Science Priorities for Understanding Climate Change Impacts on the Ecosystems of San Francisco Bay and the Gulf of the Farallones

A workshop convened by the Bay Area Ecosystems Climate Change Consortium

Tuesday, April 24, 2012, 8:30 am - 3:00 pm
Board Room, California Academy of Sciences
55 Music Concourse Drive
San Francisco, CA

Meeting Summary

Attendees:

Bill Bennett, UC Davis
Richard Dugdale, SF State
Toby Garfield, SF State
Matt Gerhart, Coastal Conservancy
Andy Gunther, BAECCC
Wim Kimmerer, SF State
Jeff Koseff, Stanford
John Largier, UC Davis
Tom Mumley, SF Regional Water Board
Dave Schoellhamer, USGS
Mark Stacey, UC Berkeley
Bill Sydeman, Farallon Institute
Jan Thompson, USGS
Sam Veloz, PRBO Conservation Science

Invited but unable to attend:

Noah Knowles, USGS
James Cloern, USGS
Steve Monismith, Stanford

Summary of Outcomes

The group:

- Identified a list of key climate change drivers and key ecosystem attributes that relate to management goals for protection of the beneficial uses of the bay and gulf.

- Identified science priorities “internal” to the bay/gulf region and ones that are “exogenous” or boundary-condition dependent, whether management-mediated or climate-mediated.
- Discussed each driver and elaborated key linkages by which ecosystem attributes will be affected.
- Identified which drivers currently have robust projections associated with them and which do not.
- Ranked both the relative importance of each climate-driven linkage in terms of its overall impact on the ecosystem and the level of uncertainty associated with that potential effect.
- Developed criteria for what mix of importance and uncertainty may elevate a climate change/ecosystem attribute linkage as priority for further research.

Introduction/Context. Andy Gunther gave a brief summary of the Bay Area Ecosystems Climate Change Consortium (BAECCC), stressing the BAECCC’s approach of establishing iterative opportunities for natural resource managers and scientists to work together to identify research priorities that address the challenges of ecosystem adaptation to climate change. Matt Gerhart noted that there are many land and resource managers in the region already seeking guidance from the scientific community regarding how to make “climate smart” decisions for the land and resources under their management. Managers include a broad community from those making decisions on their own lands, to organizations facilitating development of natural resource management strategies, to local regional and state policymakers, land use authorities, and regulators influencing land management and pollution-control decisions.

Management goals for the ecosystem. Participants noted that for scientists to support managers as requested it would be most helpful to understand management goals, which can be challenging for an ecosystem. Andy Gunther noted that the *State of the Bay 2011* approached this problem by utilizing the framework recommended by the US EPA Science Advisory Board, in which management goals are expressed as valued ecosystem attributes and indicators of these attributes. Andy noted that one of BAECCC’s goals in creating iterative opportunities for communication between the management and scientific community is to identify significant impacts to valued attributes likely to be caused by climate change.

The group then identified and organized key attributes (and indicators) as habitat (*e.g.* wetlands extent), populations (fish, bird, mammal abundance/composition), water quality (biogenic components, contaminants, phytoplankton, nuisance/toxic algal blooms), community composition (invasive species), and healthy (productive/resilient) food webs. Andy noted that for the *State of the Bay 2011* a similar set of attributes of a healthy Bay was developed (habitat, water quality, water quantity, living resources, ecological processes).

Criteria for identifying research priorities. The group agreed that research priorities are areas where ecosystem impacts linked to climate change are expected to be significant and where there are important uncertainties that can be reduced through research. These include both areas where there is relative certainty regarding the forcing mechanisms at play (*e.g.,* sea level rise) but new information is needed to establish the most likely effects on the ecosystem, and areas where uncertainties in forcing mechanisms themselves exist that can feasibly be reduced through research.

When the likelihood of a net climate change impact is less clear (*e.g*., future Bay temperatures), a climate/ecosystem linkage might be less of a priority for research, although this judgment must be tempered by the relative consequences of impacts from the forcing. Thus, a high consequence impact from a poorly understood forcing may merit as much research attention as an impact of moderate consequence resulting from a forcing that is very likely.

Drivers of ecosystem change. The group then developed a list of the key drivers of ecosystem change that are likely to result from climate-induced changes in physical forcings. The expected alterations considered by the group to be the most robust included sea level rise, increased air temperature, and ocean acidification. While predictions of large-scale changes in wind patterns may be robust, the effects of climate change on local winds are considerably more uncertain. Other drivers with less certainty about expected alterations included precipitation (associated with changes in runoff and sediment transport), water temperature, upwelling (related to wind), and forcings remote to the region such as changes in the Pacific Decadal Oscillation or the North Pacific Gyre Oscillation.

The group then discussed how each of these drivers would be expected to impact the Bay-Gulf ecosystem to identify potential research priorities. Based upon the understanding of management goals, impacts were separated (to the extent possible) among high, moderate, or low importance in terms of their relative effects on the ecosystem. The impacts were further separated between those that were of relatively low uncertainty, where ecological responses to the changed climatic conditions can be predicted with confidence, and those where ecological response is highly uncertain. Impacts of high importance and high uncertainty would be a priority for further research, where that research can effectively reduce management-related uncertainty, while impacts of higher importance and lower uncertainty might still be priorities for specific reasons (particularly the need for additional research to clarify effective management options).

The drivers discussed were air temperature, water temperature, sea level rise, upwelling, precipitation/runoff, and remote forcing. The discussion of each of these drivers is summarized below. It is important to note that a theme running throughout these discussions was that climate change is one driver of change for the ecosystem, and should not be considered in isolation of other drivers of ecological change. These include pollution, water conveyance operations, nutrient inputs, and seismic failure of delta levees.

Air Temperature. It is highly likely that average air temperatures will rise in the Bay Area due to climate change. Ecological changes of high importance identified by the group included changes in fog and direct temperature effects on intertidal habitats. The group considered understanding of changes in the regional fog regime to be an area of high uncertainty, while impacts of temperature on the intertidal community was an area of low uncertainty.

Water Temperature. The group concluded that the impact of climate change on water temperatures in the Bay and Gulf are not clear. While some heating from higher insolation might be expected, water temperatures in the Bay are also influenced by water temperatures in the

Delta and coastal ocean. It is not certain how water temperatures in these neighboring areas will trend (particularly in the Gulf), and how the temperature of these regions will impact the Bay.

Important ecological changes in a warmer bay include increased metabolic rate (and concomitant stress) for plants (including eelgrass) and animals, and alterations in the composition of phytoplankton communities with a possible increase in harmful/nuisance algal blooms. There is high uncertainty regarding these changes. Increased temperature will also be likely to contribute to stronger stratification, although the incremental change likely to come from rising water temperatures themselves was considered of low importance in comparison to stratification resulting from changes in wind-driven mixing or salinity.

Sea Level Rise. The group considered it highly likely that sea level will rise in the Bay/Gulf, although in the Bay the actual sea level rise at any given location will be influenced by shoreline management actions (such as sea wall construction) or major shoreline alterations such as failure of key levees. Climate change impacts of high importance included potential reductions in intertidal area (will vary by embayment), changes in the location of head of tide (leading to altered sediment deposition patterns and reduced flood control capacity), shoreline erosion due to loss of tidal flats, and an increase in the tidal prism. The uncertainty associated with these changes was considered to be low except for the change in tidal prism, which was considered of medium uncertainty.

Other impacts expected in the Bay include the drowning of eelgrass beds (medium importance), salinity intrusion, increase in subtidal habitat (with potential benefits as well), and loss of marine mammal habitat (low importance, as mammals are expected to move to alternate locations).

In the Gulf of the Farallones, sea level rise will lead to changes in the location of intertidal habitat, which was considered of moderate importance and low uncertainty. Erosion of beaches is also considered a low-uncertainty impact of high importance. Loss of marine mammal haul-outs was considered an impact of low uncertainty and importance (mammals are expected to move to alternate locations).

Upwelling. Changes in upwelling patterns will have a significant impact on the Gulf of the Farallones, although the actual impacts of such changes will be greatly influenced by their strength, timing, and persistence. While stronger along-shore winds could lead to stronger upwelling, the group attached large uncertainty to the magnitude of the effect, and even greater uncertainty on the impacts for the ecosystem. If increases in upwelling are moderate, there is little uncertainty in the projections that more upwelling would bring more cold water and nutrients to the upper water column, and enhanced southward transport in the region, all changes considered of high importance. These changes will likely result in larger krill populations that will benefit krill predators such as salmon and auklets, changes the group thought were important but of moderate uncertainty. Changes in upwelling can also change the abundance and distribution of fog, an impact considered of high significance and high uncertainty. At the same time, if upwelling is too strong, it will lead to strong offshore transport and low recruitment in the pelagic community, likely leading to important negative impacts on valued ecosystem attributes ("too much" upwelling). This can also lead to changes in composition of the phytoplankton community, although this impact was considered more uncertain than changes in transport.

Stronger upwelling is also likely to produce important changes in San Francisco Bay (particularly in Central Bay), including increased flux of nutrients and organic matter, enhanced larval transport into the estuary, and enhanced in-migration of juvenile and adult animals. There is more uncertainty associated with larval transport and nutrient fluxes, and less with in-migration of marine animals. Other changes in the Bay could include, altered pH (reduction likely due to introduction of water with lower pCO2), changes in ocean-estuary exchange, transport of harmful algal blooms into the estuary, and increased stratification (reinforced by insolation and runoff). These other changes were not assessed for their importance or uncertainty during the discussion.

If upwelling were to be suppressed by climatic drivers, more water from the Bay would move into the Gulf. Bay water exiting the Golden Gate travels north along the shore to Pt. Reyes and beyond, and would have the potential to affect nearshore water quality. This change was considered of moderate importance, especially on the local scale of coastal estuaries such as Bolinas lagoon, with relatively low uncertainty.

Precipitation/Runoff. While the group agreed that it is likely that alteration of precipitation and runoff patterns due to climate change will have significant effects on the Bay/Gulf ecosystem, these alterations are hard to project for two reasons. First, there is not robust agreement among GCMs with regards to precipitation in the San Francisco Bay watershed, with some models projecting drier conditions on average while other models projecting less change in total precipitation (it was noted that for higher emissions scenarios a drier future is projected more robustly).

Second, the impacts of changes in precipitation and runoff are moderated by reservoir operations for flood control. It was noted that there is increasing incentive (given development of low lying land in the Central Valley) for reservoir operators to manage for flood control (releasing more water in winter/spring to create flood control capacity) rather than water supply (retain more water for release in summer/fall). It was noted that many watersheds in the Bay Area either have no reservoir capacity or have reservoirs that are used only for water supply. In general, increased need to manage reservoirs for flood control will likely dampen inflow variations, which will have an important negative impact on estuarine species that have evolved in a more variable environment.

While understanding these uncertainties, the group noted that models are in robust agreement that the winter precipitation season will be compressed (starting later and ending earlier), that more precipitation will fall as rain instead of snow, and that the higher overall moisture content of the atmosphere will lead to more intense rainfall events. These changes support considering the potential impacts of larger winter runoff events, while recognizing these impacts may be moderated by reservoir operations.

Larger winter runoff events would depress salinity for longer periods in the estuary, which would lead to a die-off of stenohaline aquatic species. High flows will tend to wash plankton out of the estuary, and in combination with salinity effects could lead to a shift to a community with a more dominant benthic component (a "community reset"). Higher inflows of freshwater to the Bay will also increase the rate of flushing of South Bay. These changes were considered of high importance and of relatively low uncertainty.

It was not considered likely that the climate-driven component of these larger runoff events would produce a significant change in sediment discharge from Sierra watersheds due to the sediment-trapping influence of reservoirs, although in local watersheds with no reservoirs large sediment transport events could occur during intense rainstorms. It was considered likely that the effects of sea level rise and land use (*i.e.,* recovery from hydraulic mining) will have a greater effect on the supply of sediment from the Central Valley to the Bay than changes in precipitation and runoff.

Large runoff events would also be noticed in the Gulf of the Farallones, and could be significant along the coast north of the Golden Gate where the plume from San Francisco Bay discharge tends to travel. This plume could carry pollutants and/or nutrients into the Gulf that, while not large in comparison to the nutrient contribution from upwelling, could nevertheless be influential in some near-coastal waters on shorter timescales. Large freshwater discharge to the Gulf will tend to increase near-shore stratification effects, although this was not considered to be a significant impact.

Alternatively, the group also considered the potential ecosystem impacts from a multi-year drought, as such periods also appear in model projections for precipitation in the San Francisco Bay watershed. The reduction in flows into the estuary will increase residence time and salinity, and these changes could have significant ecological effects. These include a reduction in water quality due to less flushing (particularly in South Bay), a reduction in stratification that would reduce phytoplankton productivity, and a reduction in estuarine habitat as brackish conditions give way to more marine conditions. This would also result in more marine predators (many of which are popular sportfish) entering the estuary from the Gulf. These changes were found to have low uncertainty. It was also suggested that lower freshwater flows might result in a warming of the estuary in the winter relative to conditions with more flow, but this impact was considered much more uncertain.

Remote forcing. The group did not explicitly address these, though they are understood as the series of exogenous effects that underpin many of the assumptions behind the regional thinking the group did discuss. For example, it was noted river temperatures are expected to increase over time and this will have a negative impact on salmon populations. A fuller understanding of these suites of effects should be kept implicit within any research discussion; it was noted that these become boundary conditions to more detailed analyses and that one way to explicitly address uncertainties in this realm is through alternate scenario development.

Ocean acidification. There was not time to discuss the driver of ocean acidification at the workshop. Acidification of the ocean is considered a forcing of relatively low uncertainty, but there is some question regarding how coastal processes in the region will interact with the driver to influence the pH of the region's marine and estuarine waters (include variability over tidal cycles and longer time periods). BAECCC will develop information about acidification further in coming months

Driver	Potential Impacts	Impor-tance	Uncer-tainty	Primary Attributes Linked To (H, P, WQ, CC, FW)	Consequences of Potential Concern	Relevant scale of key impacts (Regional, Meso-, Local)
Air Temperature						
	Changes in Fog	High	High	H, P, CC	Reductions in fog could result in drastic changes in local coastal temperatures and water availability for terrestrial systems	Regional to meso-scale
	Heat effects on Intertidal	High	Low	H, CC	Biological stress to key intertidal species could affect population viability	Local
Water Temperature						
	Metabolism	High	High	P, CC, FW	physiological stress on plants and animals	regional and local
	Phytoplankton Community Shifts	High	High	CC, FW, WQ	shift in food web dynamics, increase in harmful algal blooms	regional and local
	Increased Stratification	Low	Low	H, WQ	changes small compared to altered wind/salinity	regional
Sea Level Rise (Bay)						
	Reductions in Intertidal Area	High	Low	H, CC, FW, P	loss of tidal flats and marshes assuming migration restricted	regional and local
	Changes in Head of Tide	High	Low	H, WQ	flooding, deposition, tidal current changes	local
	Shoreline Erosion due to Loss of Tidal Flats	High	Low	H, P	loss of wave attenuation increases coastal erosion	
	Increase in Tidal Prism	High	Medium	H, WQ	greater prism and higher tidal velocities	regional
	Drowning of Eelgrass Beds	Medium	Medium	H, CC	loss of adequate light	local
	Salinity Intrusion	Mediu	NS	H, WQ	salinity intrusion, particularly at depth	regional

	m				
Increase in Subtidal Habitat	Medium	NS	H, P	transformation of intertidal to subtidal	regional and local
Loss of Marine Mammal Habitat	Low	NS	H	haul outs flooded; animals will select new haulouts	regional and local
Sea Level Rise (Gulf)					
Changes in Locations of Intertidal	Medium	Low	H, CC, FW, P	some intertidal converts to subtidal	local
Erosion of Beaches	High	Low	H	net erosion affected by rates of replenishment	local
Loss of Marine Mammal Haul-outs	Low	Low	H	haul outs flooded; animals will select new haulouts	regional and local
Upwelling					
Enhanced upwelling	High	medium	H,FW,WQ,P, CC	colder, nutrient rich water to surface, enhanced southern transport, more fog	regional
Suppressed upwelling	High	medium	H, FW, WQ,P,CC	More Bay water in Gulf (especially northern shore)	regional
Precipitation/Runoff					
larger winter runoff events	High	low	H, CC, WQ, P	depressed Bay salinity, plankton washout, loss of stenohaline species, some impact on Gulf nearshore water quality	regional
Multi-year drought	High	low	H, WQ, P, CC, FW	increase salinity and long pollutant residence time	

Attributes: H = habitat; P = populations (abundance, composition); WQ = water quality; CC = community composition (invasives); FW = Food webs (productive/resilient); NS = not specified