MEMORANDUM

To: Andre Krause and Julian Pancoast, Mission Rock Partners, LLC.

From: Justin Semion, Matt Osowski, and Liz Allen, WRA, Inc.

Cc: Will DiBernardo, SCAPE Studio
Dilip Trivedi, Moffat & Nichol

Date: April 17, 2020

Re: Mission Rock Tide Pool Habitat Recommendations

Introduction, Purpose and Goals

China Basin Park within the Mission Rock Mixed-Use Development Project ('Project') includes an area of created tide pools along the China Basin shoreline. The goals of the tide pools are to:

(1) Provide public access opportunities providing direct interaction with the Bay,
(2) Provide a unique educational and public outreach opportunity, and
(3) Create intertidal habitat that provides habitat for a diversity of marine life

The Mission Rock Project that will create a new mixed-use neighborhood consisting of new parks, open space, and public waterfront access improvements along the Blue Greenway trail. This memorandum focuses on the habitat related goals for the China Basin Park tide pools.

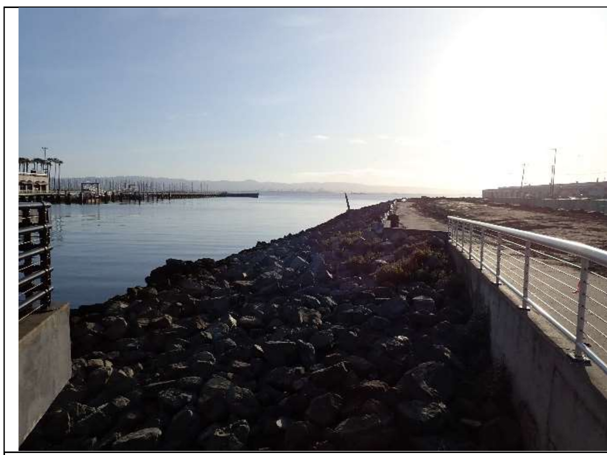
Since the Gold Rush, over 90% of the Bay's historical tidal wetlands have been lost, including a substantial amount of intertidal habitat (Callaway et al., 2011). Much of the historical natural shoreline has been replaced by hardened structures that are not as productive for many aquatic organisms. This loss and degradation of important habitat has decreased the biomass of the Bay's aquatic life (SFBSHGR, 2010). While man made shorelines can support some aquatic life, their value is reduced compared to natural rocky intertidal areas due to factors such as the materials used and structural configuration. In addition, most engineered shoreline structures inhibit the ability for the public to experience the rich life that can inhabit the Bay shoreline. Much work has been done in recent years to develop shoreline structures that both protect built infrastructure and provide habitat benefits for aquatic life. The tide pools at China Basin Park are being designed to demonstrate that a balance can be achieved between shoreline protection, public access, and habitat value along the built shoreline of San Francisco Bay.

This memorandum reviews existing conditions along the shoreline of China Basin Park, provides an overview of key elements of high functioning natural rocky intertidal habitat, and provides an overview of recent research and innovation in shoreline structures designed to improve aquatic habitat conditions in the built environment. The primary objective of this memorandum is to provide a reference for project designers and engineers to inform the design and construction of the China Basin tide pools. It provides detail about factors present in naturally occurring rocky intertidal habitat, in combination with recent innovations in subtidal and intertidal restoration to help create a space where the public can see and experience the unique ecosystem hidden beneath the waters of San Francisco Bay. This can, in turn, inform efforts elsewhere within the Bay to improve aquatic habitat in areas where maintaining the quality of aquatic life is traditionally thought of as incompatible with surrounding land use.

Existing Shoreline Conditions

China Basin Park is located at the Port of San Francisco Seawall Lot 337 (Project Area), located along McCovey Cove/China Basin in San Francisco across from Oracle Park. The area is currently composed of a paved parking lot and mixed-use path with a narrow strip of landscaping containing street trees.

Seawall Lot 337's shoreline is currently composed of medium-sized engineered riprap, of relatively recent placement. The age of the shoreline material is important to note because newer engineered structures frequently support a lower abundance of aquatic life compared to older and more weathered surfaces. This trend is evident within and around the Project Area, where the newly placed rip rap along the China Basin shoreline supports a lower abundance and diversity of aquatic life compared to shorelines within Mission Creek to the west and south of Pier 50. Coastal energy also may play a role in these differences along the shoreline, with quiet and sheltered areas within Mission Creek exhibiting much more surficial mud as compared to the higher energy shoreline south of Pier 50. Increases in mud content have been shown to reduce diversity of intertidal species (Douglas, et al. 2019), and it is possible that the differences in mud content across the sites has some effect on the field observations.

	
Newer engineered rip rap along the China Basin Park shoreline	Older and weathered shoreline south of Pier 50

Aquatic species observed and photographed along the shoreline within and adjacent to China Basin Park include a number of brown, red, and green algae including rockweed (*Fucus distichus*), sea lettuce (*Ulva* spp.), and encrusting red algae (*Mastocarpus* spp.). Sessile, filter-feeding invertebrates were found in the area including mussels (*Mytilus* spp.), barnacles (*Balanus glandula*), and sponges (likely *Haliclona permollis*). Evidence of oysters was also observed, but no living oysters were detected. One mobile marine invertebrate found along the shoreline, a single mossy chiton (*Mopalia muscosa*).

Based on observations during the assessment level survey conducted, the abundance and diversity of these species increased steadily with age and weathering of the shoreline material. Species assemblages were similar at the China Basin shoreline and at Mission Creek, with higher abundance in the weathered and varied material found in Mission Creek as compared with China

Basin Park. The highest diversity and abundance was found in the oldest and most highly weathered material found south of Pier 50. This shoreline is also more exposed than the shorelines within Mission Creek and China Basin Park, and there was a noticeable difference in cover by mud at this site. The China Basin Park shoreline was noticeably less muddy than within Mission Creek, indicating that conditions may be comparatively more favorable for intertidal aquatic species in the location of the proposed tide pools.

	
Barnacles surrounded by red, brown, and green algae along the shoreline south of Pier 50.	Rockweed, barnacles, and oyster scars on the muddy shoreline of Mission Creek.

Marine and coastal birds are also known to be in the area including cormorants (*Phalacorcarax auritus* and *P. pelagicus*), great blue herons (*Arfea Herodias*), buffleheads (*Bucephala albeola*), and western grebes (*Aechmophorus occidentalis*) (WRA, personal observation; iNaturalist).

Existing conditions indicate that there is abundant opportunity for natural recruitment of rocky intertidal species within the created tide pools in China Basin Park. Key physical characteristics that appeared to influence the diversity and abundance of rocky intertidal species included the heterogeneity of the structures present, age and degree of weathering of the surface, and cover by mud (and related wave energy).

Overview of Rocky Intertidal Habitat Function and Structure

Tide pools function as important nursery grounds, feeding habitat, and refugia for a wide range of organisms. For design purpose, tide pools should be conceptualized as being part of a larger tidal ecological zone referred to as intertidal habitat. Natural tide pools are surrounded by and integrated into rocky intertidal habitat. Intertidal habitat can function without tide pools, but tide pools without surrounding rocky intertidal habitat are not likely to be highly functional ecologically, as they would lack opportunity for colonization and species interactions that many studies have shown to be important for tide pool ecology.

Intertidal habitats are areas that lie between low and high tide (SFBSHGR, 2010). These areas are alternatively submerged or exposed depending on the tidal elevation at a given point in time. Intertidal habitats are generally broken into categories based on substrate and vegetation (or lack thereof). Within San Francisco Bay, intertidal habitats include sandy beaches, natural rock outcrops, artificial or imported substrates (including rock rip rap, bulkheads, and pilings), tidal wetlands, and mud flats. An abundance of scientific literature exists regarding the restoration and design of tidal wetlands, and sandy beaches have similarly received historic attention in scientific and engineering studies. There is very little scientific research available providing specific guidance for tide pool and rocky intertidal habitat restoration and creation. Much of this is because the degree of variation in the structure of tide pools and rocky intertidal habitats makes it difficult to draw comparisons across and even within study locations (Metaxas and Scheibling, 1993). The variation present in rocky intertidal habitats is, however, the very thing that results in the diversity of species that inhabit them and the value they provide to larger ecological systems.

Maintaining this variability in depth, form, and texture for restored and created rocky intertidal habitats is critical to their success (C. Zabin, pers. comm.). The coexistence of competing organisms (such as predator and prey), plays a large role in the biodiversity of tide pools and intertidal habitats. In homogenous environments, such coexistence is not favored (Levin, 1992). Structural diversity allows for greater organismal diversity through the creation of microhabitats within the intertidal system (Firth et al., 2010). Thus, it is recommended that variation be integrated into the design of the tidal shelves as much as can be accommodated so that different micro-habitats can develop.

Because very little guidance exists guiding the design of tide pools and rocky intertidal habitats, this discussion focuses on factors from scientific literature that are consistently identified as important in determining ecological community structure. These include:

- Hydrological Factors, including depth, frequency of flooding, and wave exposure
- Shape and Form Factors, such as variations in the shape and orientation of attachment substrate
- Texture Factors, or the relative roughness and smoothness of the surface texture

Specific considerations for each of these design factors is discussed further below. Generally, these factors are discussed in terms of rocky intertidal habitat, though where specific considerations have relevance to the park tide pool design, recommendations are offered.

Hydrological Considerations

Two primary hydrological factors are important to consider for the design of tide pools and rocky intertidal habitat. The first is the elevation of the substrate in relation to tidal elevations. The second is wave energy, as demonstrated by the differences between the intertidal communities in the quiet and muddy Mission Creek as compared to the shoreline south of Pier 50.

Tidal elevations set the frequency with which areas are flooded. Intertidal species require abundant water to meet basic physiological needs, so the elevations of created and restored intertidal habitat are vital to their success. Rocky intertidal habitat can be divided into four vertical zones (NOAA, 2020). Arranged from highest elevation to lowest elevation, those zones are:

Spray Zone (also referred to as the "Splash Zone" or "Supratidal Zone"): areas at elevations that receive airborne spray or splashes of water, with lower elevations that may be tidally flooded only during king tides and storm events.

High Intertidal Zone: elevations that are typically flooded daily by the highest tides, but remains dry or pooled with water during mid and low daily tides. In San Francisco Bay, this zone generally occurs between elevations just below mean high water (MHW), to just above mean higher high water (MHHW).

Middle Intertidal Zone: elevations that are typically flooded and left dry by daily tides twice a day. In San Francisco Bay, this zone generally occurs between elevations of approximately mean low water (MLW) up to elevations just below MHW.

Low Intertidal Zone: elevations that are typically under water during most tide cycles, and drying out during the lowest of tides. In San Francisco Bay, this zone generally occurs between elevations at approximately MLW to the lowest tides, one foot or more below mean lower low water (MLLW).

The graphic below provides a summary of project site elevations for each of these zones, along with how these tidal elevations conceptually relate to these intertidal habitat zones. These elevations are conceptual, and should not be interpreted as establishing fixed vertical thresholds. In natural systems, some species may be more dominant in some zones than in others, but there is a large degree of intergradation across and between these zones by intertidal species. Mobile intertidal species, for example, are even able to move between these zones.

		Tidal Elevation	Elevation (feet NAVD88)	Elevation (feet Mission Bay Datum)
Spray Zone	+/-1.5 ft			
High Intertidal Zone	+/-2.5 ft	King Tide	+7.3	96.0
		MHHW	+6.3	95.0
		MHW	+5.8	94.5
Middle Intertidal Zone	+/-4.5 ft			
		MLW	+0.9	89.6
Low Intertidal Zone	+/-2.5 ft	MLLW	-0.2	88.5
		Lowest Tides		

Due largely to the differences in the physical environments experienced at these different elevations, different marine organisms are known to preferentially inhabit different intertidal elevations. For example, mussels, chitons, limpets, and sea urchins have been documented to prefer tide pools at higher intertidal levels (Green, 1971). Firth et al. (2013), reviewed species diversity within artificial tide pools at different tidal elevations, and found that species diversity is maximized in pools placed at middle intertidal levels. There is not currently abundant data available for San Francisco Bay to firmly establish which types of intertidal species may be dominant within each zone (C. Zabin, pers. comm.). Given this, placing pools at various tidal heights should promote diversity across all of the created intertidal area.

The shoreline south of Pier 50 presents an ideal location for use in setting more specific elevations for the design of intertidal areas at China Basin Park. Its proximity to the Project Site and observed abundance of intertidal species should be used to provide a model for elevations and species diversity for the Mission Rock tidal shelves. Surveyed elevations of different zones containing intertidal species along this shoreline would set a reasonable expectation of what species to expect in those same elevations at China Basin Park[1].

The last important hydrological factor to consider for intertidal habitat is the energy from waves, wakes and currents. The local hydrology will influence the level of sedimentation the artificial tide pools experience. Any structure placed within a coastal environment modifies the wave regime and sediment depositional process, thereby influencing the assemblage of species present (Martin et al., 2005). While some sedimentation may be helpful for promoting initial colonization of created intertidal areas, too much sedimentation, in particular coverage by mud, can be detrimental to species abundance and diversity (Douglas, et al. 2019). This is evidenced near the Project Site by the differences observed within the quiet and muddy environment at Mission Creek, as compared to the higher energy environment south of Pier 50. The shoreline of China Basin Park is situated between these two areas. Observations of shoreline conditions show that some mud deposition occurs there, though not at the levels observed within Mission Creek. These observations indicate that there is some risk that excessive sedimentation could occur in some areas within the shelves, reducing species abundance and diversity. If feasible, it may be advisable to integrate structures and forms into the tidal shelves that intentionally restrict tidal flows to encourage a higher energy tidal environment as a way to manage this risk of sedimentation.

Shape and Form Considerations

The depth of tidal pools and overall three-dimensional complexity of intertidal areas are important factors to consider for the shape and form of the tidal shelves.

Tide pool depth can strongly influence species diversity within a pool (Browne and Chapman, 2014) while pool area alone has little influence (Martins et al., 2007). Deeper tide pools, typically defined as those over one foot deep, experience less-extreme fluctuations in temperature, salinity, dissolved oxygen, and pH, making them naturally more stable environments for more stress-sensitive species. Accordingly, deeper pools may support more species diversity than shallower pools (Moschella et al., 2005). Moreover, tide pools that are both large and deep can allow for zonation, with different species populating different depths of a pool, thereby promoting diversity within (van Tamelen, 1996). Shallow pools and pools containing a smaller volume of water are more extreme environments, as the chemistry of a small volume of seawater can change much faster than a larger volume between tides (Firth, et al. 2014). Given the site's location and goals of the project to promote public access and public experience of the Bay, it is probably advisable to create larger and deeper pools to avoid potential challenges with water quality that could develop in smaller pools. Thus, larger tide pools designed to be greater than one foot deep should enhance diversity and reduce risk of poor water quality within an artificial tide pool system.

The complexity, or three-dimensional structure of an artificial tide pool, is important in determining diversity and abundance. Artificial tide pools with more complex structures, such as crevices and overhangs, are associated with increased invertebrate abundance and species richness (Loke and Todd, 2016). Tide pools with ledges and algal cover have been shown to have higher abundances and diversity of intertidal fish than less structurally-complex pools (White et al. 2014). Moreover, to maximize richness, it is important that surface structures come in a variety of sizes

[1] An elevational survey was not completed at the time of the initial site visit due to complications related to the COVID-19 pandemic.

and depths to accommodate a wide range of organism sizes (Loke and Todd, 2016). Thus, tide pools with high structural complexity are preferred for promoting the recruitment of diverse species assemblages. Integration of small spaces, creation of overhangs and other overlapping planes of structure, and undulating surfaces should all be considered for tidal shelf design.

Rockweed, brown and green algae overhanging spaces beneath rocky substrate creates quality fish and invertebrate habitat.

Mussels, sponges, and oyster scars nestled within shoreline crevices.

Surface Texture Considerations

Similar to complexity in shape and form, the texture of the material used to construct artificial intertidal areas can influence the diversity of organisms that colonize the habitat, and speed with which colonization occurs. Although roughness preferences vary amongst species, most sessile organisms prefer to settle on rough surfaces (Kohler et al., 1999, Coombes, et al. 2009). These organisms form the base of the ecological structure in intertidal systems because they provide structure for more complex ecological interactions. Smooth textured surfaces, by contrast, are slower to develop intertidal communities, and those communities are not as diverse. The differences in speed of colonization between smooth and rough textured surfaces primarily relates to the development of the initial “biofilm”, a mixture of algae and bacterial organisms which provides the initial complexity and adhesion necessary for more complex structures to colonize (Ostale-Valriberas, et al. 2018). Rough textures recruit biofilm much more quickly than smooth textures, and ultimately provide more attachment substrate for intertidal organisms. Techniques used to increase roughness of surface texture include the unique concrete treatment developed by Econcrete, and the integration of oyster shells into intertidal restoration installations, such as the “Baycrete” mix developed for the San Francisco Bay Living Shorelines Project. The Wild Oyster Project in San Francisco Bay has also had success with native oyster recruitment using metal cages filled with loose oyster shell. Similar methods to increase surface roughness could be integrated into the project design.

Other Design Considerations for Intertidal Habitats

Concrete and pH

Standard industrial forms of concrete are not ideal for promoting the recruitment of marine organisms. Cured concrete is highly alkaline with a pH between 11 and 13.5 (AC Tech), while seawater has a pH of about 8. Uncured concrete is marginally better with a surface pH of 10 to 11 (Lukens and Selberg, 2004).

Low-alkalinity concrete that better matches the pH of seawater is expected to be better suited for the recruitment of marine life. Concrete composed of sulfoaluminate cement (SAC), seawater, and marine sand has a lower surface pH than standard Portland concrete (Xu et al. 2019), but has yet to be tested for its ability to recruit marine life directly. A second concrete, Econcrete, is proprietary modified concrete that has lower alkalinity than standard Portland concrete, increased surface texture, and comes in pre-cast shapes specifically designed for marine applications (Perkol-Finkel and Sella, 2014). Studies using Econcrete structures have shown that it successfully enhances local biodiversity in marine coastal areas (Perkol-Finkel and Sella, 2015). Thus, using Econcrete or similar concrete materials with a surface pH comparable to that of seawater, enhanced surface texture, and complex shapes that allow for the formation of micro-habitats is preferred for the construction of these tidal shelves.

Sea Level Rise

Sea-level rise is an important consideration for the design of the tidal shelves. Given that artificial tide pools placed in the mid-intertidal have been shown to have the most species richness (Firth et al., 2013), it is recommended that more pools be placed in the mid- and upper-intertidal than the lower-intertidal; lower pools will be less likely to be exposed between tides as sea level rises, and will therefore be less suitable for promoting diverse species assemblages. With current sea level rise estimates, the highest tidal shelves could be within the lower intertidal zone within 80-100 years. It would be prudent to design the uppermost tidal shelf so that it is capable of supporting structures installed within the middle and lower elevation shelves in the future as sea levels rise. Future adaptations to maintain the tidal shelves could also include extension of these amenities into the area currently designed as a beachfront zone. Future decisions for the maintenance and would need to be made based on future considerations including cost, public safety, and achieving a balance with other forms of public access. The form and structure of the tidal shelves as currently contemplated will continue to provide ecological benefits regardless of whether or not the tidal shelves are below sea level in the future.

Maintenance

In addition to native species, non-native species are also expected to colonize artificial tide pools. Non-native species have been shown to recruit well to most surfaces, with the particularly high recruitment of non-native species found on concrete (Glasby et al., 2007). Accordingly, non-native species can be favored over native species by nearshore, artificial structures (Tyrrell and Byers, 2006; Mineur et al., 2012).

Given that many invasive marine organisms are carried to new places by the natural flow of seawater, and given the often-microscopic size of various invasive species as larvae, it is not possible to prevent non-native species from colonizing new structures along with the desired native species. However, given the fact that native species have been shown to out-number non-native species on horizontal reef structures (Glasby et al., 2007), artificial tide pools are likely to create additional habitat for marine organisms native the San Francisco Bay without providing invasive species with a recruitment advantage.

To combat the settlement of non-native species, an early-detection and monitoring program is recommended. By systematically assessing the artificial pools, pools over-run with non-native species may be detected and manipulated as needed. Another option is to 'seed' the pools with native marine organisms to boost existing populations (Perkol-Finkel et al., 2012). Successful seeding of native species could also help prevent the colonization invasive species; for example, seeding macroalgae could help prevent colonization by invasive invertebrates (Dafforn et al., 2012).

Public Access and Education

Many marine organisms expected to be found within tidepools are sensitive to handling by humans. It is recommended that guidelines be prepared to inform the public of how to enjoy the marine life found in tide pools without causing harm. California's Cabrillo National Monument has useful guidelines for visitors that could also be applied to this development (NPS, 2015). These guidelines include touching animals as gently as you would your own eyeball, returning organisms quickly to their original location and position, and not pursuing animals that are actively resisting being handled.

There are small, but potential risks associated with interacting with tide pools, too. California State Parks has safety recommendations, including walking cautiously around pools to avoid slipping, always facing the ocean to avoid being caught by surprise by a wave (California State Parks, 2009).

Areas Abutting the Intertidal Zone

Natural areas above the intertidal zone within San Francisco Bay share characteristics in vegetation and soils due to natural history and human interventions. There is a wide range of native plant species that can thrive in this zone. These species do not require consistent flooding by the tides, and will not typically survive well if they are flooded regularly by the tides. Areas at the margins of the upper tide pool and adjacent beach area could planted with common native plant species occurring in these transitional upland habitats throughout the Bay.

Summary

In summary, the following recommendations would help increase the ecological value of the constructed tidal shelves:

(1) Intertidal areas should be designed at a variety of tidal elevations, with emphasis on the middle to upper elevations within the Middle Intertidal Zone.
(2) Design should allow for variable flow rates as pools fill and drain, and if feasible integrate structures to increase hydraulic energy and minimize mud laden sedimentation
(3) Tide pools integrated into the design should be larger in size and at least one foot deep to encourage diversity and minimize water quality risks.
(4) The intertidal areas should have complex three-dimensional structure, ideally including overhangs and overlapping structural planes
(5) Surface materials used in the intertidal areas should have a rough texture
(6) The tide pools should be composed of a modified form of concrete that has a surface pH that best matches the natural pH of seawater
(7) The tide pools should be interconnected and integrated with the surrounding intertidal areas as much as feasible

Finally, the tidal shelves at China Basin Park could serve as a model for other areas within and outside of San Francisco Bay for integrating the values of ecology, coastal defense structures, and public access. Monitoring and maintenance of the tidal shelves, particularly within the first three to five years, could provide valuable information to support future similar endeavors. Using these potential larger scale benefits to engage in partnerships with local, regional, state and federal organizations interested in intertidal restoration could help provide additional knowledge and avenues for funding to support these goals.

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Personal Communications

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