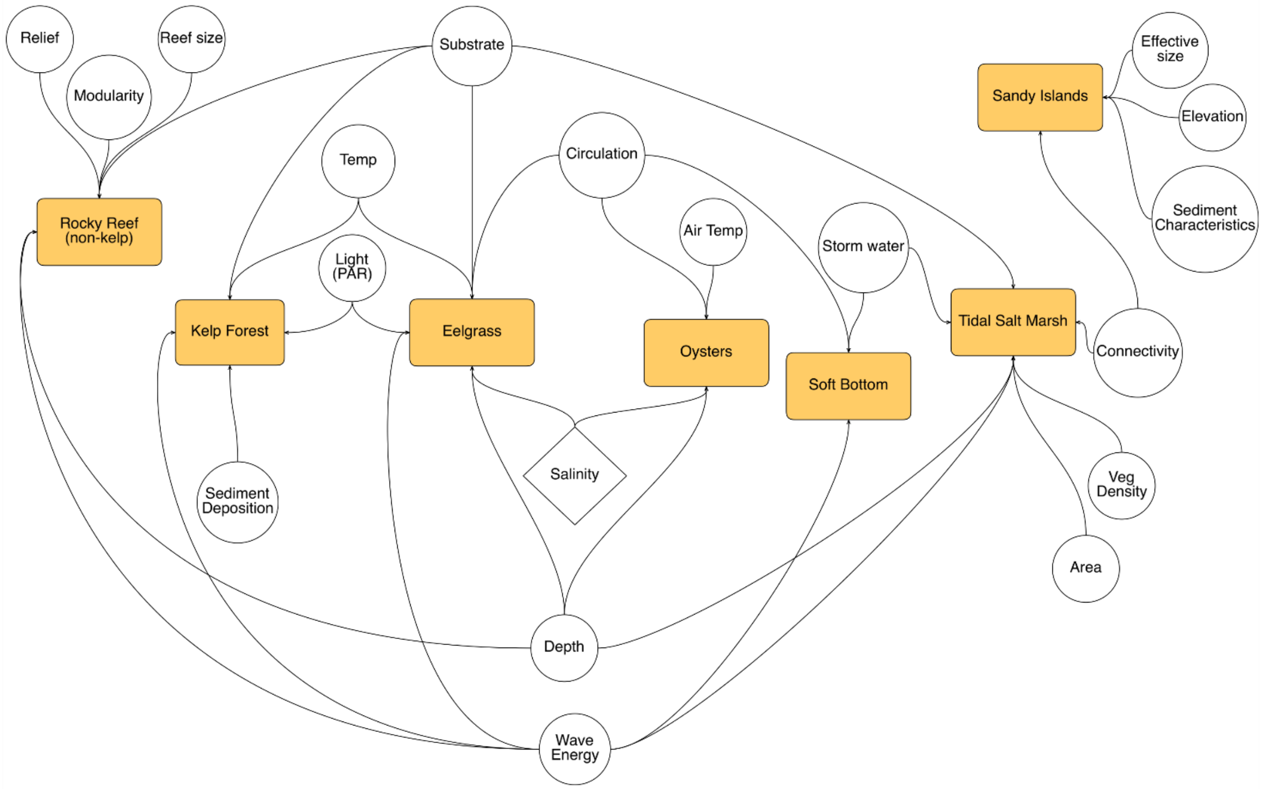


FIGURE 1. REVISED CONCEPTUAL MODEL OF THE EAST SAN PEDRO BAY ECOSYSTEM AND TARGET HABITAT TYPES.

The conceptual Habitat Suitability Model (Figure 1) was further refined during a workshop held in November 2016. This workshop was led by ERDC and participants included representatives from the District, the City and TAC members. The revised model initially focused on seven habitat types being considered as part of the restoration effort: rocky reef (non-kelp), kelp forest, eelgrass, oyster reef, soft bottom substrate, tidal salt marsh and sandy/bird islands. Soft bottom substrate was subsequently removed from the list of habitat types to model leaving six habitat types. For each habitat type, individual conceptual models were considered to identify critical physical or chemical parameters and develop mathematical curves describing the relationships between the parameters and the habitat of interest (i.e. curve development). When identifying parameters, a distinction was made between design and model parameters. Model parameters were defined as parameters that are critical for determining an index of habitat suitability. Parameters that drive placement or construction of restoration alternatives (e.g., sediment color for Sandy Islands habitat) were designated as design parameters or design considerations. Design parameters were considered during the formulation of the restoration alternatives, but excluded from the model.

Habitat Parameters and Response Curves

The following sections describe critical parameters that were identified by subject matter experts (SMEs) on the TAC within the November 2017 workshop. For each habitat parameter, a curve was developed by the SMEs using a combination of expert knowledge of a particular habitat and parameter as well as related published results from peer reviewed literature. For each habitat model parameter, we provide a visual description of the curve as well as a series of mathematical equations that describe the curve. In addition, details regarding the information used to develop each curve (i.e., expert opinion and literature) are summarized for individual parameters.

We approached the modeling of habitat benefits conservatively in that we assume the benefits per habitat type do not extend beyond the boundaries of the habitat itself. While this is a conservative approach, it does not overestimate the benefits of a specific habitat type.

The temporally dynamic input variables were generated from the hydrodynamic and water quality models (provided by Everest Consulting). Based on all available information, a two-week average for Hydro-WQ parameters is the minimum time period for which an ecological response could be observed in nature. In general, the hydrodynamic and environmental conditions in East San Pedro Bay have a biphasic cycle, changing between summer and winter. We analyzed the data provided from the summer and winter runs for the hydrodynamic/WQ models, and generated mean conditions for model parameters for both summer and winter. We then then ran a sensitivity analysis to determine which season was limiting for each habitat type. Results indicated that summer conditions were the most extreme and most critical for determining habitat suitability, so the Model uses summer values.

Rocky Reef (non-kelp)

Critical parameters identified for the rocky reef habitat include connectivity as measure of distance between reefs, reef relief and residence time as a measure of circulation. In addition, a categorical substrate parameter indicating the presence or absence of suitable substrate is critical to development and presence of rocky reef habitat. The rocky reef and the structure it provides (hard substrate, crevices, etc.) are valuable habitat for many species including target species such as the black abalone. Kelp may also opportunistically establish on rocky reef substrate even in cases in which the reef was not established as a kelp restoration site.

Connectivity

Connectivity is indicative of the distance between rocky reef habitats. As determined by the TAC, 0-500m was designated as a reasonable distance for species to cross between reefs, maintaining ideal connectivity. At distances greater than 500m, we modeled a linear decline in index value that converged to zero at 2500m.

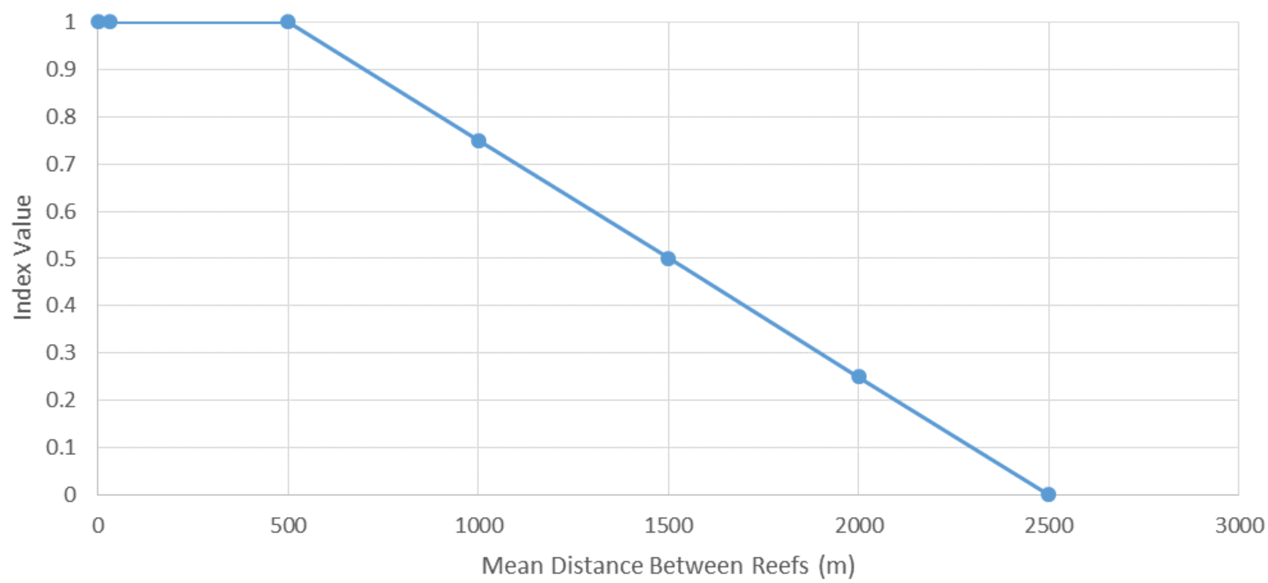


FIGURE 2. ROCKY REEF CONNECTIVITY CURVE

TABLE 2. ROCKY REEF CONNECTIVITY EQUATIONS.

Variable	Equation	Eq#
$0 \leq Distance \leq 500$	$HSI_{Distance} = 1 + (0 * Distance)$	(1)
$500 < Distance \leq 2500$	$HSI_{Distance} = 1.25 + (-0.0005 * Distance)$	(2)
$2500 < Distance$	$HSI_{Distance} = 0 + (0 * Distance)$	(3)

Reef Relief

Reef relief represents a categorical parameter based on relief type. Relief is measured as a combination of slope and elevation of reef height off bottom, and ranges from horizontal (flat) to vertical (wall) with the following designations (Pondella et al 2015; Greene et al 1999):

Flat = 0-0.1m elevation and 0-5° slope;
Low = 0.1-0.5m elevation;
Medium = 0.6-1.0m elevation;
High = 1-2m elevation;
Higher > 2m elevation; and
Wall = vertical slope of at least 90°.

Most reefs are between 1-3 m in height. Quality of rocky reef habitat has been measured as biomass production. Middle and higher relief reefs are most productive, small and flat relief reefs and walls have low production. Index values associated with each reef type were determined by SMEs in the TAC. In general, increased topographic relief also increases surface areas (Pondella et al. 2015).

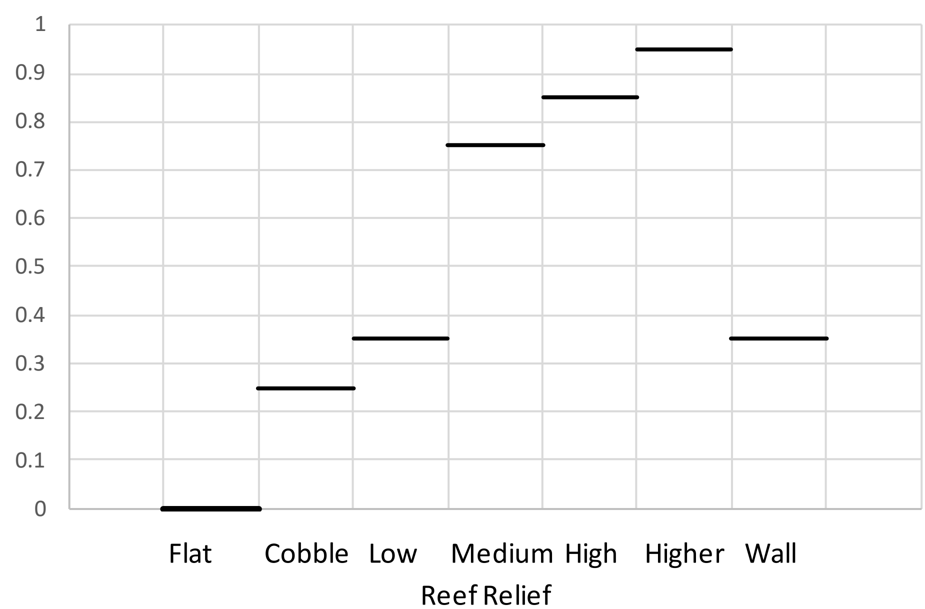


FIGURE 3. ROCKY REEF RELIEF INDEX VALUES.

Index values, as developed by the TAC and Pondella et al 2015, and Pondella personal communication, are presented in Table 2.

TABLE 3. ROCKY REEF RELIEF INDEX EQUATIONS

Relief category	Index Value
Flat	0
Cobble	0.25
Low	0.35
Medium	0.75
High	0.85
Higher	0.95
Wall	0.35

Residence Time

In a separate, related effort of the Study, a particle tracking study was developed for the bay to determine residence time with the Bay and to identify predicted circulation impacts due to proposed structural changes (such as breakwater removal or notching). This model was completed by RECON Environmental, Inc. for the LA District. For the habitat model, residence time, as determined by RECON Environmental, Inc. is used as a proxy for water circulation within the system. Higher circulation, corresponding to short water residence time, is more beneficial to species occupying rocky reef habitat than low circulation (long residence times) for a number of reasons including plankton replenishment, and improved nutrient and water quality (Lowe and Bray 2006). While the residence data are specific to one locality (East San Pedro Bay), the resulting residence time curve (Figure 4), represents a reasonable relationship between residence time and index values the is appropriate for use in localities within the regional domain.

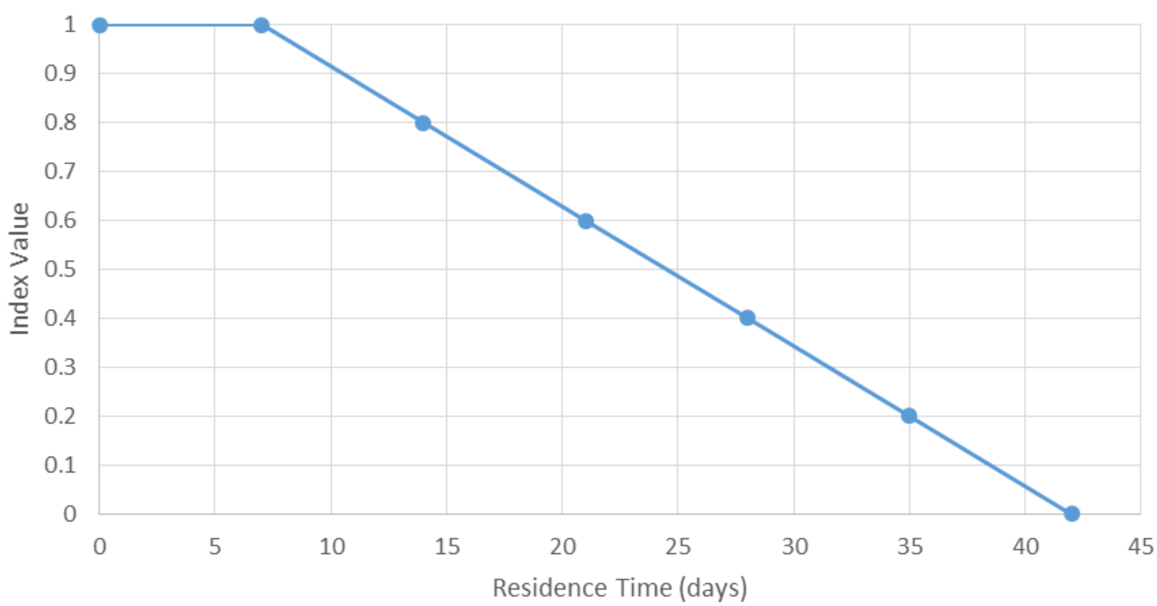


FIGURE 4. ROCKY REEF RESIDENCE TIME CURVE.

TABLE 4. ROCKY REEF RESIDENCE TIME EQUATIONS.

Variable	Equation	Eq#
7 ≤ *Residence Time* >14	$HSI_{Residence\ Time} = 1.0002 + (-0.0143 * Residence\ Time)$	(1)
14< *Residence Time* ≥42	$HSI_{Residence\ Time} = 1.201 + (-0.0286 * Residence\ Time)$	(2)
42< *Residence Time*	$HSI_{Residence\ Time} = 0 + (0 * Residence\ Time)$	(3)

Substrate

Substrate type represents a categorical parameter. As rocky reefs require hard substrate (Pondella et al 2015), the substrate index value is equal to 1 when suitable rocky substrate is present and the index value is equal to 0 when hard substrate is absent.

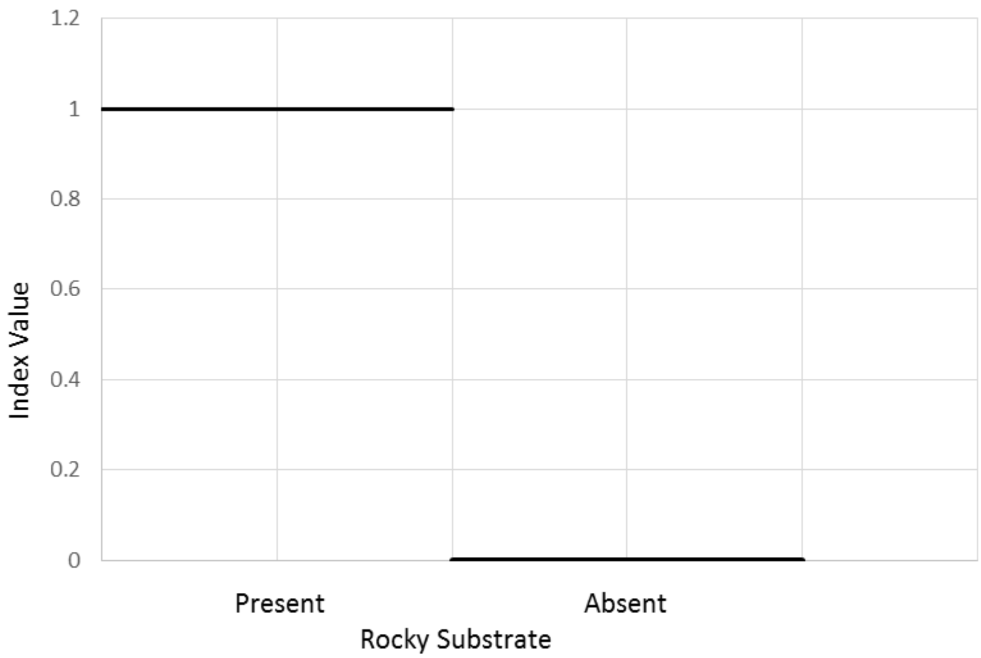


FIGURE 5. ROCKY REEF SUBSTRATE INDEX VALUES.

TABLE 5. ROCKY REEF SUBSTRATE EQUATIONS

Substrate Category	Index Value
Absent	0
Present	1

Kelp Forest

Critical parameters identified for the kelp forest habitat included water temperature, substrate and depth as an indicator of wave energy.

Temperature

There is a well-documented relationship between water temperature and density and nutrient concentrations essential for kelp growth (Jackson 1983). There is also a strong negative correlation between temperature and nitrate, the nutrient most likely to limit growth in the southern California Bight (North et al. 1982) When water temperatures are above 15°C, concentrations of nitrate are negligible and growth becomes limited (Zimmerman and Kremer 1984, Tegner and Dayton 1987 and references therein).

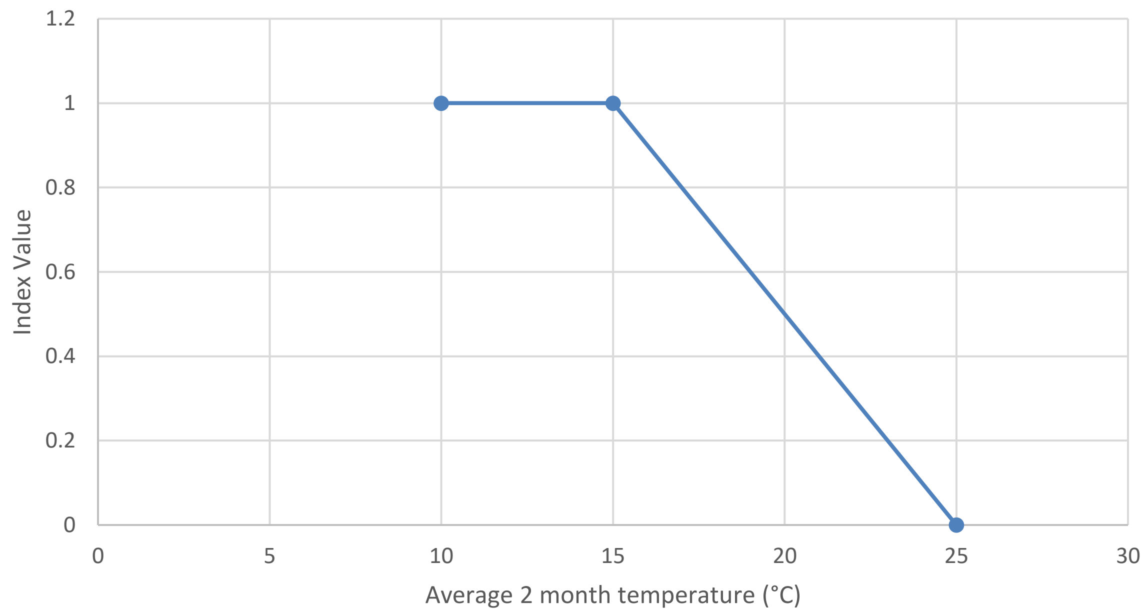


FIGURE 6. KELP TEMPERATURE CURVE.

TABLE 6. KELP TEMPERATURE EQUATIONS.

Variable	Equation	Eq#
10 ≤ *Mean two month Temperature* > 15	$HSI_{Temp} \;=\; 1 + (0 * Temp)$	(1)
15 <*Mean two month Temperature* ≤ 25	$HSI_{Temp} \;= 2.5 + (-0.1 * Temp)$	(2)
25 < *Mean two month Temperature*	$HSI_{Temp} \;=\; 0 + (0 * Temp)$	(3)

Substrate

Substrate type represents a categorical parameter. When suitable rocky substrate is present, the substrate index value is equal to 1 and when substrate is absent, the index value is equal to 0 (See North 1971).

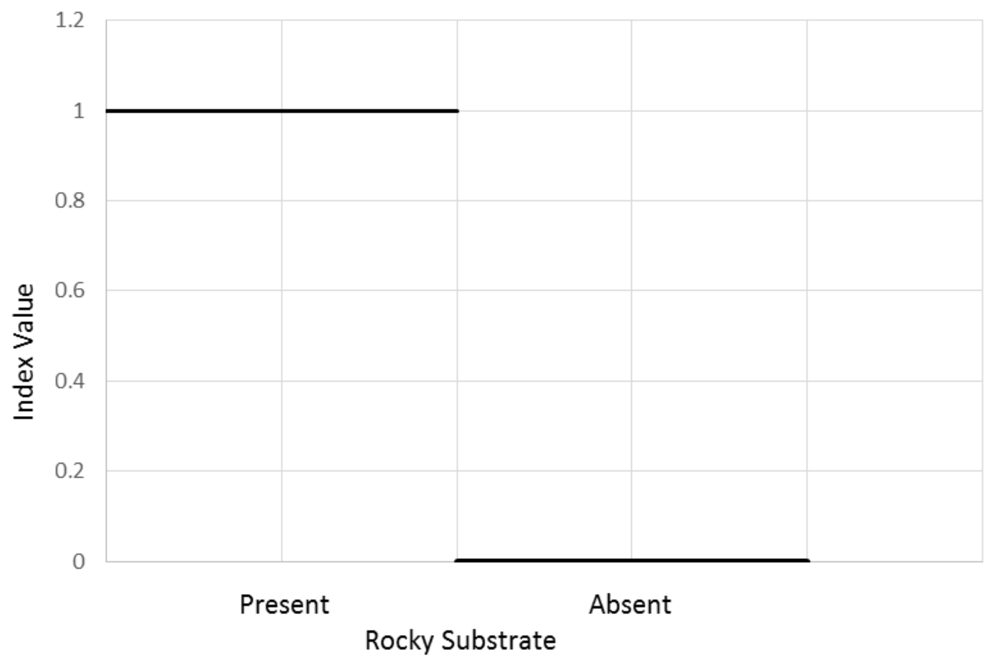


FIGURE 7. KELP SUBSTRATE INDEX VALUES.

TABLE 7. KELP SUBSTRATE EQUATIONS

Substrate Category	Index Value
Absent	0
Present	1

Depth

In Southern California, near offshore islands with clear water, kelp can grow at depths of over 30m (Feder et al. 1974). In coastal waters that are typically more turbid, kelp grows in depths as shallow as ~ 3 or 4 m (Zimmerman and Kremer 1984, Feder et al. 1974). Figure 8 and Table 5 represent a regional HSI curve and corresponding equations based on the historical literature (Feder et al. 1974; Zimmerman and Kremer 1984).

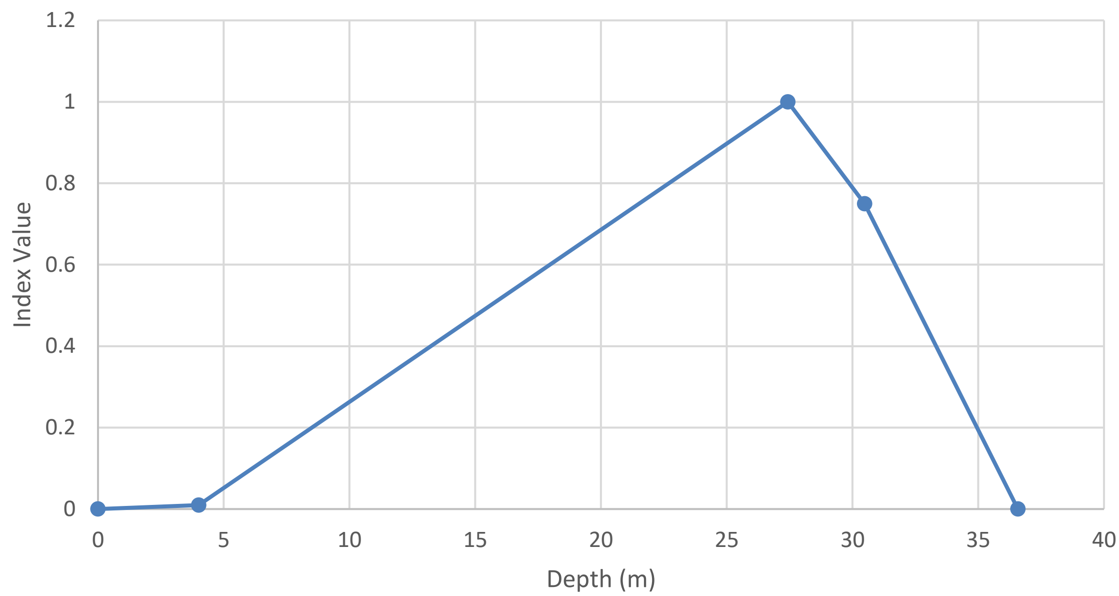


FIGURE 8. REGIONAL KELP DEPTH CURVE.

TABLE 8. REGIONAL KELP DEPTH EQUATIONS.

Variable	Equation	Eq#
0 ≤ *Depth* > 4	$HSI_{Depth} = 0 + (0.0025 * Depth)$	(1)
4 <*Depth* ≤ 27.4	$HSI_{Depth} = -0.1576 + (0.0422 * Depth)$	(2)
27.4< *Depth* ≤ 30.5	$HSI_{Depth} = 3.2494 + (-0.082 * Depth)$	(3)
30.5<*Depth* ≤ 36.6	$HSI_{Depth} = 4.4988 + (-0.123 * Depth)$	(4)
36.6<*Depth*	$HSI_{Depth} = 0 + (0 * Depth)$	(5)

Review of the kelp depth curves by members of the TAC highlighted some potential local differences in the observed contemporary kelp-depth relationship within East San Pedro Bay. Specifically, the ideal depth and depth range of existing kelp habitat within the bay is more shallow than predicted on a regional scale (Chesney and Pondella, personal communication). As a result, we used the following modified curves as a local assessment of Kelp depth HSI.

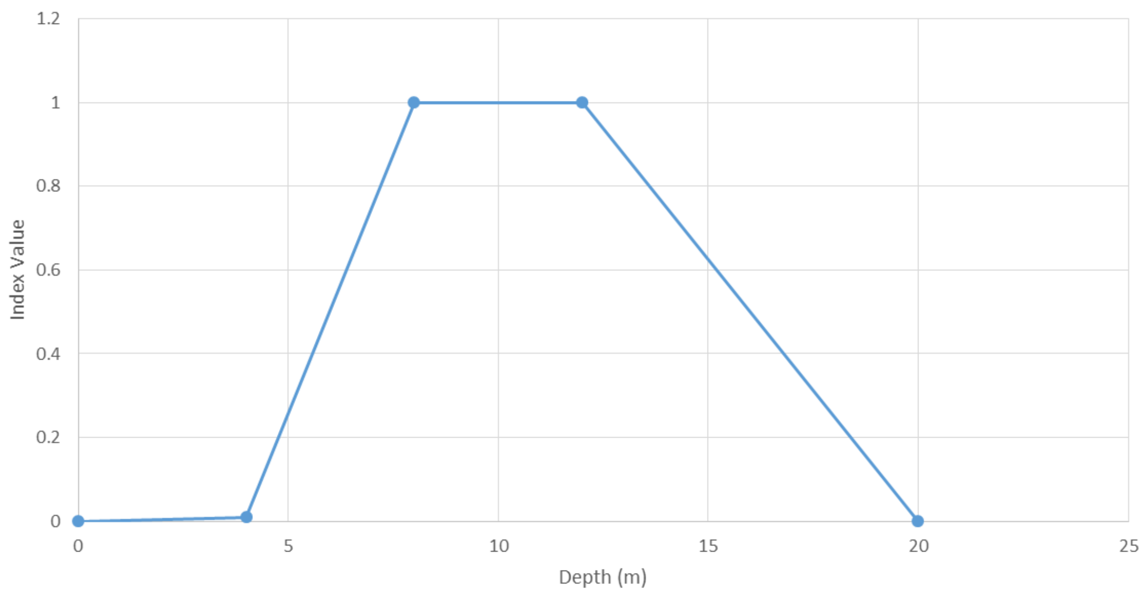


FIGURE 9. LOCAL KELP DEPTH CURVE.

TABLE 9. LOCAL KELP DEPTH EQUATIONS.

Variable	Equation	Eq#
0 ≤ *Depth* > 4	$HSI_{Depth} = 0 + (0.0025 * Depth)$	(1)
4 <*Depth* ≤ 8	$HSI_{Depth} = -0.98 + (0.2475 * Depth)$	(2)
8< *Depth* ≤ 12	$HSI_{Depth} = 1 + (0 * Depth)$	(3)
12<*Depth* ≤ 20	$HSI_{Depth} = 2.5 + (-0.125 * Depth)$	(4)
20<*Depth*	$HSI_{Depth} = 0 + (0 * Depth)$	(5)

Eelgrass

The eelgrass habitat, focused on *Zostera* sp., has the following critical parameters: water circulation, depth, substrate, and temperature. Additional design considerations include salinity and wave energy. Salinity could conceptually serve as a go/no go point within the conceptual model. If wave energy is included, it would show a curve similar to the wave energy curve for kelp, with a smaller area of optimum than kelp, and smaller values on the x-axis. In terms of design considerations, wave energy is critical, as too much wave height in a shallow depth is detrimental to eelgrass habitat.

Circulation

The index value for circulation is described in Figure 10 and is based on experience from SMEs as determined by TAC. This relationship is based on regional knowledge, but also depicts a reasonable regional curve. While *Zostera* requires flow over habitat, wave energy also has sheer stress that may uproot plants (Koch 2001).

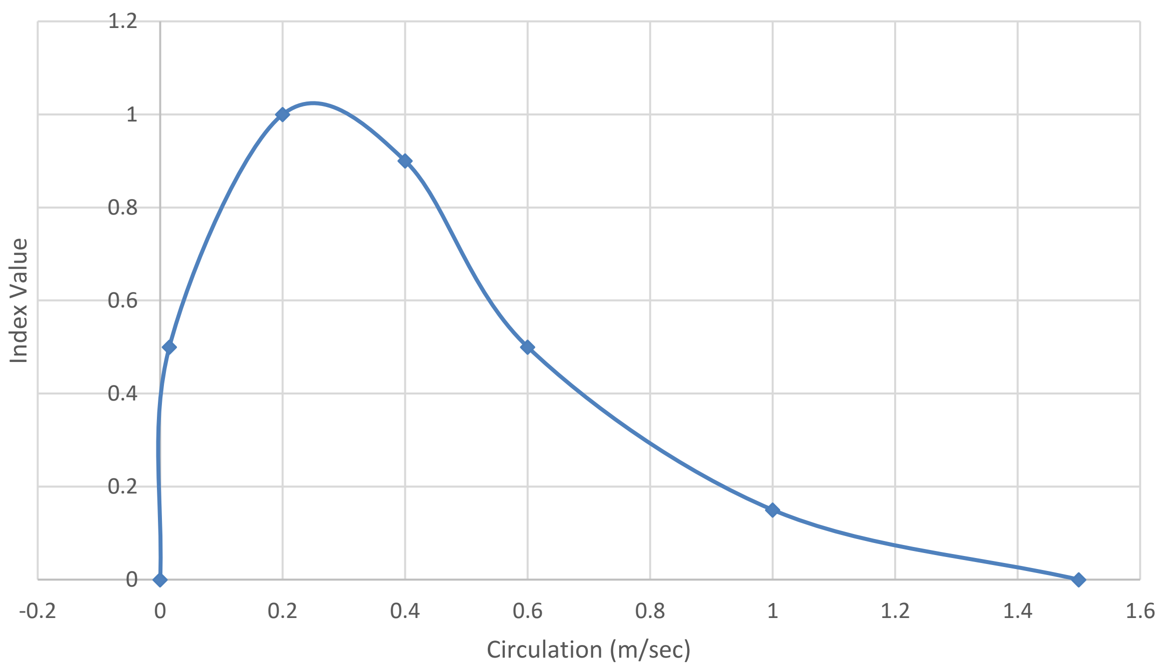


FIGURE 10. EELGRASS CIRCULATION CURVE.

TABLE 10. EELGRASS CIRCULATION EQUATIONS.

Variable	Equation	Eq#
0 ≤ *Circulation*> 0.015	$HSI_{Circulation} = 0 + (33.3333 * Circulation)$	(1)
0.0.015< *Circulation* ≤ 0.02	$HSI_{Circulation} = 0.4595 + (2.027 * Circulation)$	(2)
0.02 < *Circulation* ≤ 0.04	$HSI_{Circulation} = 1.1 + (-0.5 * Circulation)$	(3)
0.04< *Circulation* ≤ 0.06	$HSI_{Circulation} = 1.7 + (-2 * Circulation)$	(4)
0.06< *Circulation* ≤ 1.0	$HSI_{Circulation} = 1.025 + (-0.875 * Circulation)$	(5)
1.0< *Circulation* ≤ 1.5	$HSI_{Circulation} = 0.45 + (-0.3 * Circulation)$	(6)
1.5< *Circulation*	$HSI_{Circulation} = 0 + (0 * Circulation)$	(7)

Depth

Critical depth values were identified from unpublished data (Merkel and Associates) that is being finalized by National Marine Fisheries Service (NMFS). At depths that are exposed (above Mean Low Low Water (MLLW)) eelgrass may occur in some situations, but is not expected to occur within the Bay area due to stress from a combination of wave energy and beachgoer trampling. As a result, the TAC determined to limit the eelgrass depth curve to depths below MLLW.   At depths greater than ~1.5 m, water clarity and photosynthetically active light become reduced, limiting photosynthetic ability.

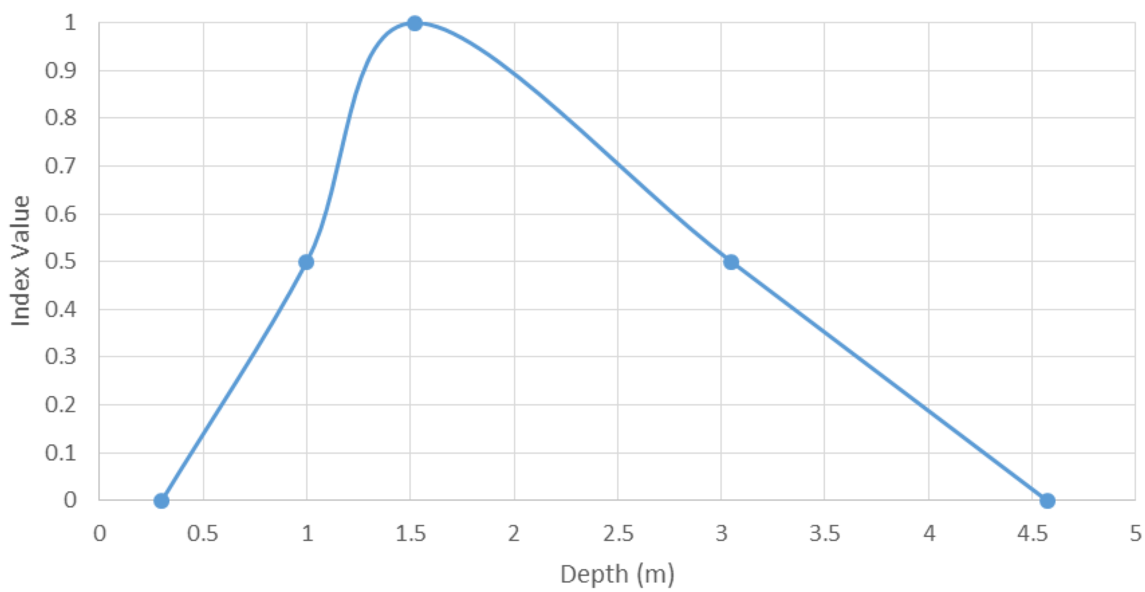


FIGURE 11. EELGRASS DEPTH CURVE.

TABLE 11. EELGRASS DEPTH EQUATIONS.

Variable	Equation	Eq#
0.3 ≤ *Depth*> 1	$HSI_{Depth} = 0.2143 + (0.7143 * Depth)$	(1)
1< *Depth* ≤1.524	$HSI_{Depth} = -0.4542 + (0.9542 * Depth)$	(2)
1.524 < *Depth* ≤ 4.572	$HSI_{Depth} = 1.5 + (-0.3281 * Depth)$	(3)
4.572< *Depth*	$HSI_{Depth} = 0 + (0 * Depth)$	(4)

Substrate

Our assumptions include the fact that the majority of current substrate conditions are sand and, with the exception of rocky reef, does not include gravel, cobble or boulders. Substrate conditions with < 20% silt and clay are ideal for seagrass restoration (Vaudry 2008, Koch 2001). Sediments within beds of SAV are finer than the sediments in adjacent, unvegetated areas (Koch 2001, Wanless 1981, Almasi et al. 1987), leading to a decrease in porewater exchange with the water column (Huettel and Rusch 2000) and potential increase in nutrient concentrations within the sediments (Kenworthy et al. 1982, Koch 2001). The range of percent fines used to develop eelgrass curves and equations (2.3 – 56.3%; Figure 12 and Table 9) represent the range of percent fines in sediments in which *Z. marina* colonizes (Koch 2001).

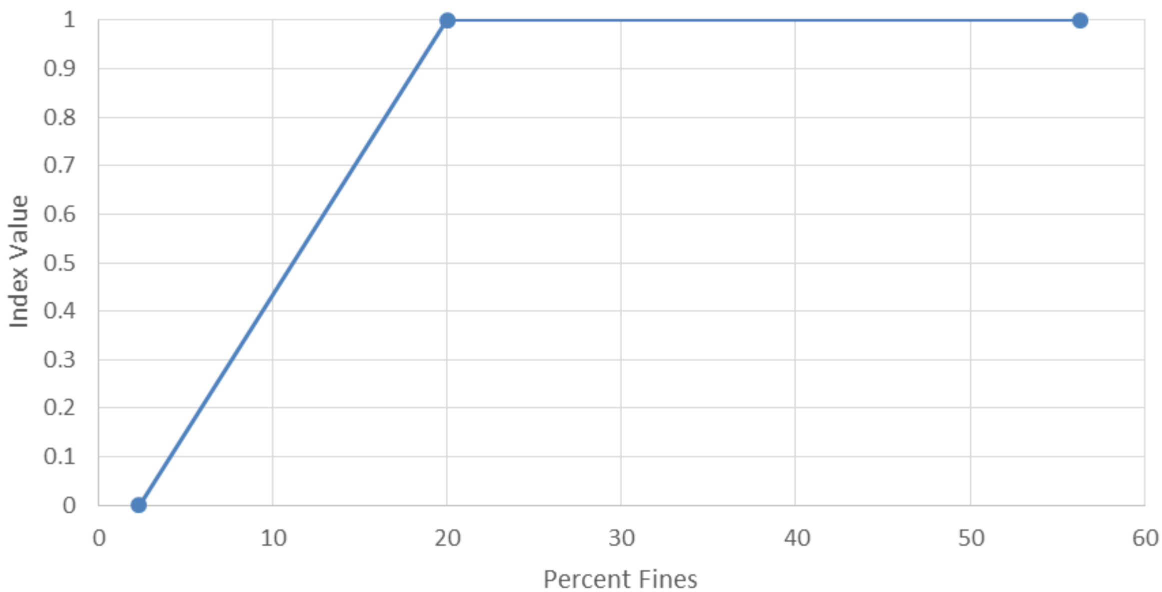


FIGURE 12. EELGRASS PERCENT FINES CURVE.

TABLE 12. EELGRASS PERCENT FINES EQUATIONS.

Variable	Equation	Eq#
2.3 ≤ *Percent Fines*> 20	$HSI_{Percent\ Fines} = -0.13 + (0.0565 * Percent\ Fines)$	(1)
20< *Percent Fines* ≤ 56.3	$HSI_{Percent\ Fines} = 1 + (0 * Percent\ Fines)$	(2)
56.3<*Percent Fines*	$HSI_{Percent\ Fines} = 0 + (0 * Percent\ Fines)$	(3)

Temperature

Critical values of temperature (°C) were determined from Moore and Jarvis, 2008. Typical winter temperature ranges may slow eelgrass growth, but survival is not impacted in the 10-20°C range. However, summer temperature ranges between 20-30^{o}C cause stress and plant mortality (Moore and Jarvis 2008). Monthly values of temperature should be used as inputs for this parameter.

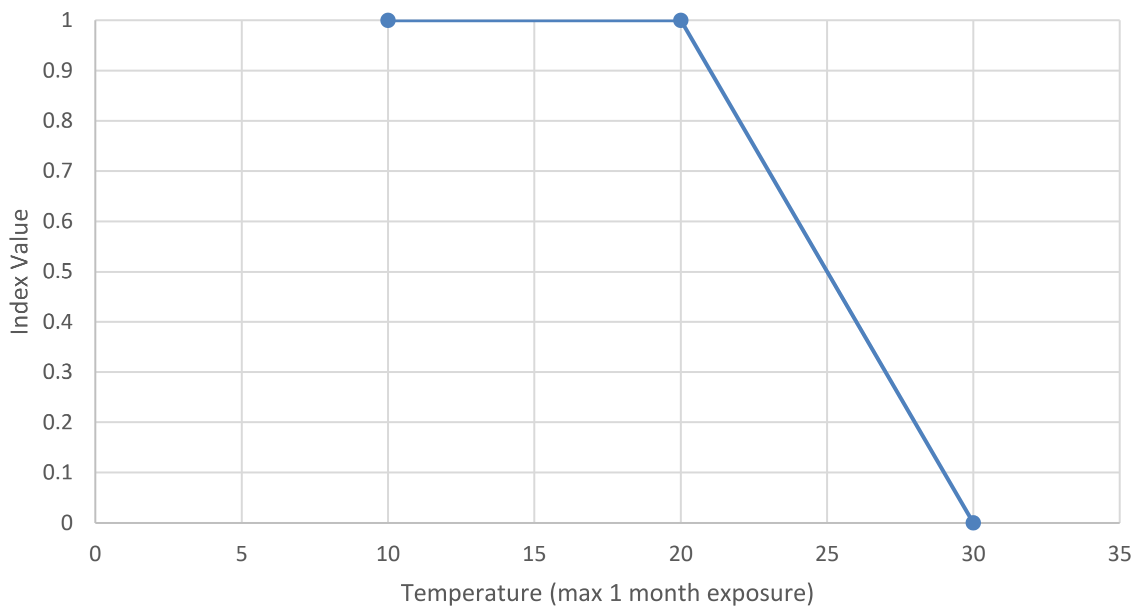


FIGURE 13. EELGRASS TEMPERATURE CURVE.

TABLE 13. EELGRASS TEMPERATURE EQUATIONS.

Variable	Equation	Eq#
10 ≤ *Temperature*>20	$HSI_{Temperature} = 1 + (0 * Temperature)$	(1)
20< *Temperature* ≤ 30	$HSI_{Temperature} = 3 + (-0.1 * Temperature)$	(2)
30< *Temperature*	$HSI_{Temperature} = 0 + (0 * Temperature)$	(3)

Oyster Reef

Primary parameters identified for oyster reef habitat were salinity and depth, which are similar parameters to other index-based oyster models (Soniat and Brody 1988 , Swannack et al. 2015). Note that these parameters are not directed at juveniles, but at adult survival. Oysters require hard substrate for attachment, but substrate was not included as a parameter because substrate placement is a design consideration in the Bay. An assumption of this model is that if the proper substrate is placed in the Bay, then oyster substrate is not limiting. Other factors that were considered but not included in the current model were ocean acidification, public access (may be more of a placement/design consideration), and Total Maximum Daily Load (TMDL) (due to liability for tissue contamination).

Salinity

Salinity of less than 25 parts per thousand (ppt) is suboptimal, greater than 25 is optimal, and salinities less than 10 ppt are detrimental to oysters (Hopkins, 1937).

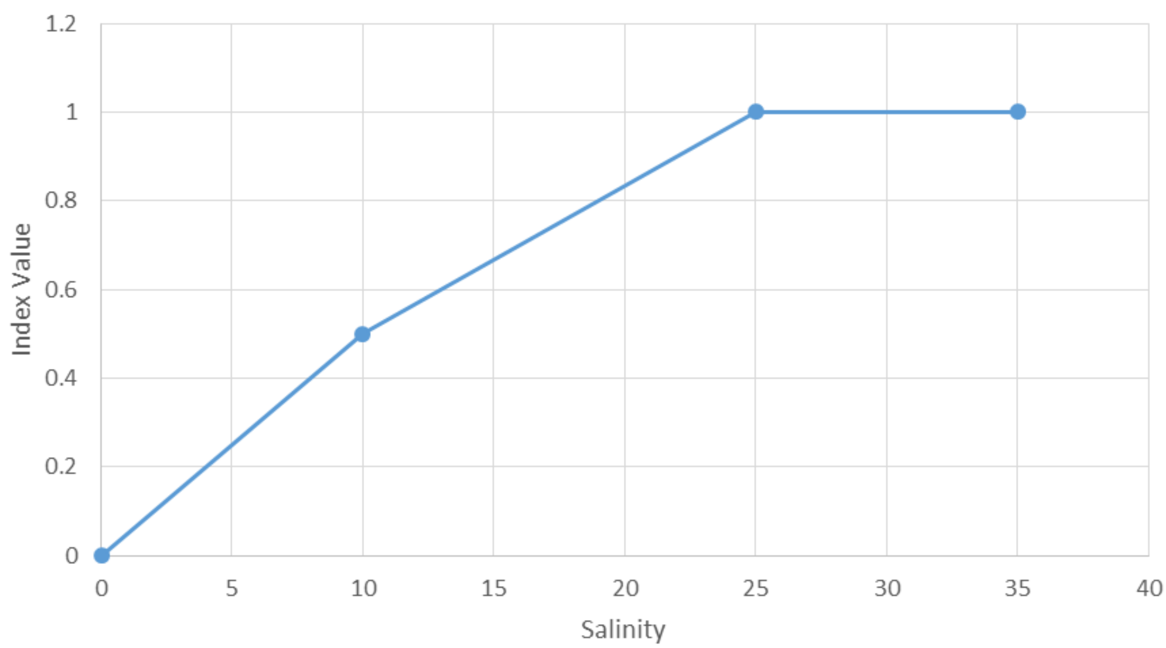


FIGURE 14. OYSTER SALINITY CURVE.

TABLE 14. OYSTER SALINITY EQUATIONS.

Variable	Equation	Eq#
0 ≤ $Salinity$ >10	$HSI_{Salinity} = 0 + (0.05 * Salinity)$	(1)
10 ≤ $Salinity$ >25	$HSI_{Salinity} = 0.1675 + (0.0333 * Salinity)$	(2)
25< $Salinity$ ≤35	$HSI_{Salinity} = 1 + (0 * Salinity)$	(3)

Depth

Optimum depth for adult oysters is 1 to -2 feet from MLLW (Baker 1995). Although -2 ft MLLW is an optimal depth, exposure to changing air temperatures will limit mortality at this depth, lowering the index value.

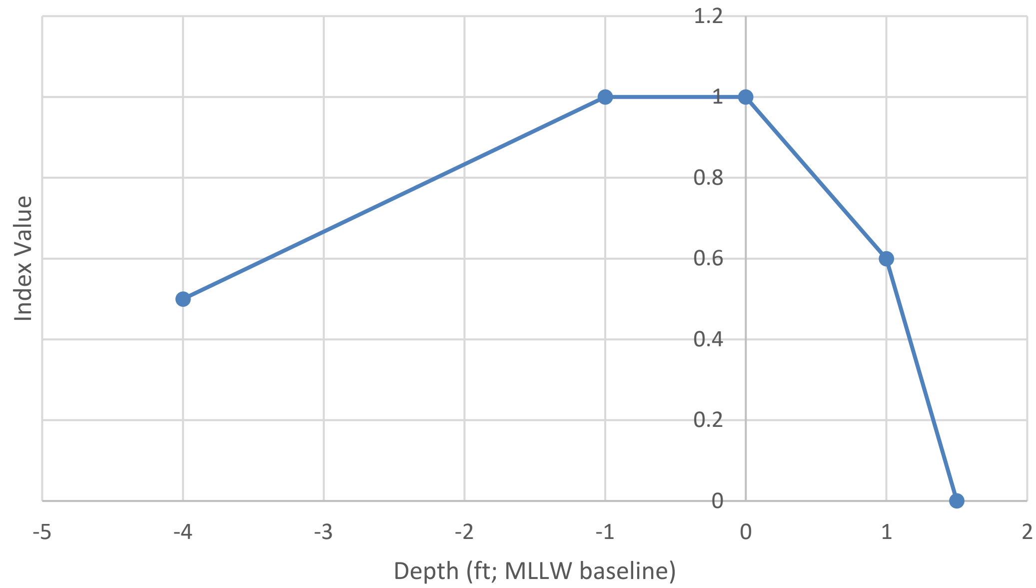


FIGURE 15 OYSTER DEPTH CURVE.

TABLE 15. OYSTER DEPTH EQUATIONS.

Variable	Equation	Eq#
-4 ≤ $Depth$ >-1	$HSI_{Depth} = 1.1667 + (0.1667 * Depth)$	(1)
-1 < $Depth$ ≤ 0	$HSI_{Depth} = 1 + (0 * Depth)$	(2)
0 < $Depth$ ≤ 1	$HSI_{Depth} = 1 + (-0.4 * Depth)$	(3)
1 < $Depth$ ≤ 1.5	$HSI_{Depth} = 1.8 + (-1.2 * Depth)$	(4)
1.5 < $Depth$	$HSI_{Depth} = 0 + (0 * Depth)$	(5)

Tidal Salt Marsh

Tidal salt marsh parameters include elevation, salinity, substrate (grain size), and connectivity (distance to other wetlands and marsh size). Marsh connectivity is coupled to persistence (stability, resilience, etc.), and freshwater flow (river flow) resulting from storm events.

Elevation

Comprehensive studies of Southern California salt marsh habitat have identified ideal elevation ranges and thresholds that define high and low marsh boundaries. These data are summarized in the curve below (Zedler et al. 1982). These elevations are tied to the duration of maximum tidal exposure (E) and submersion.

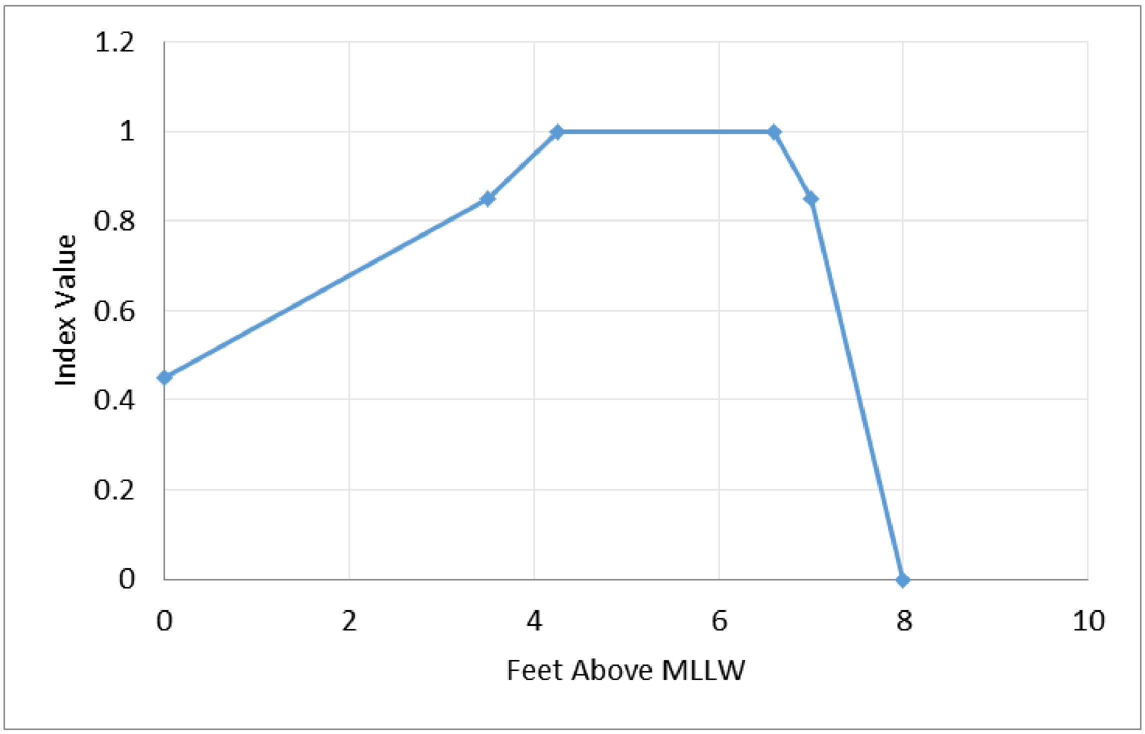


FIGURE 16. TIDAL MARSH ELEVATION CURVE.

TABLE 16. TIDAL MARSH ELEVATION EQUATIONS.

Variable	Equation	Eq#
$0 \le feet\ above\ MLLW$ >3.5	$HSI_{feet\ above\ MLLW} = 0.45 + (0.1143 * feet\ above\ MLLW)$	(1)
$3.5 < feet\ above\ MLLW \le 4.25$	$HSI_{feet\ above\ MLLW} = 0.15 + (0.2 * feet\ above\ MLLW)$	(2)
$4.25 < feet\ above\ MLLW \le 6.6$	$HSI_{feet\ above\ MLLW} = 1 + (0 * feet\ above\ MLLW)$	(3)
$6.6 < feet\ above\ MLLW \le 7$	$HSI_{feet\ above\ MLLW} = 3.475 + (-0.375 * feet\ above\ MLLW)$	(4)
$7 < feet\ above\ MLLW \le 8$	$HSI_{feet\ above\ MLLW} = 6.8 + (-.85 * feet\ above\ MLLW)$	(5)
$8 < feet\ above\ MLLW$	$HSI_{feet\ above\ MLLW} = 0 + (0 * feet\ above\ MLLW)$	(6)

Grain Size

Based on measurements of surface sediment texture and grain size, silts and sands are ideal for marsh systems (Zedler et al. 1982). Sediment grain size categories are based on the Krumbein phi/Wentworth scale and are summarized below in Table 18.

TABLE 17. TIDAL MARSH SEDIMENT GRAIN SIZE CATEGORIES.

Wentworth Grain Size Class	ϕ scale	Particle size range
Silt	8 to 4	3.9–62.5 µm
Sand	4 to 1	0.0625-0.5mm
Coarse Sand	1 to -1	0.5-2.0mm
Gravel	-1 to -6	2.0-64mm
Cobble	-6 to -8	64mm-256mm

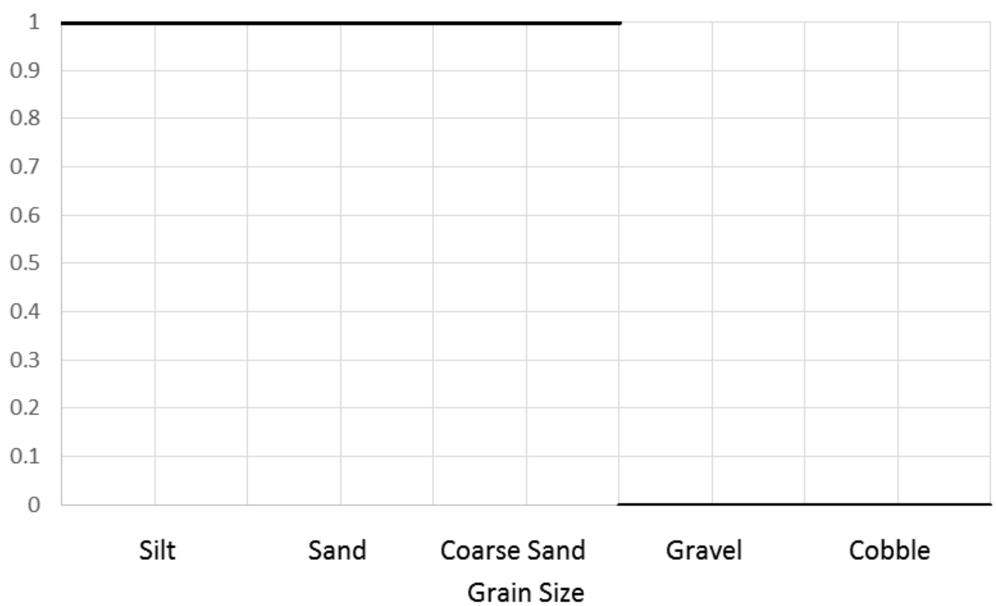


FIGURE 17. TIDAL MARSH SEDIMENT GRAIN SIZE INDEX VALUES.

TABLE 18. TIDAL MARSH GRAIN SIZE EQUATIONS

Substrate Category	Index Value
Silt, Sand & Coarse Sand	1
Gravel & Cobble	0

Salinity

Southern California coastal marshes experience wide ranges in salinity which can include long periods of hypersaline conditions in drought years (Zedler et al. 1982). Salinity can be an important driver of species community composition and plant condition. Salinity was measured over a two week period in summer.

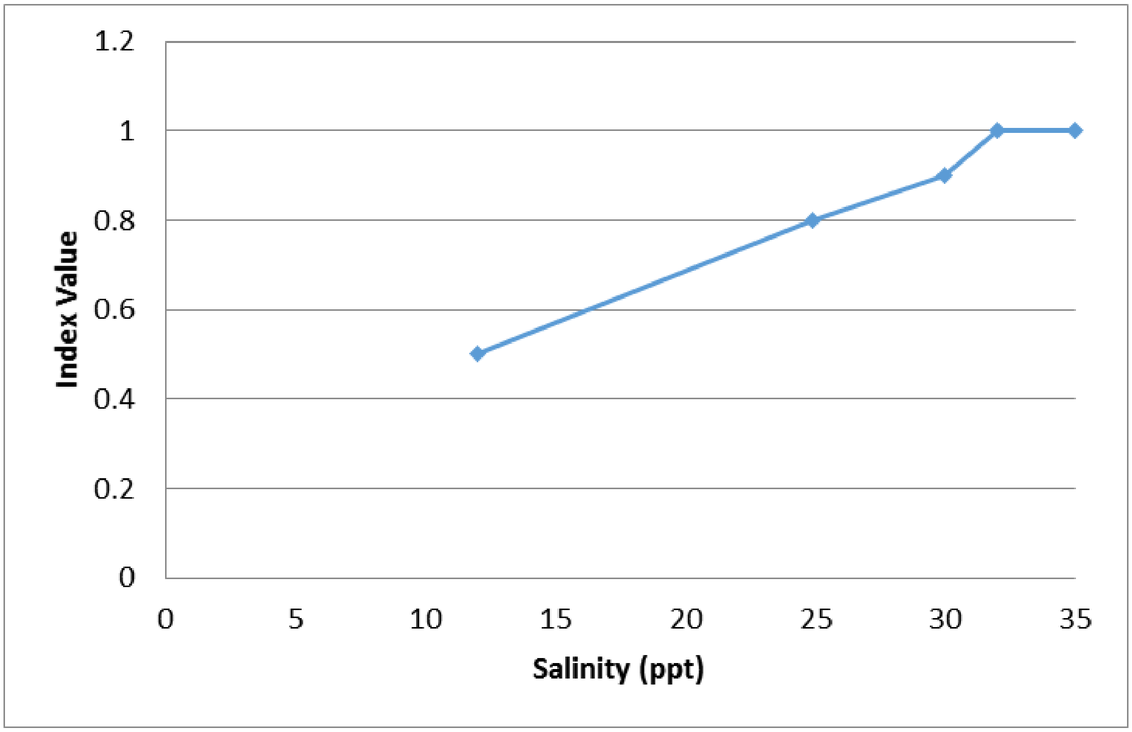


FIGURE 18. TIDAL MARSH SALINITY CURVE.

TABLE 19. TIDAL MARSH SALINITY EQUATIONS.

Variable	Equation	Eq#
12 ≤ $salinity$ >24.925	$HSI_{salinity} = 0.2217 + (0.0232 * salinity)$	(1)
24.925 < $salinity$≤ 30	$HSI_{salinity} = 0.309 + (0.0197 * salinity)$	(2)
30< $salinity$≤ 32	$HSI_{salinity} = -0.6 + (0.05 * salinity)$	(3)
32< $salinity \leq 35$	$HSIsalinity = 1 + (0 * salinity)$	(4)

Connectivity

The degree of connectivity between individual tidal marshes can influence foraging and recruitment behavior of fish, birds, and other organisms (West and Zedler 2000, Siegel et al 2010) and is often considered an important element of restoration efforts. We used a categorical approach to assessing tidal marsh connectivity by quantifying the minimum positive number of possible linkages between tidal marshes within the area of interest. For example, if one tidal marsh is present within the model domain, there would be zero linkages corresponding to an index value of zero. If two tidal marshes were present, there would be 1 linkage corresponding to an index value of 0.5 (Figure 19).

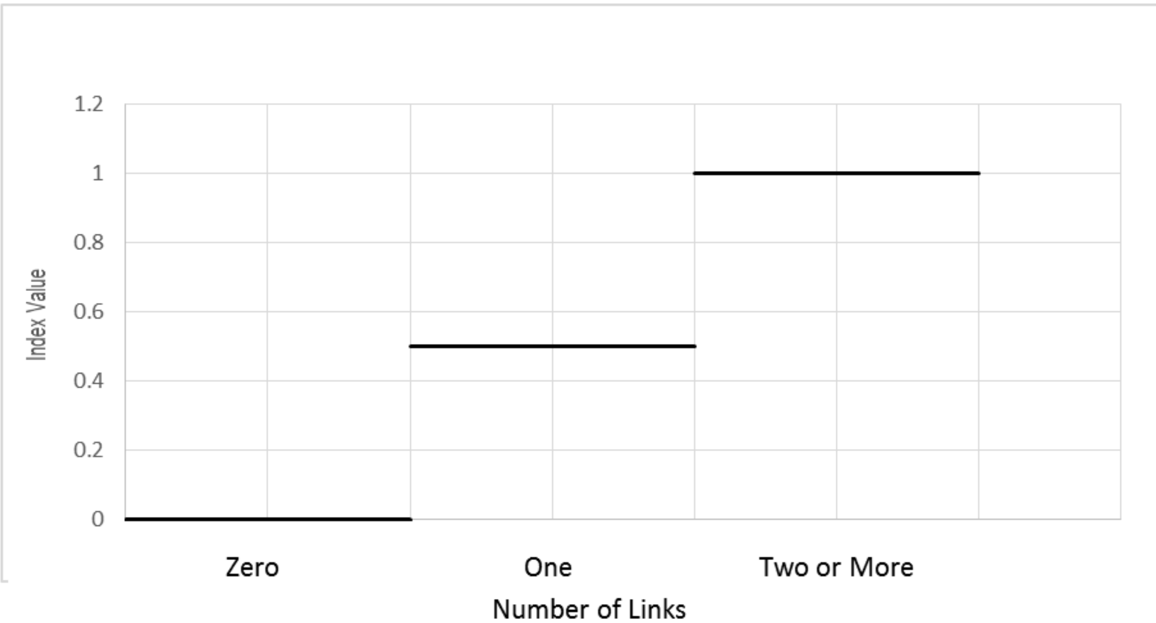


FIGURE 19. TIDAL MARSH CONNECTIVITY INDEX VALUES.

TABLE 20. TIDAL MARSH CONNECTIVITY EQUATIONS

Number of Links	Index Value
Zero	0
One	0.5
Two or more	1

Tidal Marsh Habitat Size

The size (e.g., acreage) of marsh habitat is important as there is a significant interaction between size and the dynamics of species interactions (Long and Burke 2007). Smaller patches have greater edge effects resulting in increased physical stress (e.g., wind and dehydration) as well as behavioral stress (e.g., increased predation) (Long and Burke 2007). Conversely, larger habitat patches often experience decreased overall stress. The suitability of marsh size is based on observations by the TAC. Between 1-5-acres of marsh size is less than optimal, while greater than 20-acres is optimal marsh size.

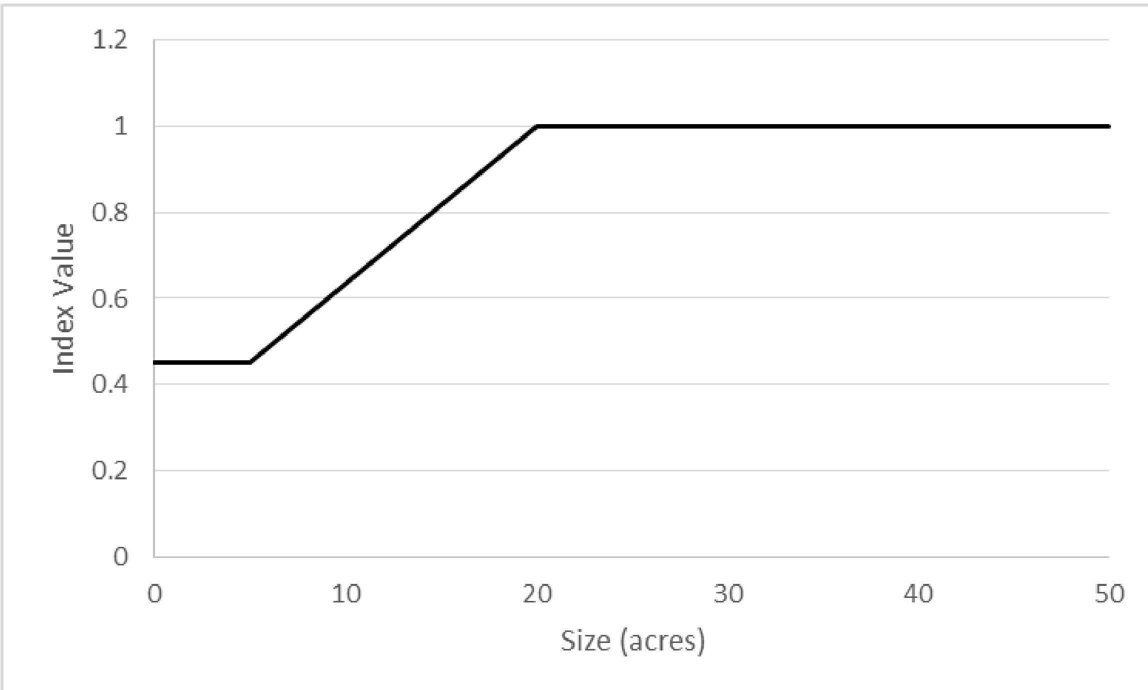


FIGURE 20. TIDAL MARSH HABITAT SIZE CURVE.

TABLE 21. TIDAL MARSH HABITAT SIZE EQUATIONS

Variable	Equation	Eq#
0≤ $marsh\ size(acres)$ >5	$HSI_{marsh\ size} = 0.45 + (0 * marsh\ size)$	(1)
5 < $marsh\ size\ (acres)$≤ 20	$HSI_{marsh\ size} = 0.266 + (0.0367 * marsh\ size)$	(2)
20< $marsh\ size\ (acres)$	$HSI_{marsh\ size} = 1 + (0 * marsh\ size)$	(3)

Sandy Islands

The goal of providing sandy Island habitat is to increase habitat for the California least tern (*Sterna antillarum browni*) and the snowy plover (*Charadrius nivosus*). While the birds are similar in some aspects of their life history and habitat utilization, there are some species-specific considerations that require the development of separate curves for each species. Critical parameters identified for the sandy islands habitat included vegetation cover (%) for least tern, vegetation cover (%) for plover, effective size of the island, elevation, sediment characteristics (color, sediment grain size) and distance from occupied habitats for bird foraging. Note that seagrass habitat could be an incidental benefit to formation of sandy islands. Design considerations include the linear length of beach (longer is better for snowy plover and there may be a minimum length needed), beach slope (gentler slope is preferred), and sediment color (e.g., least tern generally utilize white or tan sediments, while brown/gray sediments are suboptimal). When applying this suite of equations, the results generated will provide habitat suitability values for both least terns and snowy plovers. The curves that should only be applied to one of the species are noted in the description.

Vegetation Cover Least Tern

Sparse or no vegetation cover is a major driver in least tern reproduction (Kotliar and Burger, 1986) Nesting success is greater when nests are in open, sparsely vegetated areas.

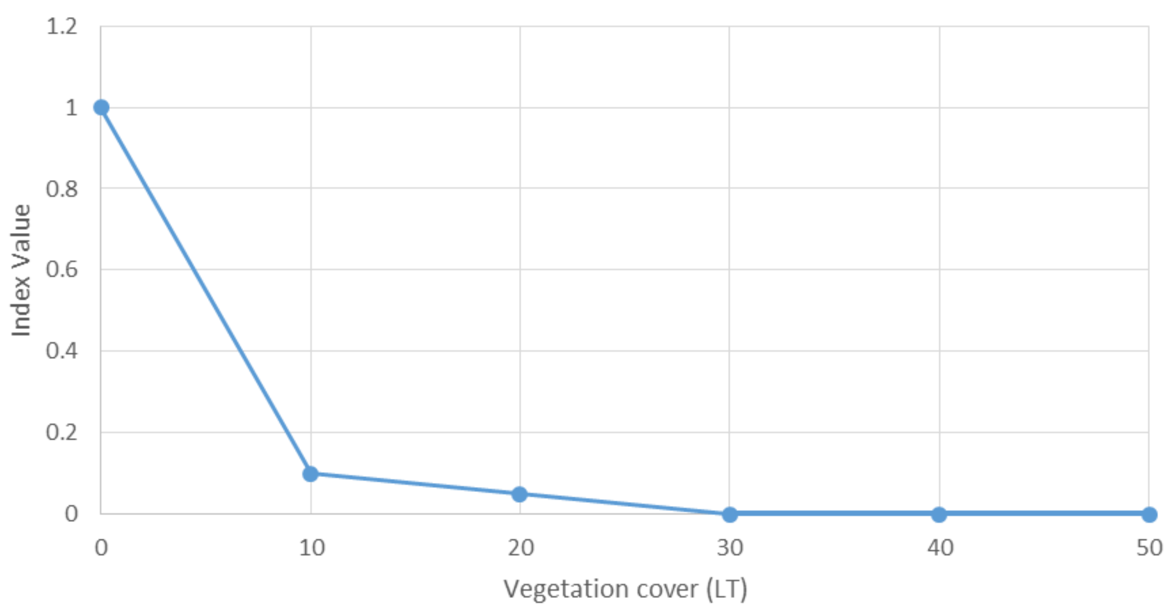


FIGURE 21. SANDY ISLANDS CURVE OF VEGETATION COVER FOR LEAST TERN.

TABLE 22. SANDY ISLANDS EQUATIONS FOR VEGETATION COVER FOR LEAST TERN.

Variable	Equation	Eq#
0 ≤ *Percent Vegetation LT* > 10	$HSI_{Percent\ Vegetation\ LT} = 1 + (-0.09 * Percent\ Vegetation\ LT\ )$	(1)
10 < *Percent Vegetation LT* ≤ 30	$HSI_{Percent\ Vegetation\ LT} = 0.15 + (-0.005 * Percent\ Vegetation\ LT\ )$	(2)
30 < *Percent Vegetation LT*	$HSI_{Percent\ Vegetation\ LT} = 0 + (0 * Percent\ Vegetation\ LT\ )$	(3)

Vegetation Cover Snowy Plover

Like least terns, vegetative cover is a major driver in snowy plover reproduction (Saalfeld et al. 2012), but snowy plover nesting success increases with vegetation cover, until cover exceeds 10%, then declines with patches containing 40% cover or greater resulting in poor habitat for reproduction.

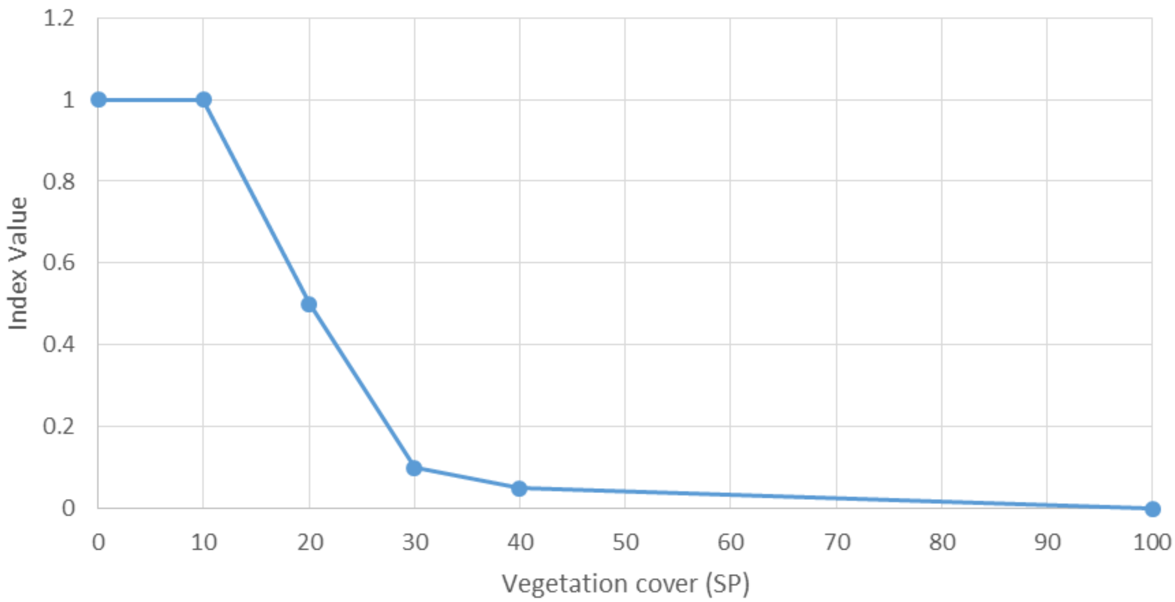


FIGURE 22. SANDY ISLANDS CURVE OF VEGETATION COVER FOR SNOWY PLOVER.

TABLE 23. SANDY ISLANDS EQUATIONS FOR VEGETATION COVER FOR SNOWY PLOVER.

Variable	Equation	Eq#
$0 \leq Percent\ Vegetation\ SP > 10$	$HSI_{Percent\ Vegetation\ SP} = 1 + (0 * Percent\ Vegetation\ SP)$	(1)
$10 < Percent\ Vegetation\ SP \leq 20$	$HSI_{Percent\ Vegetation\ SP} = 1.5 + (-0.05 * Percent\ Vegetation\ SP)$	(2)
$20 < Percent\ Vegetation\ SP \leq 30$	$HSI_{Percent\ Vegetation\ SP} = 1.3 + (-0.04 * Percent\ Vegetation\ SP)$	(3)
$30 < Percent\ Vegetation\ SP \leq 40$	$HSI_{Percent\ Vegetation\ SP} = 0.25 + (-0.005 * Percent\ Vegetation\ SP)$	(4)
$40 < Percent\ Vegetation\ SP \leq 100$	$HSI_{Percent\ Vegetation\ SP} = 0.08 + (-0.0008 * Percent\ Vegetation\ SP)$	(5)
$100 < Percent\ Vegetation\ SP$	$HSI_{Percent\ Vegetation\ SP} = 0 + (0 * Percent\ Vegetation\ SP)$	(6)

Effective Size

The size of a sand island can impact both least tern and snowy plover reproductive success. Small islands will limit the size of nesting colonies. It is assumed that larger islands provide more realized (effective) nesting habitat for both species. However, there is a threshold above six acres where the increase in habitat suitability does not increase beyond optimal. This curve applies to both species.

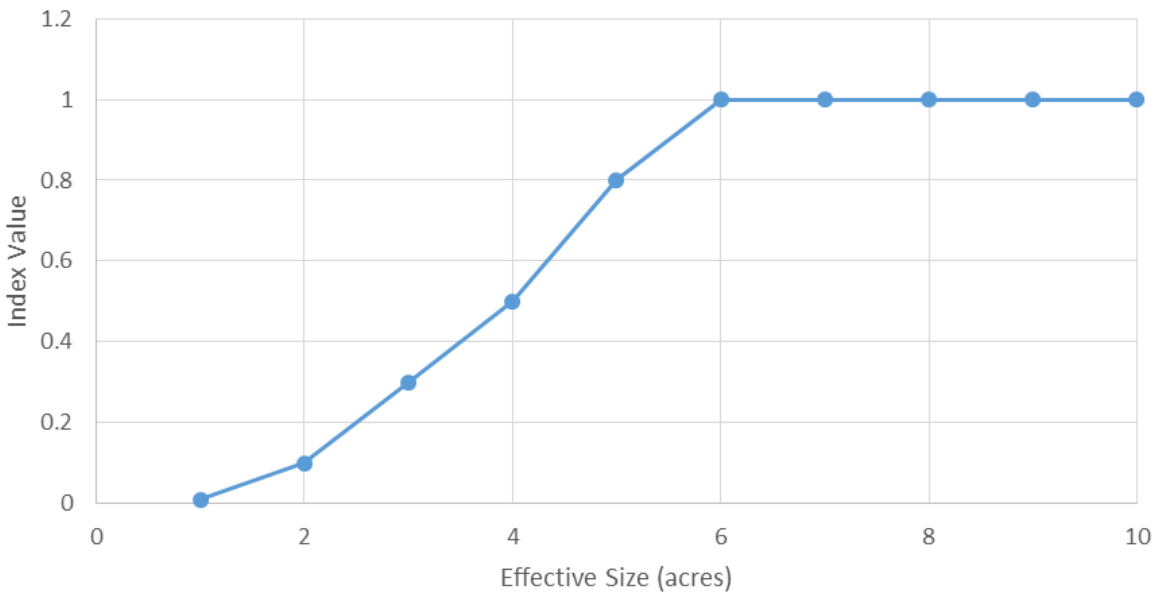


FIGURE 23. SANDY ISLANDS EFFECTIVE SIZE CURVE.

TABLE 24. SANDY ISLANDS EFFECTIVE SIZE EQUATIONS.

Variable	Equation	Eq#
$1 \leq Effective\ Size > 2$	$HSI_{Effective\ Size} = -0.08 + (0.09 * Effective\ Size)$	(1)
$2 < Effective\ Size \leq 4$	$HSI_{Effective\ Size} = -0.3 + (0.2 * Effective\ Size)$	(2)
$4 < Effective\ Size \leq 5$	$HSI_{Effective\ Size} = -0.7 + (0.3 * Effective\ Size)$	(3)
$5 < Effective\ Size \leq 6$	$HSI_{Effective\ Size} = -0.2 + (0.2 * Effective\ Size)$	(4)
$6 < Effective\ Size$	$HSI_{Effective\ Size} = 1 + (0 * Effective\ Size)$	(5)

Elevation

Elevation is a critical parameter because it is indicative of island area that is exposed during high tides. The relationship between snowy plovers and vegetative cover dictates an elevation threshold at which survival and nesting success are greatest. Briefly, snowy plovers utilize sparsely vegetated areas to nest. Lower elevations are exposed to tidal inundation, which generally maintain a beach-like shoreline (i.e., free of vegetation). Conversely, higher elevations will more likely become vegetated to the point where there is uniform, dense vegetation. Snowy plovers are less likely to occupy and colonize areas that are densely vegetated or are more prone to human access and disturbance (Webber et al 2013). There is not a maximum elevation for least terns—they will nest in any open sandy area on an island. This curve should be applied to both species.

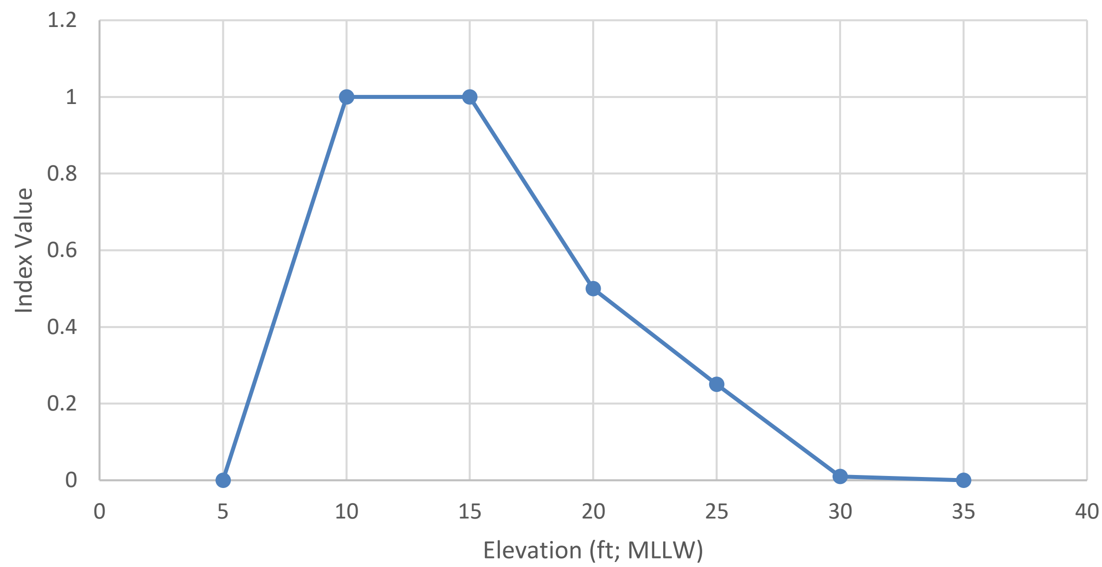


FIGURE 24. SANDY ISLANDS ELEVATION CURVE.

TABLE 25. SANDY ISLANDS ELEVATION EQUATIONS.

Variable	Equation	Eq#
5 ≤ $Elevation\ (MLLW)$ >10	$HSI_{Elevation\ (MLLW)} = -1 + (0.2 * Elevation\ (MLLW))$	(1)
10 < $Elevation\ (MLLW)$ ≤ 15	$HSI_{Elevation\ (MLLW)} = 1 + (0 * Elevation\ (MLLW))$	(2)
15 < $Elevation\ (MLLW)$≤ 20	$HSI_{Elevation\ (MLLW)} = 2.5 + (-0.1 * Elevation\ (MLLW))$	(3)
20< $Elevation\ (MLLW)$≤ 25	$HSI_{Elevation\ (MLLW)} = 1.5 + (-0.05 * Elevation\ (MLLW))$	(4)
25 < $Elevation\ (MLLW)$≤ 30	$HSI_{Elevation\ (MLLW)} = 1.45 + (-0.048 * Elevation\ (MLLW))$	(5)
30 < $Elevation\ (MLLW)$≤ 35	$HSI_{Elevation\ (MLLW)} = 0.07 + (-0.002 * Elevation\ (MLLW))$	(6)
35 < $Elevation\ (MLLW)$	$HSI_{Elevation\ (MLLW)} = 0 + (0 * Elevation\ (MLLW))$	(7)

Sediment Grain Size

Sediment Grain Size is based on categories (see Table 18 – Tidal Marsh). Sand and coarse sand are ideal and have an index value of 1. Gravel is intermediate with an index value of 0.8. Cobble and silt are undesirable with index values of 0. This curve applies to both species. Index values were determined by SME opinion of the TAC members.

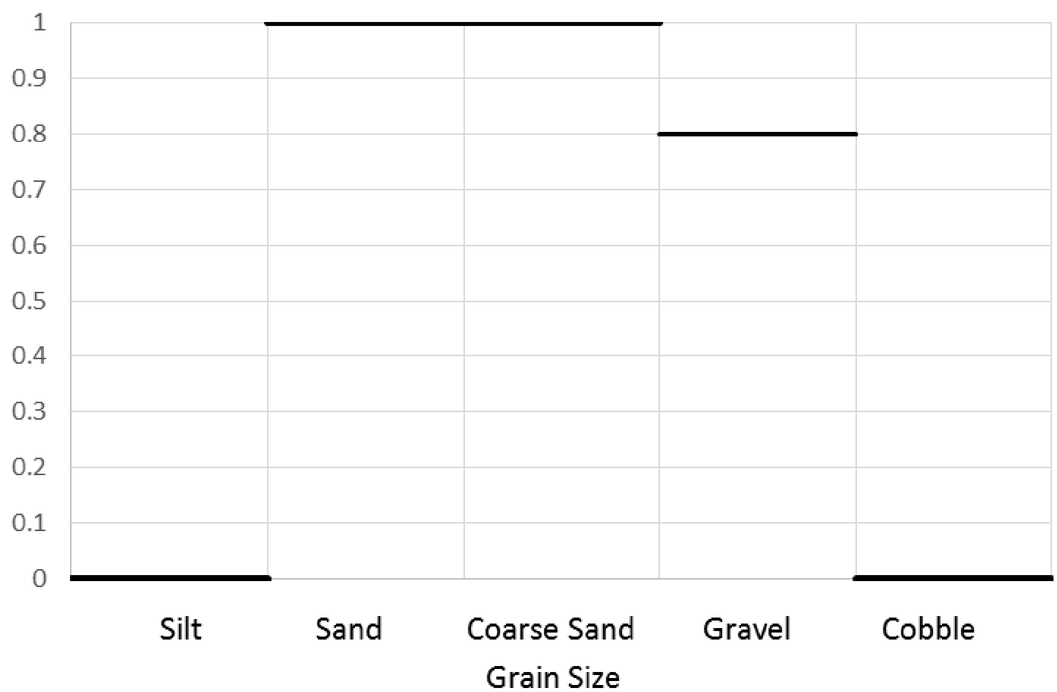


FIGURE 25. SANDY ISLANDS GRAIN SIZE INDEX VALUES.

TABLE 26. SANDY ISLANDS GRAIN SIZE EQUATIONS

Substrate Category	Index Value
Silt	0
Gravel	0.8
Coarse Sand	1
Sand	1

Distance

Successful nesting and survival for bird species depends, in part, on limiting access by terrestrial predators to nesting sites. This model assumes that optimal placement for an island is at least 300 m from other islands or the mainland (both measured as straight-line distances), as informed by TAC members.

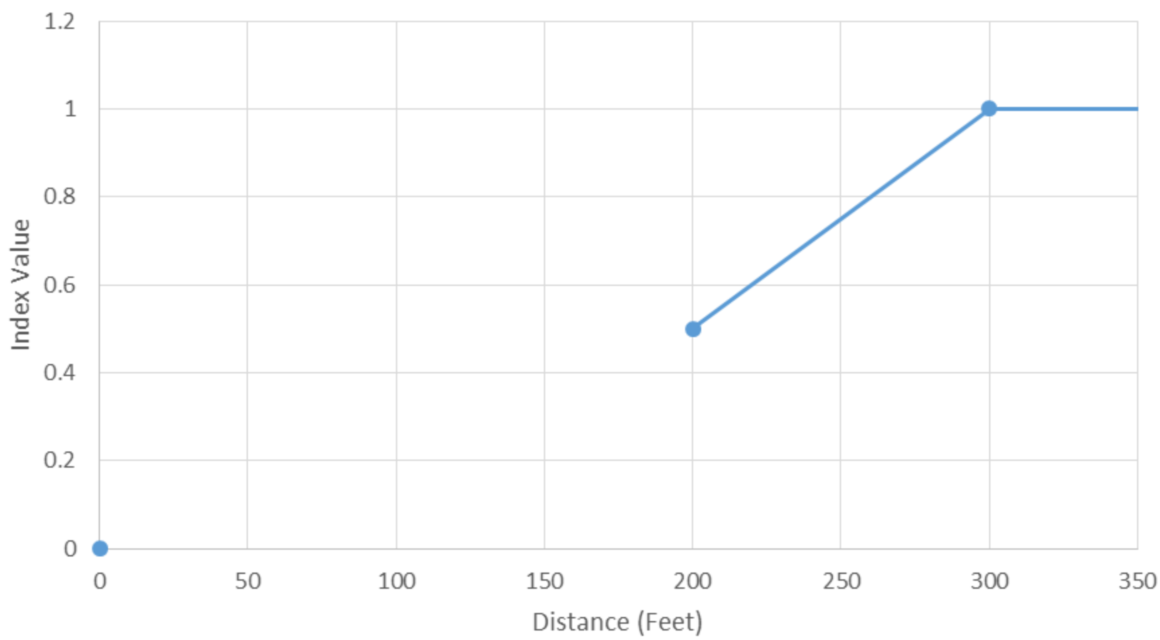


FIGURE 26. SANDY ISLANDS DISTANCE CURVE.

TABLE 27. SANDY ISLANDS DISTANCE EQUATIONS.

Variable	Equation	Eq#
0 ≤ $Distance$ >200	$HSI_{Distance} = 0 + (0 * Distance)$	(1)
200 < $Distance$ ≤ 300	$HSI_{Distance} = -0.5 + (0.005 * Distance)$	(3)
300< $Distance$	$HSI_{Distance} = 1 + (0 * Distance)$	(4)

Calculating Habitat HSI Score

This document has described six different habitat types (rocky reef, kelp forest, eelgrass, oyster reef, tidal salt marsh and sandy islands) and the critical parameters used in the model to determine habitat suitability indices. Each habitat type had between 2 and 6 critical parameters that were identified by the TAC and for which curves and equations were developed.

For each habitat type, values from these individual curves are combined to calculate a habitat suitability index score (HSI score). The HSI score is a geometric mean of all individual habitat index values for a given habitat. For a set of numbers $\{X_i\}^N$ i=1, the geometric mean is:

$$\left(\prod_{i=I}^{N} x_i\right)^{I/N} = \sqrt[n]{a_1 a_2 \ldots a_n}$$

The size and location of each habitat type under consideration in the model is identified in a GIS framework prior calculation of HIS indices or scores. The appropriate values of each parameter corresponding to the physical location of each habitat type is then determined by the user. Habitat index values for each habitat are determined for each parameter based on the curves and equations described within this document and the parameter values determined by the user. Once habitat indices are calculated, a combined HSI score can be calculated for each habitat type and location. Habitat units (HU) are the product of the HSI score and the area of a given habitat type. HUs for different habitat types are additive.

Summary of Data used in Model Development

Habitat Type	***Parameter***	***Unit***
Rocky Reef	Connectivity	distance between reefs (m)
	Reef Relief	Categorical
	Residence Time	Residence time by week
	Substrate	Categorical
Kelp Forest	Temperature	average two month temperature °C
	Substrate	Categorical
	Depth	feet
Eelgrass	Circulation	cm/second
	Depth	feet
	Substrate	Percent Fines (silt and clay particles)
	Temperature	Maximum °C/month
Oyster Reef	Salinity	ppt
	Depth	feet

Tidal Salt Marsh	Elevation	Feet above MLLW
	Salinity	ppt
	Substrate Grain Size	Categorical
	Connectivity	Number of links between discrete marshes
Sandy Islands	Vegetation Cover - Least Tern	Percent Cover
	Vegetation Cover – Snowy Plover	Percent cover
	Effective Size	acre
	Elevation	feet
	Sediment Grain Size	Categorical
	Distance	meter

Model Quantification

Although there are a number of peer reviewed, spatially explicit habitat suitability index models available (Brooks et al 1997, Brown et al 2000, Koh et al 2016), many of focus on a single habitat or species in a particular region. As our goal is to address a number of habitats simultaneously, our approach required addressing each habitat in a consistent manner to allow for an integrated evaluation of various habitat HIS values in one region. Although there are HIS models already developed for some of the habitats included in our model (e.g., eelgrass: Zhou et al 2016; oyster reef: Swannack et al 2014, Barnes et al 2007), most of the habitat types that we considered do not have existing HSI models that are useful at the habitat scale. In some cases, there are species specific models associated with habitats we included, but these models do not take into account suitability from a holistic habitat perspective. For example, Lowe et al (2003) model habitat suitability of Kelp Bass within kelp habitat, but the model does not indicate suitability for the kelp itself. In cases in which the appropriate habitat was modelled (e.g. eelgrass), the region in which the model was developed was not compatible with Southern California (Zhous et al 2016). Due to these limitations, it was necessary to develop the new model presented in this document. To our knowledge, this is the first HIS model developed within the USACE that incorporates multiple habitat types simultaneously.

In our approach, we used guidance from subject matter experts, as well as peer reviewed literature and available data to identify critical parameters or variable for each habitat. When individual parameter curves, certain parameters required units of time or space. The scale was determined by the relationship between the parameter and habitat of interest. For example, eelgrass and kelp habitats both included Temperature as a critical parameter used to calculate Habitat HSI. For eelgrass, the temperature was evaluated as a maximum monthly value, while a two month average temperature was used for kelp habitat. In computing HSI values, Model results represent a snapshot of immediate HIS conditions given current data values. To determine HSI values through time, the underlying data used to calculate HIS values must also project through time. As such, any time steps developed through use of the model are reliant on the temporal and spatial accuracy and assumptions included in the data provided by the model user.

Model Evaluation

This model is appropriate for use in the Southern California region because it relies on peer-reviewed results as well as subject matter expert opinion to support the assumptions and relationships the between parameters and habitat, and consequently, the shape and math supporting the established curves. The model relies on the user to provide input data (i.e. parameter conditions) that is in a geospatial format. The HSI equations are then applied to the input data in such that the habitat specific HSI curves are applied in the appropriate geo-spatial area (i.e., in the footprint of the proposed restoration site for the habitat of interest).

Spatial Data and Model Application

The equations discussed in the previous sections were applied in a GIS in order to subset spatial data variables (e.g. Salinity, Temperature, Connectivity, etc. as defined for the appropriate habitat of interest) and to compute an overall habitat HSI. We selected three alternative restoration plans as case studies to illustrate the application of the Model. Through evaluation of the examples, we intend to illustrate how the Model can be utilized. The following sections describe the application of the Model in two restoration scenarios, while Appendix A provides a detailed GIS guide. All data were processed in ESRI's ArcGIS 10.0/10.1 software (ArcInfo).

Several alternative restoration scenarios incorporating the six habitat types as well as structural modifications were evaluated in the East San Pedro Habitat Evaluation study. In each alternative, habitat types can be of varied sizes and in different spatial orientations within East San Pedro Bay. The first example restoration plan, Alternative 1, contains three eelgrass beds with three adjacent nearshore rocky reefs (Figure 27). The Habitat HSI scores, as calculated using model equations in a geospatial framework, are mapped in Figure 28 with a breakdown of HSI values reported per parameter, and by habitat type (Table 28). Habitat HSI scores range from 0 to 0.67 in year 0 and increase over time (table 28).

FIGURE 27.ALTERNATIVE 1, EAST SAN PEDRO BAY ECOLOGICAL RESTORATION STUDY.

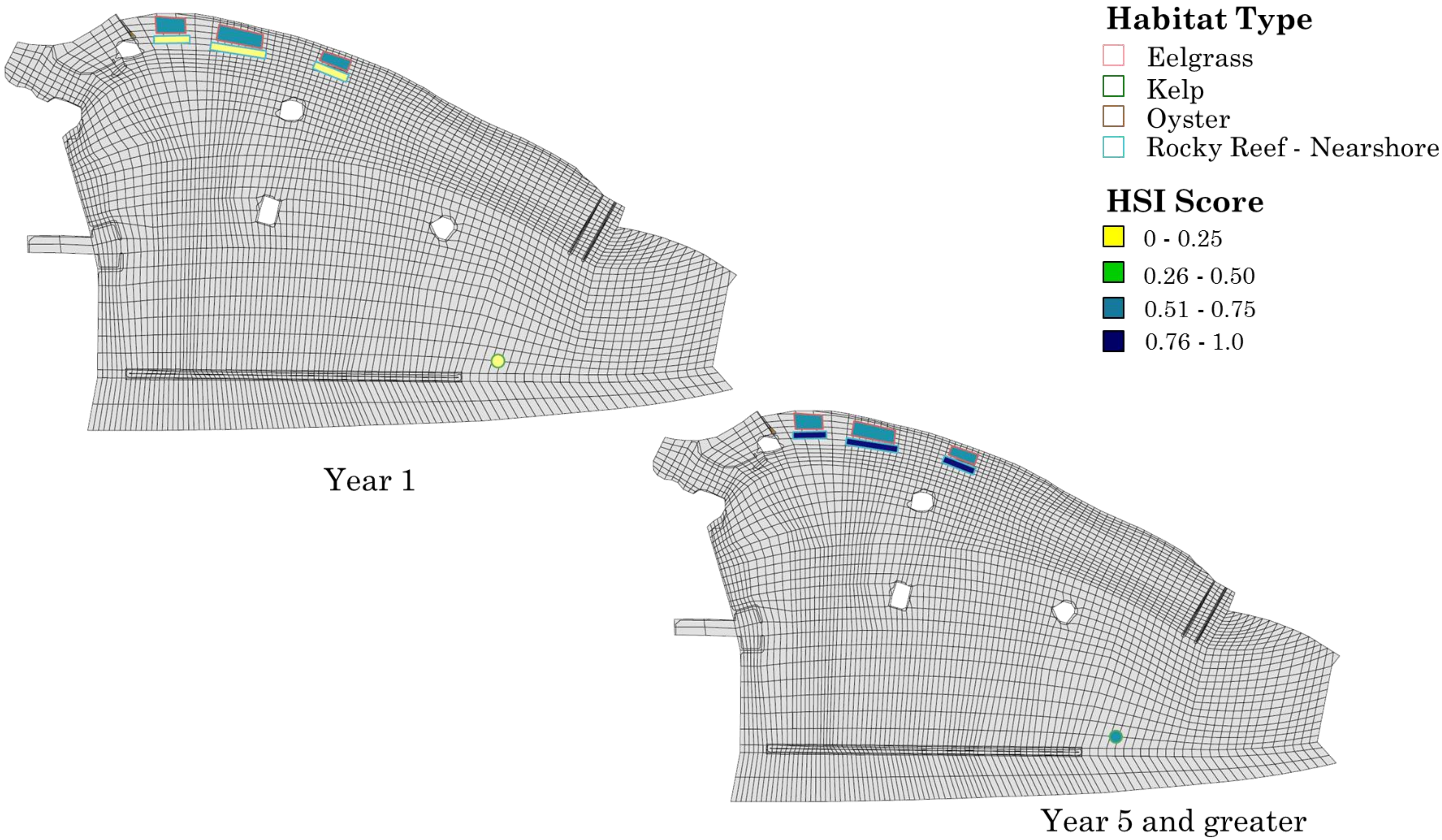


FIGURE 28.MAP OF HABITAT TYPE AND HSI SCORES DEVELOPED FOR ALTERNATIVE 1.

TABLE 28. MODELING OUTPUTS FOR ALTERNATIVE 1.

East San Pedro Bay Ecosystem Restoration Modeling Outputs					
		Baseline		Yr 5	
Alternative 1	**Unit**	Value	HSIndex	Value	HSIndex
Rocky Reef (nearshore)					
Connectivity	meter	0.00	0.01	264.35	1.00
Reef Relief	flat to wall	Flat	0.01	Low	0.48
Residence Time	days (1-43)	1.16	1.00	1.10	0.98
Substrate	Present/Absent	Absent	0.01	Present	1.00
HSI Score			**0.03**		**0.83**
Eelgrass					
Circulation	m/sec	0.11	0.71	0.07	0.66
Depth	meter	4.26	0.28	3.56	0.36
Substrate	% silt-clay	43.89%	1.00	43.89%	1.00
Temperature	Celsius	17.90	1.00	17.90	1.00
HSI Score			**0.67**		**0.70**
Kelp (open water)					
Temperature	Celsius	17.90	0.71	17.90	0.71
Substrate	Present/Absent	Absent	0.00	Present	1.00
Depth	m (0-37)	14.01	0.75	13.28	0.84
HSI Score			**0.00**		**0.84**
Oyster Reef (LA River)					
Salinity	ppt	32.72	1.00	32.72	1.00
Depth	meter	4.91	0.00	-0.93	0.90
HSI Score			**0.00**		**0.95**

The second example restoration plan, Alternative 4, contains three eelgrass beds with three adjacent nearshore rocky reefs, two offshore rock reef and five kelp beds (Figure 29). The Habitat HSI scores, as calculated using model equations in a geospatial framework, are mapped in Figure 30 with a breakdown of HSI values reported per parameter, and by habitat type (Table 29). Habitat HSI scores range from 0 to 0.67 in year 0 and increase over time (Table 29).

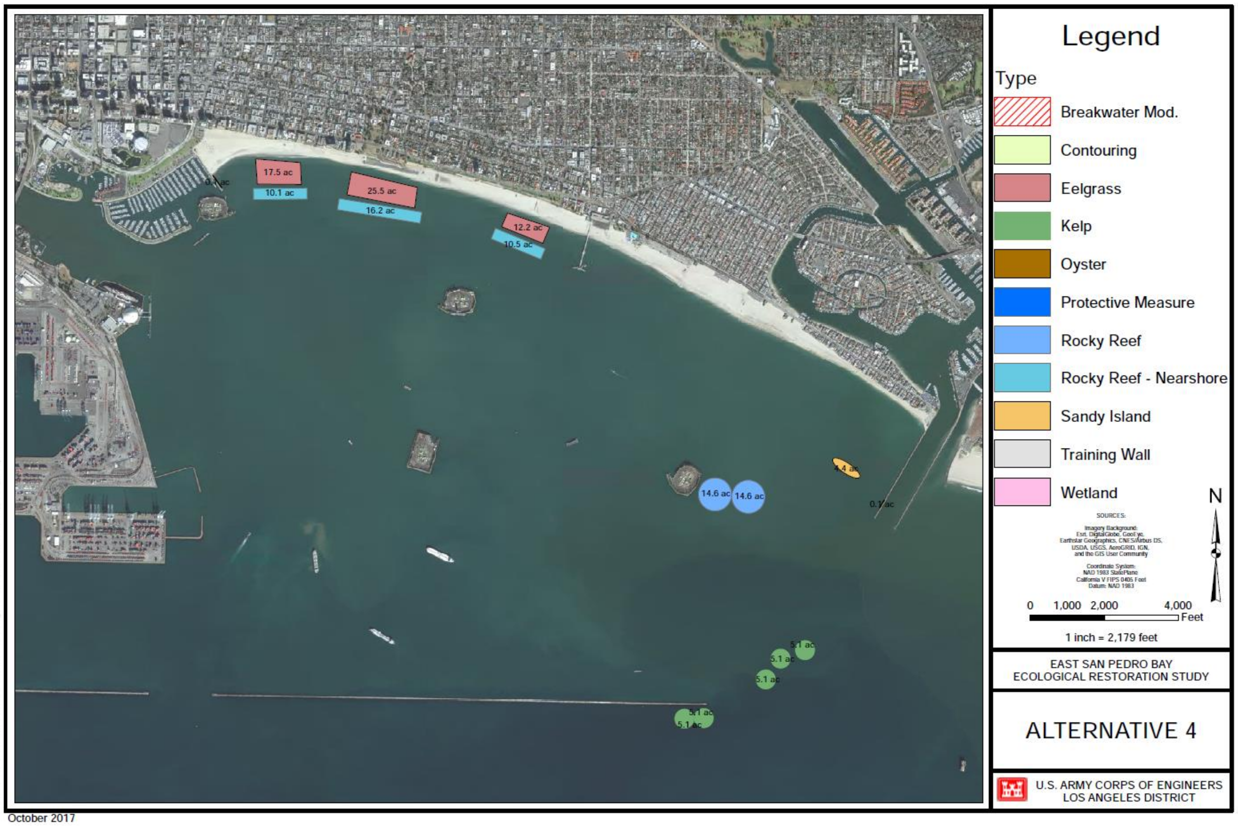


FIGURE 29. ALTERNATIVE 4, EAST SAN PEDRO BAY ECOLOGICAL RESTORATION STUDY.

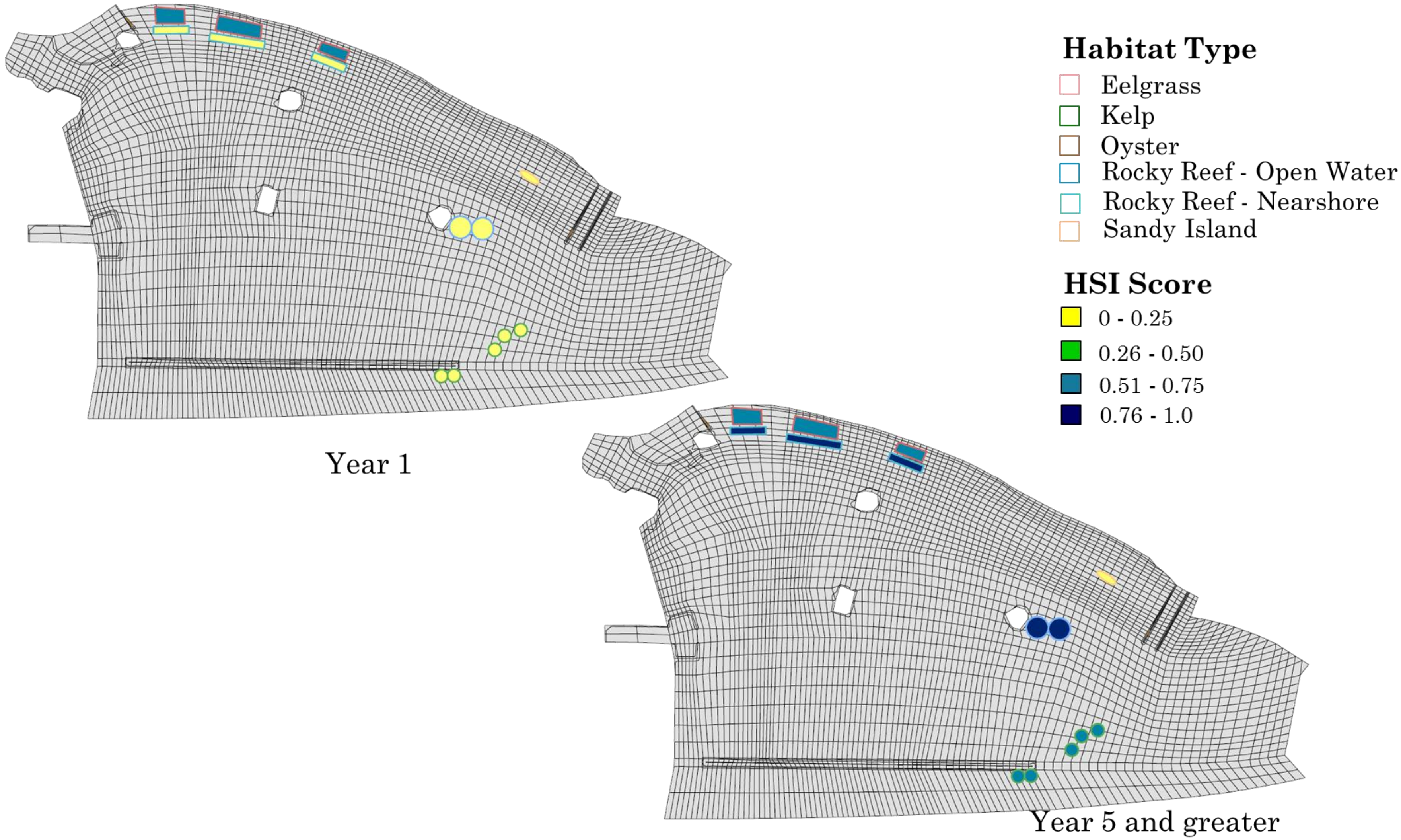


FIGURE 30. MAP OF HABITAT TYPE AND HSI SCORES DEVELOPED FOR ALTERNATIVE 4

TABLE 29. MODELING OUTPUTS FOR ALTERNATIVE 4.

East San Pedro Bay Ecosystem Restoration Modeling Outputs					
		Baseline		Yr 5	
Alternative 4	**Unit**	Value	HSIndex	Value	HSIndex
Rocky Reef (nearshore)					
Connectivity	meter	0.00	0.00	264.35	1.00
Reef Relief	flat to wall	Flat	0.00	Low to Med	0.48
Residence Time	days (1-43)	1.16	1.00	1.10	0.98
Substrate	Present/Absent	Absent	0.00	Present	1.00
HSI Score			**0.00**		**0.83**
Eelgrass					
Circulation	m/sec	0.11	0.71	0.07	0.66
Depth	meter	4.26	0.28	3.56	0.36
Substrate	% silt-clay	43.89%	1.00	43.89%	1.00
Temperature	Celsius	17.90	1.00	17.90	1.00
HSI Score			**0.67**		**0.70**
Island (nearshore)					
Vegetation Cover - Least Tern	% cover	NA	0.00	2.33%	0.79
Vegetation Cover - Snowy Plover	% cover	NA	0.00	2.33%	1.00
Effective Size	acres	NA	0.00	4.44	0.63
Elevation	MLLW	NA	0.00	2.21	0.56
Sediment Grain Size	silt to cobble	NA	0.00	Coarse mix	0.67
Distance	feet	NA	0.00	205.33	0.68
Sediment color	white to brown/gray	NA	0.00	White/Tan	1.00
HSI Score			**0.00**		**0.74**
Oyster Reef (nearshore)					
Salinity	ppt	32.78	1.00	32.78	1.00
Depth	meter	5.58	0.00	-1.95	0.77
HSI Score			**0.00**		**0.88**
Rocky Reef (open water)					
Connectivity	meter	0.00	0.00	<2	1.00
Reef Relief	flat to wall	Flat	0.00	Low to Med	0.49
Residence Time	days (1-43)	1.00	1.00	1.05	0.99
Substrate	Present/Absent	Absent	0.00	Present	1.00
HSI Score			**0.00**		**0.84**
Kelp (open water)					
Temperature	Celsius	17.90	0.71	17.90	0.71
Substrate	Present/Absent	Absent	0.00	Present	1.00
Depth	m (0-37)	13.28	0.84	12.57	0.91
HSI Score			**0.00**		**0.86**
Oyster Reef (LA River)					
Salinity	ppt	32.70	1.00	32.70	1.00
Depth	meter	3.69	0.00	-1.47	0.88
HSI Score			**0.00**		**0.94**
Kelp (breakwater)					
Temperature	Celsius	17.90	0.71	17.90	0.71
Substrate	Present/Absent	Absent	0.00	Present	1.00
Depth	m (0-37)	16.02	0.50	13.53	0.57
HSI Score			**0.00**		**0.74**

The third example restoration plan, Alternative 12, contains three eelgrass beds with three adjacent nearshore rocky reefs, four more nearshore rock reefs seven offshore rock reefs and eleven kelp beds, two tidal marsh wetlands, one sandy island and some structural features (Figure 31). The Habitat HSI scores, as calculated using model equations in a geospatial framework, are mapped in Figure 32 with a breakdown of HSI values reported per parameter, and by habitat type (Table 30). Habitat HSI scores range from 0 to 0.67 in year 0 and increase over time (Table 29).

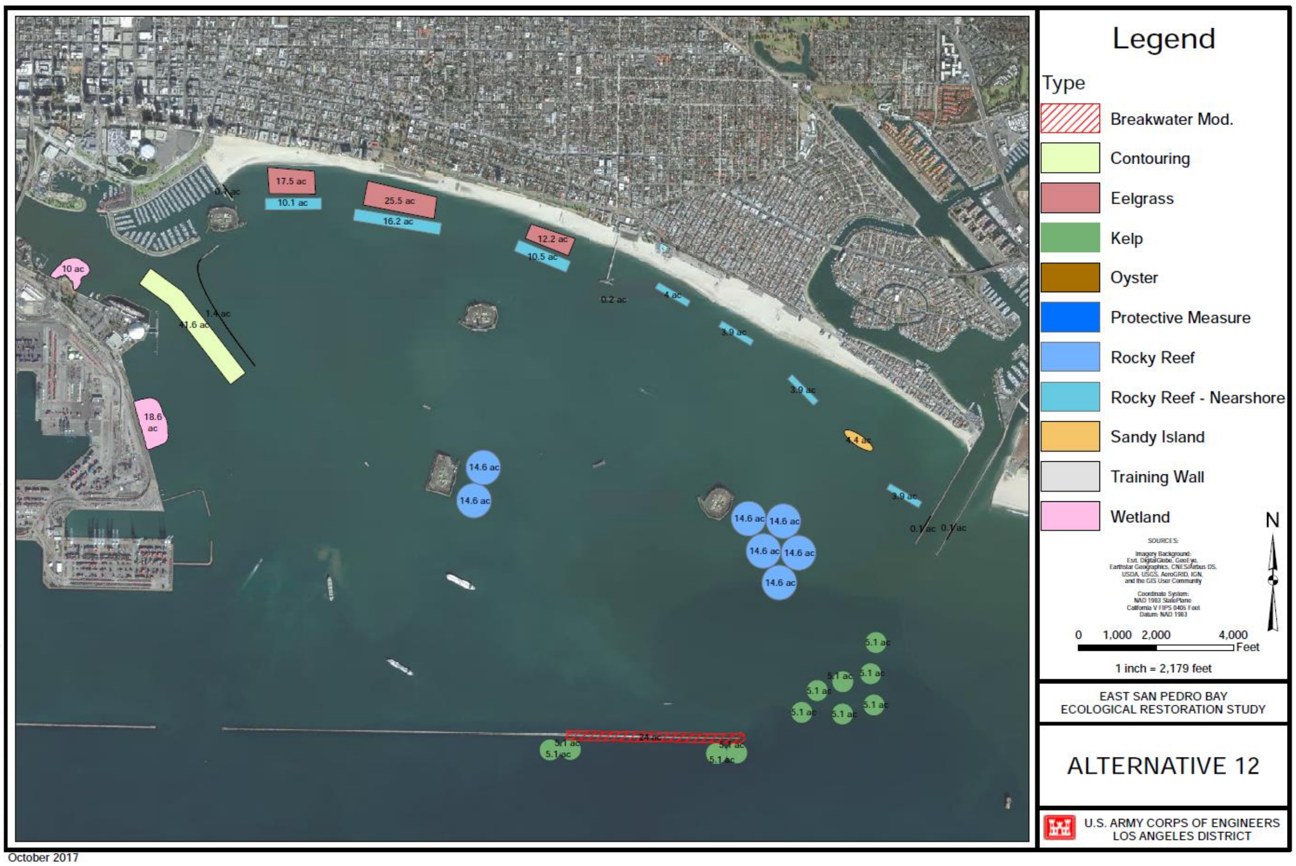


FIGURE 31. ALTERNATIVE 12, EAST SAN PEDRO BAY ECOLOGICAL RESTORATION STUDY.

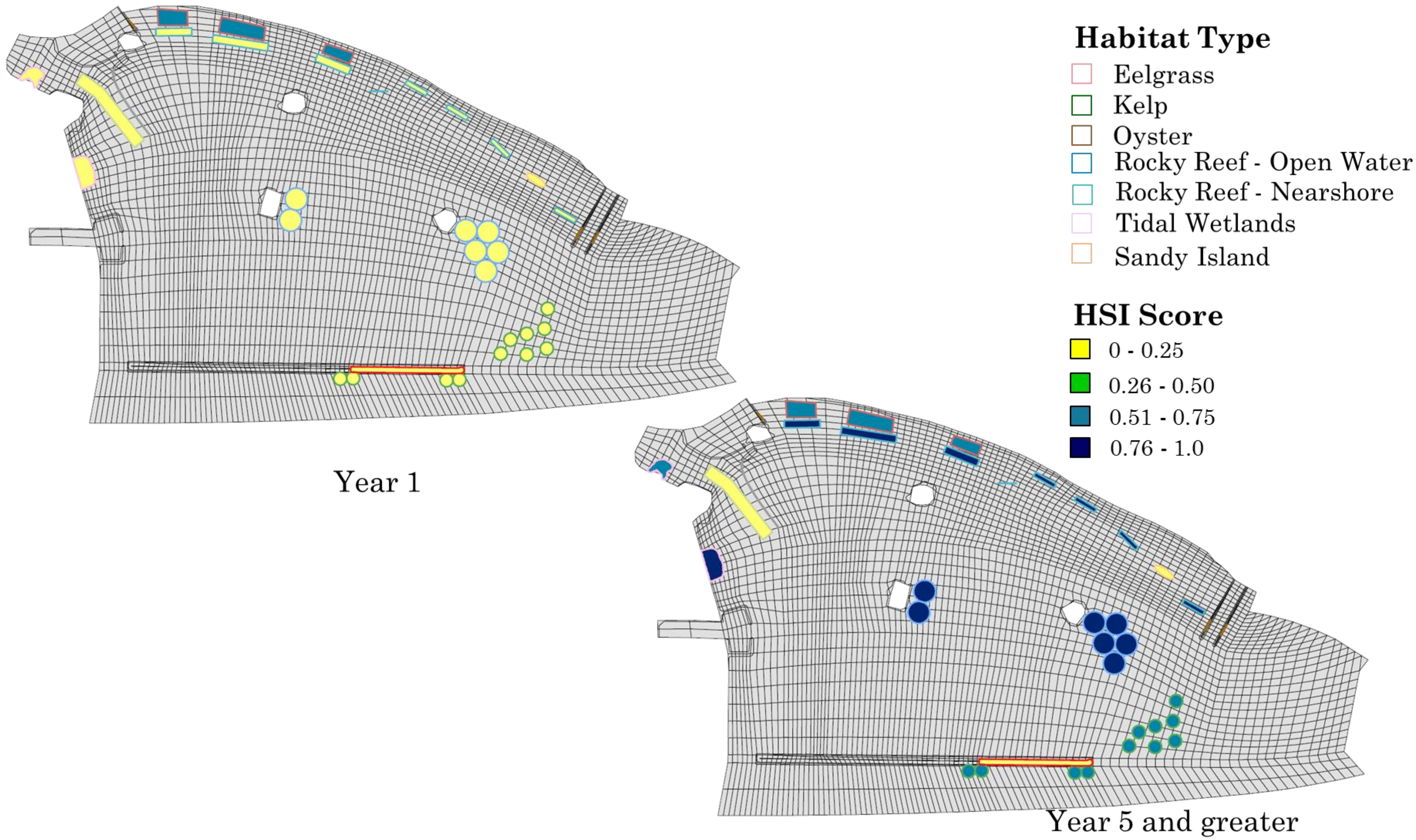


FIGURE 32. MAP OF HABITAT TYPE AND HSI SCORES DEVELOPED FOR ALTERNATIVE 12.

TABLE 30. MODELING OUTPUTS FOR ALTERNATIVE 12.

East San Pedro Bay Ecosystem Restoration Modeling Outputs					
		Baseline		Yr 5	
Alternative 12	**Unit**	Value	HSIndex	Value	HSIndex
Rocky Reef (nearshore)					
Connectivity	meter	0.00	0.00	230.32	1.00
Reef Relief	flat to wall	Flat	0.00	3.12	0.63
Residence Time	days (1-43)	1.13	1.00	1.07	0.99
Substrate	Present/Absent	Absent	0.00	Present	1.00
HSI Score			**0.00**		**0.89**
Eelgrass					
Circulation	m/sec	0.11	0.71	0.10	0.72
Depth	meter	4.26	0.28	3.56	0.36
Substrate	% silt-clay	43.89%	1.00	43.89%	1.00
Temperature	Celsius	17.90	1.00	17.90	1.00
HSI Score			**0.67**		**0.71**
Oyster Reef (nearshore)					
Salinity	ppt	31.68	1.00	31.52	1.00
Depth	meter	4.00	0.00	-1.84	0.80
HSI Score			**0.00**		**0.89**
Island (Nearshore)					
Vegetation Cover - Least Tern	% cover	NA	0.00	2.33	0.79
Vegetation Cover - Snowy Plover	% cover	NA	0.00	2.33	1.00
Effective Size	acres	NA	0.00	4.44	0.63
Elevation	MLLW	NA	0.00	2.19	0.56
Sediment Grain Size	silt to cobble	NA	0.00	Coarse mix	0.67
Distance	feet	NA	0.00	205.33	0.68
Sediment color	white to brown/gray	NA	0.00	White/Tan	1.00
HSI Score			**0.00**		**0.74**
Rocky Reef (open water)					
Connectivity	meter	0.00	0.00	<2	1.00
Reef Relief	flat to wall	Flat	0.00	Low to Med	0.48
Residence Time	days (1-43)	0.95	1.00	1.00	0.99
Substrate	Present/Absent	Absent	0.00	Present	1.00
HSI Score			**0.00**		**0.83**
Kelp (open water)					
Temperature	Celsius	17.90	0.71	17.90	0.71
Substrate	Present/Absent	Absent	0.00	Present	1.00
Depth	m (0-37)	12.34	0.91	11.65	0.95
HSI Score			**0.00**		**0.88**
Oyster Reef (LA River)					
Salinity	ppt	32.70	1.00	32.65	1.00
Depth	meter	3.69	0.00	-1.47	0.88
HSI Score			**0.00**		**0.94**
Tidal wetland (LA river)					
Depth	feet	2.16	0.70	-0.78	0.09
Salinity	psu	29.12	0.90	29.03	0.93
Size	acre	0.00	0.00	10.00	0.63
Substrate Grain Size	categories	Coarse sand	1.00	Coarse mix	1.00
Connectivity	#links	0.00	0.00	≥2	1.00
HSI Score			**0.00**		**0.55**
Tidal wetland (Port)					
Depth	feet	8.95	0.40	0.86	0.27
Salinity	psu	32.98	1.00	31.21	1.00
Size	acre	0.00	0.00	18.60	0.95
Substrate Grain Size	categories	Coarse mix	0.80	Coarse sand	1.00
Connectivity	#links	0.00	0.00	≥2	1.00
HSI Score			**0.00**		**0.76**
Kelp (breakwater)					
Temperature	Celsius	17.90	0.71	17.90	0.71
Substrate	Present/Absent	Absent	0.00	Present	1.00
Depth	m (0-37)	16.79	0.40	14.80	0.54
HSI Score			**0.00**		**0.73**

These examples demonstrate how the model equations can be used to calculate HSI values by parameter and aggregate these values using a geometric mean to calculate habitat HIS scores. Given different input data between year 0 and year 5, we see an increase in overall score due to changes in the parameter values. Interpretation of results should be considered critically by model users and stakeholders. Model results represent a line of data interpretation to help inform decision making, but the results should not be the sole basis for decision making.

Geographic Range of Model Applicability

This model is intended for use within coastal Southern California, from Point Conception to the southern California border (Figure 33). Point Conception (near Santa Barbara, California, USA) is a coastal region notable for the large number of species range limits associated with a transition in water temperature and oceanographic features (Altman et al, 2013).

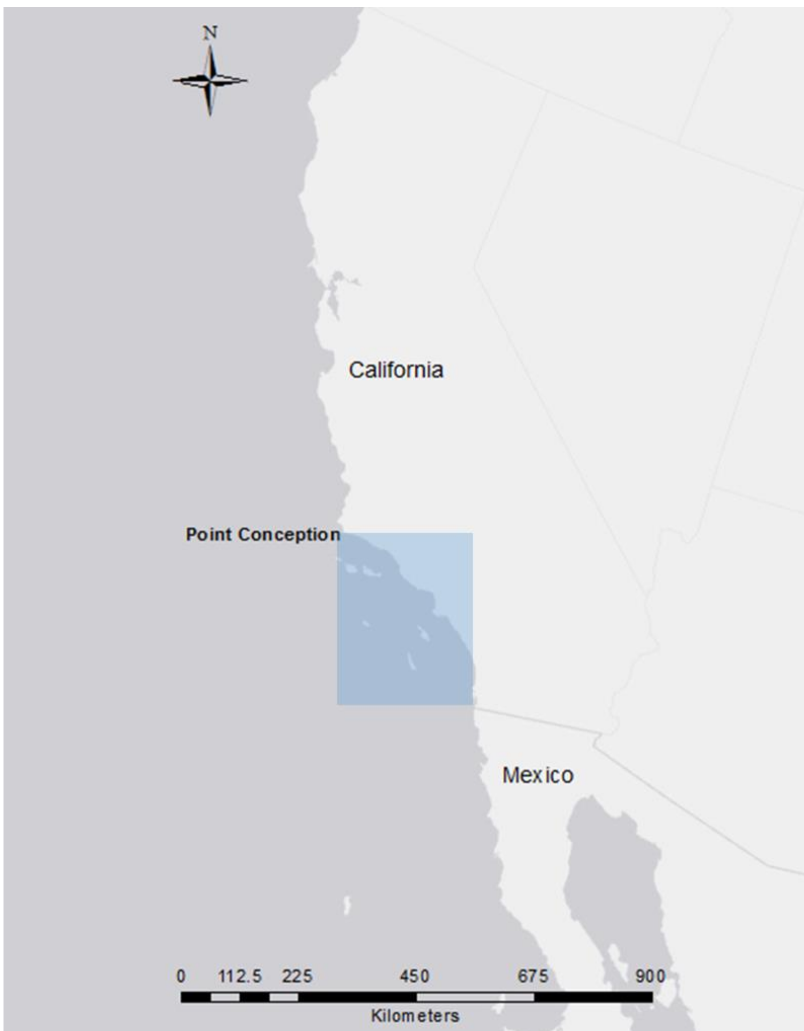


FIGURE 33. MAP OF GEOGRAPHIC RANGE OF MODEL APPLICABILITY. MODEL RANGE HIGHLIGHTED IN BLUE.

Considerations for Model Application

Before applying the ESPB model, please review the following considerations:

1) The ESPB model was developed specifically to provide insight into choosing among different potential scenarios for restoring combinations of different habitat types for large scale restoration in the bays and estuaries of Southern California. The model was not evaluated under conditions to restore single habitats, or for areas outside of the Southern California region.
2) In general, marginal habitat is often the focus of ecosystem restoration projects. Areas that have suitable hard substrate for oysters or kelp may already support a healthy populations and would not be identified as areas in need of restoration. If an area has been identified for restoration, yet hard substrate is the single lacking element for high quality habitat, then polygons representing hard substrate should be added to any substrate data layers used when executing the ESPB model.
3) The ESPB model is designed to be flexible regarding data input and spatial scales and can take input from hydrodynamic models, monitoring stations, scientific literature, and expert opinion. Cell size and spatial extent can vary, but the spatial extent must be large enough to include both suitable and unsuitable habitats. One limitation for input data is that a value must be available for each cell within the spatial domain.
4) The ESPB model was intentionally designed to only include the minimum factors required for restoration suitability for each of the habitat types. Given the complexities of restoring and sustaining ecosystems over time, other local conditions may influence sustainability, which should likewise be considered for determining restoration potential.
5) The ESPB was developed for use by technical experts with knowledge of the biology and ecology of the ESPB system. A moderate level experience in GIS processing using ESRI software is required to use the model.

References

Aiello-Lammens, M. E.,M. Chu-Agor, M. Convertino, R. A. Fischer, I. Linkov, and H. Resit Akcakaya. 2011. The impact of sea-level rise on Snowy Plovers in Florida: integrating geomorphological, habitat, and metapopulation models. *Global Change Biology*, *17*(12), 3644-3654

Almasi, M. N., Hoskin, C. M., Reed, J. K., and Milo, J. 1987. Effects of natural and artificial *Thalassia* on rates of sedimentation. Journal of Sedimentary Research, 57(5).

Altman, S. J. Robinson, J. M. Pringle, J. E. Byers, and J.P. Wares. 2013. Edges and overlaps in northwest Atlantic phylogeography. Diversity, 5, 263-275.

Baker, P. 1995. Review of ecology and fishery of the Olympia oyster*, Ostrea lurida* with annotated bibliography. Journal of Shellfish Research 14:501–518.

Barnes, T. K., Volety, A. K., Chartier, K., Mazzotti, F. J., & Pearlstine, L. 2007. A habitat suitability index model for the eastern oyster (Crassostrea virginica), a tool for restoration of the Caloosahatchee Estuary, Florida. Journal of Shellfish Research, 26(4), 949-959.

Brooks, R. P. 1997. Improving habitat suitability index models. Wildlife Society Bulletin (1973-2006), 25(1), 163-167.

Brown, S. K., Buja, K. R., Jury, S. H., Monaco, M. E., & Banner, A. 2000. Habitat suitability index models for eight fish and invertebrate species in Casco and Sheepscot Bays, Maine. North American Journal of Fisheries Management, 20(2), 408-435.

Endangered and threatened wildlife and plants: final rulemaking to designate critical habitat for black abalone, 50CFR2.226 (2011).

Feder, H. M., Turner, C. H., and Limbaugh, C. (1974). Observations on fishes associated with kelp beds in southern California. State of California, Resources Agency of California, Department of Fish and Game.

Huettel, M., and Rusch, A. 2000. Advective particle transport into permeable sediments—evidence from experiments in an intertidal sandflat. Limnology and Oceanography, 45(3), 525-533.

Hopkins, A.E. 1937. Experimental observations on spawning, larval development, and setting in the Olympia oyster (*Ostrea lurida*). Bulletin of the U.S. Bureau of Fisheries, v. 48 Bull 23 (1937): 439-503.

Jackson. G. A. (1983). The physical and chemical environment of a kelp community. In: The Effects of Waste Disposal on Kelp Communities. Institute of Marine Resources, University of California. pp. 11-37.

Johnson, T. D., A. M. Barnett, E. E. DeMartini, L. L. Craft, R. F. Ambrose and L. J. Purcell. 1994. Fish production and habitat utilization on a southern California artificial reef. Bulletin of Marine Science 55(2-3): 709-723.

Kotliar, N. B., & J. Burger. 1986. Colony site selection and abandonment by least terns *Sterna antillarum* in New Jersey, USA. *Biological Conservation*, *37*(1), 1-21.

Kenworthy, W. J., Zieman, J. C., and Thayer, G. W. 1982. Evidence for the influence of seagrasses on the benthic nitrogen cycle in a coastal plain estuary near Beaufort, North Carolina (USA). Oecologia, 54(2), 152-158.

Koch, E.W. 2001. Beyond Light: Physical, Geological, and Geochemical Parameters as Possible Submersed Aquatic Vegetation Habitat Requirements. Estuaries 24: 1-17.

Koh, I., Lonsdorf, E. V., Williams, N. M., Brittain, C., Isaacs, R., Gibbs, J., & Ricketts, T. H. 2016. Modeling the status, trends, and impacts of wild bee abundance in the United States. Proceedings of the National Academy of Sciences, 113(1), 140-145.

Long, W.C., and R.P. Burke. 2007. Habitat size, flora and fauna: Interactions in a tidal salwater marsh. Journal of Experimental Mar. Biol. And Ecol. 353(1):80-88.

Lowe, C. G. and R. N. Bray. 2006. Movement and Activity Patterns. Chapter 4, In: The Ecology of Marine Fishes: California and Adjacent Waters (L.G. Allen, D.J. Pondella, II, and M. Horn, editors) pp. 524-553. University of California Press, Los Angeles.

Moore, K.A. and JC Jarvis. 2008. Environmental factors affecting recent summer time eelgrass diebacks in the lower Chesapeake: implications for long-term persistence. Journal of Coastal Research 55:135-147.

North, W. J., Gerard, V. and Kuwabara, J. 1982. Farming *Macrocystis* at coastal and oceanic sites. In: Synthetic and Degradative Processes in Marine Macrophytes. Berlin: de Gruyter, pp. 247-262.

North, W.J. 1971. The biology of giant kelp beds (*Macrocystis*) in California. Nova Hedwigia Beihefte 32:1-600

Pondella, D.J., L.G. Allen, M.T. Craig and B. Gintert. 2006. Evaluation of eelgrass mitigation and fishery enhancement structures in San Diego Bay, California. Bulletin Marine Science 78(1): 115-131.

Pondella, D. J. II, J. Williams, J. Claisse, B. Schaffner, K. Ritter and K. Schiff. 2015. The Physical Characteristics of Nearshore Rocky Reefs in the Southern California Bight. Bull. Southern California Acad. Sci. 114(3):105-122.

Saalfeld, S. T., W. C. Conway, D. A. Haukos, and W. P. Johnson. 2012, Snowy plover nest site selection, spatial patterning, and temperatures in the Southern High Plains of Texas. The Journal of Wildlife Management, 76: 1703–1711. doi:10.1002/jwmg.404

Siegel, S., Toms, C., Gillenwater, D., and C. Enright. 2010. Suisun marsh tidal marsh and aquatic habitats conceptual model, Chapter 3:Tidal Marsh. U.S. Fish and Wildlife Service.

Soniat, T. M., & M. S. Brody. 1988. Field validation of a habitat suitability index model for the American oyster. *Estuaries and Coasts*, *11*(2), 87-95.

Swannack, T. M., M. Reif, & T. M. Soniat. 2014. A robust, spatially explicit model for identifying oyster restoration sites: case studies on the Atlantic and Gulf coasts. Journal of Shellfish Research, 33(2), 395-408.

Tegner, M. J., and Dayton, P. K. 1987. El Nino effects on southern California kelp forest communities. Advances in Ecological research, 17: 243-279.

Vaudry, J.M.P. 2008. Establishing Restoration Objectives for Eelgrass in Long Island Sound Part I: Review of the Seagrass Literature Relevant to Long Island Sound. Final Grant Report to the Connecticut Department of Environmental Protection, Bureau of Water Protection and Land Reuse and the U.S. Environmental Protection Agency.

Wanless, H. R. 1981. Fining-upwards sedimentary sequences generated in seagrass beds. Journal of Sedimentary Research, 51(2).

Webber, A.F., Heath, J.A. and R.A. Fischer. 2013. Human disturbance and stage-specific habitat requirements influence snowy plover site occupancy during breeding season. *Ecology and Evolution*, 3(4):853-863.

West, J.M., and J. Zedler. 2000. Marsh-creek connectivity: Fish use of a tidal salt marsh in southern California. *Estuaries, 23*(5), 699-710.

Zedler, J., National Coastal Ecosystems Team (U.S.), & U.S. Fish and Wildlife Service. 1982. The ecology of southern California coastal salt marshes: A community profile (Biological services program, 81/54). Washington, D.C.: Service. Zimmerman, R. C., and Kremer, J. N. 1984. Episodic nutrient supply to a kelp forest ecosystem in Southern California. Journal of Marine Research, 42(3): 591-604.

Zhou, J., Wang, Q., Zhao, W., Yu, D., & Guan, S. 2016. Habitat suitability analysis of eelgrass Zostera marina L. in the subtidal zone of Xiaoheishan Island. Chinese journal of oceanology and limnology, 34(1), 69-78.

Appendix A:
GIS User Guide for Application of the East San Pedro Habitat Evaluation Model

General GIS methods are discussed in the *Spatial Data and Model Application* section of the model documentation report, in which four case studies (different restoration alternatives considered for the East San Pedro Ecosystem Restoration Study) are illustrated in the application of the Habitat Evaluation Model (Model). The purpose of this Appendix is to provide additional detail in the form of a step-by-step guide for conducting the GIS portion of the analysis and assumes a basic level of knowledge of ArcGIS software and GIS expertise. Analysis was conducted in ESRI's ArcGIS 10.5 software but the process of using Model equations to develop Habitat Suitability Indices (HSIs) can be performed within any GIS that the user is familiar with. Examples from the four case studies are provided within the model documentation (*Spatial Data and Model Application*), illustrating different model results. Conducting such analyses in other locales with different data types may result in variations in data manipulation and geo-processing. Regardless, the application of the Model is the same, and this guide provides the detailed steps used to conduct the analysis in a GIS software environment.

1. Study Area and Pre-processing

Study area extent and cell size were determined as a function of both area of interest in terms of the project goals as well as data availability.

East San Pedro Bay

This study area was selected because it is the subject of an extensive restoration planning study that incorporates multiple habitat types (rocky reef, kelp forest, eelgrass, oyster reef, tidal salt marsh and sandy islands). Environmental and biophysical data corresponding to each of the 23 parameters identified as critical for the respective 6 habitat types were provided for the region. The Model is designed to be flexible regarding data input and spatial scales and can take input from hydrodynamic models, monitoring stations, scientific literature, and expert opinion. Cell size and spatial extent can vary, but the spatial extent must be large enough to include both suitable and unsuitable habitats and a value must be available for each cell within the spatial domain. All data are clipped to the study area (using the Geoprocessing Menu's Clip Tool) and reprojected to the same projection (using the Data Management Toolbox, Projections and Transformations Toolset, Define Projection and/or Project Tool).

2. Developing HSI and Habitat HSI Scores

General Processing Steps:

- A data layer containing values for each parameter of interest (at least one value per grid cell) is imported into the GIS spatial domain for ESPB.

- Each habitat type is considered separately. For each habitat type, the associated layers for each critical parameter are included as separate data layers.

- For each habitat type-parameter combination, the parameter equations described in *Habitat Parameters and Response Curves* are calculated for each cell within the grid domain and a parameter specific HSI layer is created for each habitat-parameter combination. For example, for Oyster Reef habitat, two separate HSI layers are created, one using the Oyster Reef-Salinity curve (*page 23*) and one using the Oyster Reef-Depth curve (*page 24*). The field calculator is used to apply a series of conditional statements and equations (if-then-else) to each specific cell for each habitat type. For example, for oyster habitat salinity the following conditional statements (presented as pseudocode) used:

  - $if\ salinity \leq 0\ and\ salinty < 25 \mid HSI_{Salinity} = 0.04 * Salinity$
  - $if\ salinity \leq 25\ or\ salinty \leq 30 \mid HSI_{Salinity} = 1$

- To determine the Habitat HSI Score, a geometric mean of all of the individual habitat-parameter HSI scores is calculated and a new layer corresponding to the Habitat HSI Score is created. For a set of numbers $\{X_i\}^N$ i=1, the geometric mean is:

$$\left(\prod_{i=I}^{n} x_i\right)^{I/n} = \sqrt[n]{a_1 a_2 \dots a_n}$$

- Using this process, a Habitat HIS Score layer with values for the entire spatial domain is created for each of the six habitat types.

- A map of each restoration alterative under consideration is then merged with each Habitat HSI Score layer to determine the location and area of habitat, by type, within each proposed alternative. Habitat HSI Score values are then extracted for the proposed restoration locations. These scores are presented for each alternative by Habitat type.

- HIS Scores can be combined with habitat acreage to calculate habitat units and compare restoration alternatives.

FINAL INTEGRATED FEASIBILITY REPORT AND ENVIRONMENTAL IMPACT STATEMENT / ENVIRONMENTAL IMPACT REPORT (EIS/EIR)

APPENDIX D-1: BIOLOGICAL SUPPLEMENT

EAST SAN PEDRO BAY
ECOSYSTEM RESTORATION STUDY
Long Beach, California

January 2022

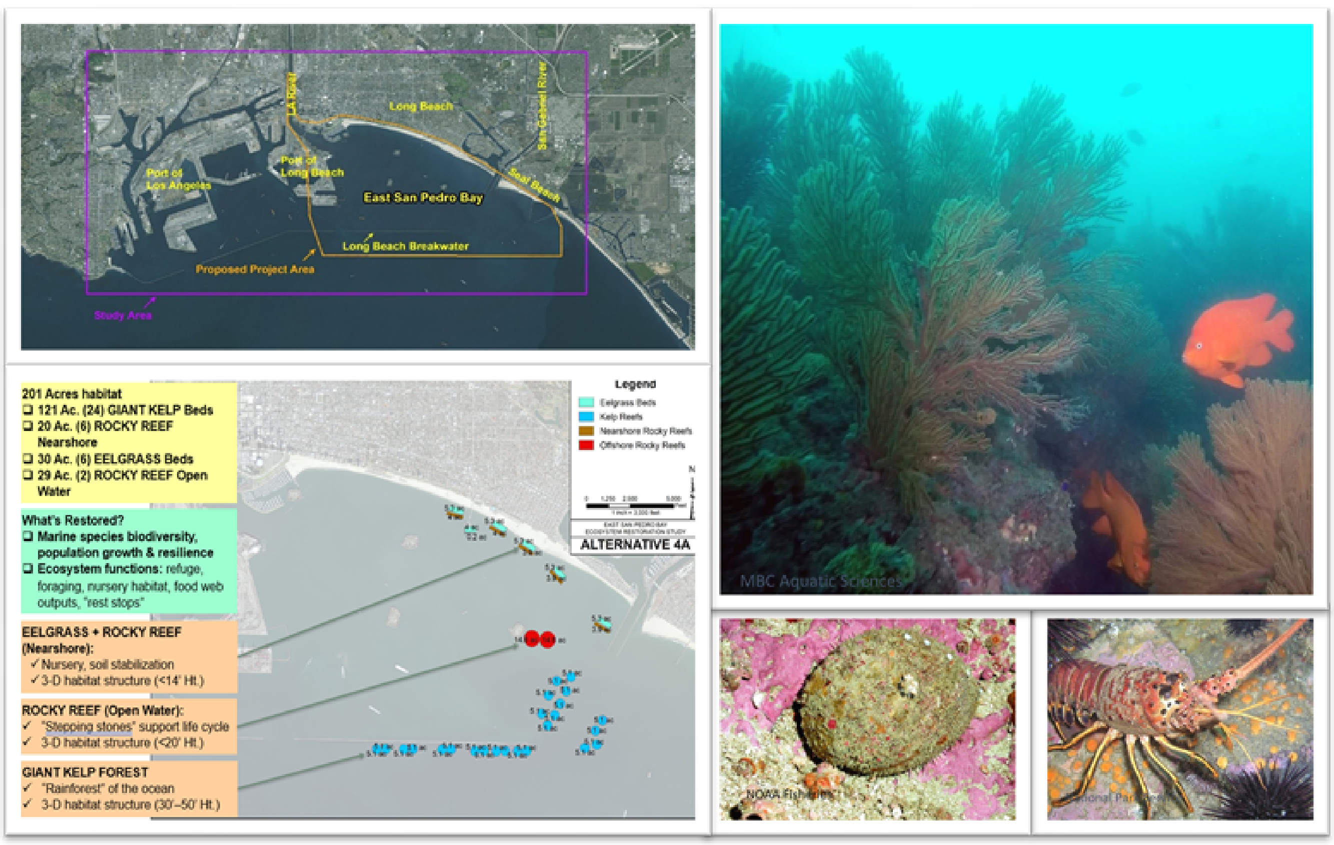


Table of Contents

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

This Appendix summarizes important peer reviewed literature, reports, and other information used to support the habitat modeling and habitat assessment analysis of the alternatives proposed for the U.S Army Corps of Engineers' (USACE or Corps) East San Pedro Bay (ESPB) Ecosystem Restoration Feasibility Study (Project). The documentation and user guide for the Habitat Evaluation Model (HEM) developed for this Study can be found in Appendix D.

This Appendix does not attempt to provide a full accounting of the biological environment of the Study Area nor duplicate environmental information already presented in the associated Integrated Feasibility Report (IFR). The intent of this Appendix is to provide quantitative or qualitative justification and rationale on the Study's objectives, assumptions, restoration targets, and decisions point as they pertain to biological and associated physical conditions for habitats targeted for restoration within the Proposed Project Area. Results and conclusions from this Appendix will provide the Study's non-Federal sponsor, resource agencies, and public with supporting information to assist in understanding this study's underlying assumptions and interpreting the quantitative output from the HEM. All attempts have been made to ensure that the information included within this Appendix is consistent with the most recent previous biological baseline studies conducted for San Pedro Bay, as well as incorporates the guidance of subject matter experts.

A glossary of technical terms and definitions is also included to aid the reader.

1.1 ECOSYSTEM RESTORATION AND THE CORPS PLANNING PROCESS

Ecosystem restoration is the process assisting the recovery ecosystem structure, function, and dynamic processes that have been degraded, damaged or destroyed (SER Primer 2004). The Corps Planning method provides a means to systematically work through this process by (1) identifying problems and opportunities and (2) inventorying and forecasting conditions, and formulating, evaluating, and comparing alternative restoration scenarios (or plans) in order to select the best, most cost effective restoration alternative for implementation and construction.

Evaluating habitat quality or suitability through a habitat assessment is the approach most often used to compare restoration alternatives. Habitat assessment serves to quantify restoration benefits that inform the cost effectiveness and cost-benefit analyses that contribute to the comparison of alternative plans developed during the Corps Planning process. In this context, habitat (i.e., the setting where a group of organisms live, interact, and reproduce) is considered a proxy for ecosystem function as a whole. In other words, if the appropriate combination of habitats is present, the entire system will function as intended. Habitat information is frequently viewed in parallel with species-specific information to gain insight to various uses, structures, and functions existing within a landscape or site.

However, improving the quality of the environment in the public interest, especially in densely populated urban areas, represents a significant challenge for the Corps. Limitations can stem from institutional barriers, the lack of few successful precedents, and limited availability of guidance on conducting ecological restoration in a dense urban environment. Challenges can further occur when attempting to integrate expertise from various disciplines and multiple, sometimes divergent, interests and goals. Complexity of a topic can result in issues with timing, capacity, communication, and collaboration as the process unfolds. Navigating this complexity while simultaneously achieving stated project goals is an inherent challenge of the Corps planning process.

1.2 CORPS ECOSYSTEM RESTORATION POLICY AND APPROACH

The objective of any Corps ecosystem restoration project is to restore degraded ecosystem structure, function, and dynamic processes to a less degraded, more natural condition. Even partial restoration may provide significant and valuable improvements to degraded ecological resources (USACE 2000). Under Corps authority (WRDA 1996), restoration opportunities that are associated with wetlands, riparian and other floodplain and aquatic systems are the ones most appropriate for Corps involvement.

Restored ecosystems should mimic, as closely as possible, conditions that would occur within the Proposed Project Area in the absence of human changes to the landscape and hydrology. Indicators of successful restoration would include the presence of a large variety of native plants and wildlife, the ability of the area to sustain larger numbers of key indicator species or more biologically desirable species, and the ability of the restored area to continue to function and produce the desired habitat benefits with a minimum of continuing human intervention (USACE 2000).

Additional guidance for ecosystem restoration in the Civil Works Program assures that civil work investments in ecosystem restoration have the intended beneficial effects and would be conducted in the most cost effective manner (USACE 2000). Corps guidance requires that the ecosystem related benefits of proposed alternatives be subjected to detailed economic analysis, allowing an explicit comparison of the costs and benefits associated with the alternatives. Consequently, it is necessary that the environmental benefits of the alternatives be based on some quantifiable unit of value. Because restoration value is difficult to quantify from a fiscal perspective, the Corps calculates the value and benefits of its ecosystem restoration projects using established habitat evaluation methodologies, rather than calculating benefits in strict monetary terms. Comparing the alternatives in this manner facilitates the determination of the most cost-effective restoration alternative that meets restoration goals (USACE 2000).

1.3 STUDY SIGNIFICANCE

Coastal habitats are an indispensable part of the nation's significant natural resources (USCOP 2004). The embayments, marshes and estuaries along the southern California coast are considered among the most productive habitats on the Pacific coast (Dailey et al. 1993). These environments are characterized by a unique physical landscape comprised of structurally complex habitat types including rocky reefs, seagrass communities, kelp beds, sandy shorelines, and wetlands, features of which not only define California's coastal ecosystems, but are key to the survival of many species dependent on them. Coastal habitats also sustain much of the Nation's economy (USCOP 2004). In southern California, coastal serve as the major economic engine for the State and are home to a substantial proportion of its residents and industry.

Bays and estuaries, in particular, are coastal habitats that support substantial biological diversity and perform essential ecosystem services i.e., benefits that humans derive from properly-functioning ecosystems (MEA 2005). They serve as breeding and nursery areas for a wide array of coastal fishes, provide habitat for unique assemblages of fishes, and support large populations of small fishes that are important forage for high level consumers in the ecosystem. In addition to providing essential habitat for fisheries, estuaries can play a role in improving water quality, serve as buffers for coastal upland property, and enhance the well-being of local citizens via the outdoor and recreational opportunities they provide. Estuaries and coastal areas are also home to many ports and industrial areas, and the communities that depend on them. They play vital roles in supporting the U.S. economy by providing access for maritime trade.

As development along the coast has increased, alterations to this landscape have threatened many of these physical features and their associated habitats. In southern California, for example, estuarine wetlands have been eliminated by 75 percent to 90 percent as a result of filling or dredging in the last century (Ferren et al. 1995). In addition, the persistence of these habitats is expected to be the most vulnerable to the effects of climate change and sea level rise over time. Sustaining complex physical processes and habitat structures depends on restoring and maintaining key habitats, addressing shoreline management, and supporting efforts to adapt to the uncertainties of climate change. With 75% of California's population living within coastal communities, and as southern California's coastal habitats continue to face unprecedented pressures associated with water supply, population growth and development, it is critical to address these ever-increasing challenges to coastal marine ecosystems. Preservation and enhancement of existing coastal and estuarine habitats are critical components to the sustainability of these habitats.

Harbors, in particular, are artificial habitats formed by breakwaters that slow the movement of water and affect other changes making them in some ways similar to natural, semi-enclosed bays and estuaries. These habitats are frequently characterized by calm, nutrient-rich waters and a variety of substrates. The protected rocky environment on the leeward side of a breakwater becomes an important and distinct habitat for shallow, subtidal fishes. Due to the limited amount of natural bay-estuarine habitat in southern California as a result of human activities, the numerous harbors of the region supplement or replace the few natural estuaries as nursery areas for juvenile fishes (Stephens 1978). Los Angeles/Long Beach Harbor is such a habitat that in recent years has been shown to support diverse and abundant fish faunas (Horn 1980). For these reasons, harbors represent valid opportunities for focused restoration efforts in the region.

Communities in coastal areas of southern California are experiencing environmental changes that create uncertainty and challenges for future adaptation, such as (1) accelerating rates of shoreline erosion due to increased storminess and amplified wave heights associated with climate change, and (2) disruption of coastal resources due to shifts in seawater chemistry tied to ocean acidification. These two problems are connected in nearshore habitats via kelp forests and their interaction with surrounding waters. Kelps and other aquatic vegetation have the capacity to attenuate ocean waves, and by means of their photosynthetic activities, can alter the carbonate chemistry of seawater. Such effects suggest that the above challenges could serve as simultaneous targets for amelioration through restoration of degraded kelp forests. In addition, estuaries and vegetated habitats along the shoreline can play a significant role in reducing shoreline erosion, increasing habitat for important species, and providing recreational areas for human use. Recognizing that the biology and physical processes of coastal and marine habitats are inextricably linked (i.e., what restores one protects the other), restoration of coastal and marine habitats can have a net positive effect on the delivery of cultural services (e.g., recreation), provisioning services (e.g., increase in biotic resources), climate regulation, storm protection, water quality enhancement, and conservation of native biodiversity.

1.4 STUDY GOALS AND OBJECTIVES

Given the above, the USACE Los Angeles District, city of Long Beach, and key agencies and stakeholders developed specific planning objectives to guide the formulation and evaluation of restoration alternatives and the development of a recommended plan for the Study (Project). The overall Study objective is to restore target "complex" aquatic habitat types historically present in the greater San Pedro Bay ecosystem, inclusive of kelp reef, rocky reef, eelgrass, oyster beds, sandy emergent islands, and coastal wetlands, of sufficient quantity and quality to support diverse resident and migratory marine and terrestrial species associated with the bay. Three (3) associated sub-objectives, refined throughout the formulation process, were developed for the Project:

a. Increase the extent (total area) of complex aquatic habitats within the Proposed Project Area.

   - Rationale: Currently, the Proposed Project Area offers one of the few opportunities within San Pedro Bay to conduct large-scale restoration of nearshore and open water habitats within a protected embayment. Current habitat conditions in the Proposed Project Area are characterized by a general lack appropriate substrate conditions (e.g., gently sloping topography in the intertidal zone, areas of protected shallow water, hard and/or rocky surfaces) to support marine communities, such as kelp forests, eelgrass beds, and rocky reef species to the extent that they once occurred in the Southern California Bight (SCB).

b. Increase the diversity and spatial heterogeneity of complex aquatic habitat types within the Proposed Project Area.

   - Rationale: Habitat heterogeneity plays an important role in structuring ecological communities, as heterogeneous habitats (both spatially and structurally) generally support increased species density, richness, and diversity across terrestrial freshwater, and marine ecosystems. Habitat heterogeneity influences fundamental processes that organize communities, including species coexistence, dispersal recruitment success and mortality predation risk resource acquisition and the strength of trophic cascades (Paxton et al. 2017)

c. Increase the overall connectivity of complex aquatic habitat types within the Proposed Project Area by restoring habitat areas in a way to facilitate the movement of species between habitat nodes to support and enhance existing food webs.

   - Rationale: Connectivity is a defining characteristic of marine ecosystems (Carr et al. 2003). The persistence of many species depends on individuals successfully migrating among multiple, connected, patches or habitats (Sale et al. 2005; Hastings and

> Botsford 2006). Increased connectivity can benefit all life stages of marine organisms: larval, juvenile, and adult. For example, Brown et al. (2016) suggest connectivity between different types of habitats that occur in sheltered environments (e.g., seagrass, salt marshes) potentially have desirable characteristics for biodiversity conservation and can support local fisheries through spatial coupling and linkages between species life-history types.

The increased interchange between adjacent habitat types in terms of nutrient cycles, colonization, and recruitment of species would help to maintain or increase biodiversity and ecosystem function within the Proposed Project Area. Organisms, organic matter and nutrients are transferred between habitat types, for example, between freshwater and the ocean via estuaries, pelagic (open water) and nearshore coastal waters, and kelp beds, seagrasses, and rocky reefs (Fairweather & Quinn 1993). The goal of restoration within a sheltered environment like ESPB should not only increase the amount and types of habitats within the bay (addressing sub-objectives 1 and 2), but create synergistic increases in overall species diversity, and sustain this diversity over time. For example, increases in fish species diversity abundance can be achieved through increases in nearshore nursery habitat for larval fish, as well as through increased habitat for juveniles on adjacent open water reefs. This can lead to higher retention of species within an area over the long term, resulting in desirable characteristics for regional biodiversity conservation and support for local fisheries (Brown et al. 2016). Fish species diversity provides a central linkage in the analysis of marine food webs, and therefore, can serve as a reasonable and cost-effective indicator of habitat value across a wide range of marine habitats (Bond et al. 1999).
Habitat “Node” Approach to Restoration

The proposed Project for ESPB takes a nodal approach to habitat restoration. A habitat node is area or patch of habitat associated with a physical location. Nodes can be isolated habitat patches or can be connected to some extent by edges between adjacent nodes. An edge between two nodes implies there is some ecological connectivity or exchange between the nodes, such as via propagule dispersal or material (e.g., nutrient) flow (Urban and Keitt 2001).

Nodes in any landscape (or in this case, seascape) contribute significantly to the integrity of the larger ecosystem by supporting meta-populations (assemblages of local populations connected by migration) (Hanski & Gilpin 1991). By increasing patch sizes and reducing the distances between them, colonization among populations improves (Hanski & Thomas 1994). Meta-populations depend on propagule dispersal and movements or organisms between nodes to persist, and such dispersal is in turn dependent on the connectivity of the landscape (Schippers et al. 1996). Improving nodal connectivity help to address aquatic habitat fragmentation.

Nodes may be larger or smaller. Large habitat nodes support colonization of the smaller nodes by organisms, while smaller nodes act as peripheral refuge habitat (Rudd et al. 2002). Large nodes tend to have high biodiversity and provide important breeding and seeding habitat for smaller nodes, as well as edge species and transients. Smaller nodes are partly or entirely dependent on individuals immigrating from the larger nodes as they have a higher rate of extinction and therefore need to be repopulated constantly (Hansson 1991; van Apeldoorn et al. 1992). Smaller nodes (those under 250-acres) may not be able to support large numbers of species on their own, but are able to provide important peripheral habitat to species in the larger nodes (Hansson 1991). Generally, nodes have a greater overall interaction when they are larger and closer together (Linehan et al. 1995).

The connectivity of habitats and concept of nodes is germane to the determination of the habitat "benefit area" for this Project. For USACE restoration projects, habitat units based on modeling results are typically used to predict and quantify environmental benefits gained from a project. These units can be spatially distributed throughout the project area. In the case of ESPB, the habitat model is based on the placement of discrete structural elements (hardscape) that are assumed to provide ecosystem benefit (i.e., functional lift) to the project area immediately or over time. However, the actual area of benefit is functionally much larger than this due to the increased interchange (connectivity) between adjacent habitat types as described above. In this case, the actual benefit area includes the space taken up by the actual physical structures themselves (e.g., rocks for kelp, shoals, oyster platforms, etc.) along with ALL the intervening space WITHIN a cluster of hard structures expected to colonized by rocky reef organisms over time (e.g., the interstitial space between two adjacent rocks) and BETWEEN the grouping of clusters (e.g., between an open water rocky reef and a near shore shoal/eelgrass bed). It is assumed that this interchange between is beneficial, although this is not explicitly quantified in the results of the HEM.

1.5 PLANNING ASSUMPTIONS AND CONSIDERATIONS

In this report, the term "restoration" includes creating and enhancing habitat (or the conditions for habitat establishment). The restoration goals are not intended to return habitats in ESPB to conditions that may have existed in the past, but improve upon conditions that exist today, with restoration targets based on what is known about ecosystem services provided by habitats, limiting factors, and the potential for habitats to be created or enhanced within the bay. Restoration is also designed with the long-term in mind, and planning must therefore account for expected long-term changes. For this Project, restoration is targeted to locations and situations where long-term success is most likely.

The goals of this proposed restoration Project for ESPB are intended to focus on habitats rather than individual species (except for those habitats that are created by a single or dominant species, e.g., eelgrass or oyster beds). This approach avoids prioritizing some species over others. The key decisions and planning considerations described below were developed by the Project Delivery Team (USACE and city of Long Beach), with extensive input from the Project's Technical Advisory Committee (TAC) and consultants. The following key decisions were made when identifying the goals for this Project:

- The geographic scope of the Proposed Project Area is a defined area within ESPB, located offshore from the city of Long Beach, California. However, conditions in ESPB have a relationship to the habitats (subtidal, intertidal, and transitional) of the greater San Pedro Bay ecosystem. Restoration within the Proposed Project Area would benefit the greater ecosystem of the SCB in the form of incidental, unquantified secondary benefits, including contingencies for resiliency of the ecosystem to climate change:
    - Restoration within the Proposed Project Area could support higher abundance of taxa in the region and support more significant regional connections to nearby ecological zones. Restoration could provide regional connectivity for wildlife movement and hydrologic processes between the project area and the greater port complex.

    - There would be greater potential for future direct connections to the other habitat restoration projects in San Pedro Bay, Alamitos Bay and the lower Los Angeles River.

    - Restoration within the Proposed Project Area could increase existing population levels for various state and federally managed fisheries to support agency initiatives and contribute to local economies.

- For the purposes of this restoration Project, *"subtidal habitat"* includes all submerged areas of the bay as they pertain to rocky reef, kelp beds, and eelgrass communities. The Project also addresses certain "*intertidal habitats,"* such as tidal wetlands and sandy shores associated with emergent islands. The water column and other sub-tidal soft bottom habitats of the bay were not included in the Project's restoration goals (see section 3.1.1 below).

- This Study avoids setting priorities among habitats; however, restoration of some habitats may result in conversion of others. For example, some soft substrate may be lost through restoration efforts focused on eelgrass or rocky reefs.

- Muddy soft-bottom habitat is essential for some species and supports valuable ecosystem services. Although soft bottom habitat is plentiful in the bay, it is still threatened by various activities.

- Available information about existing conditions in the bay serves as a baseline for this Project.

- The goals of the Project build upon opportunities and information developed by existing projects, including in-the-water monitoring, restoration, mitigation, and research projects in the greater San Pedro Bay.

- Because there is a great deal of uncertainty about the functions and value of the habitats and the utility and likely success of restoration, this document recommends using an adaptive management approach in implementing and achieving the goals.

- The Project's goals and objectives take into account the extent of scientific understanding of each habitat with a focus on enhancing, creating, or restoring particular habitats.

- Subtidal rocky outcrops, subtidal shoals, and tidal wetlands support valued ecosystem services and are under threat from human activities and climate change in the SCB, thus a restoration focus on these features is warranted for ESPB. Opportunities for restoration for these features are based on uncertain techniques, so this document emphasizes applying restoration methods experimentally and adapting accordingly.

The Study operates with the underlying assumption that active restoration approaches are beneficial in open marine and coastal systems where biogenic structures, such as semi-terrestrial saltmarsh vegetation, intertidal and subtidal seagrass beds, kelp beds, and rocky reefs, have been lost, reduced, or degraded (Geist and Hawkins 2016). Biogenic structuring species act as "ecosystem engineers´"(Jones et al. 1994) and restoring such species not only adds structure to habitat but also influences ecosystem functioning and ultimately services. Higher plants such as seagrasses and those from saltmarshes, seaweeds and the symbiotic algae associated with reefs are also important primary producers. In the case of macrophytic plants and algae, these provide much primary production that is either directly consumed by grazers or indirectly consumed in detrital food web (Geist and Hawkins 2016).

In most cases, biological attributes will follow structural and physical improvements through processes such as natural re-colonization (Pander et al. 2016. Increasing structural complexity that leads to an array of microhabitats, such as the creation of crevices (Aguilera et al. 2014; Coombes et al. 2015; Loke et al. 2015) that boost biodiversity, can be incorporated at the design phase of projects (Moschella et al. 2005; Firth et al. 2014), retrofitted (Evans et al. 2016) and put in place during routine maintenance (Bulleri and Chapman 2010). Such approaches can particularly benefit populations of overexploited or threatened species (Martins et al. 2010; Perkol-Finkel et al. 2012). Such habitat creation can provide at least some ecosystem services and biodiversity, especially in urban areas, and offset biodiversity loss in adjacent areas (Martin and Haney 2005).

2 REGIONAL SETTING

San Pedro Bay is located within the SCB, an oceanographically defined region of southern California that extends from Point Conception, California in the northwest to Cabo Colnett, Baja California, in the south-east, and is bounded to the west by the California Current (SCCWRP 1973; Dailey et al. 1993; Figure 1). The SCB includes an area of approximately 78, 000 km^2 with a shoreline distance of over 300 km (Dailey et al. 1993).

Figure 1: Map of the southern California, including general circulation patterns in the SCB (after Hickey 1993)

The SCB is a rich ecosystem; over 5000 species of invertebrates, 480 species of fish, and 195 species of marine birds are found in this region (Dailey et al. 1993). The diversity found in the SCB is due, in part, to its transitional zonation between two biogeographic provinces. The San Diegan Province to the south introduces sub-tropical species while the Oregonian Province to the north introduces temperate species into the SCB (Briggs 1974). Each of these provinces has distinctive biota. For example, more than 70% of all algal species found in California occur in the SCB; half of these species have their northern or southern range endpoints located within the SCB (Murray and Bray 1993).

The SCB has undergone tremendous changes over the last 100 years resulting from natural and anthropogenic alteration of the coastal zone. Rapid urbanization represents risk to the coastal ecology by encroachment of habitat and by contributing anthropogenic contaminants to the coastal environment. The loss of coastal habitat has reduced some ecosystems to critically small areas. For this reason, ecosystem restoration planning projects represent a vital conservation strategy for significant habitats that have been degraded, depleted, or are now scarce in the region.

2.1 SAN PEDRO BAY

San Pedro Bay is located on the San Pedro Shelf, a relatively broad (~ 30 miles long) continental shelf (Fig. 2) located near the middle of the SCB between Point Fermin (southeastern tip of the Palos Verdes Peninsula) on the northwest and Newport Bay/Corona del Mar bluffs at the southeast. The San Pedro Shelf is one of the broadest mainland continental shelf segments between Monterey, California, and the United States-Mexico border. The entire shelf covers approximately 400 km2 and is shallower than 100 m water depth. San Pedro Sea Valley, San Gabriel Canyon, and Newport Canyon cut into the slope off San Pedro Shelf at the west, south, and southeast, respectively. Approximately 75 to 80 percent of the San Pedro Shelf segment is composed of low-relief, sediment-covered seafloor, and the remaining 20 to 25 percent is composed of rock outcrop interspersed with boulders and cobbles (Wong et al. 2012). The Palos Verdes peninsula separates San Pedro Bay from Santa Monica Bay to the northeast. San Pedro Bay is naturally sheltered from the north by the Palos Verdes Peninsula and the southwest by Santa Catalina Island. Waves approach the Bay through corridors from the west and south (Gorsline and Grant 1972). During the summer, the largest waves are associated with the southern swell, produced by storms in the South Pacific (Horrer 1950).

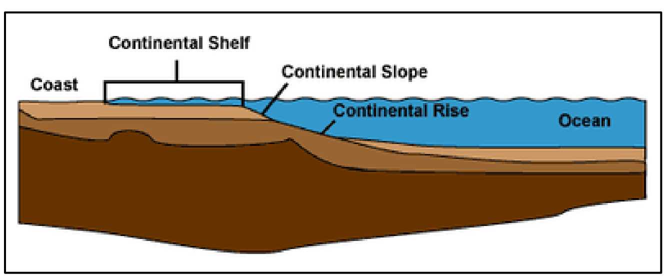


Figure 2: Basic composition of a continental shelf like located at continental margins with sediment (light brown), rocks (middle brown) and the mantle of the earth (dark brown)

At the north end of the bay, an 8.4 mile long artificial breakwater (wall) extends east from Palos Verdes and protects the harbors of Los Angeles and Long Beach. The breakwater has two openings to allow ships to enter the ports of Los Angeles and Long Beach. These openings divide the breakwater into three sections: the San Pedro Breakwater, the Middle Breakwater, and the Long Beach Breakwater. The San Pedro and Middle breakwaters protect the ports of Los Angeles and Long Beach respectively and were constructed between 1899 and 1942. The 2.2 mile Long Beach Breakwater is the eastern most section of the breakwater. The Long Beach breakwater was authorized through the Federal River and Harbor Act of 1940. Construction of the breakwater by the federal government began in 1941 and was completed in 1949. The breakwater is 60 feet high and composed of sand and granite boulders.

2.1.1 CLIMATE

Average annual precipitation within the region is highly variable and terrain-dependent, averaging fifteen (15) inches annually and mainly occurring during the winter months (November through April). Due to the atmospheric dominance of the stable marine layer, significant precipitation is rare between May and October.

During the winter months Pacific storms often push cold fronts across California from northwest to southeast. These storms and frontal systems account for the vast bulk of the area's annual rainfall. Such rainy season storms are migratory, with wet and dry periods alternating during the winter and early spring with irregularity in timing and duration. Rainfall patterns average 3.68 inches of rainfall in February to 0.01 inches of rainfall in July.

The highly developed conditions within the contributing watersheds to the bay facilitate most stormwater flows generated by the rainfall to be routed through curbs, gutters, catch basins, and storm drains to the subwatersheds, and eventually to the bay and the Pacific Ocean.

2.1.2 HISTORICAL CONDITIONS

San Pedro Bay is essentially a multi-river flood plain delta formed as detritus deposited by the Los Angeles River, San Gabriel River, Santa Ana River and several minor streams discharged into the ocean (Wiegel, 2009). During the wet, mild winter, these rivers are still the primary source of sediments to the Bay (Emery 1960).

Extensive sand dunes sloughs and other wetland areas historically existed in Long Beach, Belmont Shore and Alamitos Bay (Dorr 1976/1985; USACE 1986;; Larkey 1990). George Davidson, of the U.S. Coast Survey, wrote the following about San Pedro Bay and the contiguous coastal wetlands and floodplain in 1892, as quoted by U.S. Senator Stephen M. White in a speech in the US. Senate (White 1896, p. 42):

"The bay is the northwestern limit of a very extensive plateau of comparatively shoal water along the seaboard from Point Fermin to about Newport, and the whole country behind the shore is sandy and so low that in winter it is flooded for miles inland by the rains and the overflowing of the low banks of the numerous streams frequently changing their course. The detritus from these streams is moving seaward and principally to the westward over this plateau and helping to current."

2.1.3 ANTHROPOGENIC ALTERATIONS AND EFFECTS ON HABITAT

A Changed Estuary

The environment of the San Pedro Bay is now much different from what was described historically. During the past century, the shape, size, and composition of the bay has been altered by natural events (e.g., floods, droughts, earthquakes) and ocean waves have modified its beaches, with large wave events having caused beach erosion and destroyed or damaged buildings and infrastructure.

Human activities have also had profound effects on the bay's coastal and marine ecosystems. The conversion of shorelines from tidal salt marsh to rip-rap/seawall, diversion of water from upstream waters (preventing it from flowing into the bay), addition of innumerable structures to its edges and bottom, removal of submerged rocks, and the plying of the bay with ships, boats, trawls, and dredges have changed baseline conditions considerably. Coastal structures (harbor entrances, river mouth jetties) have been built. Construction and maintenance dredging have been performed in the bay entrance, navigation channels, turning basins, marinas, and river channels. The beaches are extensively used, and many have been nourished for decades by the addition of sediment obtained from dredging navigation projects, from "offshore borrow pits/ areas." Jetties, wharves, breakwaters and enclosed dock basins have long been a feature of coastal regions with many estuaries being dredged and straightened to help navigation, and concerns about flooding have led to the proliferation of coastal armoring (Airoldi et al. 2005). Artificially created or highly modified marine habitats are now a common feature worldwide, especially so in highly urbanized environments like San Pedro Bay.

Activities associated with fishing, marinas, shipping and ports, dredging, sand mining, transportation, recreation and industry have particularly had significant impact on the Bays subtidal habitats. Subtidal habitat is also threatened by invasions of non-naïve species (as a result of human actions, most non-intentional) legacy pollutants (such as a variety of chemicals formerly used in industry), and modern-day pollution from "point sources," such as industry and sewage treatment plants, as well as "non-point sources," such as the runoff from residential streets and inputs to local watersheds.

The course of the rivers that discharge to the bay have also changed over time due to both natural events and human modifications. In the small, steep canyons of the upper watersheds, dams, debris retention structures levees, and other river control structures have been built. In addition, sediment (sand, gravel, silt, clay) has been trapped in reservoirs and debris retention structures. Sand and gravel is also mined from river beds. This has resulted in a substantial decrease in the natural supply of sediment to the bay. During the warm, dry summer, most of the river water is now diverted upstream to recharge groundwater. Below these diversions, the rivers have a minor flow composed of dry-weather runoff, treated domestic sewage, and industrial discharges.

This loss and degradation of the ecosystem has decreased the value and extent of bay habitats for many species. The biomass of wetland and subtidal vegetation has been reduced, resources of which likely provided copious food resources to humans and animals alike in the past. The intricate matrix of wetland channels, with their three-dimensional surfaces, has been filled in to build ports and marinas. The resulting loss of habitat complexity probably reduced the abundance of many types of estuarine and marine organisms and the productivity of pelagic and benthic food webs.

Despite these changes and challenges, estuarine life persists and, in some cases, flourishes in the bay. This "novel" ecosystem now supports a diverse and surprising number of fauna with anthropogenic structures and a mix of native and invasive species (Hobbs et al. 2009; Wensink and Tiegs 2016). As a result, ESPB offers unexpected habitats of ecological value and the potential for creating and enhancing ecosystem function of existing habitats.

3 HABITATS OF SAN PEDRO BAY

Consideration of significant resources (e.g., habitats) is central to the USACE plan formulation process, especially in the context of ecosystem restoration planning because non-monetary outputs (values) are a consideration. Per Engineer Regulation 1105-2-100, significance of resources and effects will be derived from institutional, public, or technical recognition. Institutional recognition of a resource or effect means its importance is recognized and acknowledged in the laws, plans, and policies of government and private groups. Technical recognition of a resource or an effect is based upon scientific or other technical criteria that establish its significance. Public recognition means some segment of the general public considers the resource or effect of the resource to be important (USACE 2000). The importance of these resources, information specific to East San Pedro Bay, and restoration of these resources, is further described in more detail in the following sections.

A number of significant habitats are found in or associated with San Pedro Bay, the subtidal zone being a critical piece of this ecosystem. Subtidal habitat, as defined here, includes all of the submerged area beneath the bay's water surface: mud, sand, shell, rocks, artificial structures, shellfish beds, eelgrass beds, macroalgal (kelp) beds, and the water column above the bay bottom.

Throughout the SCB, including San Pedro Bay, the dominant bottom environment consists of sandy and muddy sediments (Emery 1960; Dailey et al. 1993). Sandy and muddy sediments (i.e., soft-bottom) consists of patches of sediment differing in grain size (e.g., gravel, sand, silt, clay), and are characterized by much less relief than hard-bottom habitats. Soft-bottom habitats are most extensive on the mainland shelf, slopes, and basins of the SCB. Sediments with high percentages of sand generally dominate shelf areas, whereas sediments with high percentages of silt generally dominate slopes and basins. Various species of seagrass are commonly associated with soft-bottom areas in nearshore zones.

Hard bottom areas (e.g. rocky outcrops, artificial structures, shell mounds) provides substrate for attachment of algae and sessile organisms, and crevices for refuge for mobile organisms. Habitats associated with hard-bottom frequently have abundant algal cover in shallow water. Along the mainland shelf of the SCB, rocky bottoms are most commonly found inshore near rocky headlands, along edges of submarine canyons, as outcroppings on the shelf, and at the shelf break. Only rarely do outcrops naturally occur in deep water (e.g., Santa Monica Bay and San Pedro Bay).

In addition to the subtidal zone, the intertidal zone is a unique habitat due to tidal influences. Exposed to the air at low tide and underwater at high tide, this area represents a continuum of habitat types from the bottom of the bay to tidal wetlands (e.g. mudflats), and transition zones (e.g. sandy beaches) to upland areas (e.g., sandy islands and dunes). Intertidal zone-associated habitats represent some of the most imperiled habitats in the SCB.

3.1 HABITATS NOT TARGETED FOR RESTORATION

It should be noted that muddy-soft-bottom (with the exception of sandy-bottom eelgrass habitat in nearshore areas) and the water column were not targeted specifically targeted for restoration, as the goals of this restoration effort focused on habitat creation and enhancement of rare or limited habitat types within the project area as discussed above. The following provides rationale for why the water column and soft-bottom sediments were not considered for study.

Water Column

The water column is the water covering submerged substrate of the bay, including all volume between the bay's bottom substrate and the water surface. The bay's water column is both the medium for each of the other sub-tidal habitats (e.g. eelgrass, kelp, rocky reef) and technically a separate habitat in its own right. The water column is important for transporting material and organisms to and from the other habitats, and many estuarine organisms live their lives entirely within the water column. Pelagic organisms are those associated with the water column and tend to move with and within the water. Because water-column processes influence other habitats, understanding these processes is essential for managing the other habitats.

For the purposes of this IFR, the water column was not called out as a separate habitat measure with specifically defined restoration targets. Benthic habitats (e.g., eelgrass, kelp reefs) are assumed to include the overlying water column for the purposes of setting and achieving goals for those habitats. For example, the movement of propagules (e.g., eelgrass seeds, kelp sporophytes) among beds is mediated by water motion, and therefore this motion must be considered in efforts to restore or enhance these habitats. In this case, the bay location and placement of substrates is critical so that these surfaces have the best chance of being passively colonized by the marine species that are appropriate to the habitat type being restored.

Although the existence of the water column is not threatened habitat type in the SCB, water quality could become degraded. The greatest concerns for protecting the water column in ESPB are reducing contaminants and improving water quality for marine organisms, predominantly fish. The effects of emerging contaminants (hormones, antibiotics, and other pharmaceuticals) on bay resources are a growing area of concern. Many of these pollutants are entering the bay through the rivers that drain to the bay, including the Los Angeles, and San Gabriel Rivers. For example, there are five storm drain basins, situated 100-200 feet above the water's edge, that collect, convey and discharge runoff to the Long Beach City beaches that are known to be impaired by indicator bacteria.

It is known that stressors originating in the contributing watersheds to a bay can impact affect estuarine water quality, which in turn can affect the abundance and/or quality of habitats, such as submerged aquatic vegetation or rocky reefs. The linkages from watershed stressors to water quality and then to the habitat themselves are modulated by estuarine characteristics. However, a complete analysis of these interactions was beyond the scope of the current planning study for a number of reasons. Because issues of water quality are under the purview of other existing agencies operating under various laws and authorities, such as the federal Clean Water Act and the California Porter-Cologne Water Quality Control Act, this IFR does not address them. Furthermore, pelagic organisms (those living primarily in the water column) move with the water and therefore are not subject to water quality stressors in the same way as benthic (bottom-dwelling) organisms.

From a technical standpoint, an informative water quality analysis would require access to robust data sets that are not currently not available at the scale of the entire bay and for all habitats. Such a data set could support a multivariate analysis in which causal pathways could be statistically traced from watershed stressors through intermediate water quality variables to habitat effects (e.g., Pugesek et al. 2003; Ahronditsis et al. 2007).

In terms of implications for ESPB model development, although models can potentially explain variations in habitat abundance under the low abundance conditions as they have persisted in the bay for some time, models do not necessarily explain the reason for decline itself. In order to explore the complete chain of causal linkage from landscape characteristics to water quality and then from water quality to habitat (like eelgrass), a bay-wide statistical analysis would need integrated data on the geographical characteristics, water quality, and habitat responses for the entire San Pedro Bay. The required data were available for geographical characteristics and for habitat abundance, but not water quality. There are just not enough current water quality data for analysis of habitat effects at the whole-bay scale. Water quality samples are collected from various stations within the bay, with fewer stations in certain areas and their placement is not consistent among the various sample years. Therefore, the point data cannot be integrated to give a spatially and temporally integrated measure that represents the entire San Pedro Bay estuary. In other words, the water quality cannot be made commensurate with integrated, whole estuary/bay values of the habitat response and geographic characteristics.

Soft-bottom Sediments

It is recognized that soft-bottom marine habitats comprised of soft sediments (i.e., underwater substrates comprised of sand, silt and mud) are an important component of the ESPB project area and the greater SCB ecosystem. Most of southern California coastal subtidal areas are characterized by soft bottom, with only occasional small rocky patches. Such areas provide little support for reef associated sport fishes or for development of the marine life rocky reef-associated fishes require for food and habitat.

Patches of soft sediment differing in grain size (e.g., gravel, sand, silt, clay) provide distinct habitats to different species of benthic organisms, used for both shelter and foraging grounds. Subtidal soft-bottom environments also provide habitat for sand dollars (*Dendraster* spp.), sand stars (*Astropecten* spp. & *Luidia* spp.), sea pens (*Stylatula* spp.), as well as many species of polychaetes, crustaceans, gastropods, rays, and flat fishes; however, polychaetous annelids (worms) dominate in most un-impacted regions. These bottom organisms are near the base of the food web that in turn support an abundant and diverse assemblage of bottom-dwelling fishes. Soft-bottom fish found in the bay include flatfishes, rockfishes, sculpins, combfishes, and eelpouts. Some of these fish, such as California halibut (*Paralichthys californicus*), California scorpionfish (*Scorpaena guttata*), barred sand bass (*Paralabrax nebulifer*), and white croaker (*Genyonemus lineatus*), also account for a significant percentage of recreational fish catches from piers and boats (Bay et al. 2015).

With the exception of soft-bottom nearshore areas that support eelgrass beds, soft bottom benthic habitats were not included in the HEM for ESPB for a number of technical and logistical reasons. Benthic soft-bottom substrates (i.e., sand and mud) predominate in an overwhelming percentage of the marine area along the SCB (Ambrose 1994; Schiff et al. 2000), including east San Pedro Bay. Soft-bottom habitat is considered the most extensive benthic habitat, particularly on the mainland shelf, slopes, and basins off the southern California coast. Soft-bottom habitat consists of sandy and muddy sediments with much less relief than hard bottom habitat. Thus, conversion of habitat from soft-bottom to hard-bottom habitats (e.g., rocky reefs, kelp forests) on the scale proposed under the Project would not significantly reduce the total available soft-bottom habitat to those species that rely on it. For example, relative to the predominant expanses of soft-bottom and other types of hard-bottom habitats in the southern California marine environment, kelp forests are relatively rare, with an average total of approximately 88 square kilometers (34 square miles) of canopy coverage in the SCB, including the Northern and Southern Channel Islands (Murray and Bray 1993). This coverage constitutes approximately 0.1 percent of the 78,000-square-kilometer (30,116-square-mile) area of the SCB (Dailey et al. 1993). Furthermore, increasing the extent of kelp beds along the southern California coast would provide conditions that favor the production of water column feeding fishes that are less likely to feed from contaminated benthic (sediment) communities and may therefore be less likely to accumulate contaminants.

Although soft-bottom substrates support a diversity of marine life, current habitat conditions in the Proposed Project Area of ESPB are characterized by a general lack of hard (or rocky) substrate conditions to support specific marine communities, such as kelp forests and rocky reef communities, to the extent that they once occurred in the SCB. In a study that ranked the value of various marine habitats found within the SCB base on fish guilds, kelp beds, shallow artificial reefs, and wetlands were all ranked higher than the five soft-substrate habitats evaluated in the study in terms of fish species diversity (Bond et al. 1999). In addition to the greatly enhanced habitat values exhibited on some hard substrates, there was also a decrease in habitat value with increased depth over soft bottom substrates. Subtidal sand-bottom environments are also economically important to nearshore fisheries, which trawl for white croaker, and various flatfish. Because of their low productivity, subtidal soft-bottom communities are often considered to be less important than more productive rocky reef environments, which promote increased species richness and biological productivity (NOAA 2017).

The ability to effectively measure restoration success for soft-bottom habitats was also a factor for why these habitats were not included in the HEM. The particle (grain) size of soft sediments in the Study Area vary naturally due to local conditions. For example, grain size co-varies naturally with depth on the mainland shelf of the SCB, and as a result, soft-bottom marine communities are often defined by depth (Bergen et al. 1999; Jones 1969), making it difficult to determine a specific and/or meaningful optimum input for the model parameter. Furthermore, the soft bottom habitats of the Bay has been extensively modified by human activities. Coastal structures (harbor entrances, river mouth jetties) have been built. Construction and maintenance dredging has been performed in bay entrances, navigation channels, turning basins, marinas, and river channels. The beaches are extensively used, and many have been nourished for decades by the addition of sediment obtained from dredging navigation projects, from offshore "dredge pits" (also called "offshore borrow pits"). Because of the abundance of borrow pits within the Study Area and the fact that these areas tend to be located in areas used extensively by commercial shipping navigation, a management decision was made to exclude all borrow pits from the habitat analysis. Because the borrow pits areas would be excluded, the HEM would not be applicable to any large depressions naturally occurring within the ocean floor. For these reasons, soft bottom habitats were not factored into the habitat model.

3.2 HABITAT CONVERSION AND RESTORATION TRADE-OFFS

Ecological restoration is not a substitute for conservation of ecosystems, but where ecosystems are already heavily degraded, it may be a necessary or even a more efficient strategy. Natural recovery is preferred in the absence of major environmental stressors, but in systems where the major stressor(s) cannot be removed or significantly reduced, restoration interventions should be considered and implemented as essential components of ecosystem management. Although the process of restoring a single species or particular ecosystem function(s) can be accomplished, it may come at the cost of other ecosystem elements. Understanding these trade-offs can helping guide restoration efforts (Abelson et al. 2016).

For example, it is recognized that bottom disturbance via placement or construction of artificial structures is a potential stressor of concern across several subtidal habitats in San Pedro Bay. Although the value of soft-bottom sediments are clearly recognized and efforts to preserve and protect these habitats should be encouraged wherever appropriate, protection goals for this habitat (by far the most abundant subtidal habitat type in San Pedro Bay; see Table 3-1 in the IFR: Change in Habitat/Resource Type by Alternative) should not limit restoration efforts for more desirable complex habitats (e.g., eelgrass, rocky reefs) that seek to increase biodiversity. Due to the sheer abundance of soft-bottom sediments within the project area (but correspondingly fewer sustainable opportunities to actually restore it), replacement or conversion of soft-bottom to other habitat types at suitable locations is a valid restoration strategy.

In cases where improved ecosystem services for an area are a key goal of the restoration, but extreme abiotic changes to the system have occurred as associated ecosystem services have been lost (as in the case of San Pedro Bay), changing of the structure and/or function to reverse this decline and form a healthier ecosystem (e.g., changing the substratum type or sediment grain size), even if it differs from what historically existed prior to human interference, would enable the renewal of ecosystem services in the form of a “target-designed novel ecosystem” that achieve multiple outcomes that meet multiple restoration objectives (Abelson et al. 2016).

3.3 HABITAT TYPES TARGETED FOR RESTORATION

Current habitat conditions in the proposed project area of ESPB are characterized by a general lack appropriate substrate conditions (e.g., gently sloping topography in the intertidal zone, areas of protected shallow water, hard and/or rocky surfaces) to support marine communities, such as kelp forests, eelgrass beds, and rocky reef species to the extent that they once occurred in the SCB. These important coastal biogenic habitats (e.g. tidal salt marshes, rocky reefs, seagrass beds, and kelp beds) occur in close proximity to densely populated coastal regions and as such are among some of the most heavily used and impacted environments on earth (Weslawski et al. 2004; Lotze et al 2006). Rocky reefs kelp forests, seagrass, and estuaries are also all currently considered Habitats of Particular Concern (HAPC), a discreet subset of Essential Fish Habitat (EFH) by the U.S. Regional Fishery Management

Councils (http://www.fisherycouncils.org). HAPCs provide important ecological functions and/or are especially vulnerable to degradation. Intertidal habitats such as wetlands and transitional habitats such as sandy shore are also under extreme threat and limited in the region.

For these reasons, restoration alternatives (or plans) were developed for six target habitat types: (1) subtidal rocky reef, (2) kelp forest, (3) eelgrass beds, (4) oyster beds, (5) coastal wetland, and (6) emergent sandy islands, comprising a range of intertidal and subtidal habitats. Restoration goals focused on creating more area of these habitats and/or the conditions to facilitate their establishment) within the bay. Each target habitat type is discussed in turn below, with rationale for sizing of restoration features and the species associated with each habitat type. Species lists are not intended to be exhaustive, but provide example ecological endpoints and a measure of functional equivalency for the habitat type to be restored. A companion habitat species matrix is also included by habitat type (Table 1). The species listed in Table 1 generally correspond to those listed in the appendix narrative. The goal was to focus on species both indicative of the habitat to be restored, as well as those that play a key ecological role or function for the habitat type. In addition, a classification cross walk between ESPB habitat types and other classification systems (e.g., Cowardin 1979) is found in Table 2.

3.3.1 TARGET HABITAT: SUBTIDAL ROCKY REEF

Rocky reef habitats are comprised of rock outcrops (e.g. granite, limestone, basalt) of varying relief. Rocky habitat encompasses boulders to bedrock i.e., rock that is large enough so as not to be normally moved by currents. Rocky reefs can take a variety of forms, each of which can support a different associated biological community. Southern California rocky reefs are among some of the most diverse and productive marine ecosystems in the world. Rocky reefs can support giant kelp forests, providing food, shelter, and nursery grounds for many marine species. Artificial structures, including jetties, breakwaters, and rip-rap can also support rocky reef communities (MBC Applied Environmental Sciences 1988).

Rocky reefs can be located in the *rocky intertidal zone* where they are intermittently exposed or in the *rocky subtidal zone* where they are always submerged. Distinct tidal zonation is observed, with increasing numbers of species with increasing depth (Pondella et al. 2011). Subtidal rocky reefs**,** although completely submerged even at low tide, still receive enough light for photosynthesis. They are inhabited by algae, invertebrates, and groundfishes. Perennially submerged rock outcrops in the nearshore zone provide important refuges for juvenile and smaller fishes in addition to surface area for colonization of algae and invertebrates. Rocky reefs in deeper water that do not receive enough light for photosynthesis and are dominated by sessile invertebrates and groundfishes. Most rocky reefs, regardless of the zone in which they are located, are beneficial because of the physical structure they provide to support some aspect of the marine ecosystem.

Shoals are underwater ridges, banks, or bars consisting of, or covered by, sand or other unconsolidated material, resulting in shallower water depths than surrounding areas. The term *shoal complex* refers to two or more shoals (and includes adjacent morphologies, such as troughs separating shoals) that are interconnected by past and or present sedimentary and hydrodynamic processes. Although shoals are typically composed of sand, they could be composed of any granular matter that the moving water has access to and is capable of shifting around (for example, soil, silt, gravel, cobble, or even boulders). The grain size of the material comprising a shoal is related to the size of the waves or the strength of the currents moving the material, but the availability of material to be worked by waves and currents is also important (Rutecki et al. 2014).

Reef-associated fish species have been documented on shoals and shoal complexes adjacent to or containing hard-bottom substrate (reef patches, oyster reefs, and rock outcroppings) in the South Atlantic and Florida Straits, indicating that the hard-bottom features influence the local shoal fish assemblage and increase species diversity in these shoal areas (SAFMC 1998, Zarillo et al. 2009).

3.3.1.1 RATIONALE FOR ROCKY REEF FORM AND SIZING

Any target for an optimum or minimum size for a rocky reef or rocky reef complex, in terms of restoration, would vary by individual species needs. Ambrose and Swarbrick (1989) suggest that a large, complex reef (i.e., 50 ha or larger) constructed from a natural substrate, such as quarry rock, could furnish many different habitat and microhabitat types. Placed in an appropriate location, it could support a rich assemblage of algae and associated invertebrates, thereby providing food for a number of fish species.

Giant kelp (*Macrocystis pyrifera*) was the dominant biogenic habitat structure on almost all reefs surveyed for Pondella et al. (2011). A kelp bed with a canopy size of at least five acres would be likely to persist during extended periods of unfavorable conditions (e.g., El Niño events). However, both patch size and patch isolation play into probability of extinction (Schiel and Foster 2015). Giant kelp has relatively short spore dispersal distance(s), so more isolated patches may not rebound following disturbance.

However, smaller sized reefs have been shown to support a greater fish density while larger reefs have higher biomass density from larger, but fewer, individuals (Bohnsack et al. 1994). Multiple small reefs support more individuals and more species than one large reef of equal material. Fishes recruited by larval settlement accounted for 36% of the total resident abundance but only 2% of total biomass. As reef size increased, older juvenile or adult colonists comprised a greater percentage of total biomass (94% to 99%).

Smaller reefs may also be better for overall species recruitment to the reef. There was a significant decline in mean total biomass of larval settlers as reef size increased (Bohnsack et al. 1994). This is evidence that mortality of larval settlers is higher on larger reefs due to increased competition and predation from larger resident populations and larger individual fishes.

Several small reefs have greater edge effect in that they offer more ecotone habitat based on a higher ratio of perimeter to reef area. Additionally, dispersing fauna may have a better chance of locating several small reefs than one large reef (Bohnsack 1991). Further, because small reefs have higher fish density, they could support more species by chance (MacArthur and Wilson 1967).

3.3.1.2 SPECIES ASSOCIATED WITH ROCKY REEF HABITATS

In terms of fish, kelp bass, barred sand bass, and spotted bay bass inhabit both kelp-dominated or non-kelp, rocky reef systems (D. Pondella, pers. comm.). In the Port of Long Beach and environs, all three species frequently co-occur. Other common species for both habitats include garibaldi, California sheephead, rock wrasse, black perch, blacksmith, and senorita. The following species are suggested as representative for the non-kelp rocky reef ecosystem overall. However, given the relatively shallow depths at which habitat restoration activities will occur within San Pedro Bay, rocky reefs that support giant kelp and those that do not support giant kelp are expected to support a similar mix of species (D. Pondella, pers. comm.).

Invertebrates:

- California spiny lobster (*Panulirus interruptus*): The California spiny lobster an important coastal nearshore predator that regulates the population of several key invertebrate species such as purple urchins and the mussel species *Mytilus californianus*. They also act as hosts to other marine organisms, such as sponges, hydroids, barnacles, serpulida, krill-like amphipods and nemertean (*Carcinonemertes wickhami*) (Eminike, et al. 1990; Lafferty 2004; Lindberg 1955). The species is highly sought in both commercial and recreational fisheries (Barsky 2001).

- Abalone (*Haliotis spp.*): Abalones are marine gastropod mollusks that live on intertidal and subtidal rocky substrate. Depending on the species, this habitat may include bare rock, surf grass, kelp forest, or deep, sub-canopy-forming kelps. Biological interactions include competition within and among species, predator/prey interactions, disease, and parasite/host interactions. Ocean conditions have been found to shape the dynamics that influence abalone populations (Dayton and Tegner 1984). Kelp forest community dynamics for some abalones are further confounded by human activities such as fishing (Tegner and Dayton 2000) and pollution. Subtidal abalone are typically closely associated with the kelp species that provide food and shelter. Factors that impact kelp abundance may in turn also affect abalone populations.

- California mussel (*Mytilus californianus*): Mussel beds play several important roles within marine ecosystems. Mussels are filter feeders. They draw in large amounts of seawater to trap phytoplankton, their food source. One mussel can filter 2-3 liters/hour (up to 350 liters of seawater daily) – equivalent to three full bathtubs. As the mussels filter the water, they also remove sediments and other substances that make the water murky.

Mussel beds provide a habitat for other marine organisms, such as juvenile fish invertebrates and*. For example, M. californianus* beds provide structural habitat used by many small crustaceans and other invertebrates and fish (Paine and Suchanek 1983). The shared biogeochemical functions of water clarification and bio-deposition make all suspension-feeding bivalves a valued provider of ecological services to shallow-water ecosystems (Grabowski and Peterson 2007). Because mussels are mussels are declining in abundance throughout their range, the group good intertidal species, they may be a good intertidal candidate species for investigating the effect of climate change impacts on marine species (D. Pondella, pers. comm.).

Fish: In general, fish species diversity has been shown to provide a central linkage in the analysis of marine food webs, which suggests that fish diversity is reasonable and cost-effective indicator of habitat value across a wide range of marine habitats.

- Blacksmith (*Chromis punctipinnis*): In rocky reef habitats, blacksmith can transport substantial amounts of nutrients from their feeding areas (seagrass beds or open water) to their resting areas in the reef in the form of fecal products (Meyer et al. 1983). Bray et al. (1981) calculated that blacksmith feces contribute an average of 23 mg and a maximum of 60 mg of carbon per square meter per night to smaller crevices in the reef. Geesey et al. (1984) showed that migrating blacksmith contribute to an input of phosphorus and trace minerals to crevices in reefs and other rocky areas.

- Barred sand bass (*Paralabrax nebulifer)*: Due to their abundance, barred sand bass play a significant role in the energetic balance and the structural progression of the marine environment, especially for estuaries and harbors (Allen et al. 1995). Like other serranids, the species has a high economic importance in nearshore and recreational fisheries of southern California and Ensenada, B.C., Mexico (Hammann and Rosales-Casiin 1990; Rodriguez-Medrano 1993).

3.3.2 TARGET HABITAT: KELP BEDS

Kelps are large brown seaweeds (macroalgae) associated with colder waters of the Northern Hemisphere. Kelp beds are complex, 3-dimensional marine habitats which can support over 700 described or known species, encompassing marine mammals, birds, fishes, and invertebrates (Graham 2004). Kelp forests are important to the physical and biological processes of nearshore environments. They add structural complexity to the water column and provide food, substrate, and shelter for a variety of vertebrate and invertebrate species (Quast 1968; Leighton 1971; Wing and Clendenning 1971; Edwards 1980; Harrold and Pearse 1987; Duggins et al. 1989). Due to their large size, kelps can physically alter and reduce currents and waves (Foster and Schiel 1985; Koehl and Alberte 1988), decrease light intensity (Pearse and Hines 1979; Reed and Foster 1984) and increase sedimentation (Eckman et al. 1989).

Because almost all kelp forests occur on hard substrata (North 1971), the distribution of kelp and other surface-canopy-forming macroalgae is partially dependent on the extent of available hard substratum for suitable attachment and growth (Dayton and Oliver 1985). Kelp attached to hard-bottom substrate provide vertical structure of the habitat to the sea surface. This increases the complexity of the habitat, with tangled holdfasts at the bottom, columns of kelp stipes in midwater, and a dense canopy of kelp blades at the surface. For many invertebrates, this substrate also provides a source of food. Kelp beds are typically found at depths shallower than 100 feet, being limited by light penetration (Quast 1968).

Along the southern California coast, giant kelp (*Macrocystis pyrifera*) is the largest species colonizing rocky (less frequently sandy) subtidal habitats and has the highest productivity and biomass per square meter of all the kelps. Beds of giant kelp represent one of the most diverse, productive, and dynamic ecosystems in southern California (Mann 1973; Dayton 1985; Barnes and Hughes 1988; Graham 2004), with over 200 species of algae, invertebrates, fishes, and mammals are known to inhabit giant kelp beds (North 1971; Foster and Schiel 1985). Kelp beds are patchily distributed along the southern California coast, with large beds in the Santa Barbara area, on the Palos Verdes Shelf, near Point Loma, and on the Channel Islands (CSWQCB 1964). Unlike hard-bottom habitats such as rocky reefs, the distribution and extent of giant kelp beds changes more readily, as kelps are dislodged by storm swells or die off during periods of low nutrients (Stull 1995).

Giant kelp is a very important component of coastal and island communities in southern California, providing food and habitat for numerous animals (North 1971; Foster and Schiel 1985; Dayton 1985). Giant kelp is known as a biological facilitator (*sensu* Bruno and Bertness 2001), where its three-dimensional structure and the complexity of its holdfast provides substrate, refuge, reduction of physical stress, and a food source for many fish (Carr 1989) and invertebrates grazers (Duggins et al. 1990). Stands of kelp can also affect flow characteristics in the nearshore zone, thus enhancing recruitment (Duggins et al. 1990), which further acts to increase animal biomass in the vicinity. For these reasons, giant kelp is also of great importance to sport and commercial fisheries. Drift kelp (wrack) and associated dissolved organic matter also provide an energetic resource to populations of species both within and around kelp beds (Harrold and Reed 1985; Duggins et al. 1989; Tegner and Dayton 2000; Graham et al. 2007). Water birds commonly use kelps to line their nests.

Kelps forests provide a variety of commercial and ecosystem services to people. An example of this is the harvesting of kelp for algin, a product used as a gelling agent in foods, pharmaceuticals, and water and fireproofing fabrics. The presence of the habitat itself also provides important ecosystem services. Ocean currents are slowed by drag from the large kelps. Creating a calmer habitat, this current reduction also decreases wave action onshore. By altering the waves, kelp forests reduce erosion, decreasing expensive property protections or replacement. Many outdoor enthusiasts dive or kayak among kelp forests providing important recreational and tourism benefits. Kelp is also an important habitat for a number of recreationally and commercially important fishery species (NOAA 2019).

3.3.2.1 RATIONALE FOR KELP BED SIZING

No standard sizing guidelines are available for kelp bed restoration. Five acres was used as the minimum size by for a giant kelp restoration project conducted in Laguna Beach, California (MBC Aquatic Sciences, pers. comm.). Because this project developed from an interest in the protection and preservation of giant kelp communities in the Southern California Bight, it is an appropriate regional example for the Project in ESPB. A kelp bed with a canopy size of at least five acres would be likely to persist during extended periods of unfavorable conditions (e.g., El Niño events). However, both patch size and patch isolation play into probability of extinction (Schiel and Foster 2015). Giant kelp has relatively short spore dispersal distance(s), so more isolated patches may not rebound following disturbance.

3.3.2.2 SPECIES ASSSOCATED WITH KELP BEDS

- <u>California spiny lobster</u> (see associated information for Rocky Reef)
- <u>Sea urchins</u>: Sea urchins are typically spiny, globular animals, echinoderms. As a group, they are central in structuring marine benthic communities, both as grazers and prey, and are economically valuable in fisheries. Their grazing limits algal biomass, and they are preyed upon by many predators (Pearce 2006).

- Giant kelp bass (*Paralabrax clathratus*): Giant kelp bass are a recreationally and commercially important fish species associated with kelp beds.

- Garibaldi (*Hypsypops rubicundus)*: Garbaldi was the designated as the official marine fish of California in 1995

3.3.3 TARGET HABITAT: EELGRASS

Submerged aquatic vegetation (SAV), including seagrasses, constitute a critical habitat in nearshore ecosystems, serving as a nursery ground for many fishes and invertebrates and providing numerous ecosystem services, including sediment stabilization, filtration of pollutants, and carbon storage (Larkum et al. 2006). The term "SAV" refers collectively to all species of underwater flowering plants. In the Proposed Project Area of ESPB, SAV includes sago pondweed (*Stuckenia pectinata*, formerly *Potamogeton pectinatus*), eelgrass (*Zostera marina L.*), and other species of seagrass, including the surfgrasses (*Phyllospadix torreyi* and *P. scouleri),* and widgeongrass (*Ruppia maritima*). However, because eelgrass is much more extensive than other SAV within the project area, its role and restoration potential are understood better than for other SAV.

Eelgrass is a community structuring plant that forms highly productive beds in both subtidal and intertidal habitats in shallow coastal bays and estuaries, as well as within semi-protected shallow soft bottom environments of the open coast. It is the most common species of seagrass occurring in the embayments of the SCB (Dailey et al. 1993), and functions as important nursery habitats for a diverse variety of organisms (Beck et al. 2001), including economically important fishes and invertebrates in southern California (Allen et al. 2002; Hoffman 1986).

It is possible that the construction of rock shoals within the nearshore zone may impact the availability of existing eelgrass associated with sandy bottom within nearshore areas of the project area. These areas can serve as spawning areas for market squid (*Loligo opalescens*), an important commercial species in California. In addition, sheltered, shallow soft-bottom areas in certain locations (e.g., inside the Los Angeles and Long Beach Harbor breakwaters) provide important nursery areas for several fish species, including California halibut.

In order to avoid and minimize these undesired effects, specific locations of each constructed reef, including nearshore shoal placement, will be studied during the Preliminary Engineering and Design (PED) phase of the project and selected such that limited natural habitats, like existing eelgrass beds, are not directly covered or compromised by project activities. Because of the inter- and intra-annual variation in the spatial extent of existing eelgrass, any analyses and modeling will need to be updated to reflect most current conditions so that the placement and construction of nearshore shoals has minimal (if any) impact to existing resources.

3.3.3.1 RATIONALE FOR EELGRASS BED FORM AND SIZING

Recommendations for specific targets for eelgrass restoration base on size (acreage) are lacking in the literature. Several studies have identified important considerations predictive to eelgrass transplant success, but sizing (area) was not included. Generally, substrate, temperature, salinity, nutrients, wave energy, depth and light are key considerations, rather than targets based on size alone.

It is uncertain if there is any relationship between the size or shape of a seagrass bed and its functional attributes; this is true for both planted beds and natural beds (Fonseca 1998). This is an area of study needing much additional work. However, in regard to functional success, even small patches (1-2 m^2) demonstrate higher diversity of larger invertebrates than un-vegetated areas. Thom (2001) suggests that larger scale restoration projects have more of a chance to be successful. In general, both transplant size and success increased with time, but there is no indication that size increase is the reason for improvement.

From a monitoring perspective alone, Bernstein et al (2011) suggest that eelgrass habitats of 20 m or more contribute significantly to the overall regional estimates of extent of the resource. South of Point Conception, eelgrass grows primarily in subtidal habitat and the 20-acre minimum size criterion removes systems with marginal, ephemeral, and/or small amounts of habitat that do not contribute significantly to the overall regional estimate of extent. However, there is no scientifically consistent method for applying the 20-acre criterion as a restoration target for sizing eelgrass beds.

Canopy height of eelgrass shoots provides an estimate of the three-dimensional complexity of the habitat and, thus, may be a functional attribute of habitat utilization. Evans and Short (2005) found this to be a useful metric for estimating habitat use. It also seems to be increasingly used in eelgrass monitoring programs (Duarte and Kirkman 2001).

Density of eel grass turions with a patch may also be a more informative restoration target than patch area. Bernstein et al. (2011) suggest that a minimum density of 100 eelgrass turions/m^2 may be a sufficient to maintain survival and reproductive needs of obligate and transient marine species by facilitating creation of conditions conducive to the recruitment of eelgrass propagules and growth of new eelgrass habitat over time (Bernstein et al. 2011).

3.3.3.2 SPECIES ASSOCIATED WITH EELGRASS

Bay Pipefish (*Syngnathus leptorhynchus):* Bay pipefish have been used as an indicator species for monitoring eelgrass habitats because of the species dependency on these habitats and its important role in the biomass (as a common resident) and functional ecology (as an important role in the production of organic detritus) of eelgrass beds (Fritzsche 1980; de Graaf 2006).

Bay pipefish and black surfperch were shown to have a greater association with eelgrass habitat, and epibenthic invertebrate assemblages begin to differentiate between the eelgrass and oyster reef habitats. Eelgrass presence increased the occurrence of certain fish species among oyster reef structures (bay pipefish, shiner surfperch, and saddleback gunnel), suggesting that restoring the two habitats in proximity to each other can increase the richness of species present (Boyer et al. 2017).

3.3.4 TARGET HABITAT: OYSTER REEFS

Oysters live in salty or brackish waters on all U.S. coasts, clustering on older shells, rock, piers, or any hard, submerged surface. They fuse together as they grow, forming colonial communities of dense aggregations of rock-like "reefs". Oyster reefs can provide numerous beneficial biogeochemical functions and ecosystem services, such as filtering particles, including phytoplankton, particulate organic matter, inorganic particles, and planktonic larvae of some marine invertebrates, from the water column and discharging bio-deposits. Filtering is a process that removes phytoplankton and biotic and abiotic particulates from suspension, clarifies the water column, transfers organic- and nutrient-rich particulates to the bottom, and may reduce settlement of some native marine invertebrates, and (Dame 1996; Newell 2004; Dumbauld et al. 2009).

Not all species of oysters are true reef builders. Pacific oysters (*Crassostrea gigas*), also known as Japanese Miyagi oysters, build structural reefs that project up into the water column in areas otherwise characterized by relatively flat sedimentary bottom, providing important habitat for other organisms (Coen et al. 2007; Grabowski and Peterson 2007). However, this habitat provisioning service is less pronounced in non-reef forming bivalves, such as the Olympia oyster (*Ostrea lurida*), the species native to the U.S. West Coast (including San Pedro Bay). The Olympia oyster is relatively small and usually is found attached to rocks or dead shells. Beds formed by this native species of oyster are not nearly as large or extensive as those formed by the Eastern oyster (*Crassostrea* virginica). In general, the Olympia oyster is no longer found anywhere in abundance within its historical range and oyster reefs in the classical sense do not exist on the West Coast as they do along the East and Gulf Coasts of the United States. Currently, Pacific oysters are the species representing the bulk of the mollusk biomass in the Bay. This species was introduced to California as a result of importation for cultivation (MBC 2016).

Pinnix et al. (2005) found that fish abundance was significantly greater in oyster culture habitats compared to eelgrass and mudflat habitats in Humboldt Bay, California. However, there was no difference in abundance between eelgrass and mudflat habitats. This suggests that oyster culture operations may attract a larger number of fish compared to eelgrass and mudflat habitats. It is well established that fish are attracted to structure and the greater abundance in the culture areas may be due to the increased structure in the water column that the culture provides.

3.3.4.1 RATIONALE FOR OYSTER REEF SIZING, STRUCTURE, AND PLACEMENT

Two "universal metrics," density and size frequency distribution, are recommended for oyster restoration monitoring oyster (Baggett et al. 2004). The density of adult oysters at a site can serve as a cumulative indicator of its appropriateness for conservation or restoration. Moderate to high adult densities result from one or more years of significant recruitment and survival. Densities in Newport Bay and San Diego Bay generally average 592/ft^2 and 2357/m^2, respectively (Wasson et al. 2015).

In terms of specific restoration target densities for oysters, adult density per square foot of hard substrate may not represent density at larger scales (e.g., acres), because there is very limited hard substrate. A site that has a million oysters within an acre should have greater conservation value than a site that has a thousand oysters per acre, and far greater than one that has ten oysters per acre, even if all those sites have the same density per square foot. Therefore, it is important to establish where to draw the line around a site of interest and whether or not to include the full tidal range encompassing all colonized hard substrate (Wasson et al. 2015). An order-of-magnitude estimate of the total number of oysters living at a site may serve as a good initial indicator of the site's relative conservation value.

Current smaller-scale restoration projects in southern California have ranged from deploying small structures to assess recruitment patterns and best methods, to larger-scale mixed-species restoration projects with both physical and biological objectives in a "living shorelines" model.

3.3.4.2 SPECIES ASSOCIATED WITH OYSTER BEDS

Olympia oysters, the species native to the Proposed Project Area, are primarily estuarine and generally not found on the open coast (Baker 1995). The species' natural habitat includes rocks in areas near the expanse of the low tide, and mudflats and gravel bars in estuaries and bays (Nosho 1989). In southern California, they are most abundant around the -0.3 m tide mark (Wasson et al. 2015), Mean Lower Low Water (MLLW), but have been reported from as high as 1 m above MLLW to depths of 10 m (Baker 1995). They require hard substrate on which to settle. Although Olympia oysters tolerate a range of salinity levels, low salinity exposure can reduce reproduction (Oates 2013), and cause death in severe cases (Gibson 1974). Cheng et al. (2015) found that juvenile Olympia oysters suffered significant mortality when exposed to salinity levels below 10 for five or more days. Thresholds may show local adaptation and vary across regions.

Oyster reefs in general create important habitat for hundreds of other marine species. Species like mussels, barnacles, and sea anemones settle on them, creating abundant food sources for commercially valuable fish species. Oyster reefs provide habitat to forage fish, invertebrates, and other shellfish. They also provide a safe nursery for commercially valuable fish and invertebrate species

3.3.5 TARGET HABITAT: COASTAL WETLANDS

Among coastal ecosystems, coastal wetlands are considered some of the most productive ecosystems on Earth. Coastal wetlands include saltwater and freshwater wetlands located in coastal zones that are influenced by fluctuating water levels. Wetlands provide a high number of valuable benefits to humans, including raw materials and food, coastal and shoreline protection, erosion control, water purification, maintenance of natural communities of plants, animals, and fisheries, and carbon sequestration. Wetlands also provide other vital ecosystem services that have not always been appreciated by humans. Wetlands help regulate climate, store surface water, control flooding, replenish aquifers, promote nutrient cycling, serve as critical nursery areas for fisheries, and provide opportunities for education, recreation, and tourism. No wetland provides all these services, and the level of any service varies among wetlands. The location of a wetland, its size, shape, source of water, ecological characteristics, and how it is managed determine the kinds and levels of service it can provide.

Estuarine wetlands are distinguished from non-saline estuarine wetlands (i.e., brackish or freshwater estuarine wetlands), by the obvious dominance of salt-tolerant species of emergent vascular vegetation, such as cordgrass (*Spartina* spp.), pickleweed (*Sarcocornia* spp.), and salt grass (*Distichlis* spp.) along the foreshore of the wetland and along the immediate banks of the larger tidal channels that tend to dewater at low tide. Non-saline wetlands tend to be dominated by species that don't tolerate high salinities, such as cattails (*Typha* spp.), rushes (*Schoenoplectus* species*),* and willows (*Salix* spp.)

A coastal estuarine wetland consists of the vegetated marsh plain, its pannes, potholes, hummocks, and other habitat elements of the plain, as well as the natural levees, shell beds, submerged plant beds, and other habitat elements created or supported by tidal processes and associated with tidal channels (CWMW 2014). Estuarine wetland ecosystems provide important habitat linkages between marine, aquatic and terrestrial ecosystems. Linkages between aquatic and terrestrial habitats allow wetland-dependent species to move between habitats to complete life cycle requirements. For estuarine wetlands, the function of upland transitions as refuge for intertidal wildlife during extreme high tides is especially important. The entrained canopies of estuarine wetland vegetation entrap debris including coarse plant litter that is lifted into the canopies by rising tides. As the tide goes out, the material is left hanging in the plant cover. Over time, these entrained canopies can gain enough density and thickness to provide important shelter for many species of birds and small mammals that inhabit estuarine wetlands. Most passerine birds and rails that nest in estuarine wetlands choose to nest below an entrained canopy because it protects them from avian predators, including owls and raptors such as northern harriers.

3.3.5.1 RATIONALE FOR WETLAND SIZING, STRUCTURE, AND PLACEMENT

No generalized recommendations for the sizing of constructed wetlands exist. PWA and Faber (2004) offer several design considerations for wetlands when planning, including specific suggestions based on the size of channels and intertidal buffers. They also offer specific designs to support wetland invertebrates, fish and birds. Callaway and Simenstad (2015) offer recommendations to improve success in wetland restoration and creation, but no restoration sizing guidelines were provided.

3.3.5.2 SPECIES ASSOCIATED WITH COASTAL WETLANDS

California killifish (*F. parvipinnis*): The California killifish (*F. parvipinnis*) is a common and abundant shallow-water species in southern California estuaries (Horn and Allen 1985) and a key component of the estuarine food web (Kwak and Zedler 1997). For example, F. parvipinnis are key consumers of invertebrate prey and an important link in the transfer of energy between intertidal and subtidal areas (Kwak and Zedler 1997; Johnson 1999). Killifish are also important in the diet of piscivorous birds, which are highly valued by the bird- watching public.

Arrow goby: Although little quantitative data are available to establish the importance of gobies in bay-estuarine trophic structures, their sheer abundance indicates that they would have significant position in the food web (Brothers 1975). Gobies make available the high production of eelgrass (*Zostera marina*), green algae (e.g., *Ulva* sp.), diatoms, and marsh plants to higher level carnivores. By consuming large numbers of small crustaceans and worms that directly or indirectly feed on plants or plant detritus, gobies serve to channel substantial amounts of energy to the large predators in the ecosystem. Goby larvae may be equally important in the planktonic segment of bay-estuarine food webs (Horn 1980).

3.3.6 TARGET HABITAT: SANDY ISLANDS

Exposed sandy beaches, whether associated with shores or emergent islands, provide an important transitional habitat between land and sea. Sandy beach and adjacent surf zone ecosystems are important foraging areas for wildlife and fishes, accumulate sand that can buffer the impacts of storms, filter vast volumes of seawater delivered by waves and tides, process large quantities of organic detritus and contribute to nearshore nutrient cycling, and harbor unique and endemic biodiversity. The amount of wrack and plankton cast onto sandy beaches is dynamically linked to adjacent ecosystem features, ocean climate and the population dynamics of intertidal invertebrates. However, despite their ecological importance and connectivity with other marine ecosystems, sandy beach ecosystems are not as well studied as other ecosystem features and are often overlooked in coastal conservation efforts (Dugan et al. 2010).

Coastal protection is arguably one of the most valuable services provided by sand shore ecosystems especially in the face of extreme storms, tsunamis, and sea level rise. As waves reach the shoreline they are attenuated by the beach slope and, at high tide, also by the foredune, a structure immediately behind the beach where sand accumulates in hills or ridges parallel to the shoreline. Beaches vary in their ability to attenuate waves depending on a continuum in their morphology (Carter 1991; Hesp and Short 1999; Short 1999). Coastal dunes can provide maintenance of wildlife in the form of habitat for fish, shellfish, birds, rodents, and ungulates, which have been captured or cultivated for food since humans first colonized the coast (Carter 1990; Pye and Tsoar 1990).

In the past 20 years it has become increasingly apparent that small emergent sandy islands are important to the conservation of a diverse group of nesting waterbirds. More than 30 species of colonial waterbirds and shorebirds, including gulls, terns, skimmers, herons, and egrets, depend heavily on both natural and man-made islands for nesting; this has been documented in the Great Lakes (Scharf 1978), the Gulf Coast from Texas to Florida (Landin and Soots 1978), along the Atlantic Coast from New York and New Jersey (Burger and Lesser 1978; Burger and Gochfeld 1990, 1991) to Virginia (Erwin 1979, 1980).

In southern California, areas of exposed sand on shores or island support diverse and abundant invertebrate macrofaunal communities (Dugan et al. 2000; Dugan, Hubbard et al. 2003). Invertebrate macroinfauna can attain an abundance of >80,000 individuals and biomass of >10 kgm_1 of shoreline on southern California beaches (Dugan et al. 2000, 2003). Such macrofauna may be increasingly important as prey resources for shorebirds, as the function, quality, and availability of coastal wetlands decrease regionally.

Sandy beach ecosystems are strongly linked with other nearshore ecosystems. For example, beach food webs rely largely on subsidies from adjacent ecosystems, thus the amount of wrack and plankton delivered to these food webs is dynamically linked to the features of adjacent ecosystems and nearshore ocean characteristics. The condition of beach ecosystems can in turn affect the reproductive success of fishes and birds that rely on areas of open, sandy habitat.

The connectivity of sandy shore/island habitat with rocky and kelp reefs provides many synergistic relationships that benefit both type of habitats and multiple species habitats. Rocky/kelp reefs provide a wrack source for sandy islands and are nutrient recipients from emergent islands used by shorebirds. Rocky reefs, in turn, provide foraging habitat for piscivorous (fish-eating) birds.

3.3.6.1 RATIONALE FOR SANDY ISLAND, SIZING, STRUCTURE, AND PLACEMENT

Islands between 2 and 10 ha in size are used more often by nesting shore birds than very large or very small islands (Erwin et al. 1995). Larger islands are not used if mammals are able to reach them or when they support a population of nest-predators year-round. Alternatively, very small islands may be unable to support adequate amounts of vegetation for large numbers of birds or may not attract enough birds to form a critical social mass for nesting. Larger islands can support more abundant and diverse populations of wading birds, but creating islands greater than 10 ha is not usually logistically feasible for most created habitats. Therefore, the rule of thumb should be to create as large a colony as possible without compromising other habitat requirements (e.g., set-back distances).

3.3.6.2 SPECIES ASSOCIATED WITH SANDY ISLANDS

Southern California's coastal areas, including its shorelines, estuaries, bays, and harbors, provide several types of habitat for large numbers of shorebirds and wading birds, including the Federally endangered California least tern (*Sterna antillarum browni).* This species utilizes sandy coastal areas for nesting, preferring undisturbed, open sandy/gravelly areas near a lagoon, estuary or bay that are kept free of vegetation by the tide. The California least tern is listed as "endangered" under the federal Endangered Species Act in 1973, and under the California Endangered Species Act in 1984. This species has historically nested within the larger Study Area surrounding ESPB, and known protected nesting sites are located adjacent to the Port of Los Angeles' largest container terminal on Pier 400.

The Federally threatened western snowy plover (*Charadrius nivosu nivosus*) is another shorebird species that has been occasionally observed during migration at the California Least Tern nesting site on Pier 400 (Keane Biological Consulting 2007). A few individuals also have been observed at Point Fermin and Cabrillo Beach outside the breakwater (Ryan et al. 2009).

Shore birds play an important role in mass and energy fluxes across estuarine food webs. Studies have shown that shorebirds can have an important predatory impact on the standing crop of invertebrate populations and remove a substantial proportion of the annual production of benthic macrofauna (e.g., Goss-Custard 1980; Baird and Milne 1981; Smit 1981; Baird et al. 1985). On beaches and other sandy shores, both snowy plover adults and chicks depend largely on prey resources associated with macroalgal wrack making them important species to consider as potential indicators of ecosystem condition and connectivity in baseline evaluations of marine protected areas (Dugan et al. 2015).

4 GLOSSARY

Assemblage: A grouping of species that occur together in a single area, such that they have the reasonable opportunity for daily interaction with each other

Base year: the year when the proposed project is expected to be operational.

Biogenic habitat: Biogenic habitats are habitats created by plants and animals. This may be the organism itself, such as a seagrass meadow or a bed of oysters, or arise from an organism's activities, such as the burrows created by crabs. Biogenic habitat-forming species perform other important roles within the ecosystem (Morrison et al. 2008).

Biotope: A specific area of the habitat that includes recurring, persistent, and predictable biological associations, such as plants, attached sessile fauna, and unattached but relatively non-motile fauna and bacterial colonies (Madden et al. 2005). *Macrocystis pyrifera* in kelp beds and *Zostera marina* in eelgrass beds are examples of biotopes.

Breakwater: A physical structure constructed on coasts as part of coastal management to reduce coastal erosion or to protect a boat/ship anchorage from the effects of both weather and wave intensity. Breakwaters dissipate energy and create relative calm water in their lee side (the side opposite of the windward or seaward side).

Complex habitat- Habitats with complex physical structure in terms of the diversity, size, amount and spatial arrangement of the structural features that are used as a habitat by organisms (Flores et al. 2016). The physical structure of a habitat (e.g., habitat complexity) shapes how species co-exist and interact and thus drive ecosystem processes. The amount and arrangement of habitat structure can affect ecosystem functioning because, over longer time scales, complexity increases the possibilities for niche differentiation (i.e., 'maximizes' species richness and abundance)

Connectivity: The degree to which the movement of water, nutrients and species among habitat patches is facilitated and not impeded by the seascape or other structures.

Demersal: A species that lives on or near the sea bottom for at least part of its life cycle.

Ecological niche: The role an organism plays in its respective community, i.e. decomposer, primary producer, etc.

Ecosystem: A complex or grouping habitats that are influenced by similar hydrologic, geomorphologic, chemical, or biological factors.

Ecotone: A transition area or interface region between two ecosystems where two biological communities meet and integrate. The interface between hard bottom and soft bottom marine communities is an example of an aquatic ecotone.

Estuary: A small semi-enclosed coastal body of water with a free connection with the open sea within which seawater is measurably diluted by freshwater from land drainage. This dilution of seawater must occur for at least one month of the year for the water body to “estuarine” (Josselyn et al. 1993).

Guild (or ecological guild): Any group of species that exploit the same resources, or who exploit different resources in related ways. It is not necessary that the species within a guild occupy the same, or even similar, ecological niche.

Habitat: The physical unit of the environment employed directly by the biota for food, shelter, spawning, and/or refuge (Madden et al. 2005). Descriptive terms of habitat include substrate, energy, composition, and biological association.

Habitat Node: A node is area or patch of habitat associated with a physical location. Nodes can be isolated habitat patches or can be connected to some extent by edges between adjacent nodes. An edge between two nodes implies there is some ecological connectivity or exchange between the nodes, such as via propagule dispersal or material flow.

Hard-bottom species: organisms that are commonly associated with reef or rocky substrata.

Infauna: Bottom-dwelling organisms that burrow into soft substrates that lack secure attachment sites (such as shallow, soft-bottom habitats) to prevent from being washed away by currents.

Intertidal zone: The area that is above water at low tide and under water at high tide (i.e., the area between tide marks). Also known as the foreshore, seashore or littoral zone. Habitats located in the intertidal zone are collectively termed “intertidal habitats”. Intertidal habitats can be characterized as having either hard (e.g. rocky reef) or soft bottom (e.g. eelgrass bed) substrates.

Kelp forest: An underwater ecosystem formed in shallow water characterized by the dense growth of several different species known as kelps. Kelp "anchors" called holdfasts grip onto rocky substrates. From the holdfasts, kelp plants grow toward the water's surface.

Keystone species: A species that exerts a strong influence on the dynamics of other species within an ecosystem. A keystone species is one on which other species in an ecosystem largely depend, such that if it were removed, the ecosystem would change drastically.

Macrohabitat: Spatially large and complex geomorphic, hydromorphic or vegetative structures that support multiple biological associations, and possess homogenous local climate, hydrology, and chemistry (Madden et al. 2005).

Nearshore zone: The area extending from the shoreline to depths generally less than 20 feet (6 m).
Open water zone: The area extending from the seaward edge of nearshore to depths generally greater than 20 feet (6 m).

Residence Time:* The average amount of time during which a volume of water remains within a water body before continuing through its hydrological cycle. The time involved may vary from days for small shallow bays to millions of years for deep underground aquifers with very low values for hydraulic conductivity. Knowing the residence time for a body of water is one way to determine the concentration of pollutants in the water body and how this may affect the local population and marine life. Sometimes discussed in terms of water budget for hydrologic studies.

Rocky reef: A submerged rock outcrop with varying relief, creating refuges for juvenile and smaller fishes in addition to surface area for colonization of algae and invertebrates. A rocky reef can support the growth of kelp, but does not have to include kelp.

Shoal: An underwater ridge, bank, or bar consisting of, or covered by, sand or other unconsolidated material, rising from the bed of a body of water to near the surface.

Shoal or reef complex: Two or more shoals or reefs (and adjacent morphologies, such as troughs) that are interconnected by past and/or present sedimentary and hydrographic processes.

Soft-bottom species: organisms that are commonly associated with sand or mud substrata.

Subtidal zone: The area below the intertidal zone that is continuously covered by water. This zone is much more stable than the intertidal zone. Also known as the sublittoral zone. Habitats located in the subtidal zone are collectively termed "subrtidal habitats". Subtidal habitats can be characterized as having either hard (e.g. rocky reef) or soft bottom (unconsolidated) substrates.

Water-column species: pelagic organisms (typically fish) that feed on prey that is suspended in the water column (e.g., pelagic zooplankton).

Zone: characterizes the vertical zonation (i.e., benthic, water column, and littoral) of coastal and marine regions.

*For the ESPB project, current velocities and salinity concentrations were used in the HEM as a proxy for true residence time. A particle tracking analysis was also conducted to provide insight on how long a typical parcel of water remains within the bay and the path taken that provides a representation of how the system changes due to the structural modifications.

Literature Cited

Abelson, A., Halpern, B.S., Reed, D.C., Orth, R.J., Kendrick, G.A., Beck, M.W., Belmaker, J., Krause, G., Edgar, G.J., Airoldi, L. and Brokovich, E., 2016. Upgrading marine ecosystem restoration using ecological-social concepts. BioScience, 66(2), pp.156-163.

Aguilera, M.A., Broitman, B.R. and Thiel, M., 2014. Spatial variability in community composition on a granite breakwater versus natural rocky shores: lack of microhabitats suppresses intertidal biodiversity. Marine pollution bulletin, 87(1-2), pp.257-268.

Arhonditsis, G.B., Qian, S.S., Stow, C.A., Lamon, E.C. and Reckhow, K.H., 2007. Eutrophication risk assessment using Bayesian calibration of process-based models: application to a mesotrophic lake. ecological modelling, 208(2-4), pp.215-229.

Airoldi, L., Abbiati, M., Beck, M.W., Hawkins, S.J., Jonsson, P.R., Martin, D., Moschella, P.S., Sundelöf, A., Thompson, R.C. and Åberg, P., 2005. An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. Coastal engineering, 52(10-11), pp.1073-1087.

Allen, L.G., Hovey, T.E., Love, M.S. and Smith, J.T., 1995. The life history of the spotted sand bass (*Paralabrax maculatofasciatus*) within the southern California bight. California Cooperative Oceanic Fisheries Investigations Report, pp.193-203.

Allen, L.G., Findlay, A.M. and Phalen, C.M., 2002. Structure and standing stock of the fish assemblages of San Diego Bay, California from 1994 to 1999. Bulletin-Southern California Academy of Sciences, 101(2), pp.49-85.

Ambrose, R.F. and Swarbrick, S.L., 1989. Comparison of fish assemblages on artificial and natural reefs off the coast of southern California. Bulletin of Marine Science, 44(2), pp.718-733.

Baggett, L.P., Powers, S.P., Brumbaugh, R.D., Coen, L.D., DeAngelis, B.M., Greene, J.K., Hancock, B.T., Morlock, S.M., Allen, B.L., Breitburg, D.L. and Bushek, D., 2015. Guidelines for evaluating performance of oyster habitat restoration. Restoration Ecology, 23(6), pp.737-745.

Baird, D. and Milne, H., 1981. Energy flow in the Ythan estuary, Aberdeenshire, Scotland. Estuarine, Coastal and Shelf Science, 13(4), pp.455-472.

Baird, D., Evans, P.R., Milne, H. and Pienkowski, M.W., 1985. Utilization by shorebirds of benthic invertebrate production in intertidal areas. Oceanography and marine biology, 23, pp.573-597.

Baker, P., 1995. Review of ecology and fishery of the Olympia oyster, *Ostrea lurida* with annotated bibliography. Journal of Shellfish Research, 14(2), p.501.

Barnes R. S. K. and Hughes R. N.,1988. An Introduction to Marine Ecology, Blackwell Science, Oxford, Great Britain.

Barsky, K.C., 2001. California spiny lobster. California's Living Marine Resources: A Status Report (eds Leet, W.S., Dewees, C.M., Klingbeil, R. and Larson, E.J.), pp.98-100.

Bay, S., Dojiri, M. and Gully, J., 2015. State of the Bay Report. "Habitat Conditions: Soft-Bottom Benthos." Urban Coast 5(1): 108-115.

Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J. and Orth, R.J., 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: a better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. Bioscience, 51(8), pp.633-641.

Bergen, M., Weisberg, S.B., Smith, R.W., Cadien, D.B., Dalkey, A., Montagne, D.E., Stull, J.K., Velarde, R.G. and Ranasinghe, J.A., 2001. Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. Marine Biology, 138(3), pp.637-647.

Bernstein, B., Merkel, K., Chesney, B. and Sutula, M., 2011. Recommendations for a southern California regional eelgrass monitoring program. Southern California Coastal Water Research Project, 632, p.45.

Bohnsack, J.A., 1991. Habitat structure and the design of artificial reefs. In Habitat Structure (pp. 412-426). Springer, Dordrecht.

Bohnsack, J.A., Harper, D.E., McClellan, D.B. and Hulsbeck, M., 1994. Effects of reef size on colonization and assemblage structure of fishes at artificial reefs off southeastern Florida, USA. Bulletin of Marine Science, 55(2-3), pp.796-823.

Bond, A.B., Stephens, J.S., Pondella, D.J., Allen, J.M. and Helvey, M., 1999. A method for estimating marine habitat values based on fish guilds, with comparisons between sites in the Southern California Bight. Bulletin of Marine Science, 64(2), pp.219-242.

Boyer, K., Zabin, C., De La Cruz, S., Grosholz, E., Orr, M., Lowe, J., Latta, M., Miller, J., Kiriakopolos, S., Pinnell, C. and Kunz, D., 2017. San Francisco Bay Living Shorelines: Restoring Eelgrass and Olympia Oysters for Habitat and Shore Protection. In Living Shorelines (pp.333-362). CRC Press.

Bray, R.N., Miller, A.C. and Geesey, G.G., 1981. The fish connection: a trophic link between planktonic and rocky reef communities? Science, 214(4517), pp.204-205.

Briggs, J.C., 1974. Marine zoogeography.

Brothers, E.B., 1975. The Comparative Ecology and Behavior of Three Sympatric California Gobies. University of California, San Diego.

Brown, C.J., Harborne, A.R., Paris, C.B. and Mumby, P.J., 2016. Uniting paradigms of connectivity in marine ecology. Ecology, 97(9), pp.2447-2457.

Bruno, J.F., Stachowicz, J.J. and Bertness, M.D., 2003. Inclusion of facilitation into ecological theory. Trends in ecology & evolution, 18(3), pp.119-125.

Bulleri, F. and Chapman, M.G., 2010. The introduction of coastal infrastructure as a driver of change in marine environments. Journal of Applied Ecology, 47(1), pp.26-35.

Burger, J. and Gochfeld, M., 1990. Nest site selection in least terns (*Sterna antillarum*) in New Jersey and New York. Colonial Waterbirds, pp.31-40.

Burger, J. and Gochfeld, M., 1991. Human distance and birds: tolerance and response distances of resident and migrant species in India. Environmental Conservation, 18(2), pp.158-165.

Burger, J. and Lesser, F., 1978. Selection of colony sites and nest sites by Common Terns *Sterna hirundo* in Ocean County, New Jersey. Ibis, 120(4), pp.433-449.

California Department of Fish and Wildlife (CDFW; formerly California Department of Fish and Game), 2009. The Western Snowy Plover in Los Angeles County, California. 2008 Annual Report. 56 pp. Available at https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=19493&inline

California Wetland Monitoring Workgroup (CWMW). 2014. Annual Report.

Callaway, J. and Simenstad, C.S., 2015. Improving wetland restoration success. Presentation at Pacific Coastal Wetland Restoration. Mar. 17, 2015.

Carr, M.H., 1989. Effects of macroalgal assemblages on the recruitment of temperate zone reef fishes. Journal of Experimental Marine Biology and Ecology, 126(1), pp.59-76.

Carr, M.H., Neigel, J.E., Estes, J.A., Andelman, S., Warner, R.R. and Largier, J.L., 2003. Comparing marine and terrestrial ecosystems: implications for the design of coastal marine reserves. Ecological Applications, 13(sp1), pp.90-107.

Carter, R., 1991. Near-future sea level impacts on coastal dune landscapes. Landscape Ecology, 6(1), pp.29-39.

Coen, L.D., Brumbaugh, R.D., Bushek, D., Grizzle, R., Luckenbach, M.W., Posey, M.H., Powers, S.P. and Tolley, S.G., 2007. Ecosystem services related to oyster restoration. Marine Ecology Progress Series, 341, pp.303-307.

Coen, L.D. and Luckenbach, M.W., 2000. Developing success criteria and goals for evaluating oyster reef restoration: ecological function or resource exploitation? Ecological engineering, 15(3-4), pp.323-343.

Coombes, M.A., La Marca, E.C., Naylor, L.A. and Thompson, R.C., 2015. Getting into the groove: opportunities to enhance the ecological value of hard coastal infrastructure using fine-scale surface textures. Ecological Engineering, 77, pp.314-323.

Cowardin, L.M., 1979. Classification of wetlands and deepwater habitats of the United States. Fish and Wildlife Service, US Department of the Interior.

California State Water Quality Control Board (CSWQCB), 1964. An Investigation of the Effects of Discharged Waste on Kelp. California State Water Quality Control Board, Sacramento, California. Publ. No. 26, 124 pp.

California Wetland Monitoring Workgroup (CWMW), 2014. Annual Report

Dailey, M.D., Reish, D.J. and Anderson, J.W. eds., 1993. Ecology of the Southern California Bight. University of California Press.

Daggett, T.L., Pearce, C.M. and Robinson, S.M., 2006. A comparison of three land-based containment systems for use in culturing green sea urchins, *Strongylocentrotus droebachiensis* (Müller)(Echinodermata: Echinoidea). Aquaculture Research, 37(4), pp.339-350.

Dame, R.F. and Allen, D.M., 1996. Between estuaries and the sea. Journal of Experimental Marine Biology and Ecology, 200(1-2), pp.169-185.

Dayton, P.K., 1985. Ecology of kelp communities. Annual review of ecology and systematics, 16(1), pp.215-245.

Dayton, P.K. and Oliver, J.S., 1981. An evaluation of experimental analyses of population and community patterns in benthic marine environments. Marine benthic dynamics, 11th Belle W. Baruch Symposium in Marine Science (1981), pp. 93-120

Dayton, P.K. and Tegner, M.J., 1984. Catastrophic storms, El Niño, and patch stability in a southern California kelp community. Science, 224(4646), pp.283-285.

De Graaf, R.C., 2006. Fine-scale population genetic structure of the eastern Pacific bay pipefish, *Syngnathus leptorhynchus* (Doctoral dissertation, University of British Columbia).

Dorr, J.B. 1976. A Story of Seal Beach, City of Seal Beach, CA. 1st printing, 1976; 2nd printing 1985, 45pp

Duarte, C.M., Kirkman, H., Short, F.T. and Coles, R.G., 2001. Global seagrass research methods.

Dugan, B. and Flemings, P.B., 2000. Overpressure and fluid flow in the New Jersey continental slope: Implications for slope failure and cold seeps. Science, 289(5477), pp.288-291.

Dugan, J.E. and Hubbard, D.M., 2010. Ecological effects of coastal armoring: a summary of recent results for exposed sandy beaches in southern California. In Puget Sound Shorelines and the Impacts of Armoring—Proceedings of a State of the Science Workshop. Reston, Va.: US Geological Survey Scientific Investigations Report (Vol. 5254, p. 278).

Dugan, J.E., Hubbard, D.M., McCrary, M.D. and Pierson, M.O., 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. Estuarine, Coastal and Shelf Science, 58, pp.25-40.

Dugan, J.E., Hubbard, D.M., Nielsen, K.J., Altstatt, J. and Bursek, J., 2015. Baseline Characterization of Sandy Beach Ecosystems Along the South Coast of California. Sandy Beach Ecosystems: Baseline Characterization and Evaluation of Monitoring Metrics for MPAs along the South Coast of California. 113 pp

Duggins, D.O., Simenstad, C.A. and Estes, J.A., 1989. Magnification of secondary production by kelp detritus in coastal marine ecosystems. Science, 245(4914), pp.170-173.

Duggins, D.O., Eckman, J.E. and Sewell, A.T., 1990. Ecology of understory kelp environments. II. Effects of kelps on recruitment of benthic invertebrates. Journal of Experimental Marine Biology and Ecology, 143(1-2), pp.27-45.

Dumbauld, B.R., Ruesink, J.L. and Rumrill, S.S., 2009. The ecological role of bivalve shellfish aquaculture in the estuarine environment: a review with application to oyster and clam culture in West Coast (USA) estuaries. Aquaculture, 290(3-4), pp.196-223.

Eckman, J.E., Duggins, D.O. and Sewell, A.T., 1989. Ecology of under story kelp environments. I. Effects of kelps on flow and particle transport near the bottom. Journal of Experimental Marine Biology and Ecology, 129(2), pp.173-187.

Edwards, A., 1980. Ecological studies of the kelp, *Laminaria hyperborea*, and its associated fauna in south-west Ireland. Ophelia, 19(1), pp.47-60.

Emery, K.O., 1960. The sea off southern California, a modern habitat of petroleum.

Erwin, R.M., 1979. Species interactions in a mixed colony of common terns (*Sterna hirundo*) and black skimmers (Rynchops niger). Animal Behaviour, 27, pp.1054-1062.

Erwin, R.M., 1980. Breeding habitat use by colonially nesting waterbirds in two mid-Atlantic US regions under different regimes of human disturbance. Biological Conservation, 18(1), pp.39-51.

Erwin, R.M., Hatfield, J.S. and Wilmers, T.J., 1995. The value and vulnerability of small estuarine islands for conserving metapopulations of breeding waterbirds. Biological Conservation, 71(2), pp.187-191.

Evans, N.T. and Short, F.T., 2005. Functional trajectory models for assessment of transplanted eelgrass, Zostera marina L., in the Great Bay Estuary, New Hampshire. Estuaries, 28(6), pp.936-947.

Evans, K.A. and Guariguata, M.R., 2016. Success from the ground up: participatory monitoring and forest restoration. CIFOR Occasional Paper, (159).

Fairweather, P.G. and Quinn, G.P., 1993. Seascape ecology: the importance of linkages. In: Battershill, C.B., Schiel, D.R., Jones, G.P., Cresse, R.G., and MacDiarmid, A..B (eds) Proceedings of the Second International Temperate Reef Symposium, January 7–10, 1992, Auckland. NIWA Marine, Wellington, p 77– 83

Ferren Jr, W.R., Fiedler, P.L. and Leidy, R.A., 1996. Wetlands of California, Part I: History of wetland habitat classification. Madrono, pp.105-124.

Firth, L.B., Schofield, M., White, F.J., Skov, M.W. and Hawkins, S.J., 2014. Biodiversity in intertidal rock pools: Informing engineering criteria for artificial habitat enhancement in the built environment. Marine Environmental Research, 102, pp.122-130.

Flores, L., Bailey, R.A., Elosegi, A., Larrañaga, A. and Reiss, J., 2016. Habitat complexity in Aquatic microcosms affects processes driven by Detritivores. PloS one, 11(11), p.e0165065.

Fonseca, M.S. and Bell, S.S., 1998. Influence of physical setting on seagrass landscapes near Beaufort, North Carolina, USA. Marine Ecology Progress Series, 171, pp.109-121.

Foster, M.S. and Schiel, D.R., 1985. The ecology of giant kelp forests in California: a community profile

Fritzsche, R.A., 1980. Revision of the eastern Pacific Syngnathidae (Pisces, Syngnathiformes), including both recent and fossil forms. Revisión de los Syngnathidae (Pisces, Syngnathiformes) del Pacífico oriental, incluyebdi tanto formas recientes como fósiles. Proceedings of the California Academy of Sciences., 42(6), pp.181-227.

Geesey, G.G., Alexander, G.V., Bray, R.N. and Miller, A.C., 1984. Fish fecal pellets are a source of minerals for inshore reef communities. Marine ecology progress series, pp.19-25.

Geist, J. and Hawkins, S.J., 2016. Habitat recovery and restoration in aquatic ecosystems: current progress and future challenges. Aquatic Conservation: Marine and Freshwater Ecosystems, 26(5), pp.942-962.

Gibson, G.G., 1974. Oyster mortality study: summary report, 1966-72.

Gorsline, D.S. and Grant, D.J., 1972. Sediment Textural Patterns on San Pedro Shelf, California (1951-1971): Reworking and Transport by Waves and Currents. In: Shelf Sediment Transport: Process and Pattern.

Goss-Custard, J.D., 1980. Competition for food and interference among waders. Ardea, 68(3), p.52.

Grabowski, J.H. and Peterson, C.H., 2007. Restoring oyster reefs to recover ecosystem services. Ecosystem engineers: plants to protists, 4, pp.281-298.

Graham, M.H., 2004. Effects of local deforestation on the diversity and structure of southern California giant kelp forest food webs. Ecosystems, 7(4), pp.341-357.

Graham, M.H., Vasquez, J.A. and Buschmann, A.H., 2007. Global ecology of the giant kelp *Macrocystis*: from ecotypes to ecosystems. Oceanography and Marine Biology, 45, p.39.

Hanski, I. and Gilpin, M., 1991. Metapopulation dynamics: brief history and conceptual domain. Biological journal of the Linnean Society, 42(1-2), pp.3-16.

Hanski, I. and Thomas, C.D., 1994. Metapopulation dynamics and conservation: a spatially explicit model applied to butterflies. Biological Conservation, 68(2), pp.167-180.

Hansson, L., 1991. Dispersal and connectivity in metapopulations. Biological journal of the Linnean Society, 42(1-2), pp.89-103.

Harrold, C. and Pears, J.S. 1987. The ecological role of echinoderms in kelp forests. Echinoderm Studies 2(137–233)

Harrold, C. and Reed, D.C., 1985. Food availability, sea urchin grazing, and kelp forest community structure. Ecology, 66(4), pp.1160-1169.

Hastings, A. and Botsford, L.W., 2006. Persistence of spatial populations depends on returning home. Proceedings of the National Academy of Sciences, 103(15), pp.6067-6072.

Hesp, P. and Short, A., 1999. Barrier morphodynamics. In: Short, A. (ed.) Handbook of Beach and Shoreface Morphodynamics. John Wiley, Chichester, 307-333.NSW Coastline Management Manual (1990). NSW Government, Sydney.

Hickey, B. M., 1993. Physical oceanography, in Marine Ecology of the Southern California Bight, edited by M. D. Daley, D. J. Reish, and J. W. Anderson, pp. 19–70, Univ. of Calif. Press, Berkeley, 1993.

Hobbs, R.J., Higgs, E. and Harris, J.A., 2009. Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution, 24(11), pp.599-605.

Hoffman, R.S., 1986. Fishery utilization of eelgrass (Zostera marina) beds and non-vegetated shallow water areas in San Diego Bay. Southwest Region, NOAA, National Marine Fisheries Service.

Holl, K., 2004. Primer of ecological restoration. Island Press.

Horn, M.H., 1980. Diversity and ecological roles of noncommercial fishes in California marine habitats. CalCOFI Rep, 21, pp.37-47.

Horn, M. and L. Allen. 1985. Fish community ecology in southern California bays and estuaries, p. 169–190. In A. Yañez-Arancibia (ed.), Fish Community Ecology in Estuaries and Coastal Lagoons: Toward an Ecosystem Integration. Universidad National Autonoma de Mexico Press México, Ciudad Universitaria, México.

Horrer, P.L., 1950. Southern hemisphere swell and waves from a tropical storm at Long Beach, California. Department of the Army Corps of Engineers.

Johnson, J.M., 1999. Fish use of a southern California salt marsh. M.S. thesis, Department of Biology, San Diego State University. p. 72.

Johnson, T.D., Barnett, A.M., DeMartini, E.E., Craft, L.L., Ambrose, R.F. and Purcell, L.J., 1994. Fish production and habitat utilization on a southern California artificial reef. Bulletin of Marine Science, 55(2-3), pp.709-723.

Jones, R., 1969. Fire-stick farming. Australian Natural History 16, 224.

Jones, C.G., Lawton, J.H. and Shachak, M., 1994. Organisms as ecosystem engineers. In Ecosystem management (pp. 130-147). Springer, New York, NY.

Josselyn, M. N., Larsson, B., and Fiorillo, A., 1993. An ecological comparison of an introduced marsh plant, *Spartina alterniflora*, with its native congener, *Spartina foliosa*, in San Francisco Bay. San Francisco Bay Estuary Project Report. Romberg Tiburon Centers, Tiburon, California, USA.

Keane Biological Consulting, 2007. Breeding Biology of the California least tern in the Los Angeles Harbor, 2007 Breeding Season. Prepared for the Port of Los Angeles, Environmental Management Division, under contract with the Port of Los Angeles, Agreement No. 2545. Final report November 14, 2007.

Koehl, M.A.R. and Alberte, R.S., 1988. Flow, flapping, and photosynthesis of *Nereocystis leutkeana*: a functional comparison of undulate and flat blade morphologies. Marine Biology, 99(3), pp.435-444.

Kwak, T.J. and Zedler, J.B., 1997. Food web analysis of southern California coastal wetlands using multiple stable isotopes. Oecologia, 110(2), pp.262-277.

Lafferty, K.D., 2004. Fishing for lobsters indirectly increases epidemics in sea urchins. Ecological Applications, 14(5), pp.1566-1573.

Landin, M.C. and Soots, R.F., 1978, January. Colonial bird use of dredged material islands: a national perspective. In Proceedings of the Colonial Waterbird Group (Vol. 1, pp. 62-72). Waterbird Society.

Larkey, K., 1990. Long Beach California a Pictorial View of the Beach the Way it Was (Photo book) includes Poems The Gardens of the Sea & A Wish, Early Beach, West, Rainbow Lagoon, Belmont Shore. Beach Souvenir Post.

Larkum, A.W.D., Drew, E.A., and Ralph, P.J., 2006. Photosynthesis and metabolism in seagrasses at the cellular level. Larkum, A.W.D., Orth, R.J., and Duarte, C.M. (Eds.), Seagrasses: Biology, Ecology and Conservation, Dordrecht, Springer (2006), pp. 323-345

Leighton, D.L., 1971. Grazing activities of benthic invertebrates in Southern California kelp beds. Nova Hedwigia 32(421–53)

Lindberg, R.G., 1955. Growth, Population Dynamics and Field Behavior in the Spiny Lobster, *Panulirus Interruptus* (Randall), by Robert G. Lindberg. University of California Press.

Linehan, J., Gross, M. and Finn, J., 1995. Greenway planning: developing a landscape ecological network approach. Landscape and urban planning, 33(1-3), pp.179-193.

Loke, L.H., Ladle, R.J., Bouma, T.J. and Todd, P.A., 2015. Creating complex habitats for restoration and reconciliation. Ecological Engineering, 77, pp.307-313.

Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H. and Jackson, J.B., 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science, 312(5781), pp.1806-1809.

MacArthur, R.H. and Wilson, E.O., 2001. The theory of island biogeography (Vol. 1). Princeton university press.

Madden, C.J., Grossman, D.H. and Goodin, K.L., 2005. Coastal and marine systems of North America: framework for an ecological classification standard: version II. NatureServe.

Mann, K.H., 1973. Seaweeds: their productivity and strategy for growth. Science, 182(4116), pp.975-981.

Martin, J.W. and Haney, T.A., 2005. Decapod crustaceans from hydrothermal vents and cold seeps: a review through 2005. Zoological Journal of the Linnean Society, 145(4), pp.445-522.

Mendoza-Carranza, M. and Rosales-Casian, J.A., 2000. The feeding habits of spotted sand bass (*Paralabrax maculatofasciatus*) in Punta Banda estuary, Ensenada, Baja California, México. CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS REPORT, pp.194-200.

Millennium Ecosystem Assessment (MEA)., 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. https://www.millenniumassessment.org/en/index.html

Meyer, J. L., Schultz, E. T., and Helfman, G. S., 1983. Fish schools: an asset to corals. Science, 220(1047–1049)

Morrison, M., Consalvey, M., Berkenbusch, K. and Jones, E., 2008. Biogenic habitats and their value to New Zealand fisheries. Available at https://niwa.co.nz/publications/wa/vol16-no4-december-2008/biogenic-habitats-and-their-value-to-new-zealand-fisheries

Moschella, P.S., Abbiati, M., Åberg, P., Airoldi, L., Anderson, J.M., Bacchiocchi, F., Bulleri, F., Dinesen, G.E., Frost, M., Gacia, E. and Granhag, L., 2005. Low-crested coastal defence structures as artificial habitats for marine life: using ecological criteria in design. Coastal Engineering, 52(10-11), pp.1053-1071.

Murray, S. N., and Bray, K. N., 1993. Benthic macrophytes. In Ecology of the Southern California Bight, Dailey, M. D., Keish, D. J., and Anderson, J. W. (eds.) Berkeley: Univ. Calif Press, pp. 304-368.

Newell, R.I., 2004. Ecosystem influences of natural and cultivated populations of suspension-feeding bivalve molluscs: a review. Journal of Shellfish research, 23(1), pp.51-62.

National Oceanic and Atmospheric Administration (NOAA), 2016. Habitat Enterprise Strategic Plan. 30pp. Available at https://repository.library.noaa.gov/view/noaa/14994

NOAA, 2017. Palos Verdes Reef Restoration Environmental Assessment. Available at https://www.montroserestoration.noaa.gov/wp-content/uploads/2017/02/PV_EA-_15-Feb-2017.pdf

NOAA, 2021a. Essential Fish Habitat. Available at https://www.fisheries.noaa.gov/national/habitat-conservation/essential-fish-habitat

NOAA, 2021b. Fishery Management Plans. Available at https://www.fisheries.noaa.gov/rules-and-announcements/plans-and-agreements

North, W.J., 1971. Growth of individual fronds of the mature giant kelp, *Macrocystis*. Nova hedwigia. Beihefte.

Nosho, T.Y., 1989. Small-scale oyster farming for pleasure and profit. Washington Sea Grant, Marine Advisory Services.

Oates, L.M., 2013. Generation of fluorescent strains to evaluate probiotic and pathogenic bacterial interactions in larvae of the eastern oyster, *Crassostrea virginica*. University of Maryland, Baltimore County.

Paine, R.T. and Suchanek, T.H., 1983. Convergence of ecological processes between independently evolved competitive dominants: a tunicate-mussel comparison. Evolution, pp.821-831.

Pander, J. and Geist, J., 2016. Can fish habitat restoration for rheophilic species in highly modified rivers be sustainable in the long run? Ecological Engineering, 88, pp.28-38.

Paxton, A.B., Pickering, E.A., Adler, A.M., Taylor, J.C. and Peterson, C.H., 2017. Flat and complex temperate reefs provide similar support for fish: Evidence for a unimodal species-habitat relationship. PloS One, 12(9), p.e0183906.

Pearse, J.S. and Hines, A.H., 1979. Expansion of a central California kelp forest following the mass mortality of sea urchins. Marine Biology, 51(1), pp.83-91.

Perkol-Finkel, S., Ferrario, F., Nicotera, V. and Airoldi, L., 2012. Conservation challenges in urban seascapes: promoting the growth of threatened species on coastal infrastructures. Journal of Applied Ecology, 49(6), pp.1457-1466.

Pinnix, W.D., Shaw, T.A., Acker, K.C. and Hetrick, N.J., 2005. Fish communities in eelgrass, oyster culture and mudflat habitats of north Humboldt Bay, California, Final Report. US Fish and Wildlife Service, Arcata, California Technical Report, 2.

Pister, B., 2009. Urban marine ecology in southern California: the ability of riprap structures to serve as rocky intertidal habitat. Marine Biology, 156(5), pp.861-873.

Pondella, D.J., Williams, J.P., Claisse, J.T., Schaffner, B. and Schiff, K. 2011.Physical and biological characteristics of nearshore rocky reefs in the Southern California Bight: A report the to the Southern California Water Research Project. 26 pp.

Pugesek, B.H., Tomer, A. and Von Eye, A. eds., 2003. Structural equation modeling: applications in ecological and evolutionary biology. Cambridge University Press.

Philip Williams & Associates (PWA) and Faber, P.M., 2004. Design guidelines for tidal wetland restoration in San Francisco Bay. Prepared for The Bay Institute. Dec. 29, 2004.

Pye, K. and Tsoar, H., 1990: Aeolian Sand and Sand Dunes. London: Unwin Hyman. 396

Quast, J.C., 1968. Observations on the food and biology of the kelp bass, *Paralabrax clathratus*. With notes on its sport fishery at San Diego, California. In W.J. North and C.L. Hubbs (eds.), Utilization of kelp-bed resources in southern California, p.81-108. Calif. Dep. Fish Game, Fish Bull. 139

Reed, D.C. and Foster, M.S., 1984. The effects of canopy shadings on algal recruitment and growth in a giant kelp forest. Ecology, 65(3), pp.937-948.

Robbins, E.A., 2006. Essential Fish Habitat in Santa Monica Bay, San Pedro Bay, and San Diego Bay: A Reference Guide for Managers (Masters Thesis, Duke University).

Robles, C., Sweetnam, D. and Eminike, J., 1990. Lobster predation on mussels: Shore-level differences in prey vulnerability and predator preference. Ecology, 71(4), pp.1564-1577.

Rodŕiguez-Medrano, M.C., 1993. Descripción y análisis de la pesca deportiva en Bahía de Todos Santos, Ensenada, BC.

Rudd, H., Vala, J. and Schaefer, V., 2002. Importance of backyard habitat in a comprehensive biodiversity conservation strategy: a connectivity analysis of urban green spaces. Restoration ecology, 10(2), pp.368-375.

Rutecki, D., Dellapenna, T., Nestler, E., Scharf, F., Rooker, J., Glass, C. and Pembroke, A., 2014. Understanding the Habitat Value and Function of Shoals and Shoal Complexes to Fish and Fisheries on the Atlantic and Gulf of Mexico Outer Continental Shelf. Literature Synthesis and Gap Analysis. Literature Synthesis and Gap Analysis. Prepared for the US Dept. of the Interior, Bureau of Ocean Energy Management. Contract, pp.2015-012.

Sale, P.F., Cowen, R.K., Danilowicz, B.S., Jones, G.P., Kritzer, J.P., Lindeman, K.C., Planes, S., Polunin, N.V., Russ, G.R., Sadovy, Y.J. and Steneck, R.S., 2005. Critical science gaps impede use of no-take fishery reserves. Trends in Ecology & Evolution, 20(2), pp.74-80.

Southern California Coastal Water Research Project (SCCWRP), 1973. The ecology of the Southern California Bight: Implications for water quality management. El Segundo: SCCWRP. Available at https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/010_3yrRptEcoImplicationsWQmgt.pdf

Schiel, D.R. and Foster, M.S., 2015. The biology and ecology of giant kelp forests. Univ of California Press.

Schiff, K.C., Allen, M.J., Zeng, E.Y. and Bay, S.M., 2000. Southern California. Marine Pollution Bulletin, 41(1-6), pp.76-93.

Schippers, P., Verboom, J., Knaapen, J.P. and Van Apeldoorn, R.C., 1996. Dispersal and habitat connectivity in complex heterogeneous landscapes: an analysis with a GIS-based random walk model. Ecography, 19(2), pp.97-106.

Short, F.T. and Neckles, H.A., 1999. The effects of global climate change on seagrasses. Aquatic Botany, 63(3-4), pp.169-196.

Smit, C. J. 1981. Production of biomass by invertebrates and consumption by birds in the Dutch Wadden Sea. In: Smit, C. J., Wolff, W. J. (ed.) Birds of the Wadden Sea. Balkema, Rotterdam, p. 29 & 301

Stephens, A.W., 1978. The northern entrance to Moreton Bay.

Stull, J.K., 1996, September. Ocean monitoring off Palos Verdes, Southern California, 1970-1995. In OCEANS 96 MTS/IEEE Conference Proceedings. The Coastal Ocean-Prospects for the 21st Century (Vol. 1, pp. 299-306). IEEE.

Tegner, M.J. and Dayton, P.K., 2000. Ecosystem effects of fishing in kelp forest communities. ICES Journal of Marine Science, 57(3), pp.579-589.

Thom, R.M., Borde, A.B., Williams, G.D., Southard, J.A., Blanto, S.L., and Woodruff, D.L., 2001. Effects of multiple stressors on eelgrass restoration projects. Puget Sound Research 2001.

Urban, D. and Keitt, T., 2001. Landscape connectivity: a graph-theoretic perspective. Ecology, 82(5), pp.1205-1218.

U.S. Army Corps of Engineers (USACE), 2000. ER 1105-2-100: Planning Guidance Notebook. 712 pp

U.S. Commission on Ocean Policy (USCOP), 2004. An Ocean Blueprint for the 21st Century Final Report of the U.S. Commission on Ocean Policy. Available at https://govinfo.library.unt.edu/oceancommission/documents/full_color_rpt/welcome.html

Van Apeldoorn, R.C., Oostenbrink, W.T., Van Winden, A. and Van Der Zee, F.F., 1992. Effects of habitat fragmentation on the bank vole, *Clethrionomys glareolus*, in an agricultural landscape. Oikos, pp.265-274.

Wasson, K., Hughes, B.B., Berriman, J.S., Chang, A.L., Deck, A.K., Dinnel, P.A., Endris, C., Espinoza, M., Dudas, S., Ferner, M.C. and Grosholz, E.D., 2016. Coast-wide recruitment dynamics of Olympia oysters reveal limited synchrony and multiple predictors of failure. Ecology, 97(12), pp.3503-3516.

Wasson, K., Zabin, C., Bible, J., Ceballos, E., Chang, A., Cheng, B., Deck, A., Grosholz, T., Latta, M. and Ferner, M., 2015. A guide to Olympia oyster restoration and conservation: environmental conditions and sites that support sustainable populations. Elkhorn Slough National Estuarine Research Reserve.

Water Resources Development Act (WRDA), 1996. Available at https://www.govinfo.gov/content/pkg/PLAW-104publ303/pdf/PLAW-104publ303.pdf

Wensink, S.M. and Tiegs, S.D., 2016. Shoreline hardening alters freshwater shoreline ecosystems. Freshwater Science, 35(3), pp.764-777.

Weslawski, J.M., Snelgrove, P.V., Levin, L.A., Austen, M.C., Kneib, R.T., Iliffe, T.M., Carey, J.R., Hawkins, S.J. and Whitlatch, R.B., 2004. Marine sedimentary biota as providers of ecosystem goods and services. Sustaining Biodiversity and Ecosystem Services in Soils and Sediment, pp.73-98.

Wiegel, R.L., 2009. San Pedro Bay Delta. Southern California Shore and Shore Use Changes during Past 1-1/2 Centuries from a Coastal Engineering Perspective, pp.2009-2.

Wing, B.L. and Clendenning, K.A., 1971. Kelp surfaces and associated invertebrates. Nova hedwigia. Beihefte.

Wong, F.L., Dartnell, Peter, Edwards, B.D., and Phillips, E.L., 2012, Seafloor geology and benthic habitats, San Pedro Shelf, southern California: U.S. Geological Survey Data Series 552. Available at https://pubs.usgs.gov/ds/552/.

Zarillo, G.A., Zarillo, K.A. and Finnegan, C.R., 2009. Physical characterization of nearshore and offshore borrow sites on the inner continental shelf of northeast and west Florida. Journal of Coastal Research, (56), p.1095.

Table 1: Species function by habitat type matrix

ESPB HABITATS*	TAXON	ASSOCIATED SPECIES	Habitat Association	Feeding technique	**Function 1** Keystone and/or potential indicator species for the habitat type	**Function 2** Predatory species that regulates the population of other species	**Function 3** Important host species to other organisms	**Function 4** Important prey species for other organisms	**Function 5** Habitat-forming "foundation" or "ecosystem engineering" species	**Function 6** Important in nutrient cycling for food webs	**Function 7** Important commercial and recreational marine fishery	Conservation Status Notes
ROCKY REEF	invertebrate	California spiny lobster (*Panulirus interruptus*)	benthic; pelagic larvae	predator		X	X				X	Most economically important lobster on American West Coast; CDFW sets and enforces regulations pertaining to recreational fishing
		California mussel (*Mytilus californianus*)	benthic	filterer	X			X	X			
		sea star (*Pisaster* sp.)	benthic	predator	X	X						
	fish	blacksmith (*Chromis punctipinnis*)	substrate associated	water cloumn foragers, schooling, selective feeding, usually benthic refugers, diurnal		X				X		
		barred sand bass (*Paralabrax nebulifer*)	substrate associated	non-schooling, diurnal, engulfer		X				X	X	
		California scorpionfish (*Scorpaena guttata*)	substrate associated	nocturnal; ambush predator		X						
KELP FOREST	plant/alga	giant kelp (*Macrocystis pyrifera*)			X				X			
	invertebrate	sea urchins (echinoderms)	benthic	grazer				X		X	X	
		whelks (sea snails)	benthic	predator, scavenger				X				
	fish	kelp rockfish (*Sebastes atrovirens*)	Substrate	nocturnal		X				X		

ESPB HABITATS*	TAXON	ASSOCIATED SPECIES	Habitat Association	Feeding technique	**Function 1** Keystone and/or potential indicator species for the habitat type	**Function 2** Predatory species that regulates the population of other species	**Function 3** Important host species to other organisms	**Function 4** Important prey species for other organisms	**Function 5** Habitat-forming "foundation" or "ecosystem engineering" species	**Function 6** Important in nutrient cycling for food webs	**Function 7** Important commercial and recreational marine fishery	Conservation Status Notes
		garibaldi (*Hypsypops rubicundus*)	Substrate	Benthic forager, schooling/non schooling, diurnal, specialist, territorial, sometimes herbivore	X							Designated as the official marine fish of California in 1995
		giant kelpfish (*Heterostichus rostratus*)	Substrate	Non-schooling, diurnal, engulfer							X	
		kelp bass (*Paralabrax clathratus*)	Substrate, but enters water column	Non-schooling, diurnal, engulfer							X	
EELGRASS	plant/alga	eelgrass (*Zostera maritima*)		NA	X				X			Designated Essential Fish Habitat and a Habitat of Particular Concern under the 1996 Magnuson-Stevens Fishery Conservation and Management Act
	invertebrate	tube anemones (ceriantharians)	benthic	siphon					X	X		
	fishes	giant kelp fish (*Heterostichus rostratus*)			X						X	
		spotted sand bass (Paralabrax maculatofasciatus)		Non-schooling, diurnal, engulfer							X	
		barred sand bass (*Paralabrax nebulifer*)		Non-schooling, diurnal, engulfer							X	
		shiner surfperch (*Cymatogaster aggregata*)	Water column and substrate	Benthic forager, schooling, often benthic refuging, diurnal, picker				X				

ESPB HABITATS*	TAXON	ASSOCIATED SPECIES	Habitat Association	Feeding technique	**Function 1** Keystone and/or potential indicator species for the habitat type	**Function 2** Predatory species that regulates the population of other species	**Function 3** Important host species to other organisms	**Function 4** Important prey species for other organisms	**Function 5** Habitat-forming "foundation" or "ecosystem engineering" species	**Function 6** Important in nutrient cycling for food webs	**Function 7** Important commercial and recreational marine fishery	Conservation Status Notes
		bay pipefish (*Syngnathus leptorhynchus*)		suction (suspensorial abduction)	X							
COASTAL WETLAND												
	plant/alga	Pacific cordgrass (*Spartina foliosa)*	low marsh zone	NA					X			
		pickleweed (Salicornia sp.)	mid-marsh plain	NA					X			
	invertebrate	horn snails (*Cerithideopsis californica*)	benthic				X	X				
	fishes	silverside (atherinopsidae)						X				
		diamond turbot (*Hypsopsetta guttulata*)	benthic	digger and extractor						X		
		arrow goby (*Clevelandia ios*)	benthic	hider (in holes and crevices), diurnal				X		X		
		California killifish (*Fundulus parvipinnis*)	Water column and substrate	Benthic forager, schooling, often benthic refuging, diurnal, picker			X	X		X		
	avian	western sandpiper (*Calidris mauri*)	mid- and low-marsh plain; pannes and ponds	benthic surface probers, grazers of biofilm on surface of mudflats	X	X				X		
SANDY ISLAND												
	invertebrate	Pacific sand crab (*Emerita analog*)	terrestrial	burrower				X		X		
		California beach hopper (Megalorchestia californiana)	terrestrial	burrower				X		X		
	avian	snowy plover (*Charadrius nivosus*)	terrestrial	visual foragers, probers		X				X		federally listed as threatened

ESPB HABITATS*	TAXON	ASSOCIATED SPECIES	Habitat Association	Feeding technique	**Function 1** Keystone and/or potential indicator species for the habitat type	**Function 2** Predatory species that regulates the population of other species	**Function 3** Important host species to other organisms	**Function 4** Important prey species for other organisms	**Function 5** Habitat-forming "foundation" or "ecosystem engineering" species	**Function 6** Important in nutrient cycling for food webs	**Function 7** Important commercial and recreational marine fishery	Conservation Status Notes
		California least tern (Sterna antillarum browni)	terrestrial	inshore feeder, hovering/diving		X				X		federally listed as endangered
OYSTER REEF												
	invertebrate	Olympia oyster (*Ostrea lurida*)	intertidal, sessile	filterer	X				X		X	

* "ESPB habitats" is a generic term used for illustrative Project purposes.

Table 2: Habitat classification cross walk

ESPB Habitat	Cowardin Class	Generic Type	Habitat	Description
Coastal salt marsh	Emergent wetland	Coastal wetland/tidal salt marsh	Coastal wetlands	Patchwork of sand flats, mud flats, and saltmarshes
			Saltmarshes	Low coastal vegetated plain frequently flooded by tidal flow
Eelgrass	Aquatic bed (rooted vascular)	Shallow vegetated	Seagrass beds	Beds of rooted, flowering plants (four species)
Kelp or kelp forest	Aquatic bed (algal)		Kelp forest or kelp bed	Kelps, fucoids, and other complex, erect macroalgae
			Benthic algae	Bushy, flat, or crustose algae
Oyster reef	Reef	Biogenic reefs and beds	Oyster reef	Three-dimensional structures created by oysters, mussels, or marine polychaete worms spanning intertidal to subtidal areas
			Mussel beds	
			Worm reef	
Rocky reef	Rock bottom	Hard structure	Rocky shore	Intertidal rock, boulders, and cobble
			Rocky reef	Subtidal rock, boulders, and cobble
NA	NA		Artificial substrates	Manmade structures constructed of hard substrates (e.g. rip-rap, pier support footing)
Emergent island	Uncosolidated shore	Exposed sandy beach	Sandy shore	Transitional habitat between land and sea with no or sparse vegetation
Soft-bottom*	Unconsolidated bottom	Soft bottom	Intertidal flats	Intertidal mud and sand flats
			Subtidal soft bottom	Subtidal mud, sand, and mixed sediments
Open water*	NA	Open water	Shallow open water	Water depths shallower than 30 m but not directly next to the coast

* denotes a habitat type not targeted by the Project for restoration