Estuaries: ephemeral (seasonal) and year-round open

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 and Bolinas Lagoon. San Francisco Bay is a major estuary located outside of the study region, but with important influences on the region.

The bulk of the content for this report comes from the Climate Change Impacts Report (Largier et al. 2010), a working group report of the Gulf of the Farallones Sanctuary Advisory Council as well as from the Gulf of the Farallones 2010 Condition Report (Office of National Marine Sanctuaries 2010). Additional sources since the publication of this report are also cited.

Habitat Sensitivity

1. Direct Sensitivities to air and water temperature and precipitation

A. Temperature (Content excerpted from Largier et al. 2010, except Ekstrom and Moser 2012)

- Lebassi et al. (2009) analyzed 253 California National Weather Stations from 1950 – 2005 and found that **air temperature** in low-elevation coastal areas cooled (-0.30°C/decade) and inland stations warmed (0.16° C/decade). However, a gradual retraction of the North Pacific High could contribute to decreased formation of the marine layer with declines in coastal fog and increases in temperature (Johnstone and Dawson 2010).
- By the end of the century **extreme heat days are expected to increase** dramatically for all areas in the Bay Area, but coastal areas (including San Francisco) are estimated to endure a much higher number of such events (Ekstrom and Moser 2012).
- Over the north-central California continental shelf has cooled over the last 30 years (by as much as 1C in some locations) due to stronger and/or more persistent upwelling winds during spring, summer and fall (Mendelssohn and Schwing 2002; Garcia-Reyes and Largier 2010)

Habitat's sensitivity and response to changes in 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).

B. Precipitation (excerpted from Largier et al. 2010)

Historical

- The past 200 years have consistently been wet when compared with longer-term records (Meko et al. 2001), and statistically significant trends indicate that precipitation (Groisman et al. 2001, Mote et al. 2005) in California has increased since the early 20th century. This is consistent with a 10% increase in precipitation for all of North America since 1910.
- However, analyses by California state climatologist James Goodridge suggest no trend in precipitation from 1890-2002 for the entire state (DWR 2006), with a slight increase in precipitation in northern California.
- Observed increases have been documented in extreme precipitation during single-day events

(Groisman et al. 2001; Kundzewicz et al. 2007) and in precipitation variability (drier dry years, wetter wet years)

Future

- Kim et al. (2002) and Snyder et al. (2002) used global climate models to show that precipitation in California is likely to continue to increase, with the greatest change centered in northern California.
- The rising temperature will cause the form of some precipitation to shift from snow to rain. This is especially important for areas like California that depend on snowpack for water supply. The timing and intensity of precipitation may also change.
- Increased frequency of extreme events is expected, as is increased variability (drier dry years, wetter wet years).

Habitat's sensitivity and response to changes in 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. This habitat is likely to be highly impacted, and therefore, highly sensitive to changes in precipitation. More information is included below.

2. Sensitivities to other climate and climate-driven changes

(Content excerpted from Largier et al. 2010)

The physical structure of estuarine habitat is likely to undergo significant changes in the face of changing climates. Sea level rise is among the most important climate change factors forcing changes in the physical structure of estuarine systems in the coming decades. Other factors such as increasing air and sea surface temperatures and CO_2 may interact with sea level rise to influence the physical environment of these habitats. Climate change is also projected to result in changes in oceanographic and atmospheric linkages resulting in changes in ocean currents and storm cycles that will likely influence estuarine geomorphology, including saltwater intrusion. Finally, the hydrological cycle, including rainfall and outflow from rivers into estuaries will also influence the transport and deposition of sediments with long-term consequences for the physical structure of California estuaries.

The climate-related changes in estuary conditions that are of primary concern are: (i) changes in mouth opening and closure timing and persistence, (ii) changes in degree and frequency of flooding, (iii) upstream salinity intrusion, and (iv) fate of estuary outflows. The extent of changes depends on the interacting drivers, specifically river flow rate, sea level rise, wave energy and wind-forced currents.

A. Sea Level Rise (Content excerpted from Largier et al. 2010)

- A significant increase in sea level is expected, resulting in flooding of littoral marshes and low-lying lands, unless there is a concomitant elevation of the land surface due to flood-induced sedimentation. Rising sea level may alter how tides propagate into estuaries, altering the timing and extent of the tidal rise and fall of water levels.
- Potential effects of sea level rise include shoreline erosion, saltwater intrusion into groundwater aquifers, inundation of wetlands and estuaries, and threats to cultural and historic resources as well as infrastructure. Sea level rise may also increase salinity in the San Francisco delta and other estuaries by as much as 9 practical salinity units (psu) (Knowles and Cayan, 2002), particularly if the period of seasonal low flow expands (Gleick 2000).

- Despite the certainty of rising sea levels, much uncertainty surrounds the long term effects of sea level rise on the physical habitats of estuaries. Many other factors can potentially interact with climate change to influence the rates at which tidal elevation is altered and consequently the extent to which estuarine habitat is lost. For instance, increasing inundation may be offset by increased rates of inorganic sediment deposition (Friedrichs and Perry 2001). Also, increasing CO2 levels may also result in greater production of C3 plants thereby increasing rates of organic deposition (Morris et al. 2002; Körner 2006). However, this increased deposition could, in turn, be offset by increased freshwater intrusion, which can increase rates of decomposition (Weston et al. 2006). In particular, estuarine habitats more dependent on organic rather than inorganic deposition may be more subject to the influences of changes in sea level (Stevenson et al. 1986). Sediment supply remains an important if not completely understood indicator of wetland and estuary resiliency.
- Among the most sensitive species to sea level rise in estuarine habitats are shorebirds because of their dependence on exposed intertidal mudflat habitats for foraging. Studies of restoration planning efforts have shown the importance of tidal elevation for maintaining populations of foraging shorebirds (Stralberg et al. 2008; Goss-Custard and Stillman 2008). Other studies have indicated that sea level rise may have negative effects on foraging budgets of individual shorebirds and influence choice of foraging habitats, such as movement from bays to outer coast areas (Durell et al. 2006, Goss-Custard and Stillman 2008). Pinnipeds are also very sensitive to changes in sea level because their resting and breeding habitat is inundated. Loss of intertidal habitats may not be replaced by inward migration and there may be no alternate habitat for seals to rest and breed (pers. comm., Sarah Allen, NPS). Sea level rise is also likely to strongly influence the plant and animal communities of the nearshore benthos (Scavia et al. 2002).
- Sediment delivery and availability will strongly influence the ability of estuaries to adjust to rising sea level and maintain intertidal estuarine habitat (Ackerly et al. 2012).
- Projected rise in sea levels along the California coast may shift species interactions, particularly in urbanized estuaries or other ‘armored’ habitats where migration to higher tidal elevations is restricted (Heberger et al. 2009). Estuaries with reduced tidal exchange (microtidal) experience slower rates of vertical accretion resulting from the accumulation of organic matter. Therefore, species in these estuaries may be at greater risk of inundation due to sea level rise than species in estuaries with greater tidal exchange (mesotidal), where more rapid accumulation of inorganic sediments may be more likely to compensate for rising sea levels (Stevenson and Kearney 2009).

B. Erosion

Brackish and salt marsh estuarine habitats are likely to be exposed to salt water more frequently and at higher elevations. This expansion of subtidal wetlands will increase the area for wind wave formation potentially accelerating erosion along the marsh edges (Content excerpted from Largier et al. 2010). Sedimentation from erosion in the watersheds may increase the duration of mouth closures, as has been the case in Estero Americano and Estero de San Antonio (Office of National Marine Sanctuaries 2010).

C. Flooding and increased wave action (Content excerpted from Largier et al. 2010)

- Increases in storm intensity, rain intensity and sea level rise would lead to more frequent and more severe flooding of low-lying lands, requiring decisions on the merits of flood control versus natural functioning and system adaptation.
- River flow working with tidal flow is important in maintaining an open mouth in bar-built estuaries, removing sediment deposited in the mouth by wave action. The seasonal cycle of estuary mouth

opening and closure will change in response to changes in river flow, tidal prism changes due to sea level rise, and changes in wave energy. If river flow is enhanced (stronger and more persistent) or wave forcing becomes weaker, then the mouth will remain open longer – or, alternatively the mouth will tend to close for weaker river flow and/or stronger waves. In addition to changes in intensity, changes in the relative seasonal timing of river flow and wave energy are important. If river flow continues later in spring, this may keep the mouth open beyond the time when waves are big enough to close an estuary – in which case that estuary could remain open much longer than previously (e.g., Behrens et al. 2008). Alternatively, if river flow decreases early, while waves are still large, the estuary will close much earlier than previously (and may prevent estuary-ocean migrations that typically occur in spring, e.g., smolts emigrating to the ocean). Under severe drought conditions, estuaries may not open in sync with salmonid life cycles, preventing upstream migration for spawning.

D. Water Chemistry (Content excerpted from Largier et al. 2010 except ONMS 2010)

- Sea level rise and reduced freshwater inflow are expected to result in landward movement of saline waters (unless the estuary mouth closes before the seasonal decrease in river flow). In estuaries fed by coastal watersheds, concern is more related to winter periods as many estuary mouths close in summer. However, the mouths of the tributary estuaries in the semi-enclosed bays do not close (e.g., Lagunitas Creek) and the combination of rising sea level and decreased summer runoff is expected to result in significant intrusion of saline waters, affecting local water resources.
- When estuaries are closed in summer, they function as a salt-stratified lake. The lower, high salinity layer is trapped and may develop hypoxic or anoxic conditions (e.g., Russian River) and/or very high water temperatures (e.g., 34^{o}C in Salmon Creek, Largier et al. 2007). Longer closures may aggravate these conditions. When estuaries are open, there is a continual exchange of ocean and estuary waters – and a surface plume of estuarine water forms during ebb tides (or continuously during periods of strong river flow). This plume delivers biogenic material, sediment and contaminants to nearshore waters. The fate of these plume waters and their loading will change with climate-related changes in outflow water density (due to salinity), mouth condition, nearshore wave-forced currents, and offshore wind-forced currents. When estuaries are open, there is a continual exchange of ocean and estuary waters – out on the ebb tide and in on the flood tide. During strong river flows, there may be continuous outflow. Whether these estuarine outflows are primarily aged ocean water or land runoff water, the outflow forms a distinct jet near the mouth that evolves into a stratified plume at greater distances from the source. This plume delivers biogenic material, sediment and contaminants to nearshore waters (and offshore waters in the case of larger outflows, such as San Francisco Bay and Russian River estuary).
- The reduced tidal prism (the volume of water covering an area between a low tide and the subsequent high tide) results in reduced flushing and reduced scour of the mouth when it does open. As a result, the esteros may be hypersaline at times (Hickey 2007) or evolve into low-salinity "lakes" if they remain closed for more than a year (J. Largier, Bodega Marine Lab and The Ocean Conservancy, pers.com.) Similar problems occur in the watershed of Bolinas Lagoon, where diversion of freshwater inputs from creeks and streams flowing into the lagoon and increased sedimentation from natural and anthropogenic sources have reduced the tidal prism of the lagoon (Leet et al. 2001, SWRCB 2006, GFNMS 2008a). (Content excerpted from Office of National Marine Sanctuaries 2010)
- Ocean acidification may adversely affect estuaries because they are subject to freshwater input that lowers buffering capacity as well as intrusion of upwelled waters from the adjacent coastal ocean.
- Freshwater inundation may lower the pH of estuaries by reducing the buffering capacity of estuaries with lower salinities, higher organic inflows and more acidic freshwater. These are conditions found in Tomales Bay (Smith and Hollibaugh 1997; Marshall et al. 2008).

E. Runoff

- Significant climate-related changes in land runoff strength and timing are expected in addition to changes due to water management in each watershed. Strong runoff is key in flushing estuary basins, but also may scour bottom sediments and erode estuary banks. Where banks are compromised (due to human activities), extreme flow events will lead to major changes in morphology and disruption of socio-economic activities (Content excerpted from Largier et al. 2010).
- Estuaries with regular and substantial inputs of freshwater may be influenced by changes in watershed outflow (Kimmerer 2002). Predictions for much of California suggest that the amount of water entering estuaries will have increased interannual variation (Cayan 2008). However, equally influenced may be estuaries where the outflow and connection to coastal marine waters may be seasonal or intermittent (Largier and Taljaard 1991). These 'barbuilt' estuaries, which include Estero Americano and Estero de San Antonio in GFNMS, are strongly influenced by the creation of sandbars that are in turn affected by changes in the magnitude and variability of runoff (Kensch 1999).

3. Sensitivities to non-climate stressors

A. Shoreline armoring (Content excerpted from Largier et al. 2010)

- Along estuaries with *unarmored* barrier spits (e.g., Drakes Estero) overwash events will be more frequent, depositing sediment on the inland side of the spit. These overwash deposits generally form small deltas, which over time can result in a "rollover" of the spit, or landward migration of the entire spit toward the mainland. This "rollover" may reduce the tidal prism and flushing characteristics of the lagoon and potentially lead to changes in frequency and duration of breaching events.
- An important factor that will influence estuarine response to sea level rise is the ability of estuaries to migrate where the upland border abuts roads, levees or other armored structure or by natural steep slopes or bluffs. This upper border may result in an accelerated loss of habitat as has been demonstrated for sandy beaches (Fletcher et al. 1997; Dugan et al. 2008). It also may severely limit the upland migration of estuarine plants and animals as rising sea levels inundate lower tidal elevations (Dugan et al. 2008). Areas where estuarine upland borders are partly or entirely surrounded by armored structures or by bluffs and slopes are therefore significantly at risk of habitat loss.
- Road construction and coastal armoring continues to be a problem along sections of the coastal highway (Bolinas and Tomales) and in other areas of coastal development. Although localized, these activities can have a high impact as they can convert the habitat type, increase erosion rates and have the potential to result in large-scale debris (Content excerpted from Office of National Marine Sanctuaries 2010).

B. Human use (fishing, recreation)

(Content excerpted from Office of National Marine Sanctuaries 2010)

- Fishing in the estuaries includes commercial harvest of oysters in aquaculture facilities, sport take of clams, and some fishing for herring, rock crab, perch and halibut, all in Tomales Bay. Generally, however, there is not a great deal of commercial or recreational extraction of native species in the estuaries, and targeted species are highly variable depending on environmental conditions (e.g., El Niño influences and sedimentation shifts).
- Vessel activities and recreational shell fishing has caused disturbance of marine mammal haul-outs in Tomales Bay and Bolinas Lagoon.

- Fishing activities can also displace eelgrass and oyster beds. Further, mariculture of several bivalve species in Tomales Bay includes potential negative impacts: (i) the presence of mariculture-farming equipment can reduce eelgrass cover and alter sediment deposition patterns; (ii) maintenance operations can trample sediments and damage eelgrass beds; and (iii) bivalve shells and associated farming equipment often provide large amounts of hard substrate habitat that is not naturally present, thus altering species communities (Carr et al. 2008).
- Sedimentation can bury eelgrass and oyster beds, although rates are improving in Tomales Bay due to recent restoration efforts (Kimbro and Grosholtz 2006). Tomales Bay has shown substantial loss of native oyster beds, which may be the result of human-caused impacts, such as past coastal armoring, increased moorings, anchoring and abandoned vessels impacting the benthic habitat, and roadside maintenance activities that result in increased sediment discharges, causing a decline or change of the tidal prism.

C. Pollutants/Contaminants

(Content excerpted from Office of National Marine Sanctuaries 2010)

- Land use pressures have impacted water quality in some of the estuaries in the sanctuary, resulting in changes to sediment and freshwater regimes; increased restoration activities and best management practices may offset water quality problems that have historically resulted in loss of eelgrass beds.
- There have been consistent closures of aquaculture and shellfish harvesting in Tomales Bay, and to a lesser extent Drakes Estero (within the Point Reyes National Seashore), due to predictable impacts from nonpoint sources of contamination linked with rainfall. Significant rainfall results in levels of indicator bacteria (e.g., fecal coliform) that exceed national standards for commercial shellfish growing areas.
- The dinoflagellate *Alexandrium* spp. is a normal constituent of the phytoplankton community along the nearshore and estuarine areas of the sanctuary and is more commonly found than other biotoxin producing phytoplankton, but there have been no reports of high toxin levels in shellfish within the sanctuary since the early 1990s (G. Langlois, CA Dept. of Public Health, pers. comm. 2010). Therefore, selected conditions may preclude full development of living resource assemblages and habitats, but are not likely to cause substantial or persistent declines and this question is rated "good/fair." However, it is "undetermined" if there is a detectable trend or change in the occurrence of eutrophic conditions.
- Watershed stressors from mining, municipal dumps, leaking septic tanks, livestock grazing, agricultural runoff (primarily animal waste from dairies and rangelands) and vessels can result in high coliform and bacterial contamination, increased sedimentation and contamination with toxic materials (e.g., high mercury levels) in the estuary waters, impairing their health. 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) - see Table 6. The impairments constitute a broad range of impacts, from high nutrient loading to increased siltation and bacteria. Identified water quality impacts result in seasonal closure and rainfall closure of shellfish beds to minimize inputs due to runoff (Table 7).
- Due to the proximity of Bolinas Lagoon to the busy maritime ports and harbors in San Francisco Bay and the presence of major vessel traffic lanes, there is a high risk of oil and/or other hazardous material spills. Oil spills can pose serious threats to intertidal communities, seabirds and marine mammals. Socioeconomic impacts to commercial and recreational industries such as fishing and wildlife viewing/tourism can arise as the result of an oil spill (Content excerpted from Bolinas Lagoon 2008).

Table 6
Impaired bodies of water in the sanctuary estuarine habitat as listed under the State 303(d) list. 303(d) lists are prepared as part of the Water Quality Assessment of the state's major water bodies, and meet a requirement of section 303(d) of the federal Clean Water Act. (Source: SWRCB 2006)

Water Segment	Source of Impairment	Weight of Evidence
Bodega Harbor (adjacent to the sanctuary)	Exotic Species	Source unknown.
Estero Americano and Estero de San Antonio	Nutrients, Sedimentation/Siltation, Total and Fecal Coliform Bacteria, and Indicator Bacteria	Pasture and range grazing (riparian and upland); intensive animal feeding operations; manure lagoons and dairies in watershed; hydromodification and streambank modification or destabilization; removal of riparian vegetation; nonpoint source for some coliform bacteria.
Tomales Bay: Lawson's Landing, Lagunitas Creek, and Walker Creek and Delta	Mercury, Nutrients, Sedimentation/Siltation, and Indicator Bacteria	Past surface mining and mine tailings in watershed (leftover substrate); agriculture; upstream impoundment; urban runoff and storm sewers; unknown sources.

Table 7
The number of rainfall closure days, by zone, in Tomales Bay, 2003-2008. See Figure 40 for corresponding map of Growing Area locations, A-D and rainfall closure sections. (Source: CA Dept. of Public Health)

Rainfall closure rules for all conditionally approved commercial shellfish growing areas in Tomales Bay are based on a joint study by the California Department of Health Services and the U.S. Food and Drug Administration conducted in winter 1980. This study concluded that rainfall-related runoff was the principal cause of observed elevated bacterial levels (Source: State of Tomales Bay Proceedings 1992).

Growing Area	**Days Closed (July 2007-Febuary 10, 2008) Total Rainfall 21.30"(2/7/2008)**	Days Closed (July 2006-July 2007) Total Rainfall 20.03"	Days Closed (July 2005-July 2006) Total Rainfall 45.20"	Days Closed (July 2004-July 2005) Total Rainfall 31.42"	Days Closed (July 2003-May 2004) Total Rainfall 22.01"
A	**63**	**75**	116	105	83
B	**59**	**61**	100	89	78
C	**66**	**70**	106	103	88
D	**72**	**94**	125	127	99

D. Invasive Species

Several exotic species discharged in vessel ballast water (and from other sources) have been identified in local bays and estuaries. A major source of invasive species in Tomales Bay is dispersal along the coast from major ports due to the movement of boats (T. Grosholz). These estuary waters provide optimal environments for their growth. An invasive species inventory for the sanctuary was completed in 2007 to gain a more complete picture of the species involved and their potential effects. The sanctuary plans additional studies to determine their distribution and abundance. Plans are also underway for a volunteer monitoring program for early detection of newly introduced species (SIMoN). Sea level rise could favor introduced species more tolerant of increased tidal inundation relative to natives, and projected increases in storm intensity and frequency and resulting changes in coastal geomorphology (Day et al. 2008) could provide more opportunity for spread of opportunistic coastal invaders. Climate change is likely to interact with coastal invaders in ways that are likely to increase their impacts, facilitate their spread and necessitate additional management actions.

- The establishment of invasive species, such as green crabs and mud snails, is expected to continue to impact these relatively small ecosystems. In general, introduced species in the marine and estuarine environment alter species composition, threaten the abundance and/or diversity of native marine species, interfere with the ecosystem's function and disrupt commercial and recreational activities (GFNMS 2008a).
- Marshes within the San Francisco Bay have been invaded by an east coast plant, smooth cordgrass *(Spartina alterniflora),* ironically introduced to stabilize the shoreline. Smooth cordgrass cross-breeds with native California cordgrass, producing “super hybrids’ that grow much taller and with denser stems than the native species, and that can survive both lower and higher intertidal zones. Threat from non-native *Spartina* in the study region has been very limited due to reduced connectivity with San Francisco Estuary and its invasive populations. However, isolated clones of hybrid *S. alterniflora* have established in Drakes Estero, Estero de Limantour, and Bolinas Lagoon. The Invasive Spartina Project has effectively used tarping for the various infestations of hybrid *S. alterniflora* on the marsh plain in the outer coast region due to restrictions on herbicide use, and digging of *S. densiflora* has greatly reduced those isolated colonies to near eradication (Rohmer 2014). If hybrid cordgrass became well established within the estuaries these outer coast estuaries, it could fill many of the mudflats used by shorebirds, drastically reducing the birds foraging areas. The small invertebrates that live within the sediment of salt marshes and mudflats are the food of migrating shorebirds and form the base of the food web (Brusati 2006).
- Changing patterns of precipitation and consequently outflow may have significant affects on the biota of estuaries as well (Kimmerer 2002). Predictions for much of California suggest increasingly interannual variability in rainfall and outflow patterns (Cayan et al. 2008). Current predictions suggest that these increasingly variable flows may favor the invasion of coastal estuaries by invasive species. These changing patterns of outflow will mean that there will also be increasing changes in the salinity gradient with substantial consequences for estuarine biota (Content excerpted from Largier et al. 2010).

E. Harmful Algal Blooms

- There are anecdotal reports of macroalgae eutrophication in sanctuary estuaries, but no regular surveys to properly assess this (Office of National Marine Sanctuaries 2010).
- Metabolism (and therefore oxygen consumption) in Tomales Bay is fueled by inputs of phytoplankton biomass produced in the adjacent upwelling system [Smith et al., 1996]. Harmful algal blooms in coastal waters provide inocula for blooms of harmful species to develop in estuaries [Cloern et al., 2005]. Therefore, inputs from the ocean and especially from upwelling systems can have similar consequences to those of anthropogenic nutrient enrichment: high nutrients and phytoplankton biomass, low DO, and harmful algal blooms (Content excerpted from Cloern and Jassby 2012).
- As storm-induced floodwaters recede, they will draw debris, fertilizers, and other contaminants into coastal waters and estuaries, compromising water quality. Such an increase in runoff has the potential to increase the frequency and intensity of harmful algal blooms (HABs) in the sanctuary, posing serious threats to local fisheries, birds and marine mammal populations (Content excerpt from SIMoN).

F. Disease

- Increased temperatures may generally put greater stress on plants and animals and magnify problems with parasites and pathogens (Largier et al. 2010).

- There have been two outbreaks of *Norovirus* in Tomales Bay within the past 10 years, causing gastrointestinal illness in over 170 people (Langlois et al. 1998).

Habitat Adaptive Capacity

1. Extent, Integrity and Continuity

A. Geographic extent of habitat: endemic, transcontinental, etc?

Estuaries occur world-wide along the coastal zone, wherever rivers meet the ocean. They cover a global area of around 10^6 km^2 and encompass around 4% of the world's continental shelf.

Some of the State's largest wetlands occur in the central region of California, which extends from Cape Mendocino to Point Conception. Numerous small coastal wetlands, usually at the terminus of coastal streams exist in this region.

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. These estuaries provide important marine and nearshore habitats for a diverse array of marine mammals and birds in addition to fishery, plant, algal and benthic resources. They are also important components of the Pacific Flyway, one of the four principal bird migration routes in North America. Bolinas Lagoon and Tomales Bay are designated "wetlands of international importance" under the Convention on Wetlands of International Importance (the Ramsar Convention). The Esteros Americano and de San Antonio are coastal estuaries located on Bodega Bay. Estero Americano drains into Bodega Bay at the Sonoma-Marin County line. South of Estero Americano, Stemple Creek becomes the Estero de San Antonio, also draining into Bodega Bay (SIMoN). Estuaries at the mouths of smaller watersheds, like Rodeo Lagoon and Redwood Creek in Marin County, also provide significant habitat for endangered species including tidewater goby and salmonids (pers. comm., Daphne Hatch, GGNRA).

B. Structural and functional integrity in study region: is the habitat typically pristine or degraded?

Overall, resources of the region's estuarine and lagoon areas appear to be in good/fair to fair/poor condition. Land use pressures have caused changes to sediment and freshwater regimes. However, water quality may possibly improve due to implementation of best management practices, cleanup of mining pollutants, and removal of derelict vessels. Pressures on habitat that have caused key habitat loss or alteration include decades of poor watershed practices resulting in water diversion, in-flow of heavy metals from abandoned mines, pollutants from dairy ranches, and increased sedimentation resulting in loss of ecologically important eelgrass beds (a key species of the sanctuary). Living resources have experienced a loss of biodiversity, causing declines in some, but not all, ecosystem components. Non-indigenous species are a threat to the health of the sanctuary, but while most of these 143 species are located in the estuarine and lagoon environment, there is little data on their abundance and distribution (2010 GFNMS Condition Report). Little is known about the integrity of maritime archaeological resources in the estuarine and lagoon zone; however, based on available information, there are no known threats at this time, though NPS monitoring in Drakes Estero and Tomales Bay indicates that sea level rise and erosion will likely threaten these resources in the future (pers. comm., Sarah Allen, NPS). More data collection and targeted data analyses are needed for determining status and trends in water quality, living resources (particularly non-indigenous species), and especially maritime archaeological resources. More information is also needed regarding the effects that restoration actions have had on sanctuary resources (2010 GFNMS Condition Report). Unlike many coastal wetlands in the State, the Estero Americano is relatively undisturbed. This is due, in large measure, to the unique continuity of land ownership and land use patterns in the watershed (Hickey 2007).

Biodiversity in the estuaries of the Gulf of the Farallones sanctuary is rated "fair/poor" and "declining," because it is probable that selected habitat loss or alteration has caused or is likely to cause severe declines in some but not all ecosystem components and reduce ecosystem integrity. The principal reason for the low rating is the loss of eelgrass (*Zostera marina*), a key habitat for estuarine species, particularly in Bolinas Lagoon (T. Moore, CDFG, pers. comm.).

C. Continuity of the habitat: is it continuous or occur in isolated spots?

Large-scale evolutionary processes have acted to produce a highly variable coastal zone with numerous relatively isolated and unique wetland landscapes (excerpted from Procedural Guidance 1994).

Climate change is likely to alter linkages between atmospheric and oceanographic forces resulting in changes in upwelling, coastal advection and variety of processes influencing the transport of organisms within and between estuaries (Gawarkiewicz et al. 2007). These changes in coastal ocean transport processes are likely to result in changes in the frequency or magnitude of delivery of plankton and various larval and adult dispersal stages among estuaries (Harley et al. 2006). Therefore, the degree of connectivity among populations and communities, both from a population genetic and a population dynamic perspective, are likely to be altered with unknown consequences (excerpted from Largier et al. 2010).

2. Habitat Diversity

A. Diversity in topographic and physical characteristics

A diverse range of coastal landforms fall into the estuary designation, including bays, harbors, inlets, lagoons, wetlands, esteros and marshes. Estuaries may be bar-built (ephemeral), open river mouths (open year-round due to large freshwater flows), or perennially tidal (open year-round) (SWRCB). In bar-built estuaries, a strong fluvial influence results in the formation of a sand bar at some point during the year. A pond forms behind the bar and connection with the marine environment is reduced or severed. The Estero Americano is considered a “seasonal estuary” due to the formation of a sand bar at the mouth of the estuary during the late spring and summer months. A barrier beach across the mouth of the Estero controls the fluctuation and recurrence of tidal inflows. Bar formation appears to be a function of the prevailing northwest winds and to result from littoral currents carrying tidal sediment loads from local beaches and possibly from Doran Spit (Buell, 1988). (Content Excerpted from Hickey 2007)

B. Diversity in species/functional groups

Estuaries represent the confluence of terrestrial, freshwater and marine ecosystems, creating multiple unique habitats that support highly diverse communities and provide crucial links to many nearby ecosystems (excerpted from SIMoN). Eelgrass beds provide refuge, food source and nursery space that supports a rich diversity of fish and wildlife, including many commercially and recreationally important fish species, shorebirds, waterfowl, crabs, shrimp and many other invertebrates. Estuaries act as critical habitat for fishes that utilize these areas for all or a part of their life history, and for foraging predatory fish, birds and marine mammals. Climate change may affect commercially and recreationally fished species such as juvenile California halibut (*Paralichthys californicus*), bat rays (*Myliobatis californicus*), and leopard sharks (*Triakis semifasciata)* that utilize estuaries as nursery or feeding grounds by modifying estuarine habitat (excerpted from Largier et al. 2010).

C. Dependence on a single keystone species? (Content excerpted from Office of National Marine Sanctuaries 2010)

Key species particularly important to these habitats include eelgrass, tidewater goby and Black Brant. There are many other important and endagnered species located in the estuarine and lagoon zones of the sanctuary, including herring, leopard shark, bat ray, harbor seal, Snowy Plover and Brandt's Cormorant. Insufficient data exist on the health of these species in the region's estuaries. The two native species that form biogenic habitat in the estuaries of the sanctuary, **eelgrass** (*Zostera marina*) and **native oyster** (*Ostreola conchaphila*), have experienced a reduction in abundance from historic levels in some (not all) systems (Kimbro and Grosholtz 2006). Therefore, selected habitat loss or alteration may inhibit the development of living resources, and may cause measurable but not severe declines in living resources or water quality.

Eelgrass (*Zostera marina*) is a keystone species that has shown signs of decline in some estuaries, including nearly extinct levels in Bolinas Lagoon but not in Tomales Bay (Leet et al. 2001, GFNMS 2008a). The loss of eelgrass beds has a cascading effect on the countless other species that depend on this habitat for survival. Ten to 100 times more animals can be found in eelgrass beds compared to adjacent sandy and muddy habitats (Olyarnik 2007). Eelgrass plays an important role within the estuaries:

- More than 20,000 shorebirds and seabirds — including loons, grebes, geese, cormorants and duck — winter in Tomales Bay; these migratory birds feed upon the abundant fish and invertebrate species associated with the eelgrass beds.
- Harbor seals and sea lions forage in eelgrass beds on spawning fish such as herring in Tomales Bay.
- Pacific herring use the beds for spawning.
- Eelgrass also supports a diverse invertebrate community, including snails, shrimp, nudibranchs and sea hares.
- The beds also help trap sediments and reduce excess nutrients and pollutants in the water column, and they serve as buffer zones, protecting the coast from erosion.

Supplemental Species Information

Pacific Herring:

- Uses Eel grass as spawning beds and are mainly found in Tomales Bay (SIMoN).

Chinook Salmon: (Content excerpted from Office of National Marine Sanctuaries 2010)

- The productivity of estuaries and lagoons may change with large-scale fluctuations in climate. Populations of some species, including salmonids, vary with climate fluctuations and changes to migration corridors and spawning habitats. For example, in the mid-1970s, the Pacific changed from a cool water regime where anchovy dominated to a warm water regime where sardine dominated. A shift back to an anchovy regime occurred in the middle to late 1990s (Chavez et al. 2003). These changes in salmonid forage fish may have cascading trophic impacts.
- The disturbance and destruction of upland salmon spawning habitat and the creation of dams have resulted in declines of all populations of salmon. Several subpopulations of Chinook salmon (Figure 44), Coho salmon, and steelhead trout in Central California are extinct, and the remaining populations have been listed as federally endangered and threatened.

Tidewater Goby:

- The endangered tidewater goby, *Eucyclogobius newberryi*, breeds in the shallow waters of Estero de San Antonio, Rodeo Lagoon, and the Giacomini wetlands at the southern end of Tomales Bay, with a translocated population on the west shore of Tomales Bay. There may be some extant populations in San Mateo County (SIMoN; pers. comm., Daphne Hatch, GGNRA).
- The tidewater goby has lost a major portion of its habitat during the past 150 years to coastal development activities and was listed as a federally endangered species in 1994. The goby has nearly disappeared in California due to habitat loss and degradation, and requires continuous low salinity conditions and tidal wetland habitat typical of upper estuaries (Hickey 2007).
- Although the endangered tidewater goby *(Eucyclogobius newberryi*) appears to be stable and locally abundant in some sanctuary estuaries, including Estero Americano and Estero de San Antonio, in general their abundance has declined substantially due to habitat loss and degradation and poor salinity and other water quality conditions (USFWS 2005, excerpted from Office of National Marine Sanctuaries 2010).

Harbor seal:

- Harbor seals (*Phoca vitulina*) are the only year round marine mammal resident of estuaries. They breed on intertidal sand bars within the estuaries and on protected shoreline beaches.
- Seal numbers have increased in the Sanctuary waters since passage of the Marine Mammal Protection Act in 1972 and numbers are relatively stable over the past decade (Sydeman and Allen 1999). Within Tomales Bay, though, human activities such as recreational shellfishing and boating disturb seals resting and nursing on sandbars. NOAA had a volunteer protection program for several years that helped to reduce disturbances (SEALS), but in recent years the rate of disturbance has increased which may explain the lower number of pups born there (Codde et al. 2013).
- Climate change effects from loss of intertidal habitat to SLR and increased ENSO events may reduce seal productivity and overall population if there are no alternative habitats.

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