Estuaries: ephemeral and year-round[1]

Executive Summary

Estuaries	Score	Confidence
Sensitivity	4 Moderate-High	3 High
Exposure	5 High	3 High
Adaptive Capacity	4 Moderate-High	3 High
Vulnerability	4 Moderate-High	3 High

The estuarine habitat includes small and sandbar-built estuaries within the study region, such as Pescadero Marsh, Estero Americano and Estero de San Antonio, and moderately sized bays such as Tomales Bay, Drakes Estero, and Bolinas Lagoon. Key climate sensitivities identified for this habitat by workshop participants include sea level rise, sea surface temperature, precipitation, and wave action. Key non-climate sensitivities include land use change, overwater/underwater structures, roads and armoring and invasive species. This habitat has a transcontinental geographic extent, is patchily distributed throughout the study region, and is considered to be in a somewhat degraded condition, due to land use pressures, water diversion, pollutants and sedimentation. A diverse range of coastal formations and the interplay of terrestrial, freshwater and marine influences result in a highly diverse and productive community that supports multiple commercial and recreational fisheries and provides protection from coastal erosion that may impact populated coastal communities. Resistance to stressors is low, though recovery from stressors may be possible with appropriate conservation efforts and ongoing management activities.

Sensitivity

I. Sensitivities to climate and climate-driven factors

Climate and climate-driven factors identified (score[2], confidence[3]): sea level rise (5, high), sea surface temperature (4, high), wave action (4, high), precipitation (4, high), air temperature (3, high), dissolved oxygen levels (3, high), pH (3, high), coastal erosion (3, moderate), dynamic ocean conditions (currents/mixing/stratification) (2, high), salinity (2, high), turbidity (2, moderate)

Climate and climate-driven factors that may benefit the habitat: none provided

Overall habitat sensitivity to climate and climate-driven factors: Moderate-High

- Confidence of workshop participants: High

Supporting literature

Literature review was conducted for those factors scoring 4 or higher, although the other sensitivities identified should also be considered.

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[1] Refer to the introductory content of the results section for an explanation of the format, layout and content of this summary report.

[2] For scoring methodology, see methods section. Factors were scored on a scale of 1-5, with 5 indicating high sensitivity and 1 indicating low sensitivity.

[3] Confidence level indicated by workshop participants.

Sea Level Rise

Sea level rise will exacerbate shoreline erosion and cause saltwater intrusion, possibly increasing salinity by as much as 9 practical salinity units in the region's estuaries (Knowles and Cayan 2002). Unless there is a comparable increase in elevation of the land surface due to sediment delivery and availability, estuarine habitat will not be able to adjust to rising sea levels, and flooding will also be expected (Largier et al. 2010, Ackerly et al. 2012). Tidal flux may be altered, including the timing and extent of the rise and fall of the tide (Largier et al. 2010). Estuarine habitats more dependent on organic deposition (microtidal) rather than inorganic sediment deposition (mesotidal) will likely be more impacted by changes in sea level (Stevenson et al. 1986, Stevenson and Kearney 2009).

Sea Surface Temperature

Increasing water and air temperatures are magnified in estuaries relative to the outer coast and are important drivers of community and ecosystem responses in estuaries. Increasing water temperatures can result in the range expansion of both native and non-native species into new areas (Williams and Grosholz 2008), and can have significant demographic effects as well. Water temperatures may also impact the incidence of disease in estuarine species, estuarine circulation, the amount of oxygen that can dissolve in the water (which is critical for the survival of estuarine species), and key physiological processes in estuarine species that are temperature-dependent (NOAA Ocean Service Education 2008).

Precipitation

Changing patterns in precipitation may have consequences for the impact of invasive species, sediment deposition, erosion, flooding, river flow (which may impact the timing of mouth opening and closure of some estuaries), water chemistry and run-off. The seasonality of estuarine hydrology, including rainfall and water flow from rivers into estuaries will influence the transport and deposition of sediments with long-term consequences for estuarine physical structure. Increase in storm and precipitation intensity will likely lead to more frequent and severe flooding of estuaries and will greatly impact river flow, which will likely alter the timing of estuarine mouth opening and closing (Largier et al. 2010).

Wave Action

Increased storm activity, including wave action, will have important implications for flooding of estuarine habitat, the state of the estuarine mouth, and the timing of estuarine mouth opening and closing (Largier et al. 2010). The mouths of estuaries will tend to close with stronger wave energy, and may close earlier or later than usual depending on the interaction with river flow.

II. Sensitivities to disturbance regimes

Disturbance regimes considered: storms, flooding, and disease

Overall habitat sensitivity to disturbance regimes: Moderate-High

- Confidence of workshop participants: High

Supporting literature

Flooding

Increased flooding is expected with sea level rise and more intense precipitation events (see above). The estuarine habitat is highly sensitive to flooding because of the critical habitat that may be inundated, including mud flats for shorebird foraging (Stralberg et al. 2008) and pinniped resting and breeding (Sarah Allen, pers. comm., 2014). Landward migration of intertidal habitat may be restricted due to armoring, roads, and other structures.

Storms

Models suggest that the tracks of storms in the northeast Pacific Ocean will experience an increase in occurrence of extreme conditions, though the number of extreme events may not change (Largier et al. 2010). Increased storm intensity will impact both wave energy and the timing and intensity of precipitation events, with major consequences for estuarine habitat (see *Wave Action* and *Precipitation* sections above).

III. Sensitivity and current exposure to non-climate stressors

Non-climate stressors identified (score[4], confidence[5]): land use change (5, high), coastal roads/armoring (4, high), invasive species (4, high), overwater/underwater structures (4, high)

Overall habitat sensitivity to non-climate stressors: High

- Confidence of workshop participants: High

Overall habitat exposure to non-climate stressors: Moderate-High

- Confidence of workshop participants: High

Supporting literature

Land Use Change

Land use pressures have impacted water quality in some of the region's estuaries, resulting in changes to sediment and freshwater regimes (ONMS 2010). Increased sedimentation can result from land use, causing the burying of oyster and eelgrass habitat and increasing the duration of mouth closure. Livestock grazing and agricultural runoff (primarily animal waste from dairies and rangelands) can result in high coliform and bacterial contamination, increased sedimentation and contamination with toxic materials (e.g., high mercury levels) in estuary waters (ONMS 2010). Freshwater diversions for agriculture and other human uses cause hypersaline conditions, slow circulation, and may result in the persistent closing of estuarine mouths due to reduced tidal prism (ONMS 2010).

Overwater/Underwater Structures

Fishing activities can impact eelgrass and oyster beds, and mariculture of several bivalve species in Tomales Bay has potential negative impacts, including the presence of mariculture-farming equipment that can reduce eelgrass cover, alter sediment deposition patterns, and provide large amounts of hard substrate that is not naturally present, thus altering species communities, and maintenance operations that trample sediments and damage eelgrass beds (Carr et al. 2008). Substantial loss of native oyster beds in Tomales Bay has resulted from increased moorings and anchored and abandoned vessels that impact the benthos. Vessel propellers, anchors, and moorings can damage the underground root and rhizome system of eelgrass and impact oyster beds (ONMS 2010).

[4] For scoring methodology, see methods section. Factors were scored on a scale of 1-5, with 5 indicating high sensitivity and 1 indicating low sensitivity.

[5] Confidence level indicated by workshop participants.

Roads/Armoring
An important factor that will influence estuarine response to sea level rise is the ability of estuaries to migrate inland. Where the upland border abuts roads, levees or other armored structures, an accelerated loss of habitat may be expected (Fletcher et al. 1997, Dugan et al. 2008). Road construction and coastal armoring continues to be a problem in the study region, specifically Bolinas Lagoon and Tomales Bay, and in other areas of coastal development. Although localized, these activities can have a high impact as they can convert habitat type, increase erosion rates, and have the potential to result in large-scale debris (ONMS 2010).

Invasive species and other problematic species
Invasive species effectively out-compete native species and decrease native species diversity and abundance. These impacts are more largely felt near harbors, including San Francisco Bay, Pillar Point Harbor, and Bodega Harbor. It is estimated that about 143 species of invasives are present in the region, most of which exist in the estuarine zone (Byrnes et al. 2007), including European green crabs (*Carcinus maenas*) which prey on and compete with native crabs, Japanese mud snails (*Batillaria attramentaria*) whose dense aggregations impact mudflat communities (Dewar et al. 2008), and smooth cordgrass (*Spartina alterniflora*) and its hybridization with the native cordgrass (*Spartina foliosa),* resulting in loss of habitat for salmon and oysters, and economic losses for those who rely on these species (Brusati 2008, ONMS 2010). Invasive species threaten the abundance and/or diversity of native species, disrupt ecosystem balance and threaten local marine-based economies (SIMoN 2014). Climate change is likely to enhance the negative impacts of coastal invaders. Stachowicz et al. (2002) documented earlier and greater recruitment of invasive tunicates as well as increased growth under warmer sea surface temperatures, and predicted that increasing temperatures will ultimately lead to more successful invasive species.

IV. Other sensitivities

Other critical factors likely to influence habitat sensitivity to climate change: restoration potential, resilience, and public awareness

Degree to which these factors influence habitat sensitivity to climate change: High

- Confidence of workshop participants: High

Adaptive Capacity

I. Extent, integrity, and continuity

Geographic extent of the habitat: 5 (Transcontinental)

- Confidence of workshop participants: High

Structural and functional integrity of habitat: 2 (somewhat degraded)

- Confidence of workshop participants: High

Continuity of habitat: 2 (somewhat isolated and/or fragmented, i.e. patchy)

- Confidence of workshop participants: High

Supporting literature

Estuaries occur worldwide along the coastal zone wherever rivers meet the ocean; they cover a global area of around 106 km^2 and encompass around 4% of the world's continental shelf. Major estuaries found in the study region include Tomales Bay, Bolinas Lagoon, Estero Americano and Estero de San Antonio, Drakes and Limantour Esteros, and Abbotts Lagoon. Pescadero and Scott's Creek marshes are also in the study region. The 2010 GFNMS Condition Report rates the region's estuaries and lagoons as good/fair to fair/poor condition due to land use pressures, water diversion, pollutants and sedimentation. The state has listed Tomales Bay, Estero Americano and Estero de San Antonio as impaired bodies of water under the 303(d) listing (SWRCB 2006) due to a broad range of impacts, including high nutrient loading, increased siltation and bacteria. Biodiversity in the region's estuaries is rated as fair/poor to declining, due to loss and alteration of eelgrass habitat, a key habitat for estuarine species, particularly in Bolinas Lagoon (T. Moore, pers. comm., as cited in ONMS 2010).

II. Resistance and recovery

Habitat resistance to stressors/maladaptive human responses: Low

- Confidence of workshop participants: High

Ability of habitat to recover from stressor/maladaptive human response impacts: Moderate-High

- Confidence of workshop participants: High

Supporting literature

Conservation efforts may help achieve partial recovery of upper trophic levels, but have failed thus far to restore ecosystem structure and function (Lotze et al. 2006). In a comprehensive review of estuarine and coastal recovery, Borja et al. (2010) concluded that, though estuaries do respond well to restoration efforts, full recovery of an estuarine system may take a minimum of 15-25 years, with biodiversity of the system lagging behind. Recommendations for climate-smart restoration solutions include raising infrastructure off the marsh to allow for flooding and movement, allowing estuaries to open and close as conditions change, embrace resiliency and restore living shorelines (Ross Clark, pers. comm., Headwaters to Ocean Conference, 2014).

III. Habitat diversity

Physical and topographical diversity of the habitat: High

- Confidence of workshop participants: High

Diversity of component species within the habitat: High

- Confidence of workshop participants: High

Diversity of functional groups within the habitat: Moderate-High

- Confidence of workshop participants: Moderate

Keystone or foundational species within the habitat: none identified

Supporting literature

A diverse range of coastal formations is included in the estuary designation, including bays, inlets, lagoons, wetlands, marshes and esteros. Estuaries may be bar-built and ephemeral, year-round open river mouths, or perennially tidal (SWRCB 2006). Because of this diversity in terrestrial, freshwater and marine influences, estuaries support highly diverse communities, including eelgrass nursery habitat for commercially and recreationally important fish species, shorebirds, waterfowl, crabs, shrimp and many other invertebrates (Largier et al. 2010, SIMoN 2014). Eelgrass (*Zostera marina)* is a keystone species in the estuarine habitat; 10 to 100 times more animals can be found in eelgrass beds compared to adjacent sandy and muddy habitats (Olyarnik 2007). This species has shown signs of decline in some estuaries, including nearly extinct levels in Bolinas Lagoon (Leet et al. 2001, GFNMS 2008). A key factor for eelgrass health is water clarity and quality, which is greatly impacted by human activities and land use. An additional component of estuarine habitat is sand bars that are exposed at low tides and provide important habitat to shorebirds, waterbirds and pinnipeds (Sarah Allen, pers. comm., 2015).

IV. Management potential

Value of habitat to people: Moderate-High

- Confidence of workshop participants: High
- Description of value: no information provided

Likelihood of managing or alleviating climate change impacts on habitat: Moderate

- Confidence of workshop participants: Low
- Description of likelihood of managing or alleviating climate change impacts: The likelihood of managing or alleviating climate change impacts will depend on the extent of existing habitat and the value of the habitat.

Supporting literature

Estuaries are valued, in part, due to the fisheries that are supported by nursery grounds, including commercial harvest of oysters in aquaculture facilities, sport take of clams, and some fishing for herring, rock crab, perch and halibut (ONMS 2010). Estuaries are also recognized as providing a buffer from coastal erosion and inundation for populated communities along the coast. Past and ongoing management activities that have reduced impacts to the region's estuaries include implementation of best management practices to reduce runoff, the closure and restoration of a mercury mine, the development of a vessel management plan to address illegal moorings in eelgrass, and the removal of abandoned vessels from Tomales Bay (ONMS 2010). Information on current management activities can be found for Bolinas Lagoon (http://farallones.noaa.gov/eco/bolinas/bolinas.html) and Tomales Bay (http://farallones.noaa.gov/eco/tomales/tomales.html).

V. Other adaptive capacity factors

Other critical factors that may affect habitat's adaptive capacity: room to migrate

Degree to which factors affect habitat's adaptive capacity: High

- Confidence of workshop participants: High

Additional participant comments

Beach and dune habitats that are bound by natural or human built structures will have a low adaptive capacity to climate change impacts.

Exposure

I. Future climate exposure[6]

Future climate and climate-driven changes identified (score[7], confidence[8]): changes in precipitation (5, high), changes in sea surface temperature (5, high), increased coastal erosion and runoff (5, high), increased storminess (5, high), increased flooding (5, high), changes in air temperature (4, high), sea level rise (4, moderate), decreased pH (3, moderate), decreased dissolved oxygen (3, moderate)

Exposure of habitat to future climate and climate-driven changes: High

- Confidence of workshop participants: High

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[6] Supporting literature for future exposure to climate factors is provided in the introduction.
[7] For scoring methodology, see methods section. Factors were scored on a scale of 1-5, with 5 indicating high exposure and 1 indicating low exposure.
[8] Confidence level indicated by workshop participants.

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