Detailed summary

This report provides recommended resource allocations for conserving natural resources in four subregions of San Francisco (SF) Bay, including North Bay, Suisun, Central Bay and South Bay. These recommendations are based on quantitative, subregional decision tools that were developed in collaboration with stakeholders working in each subregion. The overarching conservation objective to be achieved and supported through the decision tools and recommendations for the subregions was:

Perpetuate the physical integrity, functions, biodiversity, and wild populations of estuarine ecosystems, while meeting demands for human health, safety, and well-being.

To achieve this objective, we identified a recommendation that was consistent among subregions and remained the same even when changing assumptions about external drivers including extreme weather events and availability of resources (funding, staff, and equipment for conservation actions).

We found that the recommendation for all subregions was to allocate resources in a way that assumes a rosy future for external environmental conditions (including sea level rise and extreme storms) and for availability of resources. Stakeholders were on average more optimistic about the effectiveness of allocation options, over the near-term and long-term, that assume a rosy future even if the future turns out to be not so great in terms of the external drivers (e.g., sediment, storms, sea level rise, funding). In other words, stakeholders believed the assume-rosy allocation in each subregion to be robust to worse-case scenarios for the external drivers.

This detailed summary is a digest of the motivation for the project, Bayland-wide framework, and products for informing conservation of the SF Bay Estuary.

Motivation

Uncertainties about future sea-level rise, intensity and frequency of extreme weather events, along with human development pressures and availability of funding and other resources to implement conservation actions present a daunting problem for stakeholders concerned about the ecosystem integrity of the SF Bay Estuary. This has brought about a great need for consistently agreed-upon conservation objectives in the Estuary against which to make management decisions and measure conservation effectiveness. In particular, resource managers are asking for expertly-vetted recommendations for allocating limited resources toward accomplishing the identified conservation objectives in the Estuary.

A workshop sponsored by the California Landscape Conservation Cooperative was held in October 2011, during which stakeholders and scientists identified a recommendation to increase investment in climate adaptation actions to conserve tidal marshes of SF Bay rather than the status quo strategy that takes minimal consideration of future climate-change impacts (Thorne et al. 2015). Since 2012, the Bayland Ecosystem Habitat Goals Update (BEHGU) has been developing a list of recommended goals and actions at multiple spatial scales that address projected climate change impacts for conservation within each ecosystem of the Baylands that include SF Bay. BEHGU recommendations are meant to accommodate future climate scenarios, but there is no underlying decision process or tool to justify the ultimate selection of recommendations (from a set of candidate recommendations) nor are the recommendations specified for particular time periods or resource availability scenarios. This called for an evaluation of how alternative ways of allocating resources among BEHGU-recommended actions would be expected to perform, so that more actionable and defensible recommendations could be identified that explicitly account for uncertainties regarding management outcomes and effects of external drivers that are beyond the control of management (e.g., climate change, resource availability).

Recommendations from the 2011 workshop combined with knowledge gaps revealed through BEHGU led to six main challenges:

1) Engage a broader suite of stakeholders and experts engaged in conservation of SF Bay.
2) Account for subregional differences with regard to the costs and constraints of taking climate-adaptation actions, suites of conservation objectives, and uncertainties regarding management effectiveness, sediment dynamics, and climate-change impacts.
3) Address the linked nature of decisions, objectives and outcomes across time and space. Decisions about project-level actions taken in the near future should account for the consequences of actions taken in the more distant future. Likewise, decisions should account for project-level actions scaling up to influence the subregional and regional-level objectives.
4) Incorporate additional system components, including habitat types (e.g. tidal flats, low marsh, mid-marsh, high-marsh, upland transition, managed ponds) and species of conservation concern with contrasting requirements compared to Ridgway's Rail (e.g., salt marsh harvest mouse, shorebirds). Consider especially tradeoffs with respect to contrasting responses of multiple species/communities and associated transitions of spatial elements from one estuarine environment type to another.
5) Consider a broader response horizon going out to 2100 to bring in the full range of uncertainty about future sea-level rise.
6) Inform design of an adaptive management and monitoring program that guides and evaluates management actions by addressing key sources of uncertainty with high value of information.

In response to these six challenges the CADS (Climate Adaptation Decision Support for SF Bay) project was undertaken by the San Francisco Bay Joint Venture, a collaborative partnership for the protection, restoration, and enhancement of all types of wetlands for the benefit of birds, other wildlife, and people. CADS was an answer to a call from managers to measure the impacts of conservation actions on a landscape level while helping ensure that current conservation and management actions optimize the potential to address climate change in an era of limited resources. During each step of the project, over 25 stakeholders were engaged to ensure that the recommendations and products from this project would be defensible and useable by on-ground decision-makers. We define a stakeholder as an entity who has direct influence or is influenced by a particular decision or set of decisions for conservation in SF Bay.

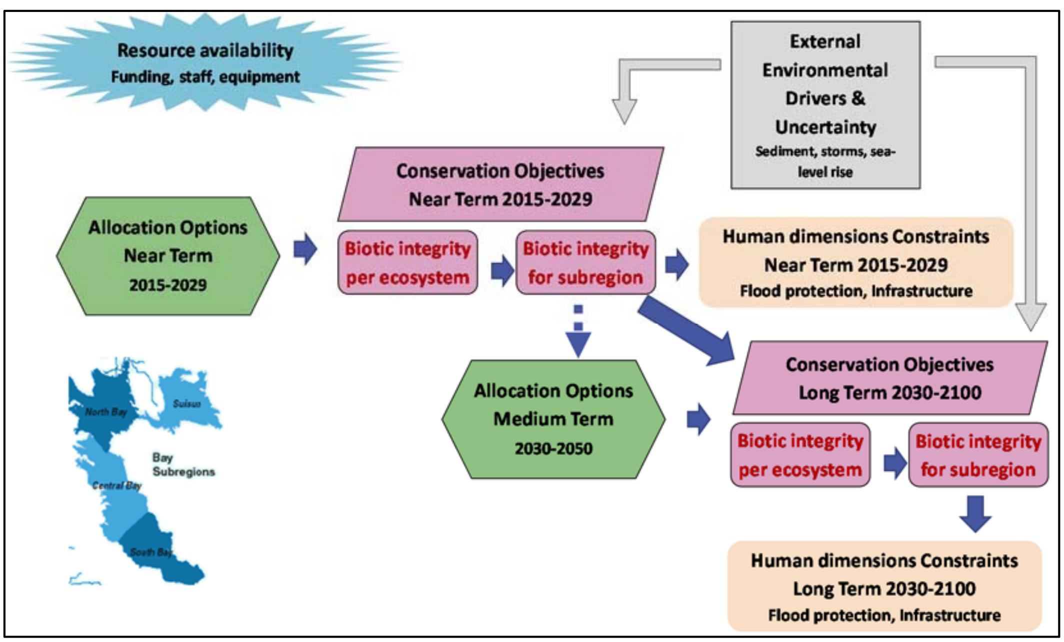
The project is divided into two phases, with Phase 1 focused on establishing regional and subregional conservation objectives leading to recommended resource allocations for each of the four subregions in SF Bay (North Bay, Suisun, Central Bay, and South Bay). Phase 2 will demonstrate how subregional recommendations can inform local-scale climate adaptation strategies. In particular, climate adaption recommendations for the North Bay subregion (from Phase 1) will be used to inform development of the San Pablo Bay National Wildlife Refuge climate adaptation plan (in Phase 2). This report describes the set-up and findings from CADS Phase 1 (henceforth, CADS).

Bayland-wide framework for conserving the SF Bay Estuary

A major first step of the project was agreeing on the type of decision (e.g., discrete choices or resource allocation) and which spatial and temporal scales to be address through CADS. These products provided a framework for developing a decision tool for each subregion of the SF Bay. In the context of the conservation problem in the SF Bay Estuary, we developed a concise question that summarizes the essential elements of the decision to be made as a decision question:

How should limited resources be allocated across time and space toward potential actions within subregions to conserve San Francisco Bay estuarine ecosystems while accounting for uncertainties and constraints regarding climate change and other factors such as management effectiveness, regulations, recreation, and sediment dynamics?

In particular, we wanted to identify a resource allocation for a near-term (2015-2029) and a longer-term (2030-2050) management time horizon to achieve conservation objectives over two outcome horizons, including the near-term (2015-2029) and the long-term (2030-2100). These time horizons were chosen to remain consistent with the BEHGU.



Conceptual diagram representing resource allocation decisions in SF Bay

For developing conservation objectives and recommendations to achieve them, we classified the Baylands surrounding SF Bay into six ecosystem classes that were also consistent with the BEHGU:

Estuarine ecosystems

1) **Sub-tidal and intertidal mudflats**

Estuarine subtidal: Those estuarine ecosystems within substrate that is permanently flooded by tidal water

Estuarine intertidal mudflats: Sedimentary intertidal habitats created by deposition in low energy coastal environments, particularly estuaries and other sheltered areas. Their sediment consists mostly of silts and clays with a high organic content.

2) **Tidal marsh**

Marsh found in estuaries where the flooding characteristics are determined by the tidal movement of the adjacent estuary, sea or ocean. According to the salinity of the flooding water, freshwater, brackish and saline tidal marshes are distinguished. Respectively, they may be classified into coastal marshes and estuarine marshes. They are also commonly zoned into lower marshes (also called intertidal marshes) and upper or high marshes, based on their elevation with respect to the sea level. They may be classified by salinity, tide range, and geomorphic setting.

3) **Managed/diked marsh and ponds**

Diked marshes and managed ponds (e.g., former salt production ponds) are generally managed by owners to provide habitat for waterfowl, shorebirds, and other water birds. Primary management strategies usually involve the manipulation of salinity (from more salty to less salty), the regulation of water levels (draining and flooding). Management of water quality and quantity require regular maintenance of infrastructure (e.g., levees/dikes, water control structures). The intensity of management can have a significant effect on the plants and animals inhabiting managed ponds and marsh.

4) **Upland transition zone**

Estuarine-terrestrial transition zones occupy the boundary between land and sea, from tidal marsh up to the effective limit of tidal influence. These zones harbor unique plant communities, provide critical wildlife support to adjacent ecosystems, and play an important role in linking marine and terrestrial processes. Includes seasonal wetlands (areas where water covers the soil only during the wet season) and vernal pools.

Non-estuarine, upland ecosystems

5) **Migration space**

Includes agricultural lands adjacent to Baylands (primarily found in North Bay) along with upland areas adjacent to any of the estuarine ecosystems. To be considered migration space, the adjacent uplands must have sufficient slope and elevation that would provide some possibility for the upland ecosystem to transition into an estuarine ecosystem with sea-level rise.

6) **Watershed**

A drainage basin or watershed is an extent or an area of land where surface water from rain and melting snow or ice converges to a single point at a lower elevation, usually the exit of the basin, where the waters join the estuary.

Components of subregional decision tools

In addition to providing management recommendations and stemming from the 2011 Bayland-wide framework for conservation, there were several other important products developed in this project when developing the subregional decision tools. Each decision tool was comprised of measurable conservation objectives that were linked to action categories and external drivers (e.g., resource availability, extreme storms). The decision tools also took into account scenarios for future uncertainties about the external drivers.

Conservation objectives

For each ecosystem, the teams defined an overarching conservation objective that the biotic integrity of the ecosystem as a whole should be stable or increasing during the near-term (2015-2029) and long-term (2030-2100) outcome horizons. Subregional teams were aware of many possible indicators that could be used to represent the biotic integrity of each estuarine ecosystem, but they chose a subset to ensure their decision tools would be tractable to complete and so they could identify recommended allocation options during the lifespan of this project. Indicators were also chosen to represent the most important desired conservation outcomes for stakeholders in each ecosystem. Birds were the most commonly chosen indicators among subregions, followed by plants, fish, and indicators that integrate disparate attributes of the ecosystem. Most often chosen bird guilds were ducks and shorebirds. Less frequently chosen indicators were mammals, physical attributes, shellfish, and herpetofauna. Selection of particular indicator species or ecosystem attributes varied widely among subregions for any given ecosystem. Only three indicators were chosen for multiple subregions: subtidal acreage with native living substrate, upland transition zone acreage dominated by native plants, and upland transition zone acreage with suitable wildlife refugia. When including indicators that integrated multiple taxonomic groups or ecosystem elements, there were multiple subregions that chose Ridgway's Rail, salt marsh harvest mouse, plant biomass, and invertebrate biomass.

Indicators of biotic integrity by ecosystem and subregion of SF Bay

A dot (●) indicates that the category of indicators was chosen for a subregion, and an X indicates a particular indicator was chosen within a category. Attribute of interest for all listed wildlife species was abundance unless otherwise noted.

Subtidal and intertidal mudflats

Indicator	North Bay	Suisun	Central Bay	South Bay
Physical			●	
Total mudflat acreage			X	
Subtidal water quality			X	
Plants	●	●		
Eelgrass acreage	X			
Acreage dominated by natives		X		
Birds	●			●
Ducks				
Divers				X
Shorebirds				
Diversity and abundance	X			
Winter abundance				X
Mammals				●
Harbor seal				X
Shellfish acreage	●			
Fish	●	●	●	
Salmonids	X			
Forage fish biomass			X	
Delta smelt		X		
Integrative	●		●	●
Acreage of native living substrate			X	X
Plant and invertebrate biomass	X		X	

Indicators of biotic integrity by ecosystem and subregion, continued.

Tidal marsh

Indicator	North Bay	Suisun	Central Bay	South Bay
Physical				●
1999 Bayland Goals criteria for marsh acreage, size, and connectivity are met				X
Plants	●			
Acreage dominated by natives	X			
Birds	●	●		●
Obligate tidal marsh species				
Diversity and abundance		X		
Ridgway’s Rail	X			
Ducks				
Dabblers				X
Mammals	●	●		
Native small-bodied diversity and abundance		X		
Salt marsh harvest mouse	X			
Fish	●			
Diversity and abundance	X			
Integrative			●	●
Recovery criteria met			X	
Total plant and invertebrate biomass			X	
Ridgway's Rail & salt marsh harvest mouse				X

Indicators of biotic integrity by ecosystem and subregion, continued.

Managed wetlands

Indicator	North Bay	Suisun	Central Bay[a]	South Bay[b]
Birds	●	●		●
Breeding waterbird				X
Salt-pond specialists				X
Ducks				
Richness and density	X			
Winter abundance		X		
Divers				X
Shorebirds				▪
Diversity and abundance	X			
Small- to medium-size abundance				X
Snowy Plover				X
Mammals		●		
Salt marsh harvest mouse		X		
Fish	●			
Diversity and abundance	X[c]			

Upland transition zone

Indicator	North Bay	Suisun	Central Bay[a]	South Bay[b]
Plants	●	●		●
Eelgrass acreage				
Acreage dominated by natives	X	X		X[d]
Total biomass				
Acres with suitable wildlife refugia	X			X[d]
Birds	●			●
Ridgway's Rail				X
Song Sparrow and Common Yellowthroat	X			
Reptile and amphibian abundance	●			
Integrative			●	
Recovery criteria met			X	

[a] Central Bay ignored managed wetlands due to their small acreage in this subregion.

[b] Only managed ponds were considered for South Bay.

[c] Abundance of native fish for near-term, and density of native fish per wetland for long-term in North Bay.

[d] Acreage with suitable refugia for near-term, and acreage dominated by natives for long-term in South Bay upland transition zone.

Conservation action categories

Subregional teams of stakeholders were aware of many possible actions that could be taken to improve the biotic integrity of their subregion, and to make the decision tool tractable we developed six action categories that were adapted by each subregion:

1) *Protect acreage*: e.g. conservation easements, land acquisition
2) *Manage sediment* -- e.g. alter dam releases, beneficial reuse of dredge material
3) *Manage/protect species of special concern* -- e.g. predator management, translocation/captive breeding
4) *Manage vegetation community* -- e.g. plant natives, remove / treat against invasives
5) *Manage water quality and quantity* -- e.g. reduce contaminant inputs, regulate salinity, change water depth
6) *Manage human disturbance* -- e.g. manage recreation access, reroute transportation corridors

Two subregions included additional action categories that were unique to their subregion:

Restore acreage (South Bay only) -- expenditures on capital costs for infrastructure and staffing needed to conduct a restoration project, distinguishing this from other action categories representing annual expenditures on operations and maintenance of (multi-year) restoration projects.

Collect information (Suisun only) – expenditures on research, monitoring, and analysis to inform adaptive management within the near-term.

Future scenarios

An important step toward identifying recommended resource allocations was developing alternative future scenarios for resource availability (e.g., staff, funding, equipment) and external environmental drivers (e.g., extreme storms, sea level rise). Considering the full range of future uncertainty about these external drivers, we developed a rosy (aka optimistic) and a not-so-great (aka pessimistic) scenario.

External driver scenarios

Rosy	Not So Great
Near-term (2015-2029)	
Extreme storm events spaced out in time and not coinciding with big high tides	Multiple (2-3) extreme storms hitting at once & coinciding with king tides (like in 1986)
Expected levels of sea-level rise[a] (+40 cm from current) and sediment	Expected levels of sea-level rise (+40 cm from current) and sediment
Infrastructure (e.g., levees, dikes) maintained	Infrastructure (e.g., levees, dikes) fails
Temperature, salinity, DO, and pH regimes okay for native aquatic biota	High temperature impacts on native aquatic biota; Ocean acidification
Resources (e.g., staff, funding) at least double current levels	Resources (e.g., staff, funding) less than double current levels
Long-term (2030-2100)	
Extreme storm events spaced out in time and not coinciding with big high tides	Multiple (2-3) extreme storms hitting at once & coinciding with king tides (like in 1986)
Optimistic sea-level rise (+55 cm from current) and low sediment availability	Pessimistic sea-level rise (+165 cm from current) and low sediment availability
Infrastructure (e.g., levees, dikes) maintained	Infrastructure (e.g., levees, dikes) fails
Temperature, salinity, DO, and pH regimes okay for native aquatic biota	High temperature impacts on native aquatic biota; Ocean acidification
Resources (e.g., staff, funding) at least double current levels	Resources (e.g., staff, funding) less than double current levels

Sea-level rise scenarios in this table are based on Stralberg et al. (2011).

Resource allocation options

For each management time horizon, each subregion developed two resource allocation options: one that assumed a rosy future scenario for external drivers and another that assumed a pessimistic future for external drivers. Subregions differed in how they allocated resources among the Bayland ecosystems, which reflected the geographic variation in the constraints and opportunities for taking conservation action. When pooling allocations by ecosystem, the ecosystem-specific percentages did not differ substantially between allocation options for a given subregion. Most of the resources were allocated to tidal marsh and managed wetland, followed by migration space, subtidal and intertidal mudflats, and watershed. When comparing action categories, most resources were allocated toward protecting acreage and managing sediment.

Action categories receiving the most resource allocation by subregion in SF Bay

X = more allocated than expected by chance among the action categories; XX = more than double the amount expected by chance was allocated.

Subregion	Management horizon	Protect acreage	Manage sediment	Manage individual wildlife	Manage vegetation	Manage water	Manage human disturbance
North Bay	2015-2029	XX	X				
	2030-2050	X	X				X
Suisun[a,b]	2015-2029	X			X	X	
	2030-2050	XX				X	
Central Bay[a]	2015-2029	XX	X				
	2030-2050	X	X	X			
South Bay[c]	2015-2029		(X)		(X)	(X)	
	2030-2050	X	X		(X)	(X)	

[a] Longer-term (2030-2050) allocation options were not analyzed for Suisun or Central Bay.

[b] There was an additional category "collect information"for Suisun, but it did not receive a large percentage allocation and is not shown for simplicity.

[c] There was an additional action category in South Bay called "restore acreage", which represented principal resources directed toward the establishment of long-term restoration projects such as staff and equipment. The "manage ___" action categories, then, represented annual expenditures to maintain the long-term restoration projects. The (X) symbols represent the large amount allocated to this added category for both time horizons.

Bayland ecosystems receiving the most resource allocation by subregion within SF Bay

X = more allocated than expected by chance among the ecosystems.

Subregion	Management horizon	Subtidal & intertidal	Tidal marsh	Managed wetlands	Upland transition zone	Migration Space	Water-shed
North Bay	2015-2029			X	X	X	
	2030-2050			X	X	X	
Suisun[a,b]	2015-2029		(X)	X	(X)		
	2030-2050		(X)	X	(X)		
Central Bay[a,c]	2015-2029		X	na	X		
	2030-2050	X	X	na	X		
South Bay[d]	2015-2029		X	X	X		
	2030-2050		X	X	X	X	

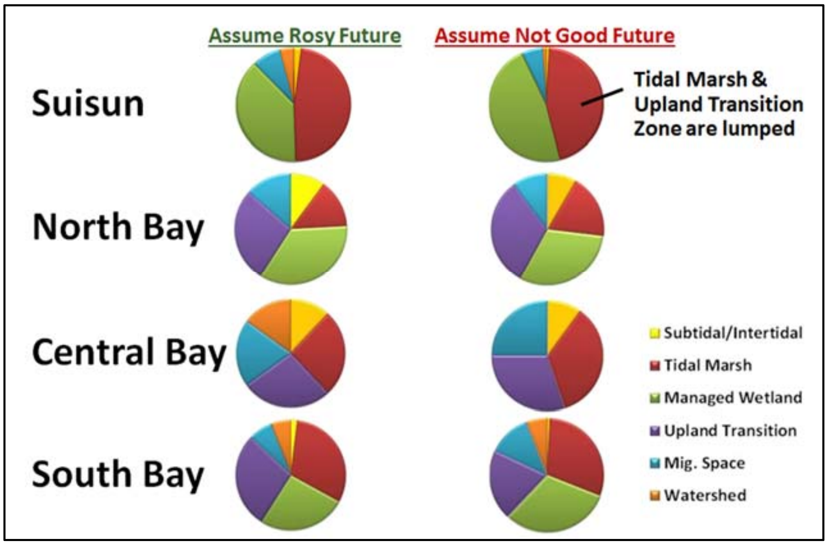
[a] Longer-term (2030-2050) allocation options were not analyzed for Suisun or Central Bay.

[b] The Suisun team considered tidal marsh and upland transition zone as a single ecosystem when assigning allocation percentages, and the (X) symbol represents the large amount allocated to this merged ecosystem in both management time horizons.

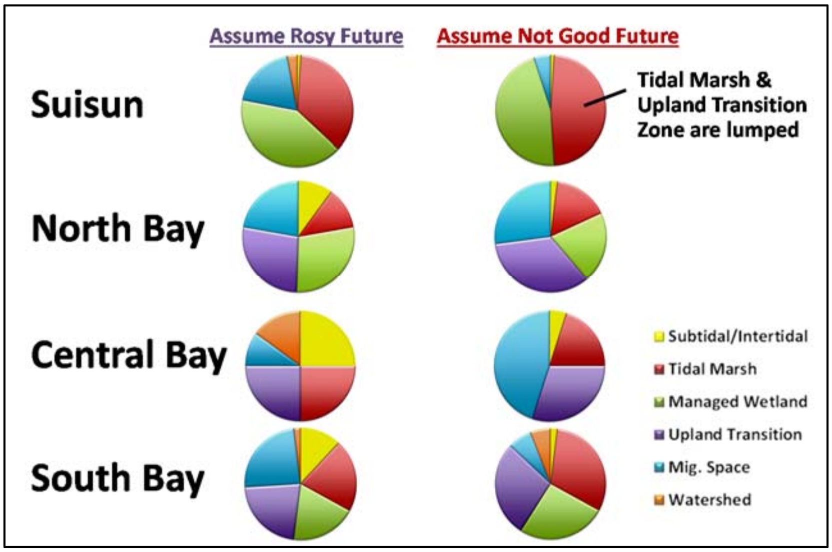
[c] Managed wetlands were ignored in Central Bay due to their scarcity in this subregion.

[d] Diked marshes were ignored within South Bay, and only managed ponds were considered within the managed wetlands ecosystem classification.

Subregional allocation options by ecosystem for the near-term (2015-2029).



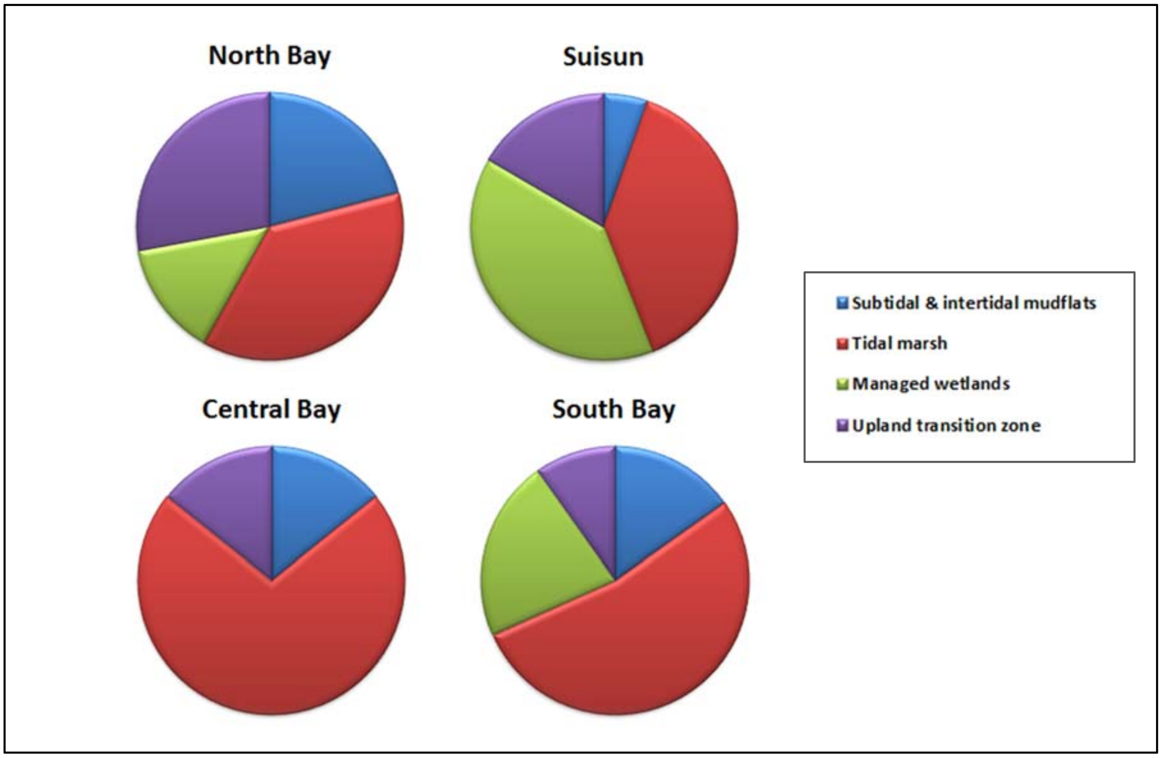
Subregional allocation options by ecosystem for the longer-term (2030-2050).



Tradeoffs between ecosystems and outcome horizons

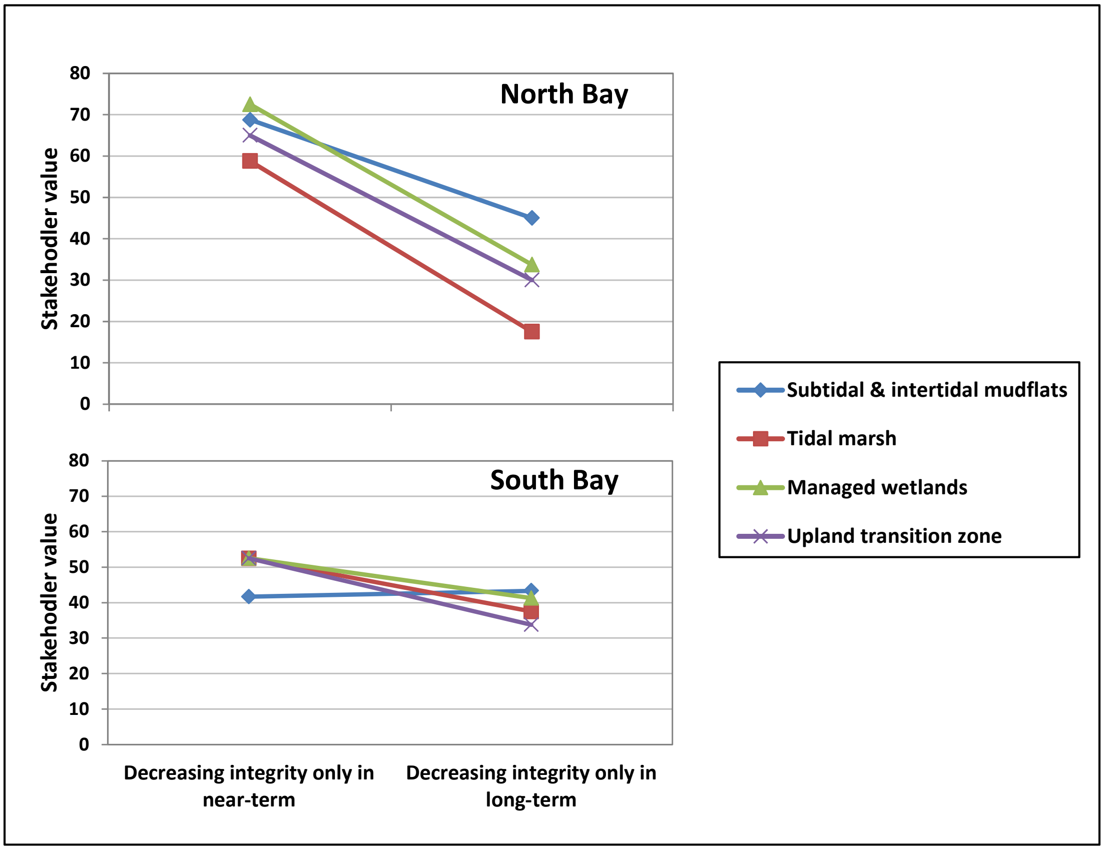
For each combination of possible outcomes for ecosystem-specific conservation objectives, stakeholders independently assigned a value on a scale from 0-100 with 0 representing the worst possible combination and 100 representing the best possible combination of outcomes. Based on these inputs, we found that tidal marsh had relatively high importance in all subregions.

Relative importance of estuarine ecosystems by subregion in the near-term (2015-2029)



North Bay and South Bay stakeholders completed the long-term portion of their decision tools. Stakeholders in each of these subregions, as was done for tradeoffs between ecosystems, independently assigned values to possible combinations of outcomes for changes in biotic integrity for the near-term (2015-2029) and long-term (2030-2100) outcome horizons. For both of these subregions, stakeholders on average were more averse to decreasing biotic integrity in the long-term than they were in the near-term for each of the estuarine ecosystems, and this contrast was most evident in North Bay. The one exception was for South Bay, where stakeholders had a similar aversion to decreasing biotic integrity for subtidal and intertidal mudflats in the near-term as they did in the long-term.

Tradeoffs between outcome horizons by ecosystem in North Bay and South Bay



Recommended allocations and main findings

As we did with the stakeholder values, each stakeholder independently provided a predicted probability for the external driver scenarios and for how these external drivers in combination with the allocation options (and in some cases intermediate drivers) affect indicators of biotic integrity. They also provided probabilities that biotic integrity as a whole would be stable or increasing based on changes in the chosen indicators. Based on a quantitative, decision-analytic approach that integrates the stakeholder values and probabilities we found that the recommendation for all subregions was to allocate resources in a way that assumes a rosy future for external environmental conditions (including climate and extreme storms) and for availability of resources.

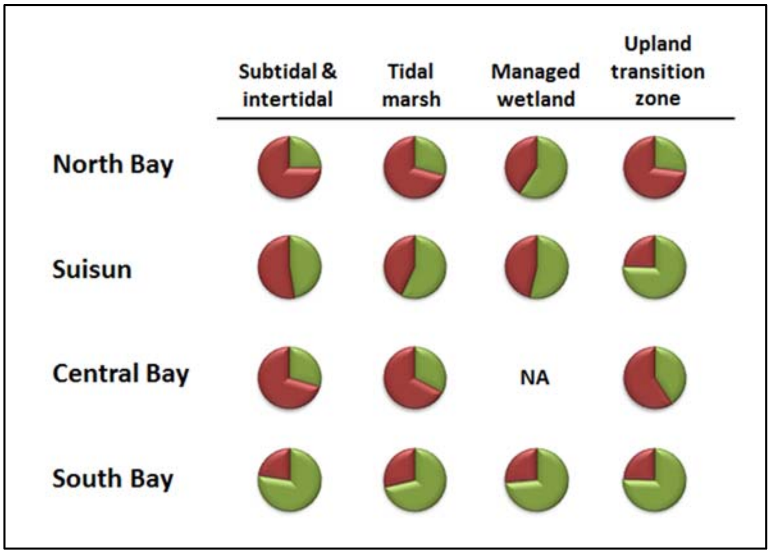
This recommendation was surprising to some stakeholders, who would have thought that a more conservative approach should be taken to conservation in the Baylands. Intuitively, we should try to do everything we can to prepare for the worst possible scenarios for external drivers including climate change and availability of sediment and resources (funding, staff, equipment). This intuitive reasoning was not supported by the results from CADS, however. Instead, stakeholders were on average more optimistic about the effectiveness of an allocation option that assumes a rosy future even if the future turns out to be not so great for the external drivers. In other words, stakeholders believed the assume-rosy allocation to be robust to worse-case scenarios for the external drivers.

South Bay had the most optimistic predictions for biotic integrity across ecosystems, and Suisun also had greater than 50% chance of stable or increasing biotic integrity in every estuarine ecosystem except subtidal and intertidal mudflats. Except for managed wetlands, North Bay and Central Bay predicted a less than 50% chance that biotic integrity would be increasing in each ecosystem. Across the board, there was substantial uncertainty about the projected trajectory of biotic integrity; the ecosystem-by-subregion probabilities of stable or increasing biotic integrity were all between 20 and 80%. Expected performance[1] ranged from 47-58% among subregions when implementing the assume-rosy-future allocation and 39-55% when implementing the assume-not-so-great-future allocation.

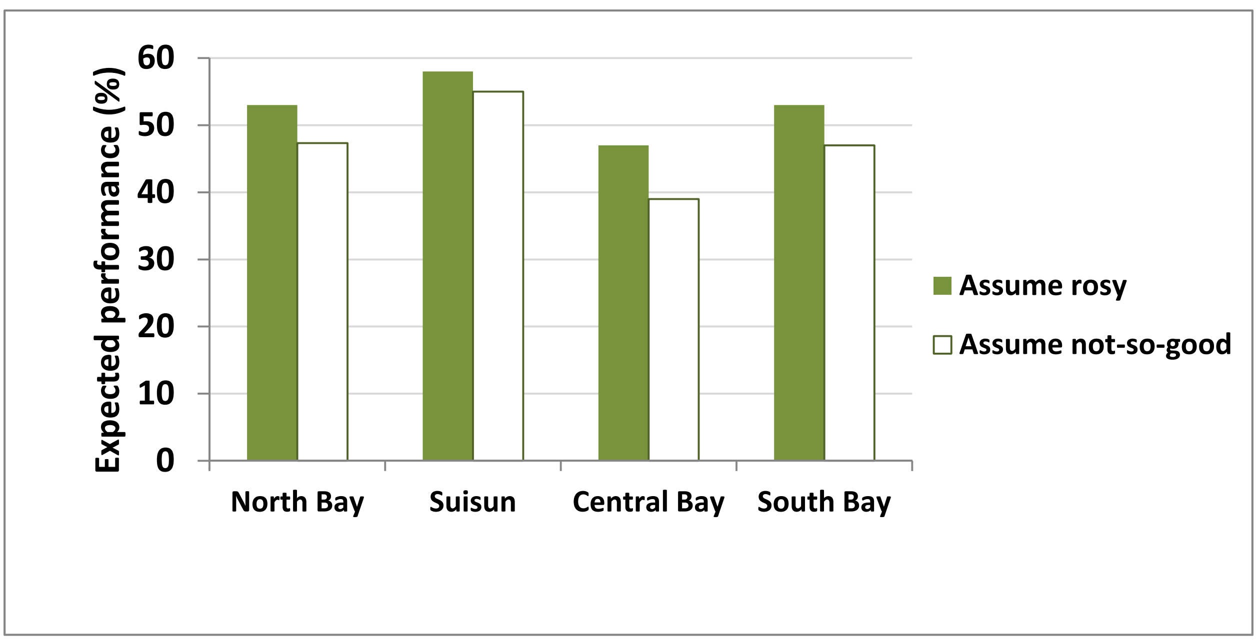
[1] Expected performance was measured in terms of the values stakeholders placed toward tradeoffs among ecosystems and, in the case of North Bay and South Bay, between the near-term and long-term outcomes. Tradeoffs were quantified in terms of possible changes in biotic integrity in the focal estuary ecosystems (see section 3.6).

Predicted changes in biotic integrity by ecosystem and subregion

The green portion of each circle represents the probability of stable or increasing biotic integrity for the respective estuarine ecosystem for each subregion in the near-term (2015-2029). Central Bay did not consider managed wetlands, and South Bay only considered managed ponds within the managed wetlands class.



Expected performance (% chance of stable or increasing biotic integrity across ecosystems) of assume-rosy resource allocation by subregion



Lessons learned

For the first time, stakeholders engaged in resource management of SF Bay have collaboratively arrived at a set of conservation objectives that were explicitly used to inform optimal allocation of resources among ecosystems and action categories for each of the four subregions. These resource allocation recommendations build upon many years of conservation planning and habitat delivery in the region, which have provided essential ingredients including conservation objectives, management options at from segment to regional scales, monitoring and scientific information, and predictive models about the effects of management actions and external environmental drivers on estuarine ecosystems. The added value of CADS Phase 1 has been to bring all these ingredients together in a transparent, collaborative decision-analytic framework to develop recommendations for allocating limited conservation resources at subregional scale.

The project design was structured such that CADS Phase 1 would be compatible with the Bayland Ecosystems and Habitat Goals Update (BEHGU), a technical update to the original Baylands Habitat Goals, which was being developed concurrently by a broad coalition of Bay Area scientists to develop management recommendations that account for projected climate change. This required much communication and coordination within the CADS leadership team itself along with communication and coordination between the leadership team and stakeholders, especially the BEHGU coordinators. The importance of strong leadership, project management and coordination, and stakeholder engagement cannot be overstated for a project with this level of complexity.

A particular strength of CADS was engaging a broad suite of stakeholders throughout the process of developing conservation objectives, indicators of biotic integrity, action categories, allocation options, and recommendations. It is these individuals who can interpret and implement the recommended allocations in the subregions and ecosystems where they work. CADS Phase 1 was carried out on a very modest budget considering the broad scope, depth and complexity of the problem that was addressed, which has demonstrated that such an ambitious project can be accomplished without a large financial investment. The project brought together a representative set of stakeholders and made them more cognizant that resource allocations should account for future uncertainties and that the allocations differ among subregions.