DWR Grant 4600007902

Assessment Framework as a Tool for Integrating and Communicating Watershed Health Indicators for the San Francisco Estuary

FINAL PROJECT REPORT

February 28, 2011

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I. Introduction

The objective of work under this grant agreement was to continue the development of ecological indicators for the San Francisco Bay Estuary using the Watershed Assessment Framework as an organizing tool. In this document we examine, select, and describe indicators that could be adapted for use at the various geographic and dimensional scales of Bay Area watersheds to determine ecological condition. Our work included selecting candidate indicators and using a set of criteria to evaluate their suitability for assessing the condition of the estuary based upon criteria recommended by the US EPA and the National Research Council. We compiled relevant available information for the candidate indicators and evaluated their fitness to describe change in watershed conditions from an earlier assessed reference condition in a scientifically defensible and publicly meaningful manner. Once the candidate indicators were screened using the criteria, several were selected to proceed to the full evaluation phase that quantified the indicator, compared the calculated values against the reference conditions and target, assessed available trends and provided an initial interpretation of condition. The background and rationale for these indicators, the data sources, and methods for calculations are provided.

The first report for this grant submitted September 30, 2008 addressed compiling and updating technical data to support candidate indicators, evaluating data availability to address the assessment goals and quantified targets, and selecting candidate indicators. Following submittal of this report, the grant was stopped for a year by the state bond fund issue and only restarted in September 2009. Due to funding uncertainties, much of the grantee coordination and valuation efforts lapsed. This report continues the grantee's efforts to complete work under Tasks 3, 4, 6, and 7 to calculate the candidate indicators and evaluate them to assess their robustness and applicability, compare measured indicator values to identified goals, targets and reference conditions based on an evaluation protocol, and determine their utility in informing ecological condition at watershed scales.

II. Indicator Selection Criteria

A. Screening Process

Ecological indicators are characteristics of the environment that, when measured, quantify ecosystem condition, structure, function or response to a stressor, including human activities. Ecosystems are complex and dynamic—indicators are used to synthesize complex information and communicate it in simple terms that can be understood and used by non-scientists to make management decisions. Not everything that is or can be measured in an ecosystem is a useful indicator of the system's condition, function or trends in these over time. Indicators should be selected based on specific criteria to ensure that they are meaningful, consistent and can gain widespread acceptance. For this project to develop indicators for the San Francisco Bay estuary, we identified, evaluated and developed all candidate indicators based on the following criteria. Indicators should be:

- Relevant to ecological conditions and/or function (i.e., the indicator fits within or relates to one of the Watershed Assessment Framework categories; USEPA 2002, and see SFEIT 2008)
- Relevant to societal concerns and/or management goals (i.e., in the case of San Francisco Bay estuary and watershed, relates to one or more goals of the Comprehensive Conservation and Management Plan, CCMP; see SFEIT 2008)
- Based on data that are available and of adequate quality and reliability
- Responsive and sufficiently sensitive to changes in stressors and/or environmental conditions
- Interpretable relative to identified goals, thresholds or reference conditions
- Scalable and transferable to other systems or geographic regions
- Meaningful to policy makers, managers and the public

These criteria are based on those developed by the U.S. Environmental Protection Agency (USEPA 2000), the National Research Council (NRC 2000), and California Environmental Protection Agency (CalEPA 2002) in their reviews, analyses and indicator development efforts, and modified specifically for this project, which is designed to use the U.S. EPA Watershed Assessment Framework (USEPA 2002) and to address the needs of the San Francisco Estuary Partnership to evaluate progress resulting from implementation of their Comprehensive Conservation and Management Plan (CCMP) (SFEP 2007).

The indicator selection criteria were applied to each indicator (or multi-metric index, as appropriate) by completing the table shown below. The first level of indicator selection criteria evaluates the conceptual relevance of the proposed indicator to the Water Assessment Framework and CCMP goals and objectives. For this project, indicators were developed specifically to meet these criteria. The next level evaluates the availability and quality of data needed to calculate the indicator. For this project, some indicators that were conceptually relevant, scientifically sound and potentially interpretable and meaningful to the public but for which suitable data were not currently available, are briefly described but not developed. The third level evaluates the responsiveness and sensitivity of the proposed indicator. Does the proposed indicator represent either an ecosystem "driver" (a physical, chemical or biological variable with known effects on one or more other physical, chemical or biological variables) or an "outcome" (a known physical, chemical or biological response to variations in one or more physical, chemical or biological variables)? How responsive is the indicator to changes in physical, chemical or biological variables and to what degree and over what time frame can the indicator detect changes in ecological conditions or functions? The fourth level assesses whether goals, thresholds or reference conditions that can be used to interpret the measured value of the proposed indicator exist or can be developed, and evaluates whether the indicator will be meaningful or compelling to the public. The final level assesses the utility of the proposed indicator for application in other ecologically similar ecosystems (i.e., watershed or estuaries) and over different geographic scales.

B. Screening Table: Selection criteria for watershed assessment indicators for the San Francisco Estuary.

(Indicator Name)				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)				
Fits with CCMP (management objectives)				
Data Availability and Adequacy				
Data available				
Data suitable quality				
Responsiveness				
Driver-outcome linkage				
Sensitivity				
Response time frame				
Spatial sampling frame				
Interpretation				
Goals, thresholds or reference conditions defined				
Meaningful to public				
Transferability				
Scalable				
Transferable to other watershed				

C. Generic Outcomes

Each of the candidate indicators was screened using the criteria and screening process described above. Based on the screening results, each candidate indicator was classified as "Not selected", "Selected but not calculated" or "Selected and calculated."

Not selected: Candidate indicator was either: a) not conceptually relevant to Watershed Assessment Framework [WAF] and/or the Comprehensive Conservation and Management Plan for the San Francisco Estuary [CCMP]; b) insufficiently responsive or sensitive to watershed conditions; c) uninterpretable relative to goals, targets or reference conditions; or d) unsuitable for use in other watersheds and/or at different geographic scales.

Selected but not calculated: Candidate indicator was conceptually relevant to the WAF and CCMP but insufficient data (quantity and/or quality) were available to calculate the indicator and evaluate its utility and effectiveness.

Selected and calculated: Candidate indicator was: a) conceptually relevant to WAF and the CCMP; b) responsive to watershed conditions; c) interpretable relative to goals, targets or reference conditions; and d) sufficient data (quantity and quality) were available.

III. Screening Results

A. Candidate Indicators

WAF Category Candidate Indicators		Selected for Screening	Not Screened
	Biotic Condition		
	Biotic Condition of Birds		
1	Tidal Marsh Bird Populations Indicator	X	
2	Marsh Bird Reproductive Success Indicator	X	
3	Heron and Egret Reproductive Success Indicator	X	
4	Wintering Waterfowl Indicator	X	
5	Heron and Egret Nest Density Indicator	X	
6	Wintering Shorebird Indicator		
	Invertebrate Diversity & Abundance		
7	Zooplankton Abundance	X	
8	Zooplankton Diversity	X	
9	Benthic Macrofauna Abundance	X	
10	Benthic Macrofauna Diversity	X	
11	Dungeness Crab Abundance	X	
12	Rock Crab Abundance	X	
13	Bay Shrimp Abundance	X	
14	Macoma (clam)	X	
15	Mya (clam)	X	
16	Native Oysters		
	Fish Community Index		
17	Fish Distribution	X	
18	Pelagic Fish Abundance	X	
19	Demersal Fish Abundance	X	
20	Northern Anchovy Abundance	X	
21	Sensitive Fish Species Abundance	X	
22	Native Fish Species Diversity	X	
23	Estuary-dependent Fish Species Diversity	X	

24	Fish Species Composition	X	
	Chemical/Physical		
25	Pollutant Loadings	X	
	Bioaccumulation	No	Included in water quality
	Sediment Quality Index	No	Protocol, no Bay data
26	Water Quality Index	X	
	Ecological Processes		
27	Carbon Sequestration	X	
28	Trophic Structure		
	a) Phytoplankton and inter-tidal subtidal chlorophyll	No	Limited data
	b) Total biomass of zooplankton, benthos & fish	No	Limited data
	c) Biomass in major food chain of selected species	No	Limited data
	d) Bird reproduction and predation	X	
	Hydro-Geomorphology		
	Spring Freshwater Inflow		
29	Annual freshwater Inflow	X	
30	Inter-annual Variation in freshwater Inflow	X	
31	Peak Flows	X	
32	Critical Dry Year Frequency	X	
33	Stream Alteration & Condition	X	
	a) % natural creeks	X	
	b) Drainage length change	X	
	Precipitation	No	External drivers
	Landscape		
34	Distribution of Salt Tolerant Tidal Vegetation	X	
35	Quality of Estuarine Tidal Habitat	X	
36	Percent Historical Wetlands, Tidal Flats, Riparian	X	
37	Landcover	X	
38	Open Water Estuarine Habitat	X	
	Natural Disturbance		
39	Deviation of Wildfire Regimes from Natural Variation	X	
	Trends in Flood Peaks	No	External drivers
	Socio-Economic		
40	Consumptive Water Use by Sector	X	
41	Green Jobs	X	
42	Quality of Life	X	
43	Ratio of Infill to Greenfield Development	X	
44	Stewardship, Public Awareness, Env Justice	X	
45	No. of Households in 50 Year Floodplain	X	

B. Evaluation Table for Each Candidate Indicator

WAF Category: Biotic Condition

Under this category birds, invertebrates, and fish were evaluated as watershed health indicators for the San Francisco Bay Estuary.

Biotic Condition-Birds

1. Tidal Marsh Bird Populations Indicator

Tidal Marsh Bird Population Indicator				
Description of Indicator: Annual Abundance Index (i.e., number of adults detected on breeding season surveys per hectare of surveyed area) for four species: Clapper Rail, Black Rail, Common Yellowthroat, and Song Sparrow, at representative tidal marshes in each region of the San Francisco Estuary. Population trends available by species and combined across the four species.				
Spatial Sampling and Estimation: Estimates available for individual marshes; these are combined to provide regional estimates. Three regions for Clapper Rail (South SF Bay, Central SF Bay, San Pablo Bay); 3 regions for Common Yellowthroat and Song Sparrow (SF Bay [South and Central], San Pablo Bay, Suisun Bay); 2 regions for Black Rail (San Pablo Bay, Suisun Bay).				
Temporal Sampling: Annual sampling during breeding season, with multiple surveys to the same marsh or survey point each year. Clapper Rail: Jan-March; other 3 species: March-May.				
	Result (yes, qualified yes, no, or partially)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (w/ regard to ecological function)	Yes	Biotic condition		
Fits with CCMP (w/ regard to management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			<u>PRBO tidal marsh bird studies:</u> c. 30 to 40 marshes surveyed in breeding season each year 1996 to 2007 for Song Sparrow, Common Yellowthroat, Black Rail. Fewer data, 2008 to 2010. <u>Clapper Rail breeding season surveys:</u> over 50 marshes surveyed 2005 to 2010, by multiple partners. Only partial Clapper Rail survey data available before 2005.

Data suitable quality	Yes			Standardized protocols are used for tidal marsh bird studies (WRMP 2002). Clapper Rail surveys use more than one protocol, but results are standardized and integrated across multiple partners. In-house QA/QC check. Data are now fed into Calif. Avian Data Center, which incorporates further data checking.
Responsiveness				
Driver-outcome linkage	Yes, qualified			Indicator metrics (abundance, change in abundance) are widely used as indicators of biotic condition in estuarine and wetland ecosystems. Differences in abundance reflect habitat condition, importance of surrounding land-use, hydrology, geomorphology, and specific vegetation characteristics. However, changes in abundance can reflect other factors that may be species-specific (e.g., influence of disease or invasive species). On the positive side, abundance or change in abundance can reflect management activity directly (e.g., predator control).
Sensitivity	Yes, qualified			Temporal variation is substantial, but good protocol/statistical procedures can reduce extraneous variation. Better to examine response of indicator over multiple years. In addition, there is substantial spatial variability. Again, ecological signal can be extracted, with appropriate statistical techniques, and by combining data across species.
Response time frame	Yes			Annual changes can be evaluated. However, better to evaluate over a multiple-year time frame (3 to 5 years).
Response spatial frame	Yes			Spatial variability: marsh to marsh, there is variation, but repeated sampling of the same sites can allow one to control for this. Sampling multiple sites is also important. Regional indices can be developed and are meaningful.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			CCMP goals for "recovery", "reversing declines" are non-quantitative. Examination of time series (going back to 1996) provides the best reference condition. Changes in abundance can be quantified and used for assessment. For Clapper Rails, estimates of population size (not just changes in abundance indices) are also important for management agencies; appropriate targets are still being developed.
Meaningful to public/agencies	Yes			Metrics of bird populations are easily understood and feed into management activities/programs.
Transferability				
Scalable	Yes, qualified			Indicator metrics are consistently measured over range of scales (e.g., estuary-wide, bay region within estuary, individual watersheds, individual marshes). They are most meaningful at the scale of a single watershed or a bay region. Whatever the scale, sampling at multiple sites is needed for meaningful metrics.
Transferable to other watersheds	Yes			In theory, yes. Trend values can be compared to other estuaries. Few other estuaries have the spatial and temporal sampling that is carried out in SF estuary.

Biotic Condition-Birds

2. Marsh Bird Reproductive Success Indicator

Marsh Bird Reproductive Success Indicator
Description of Indicator: Probability of nest survival of tidal marsh Song Sparrows (i.e., probability a nesting attempt survives to produce 1 or more fledged young)

Spatial Sampling and Estimation: Estimates determined at representative marshes in each of two regions: San Pablo Bay, Suisun Bay				
Temporal Sampling: Based on nest monitoring over entire breeding season (March-July)				
	Result (yes, qualified yes, no, or partially)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (w/ regard to ecological function)	Yes	Biotic condition		
Fits with CCMP (w/ regard to management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes, partially			Adequate data available from 1996 to 2006 (not conducted 2007-2010).
Data suitable quality	Yes			Estimates based on intensive nest-monitoring. QA/QC conducted on data. Standardized methods of analysis employed.
Responsiveness				
Driver-outcome linkage	Yes			Nest survival an important component of population viability; used in many avian studies (e.g., breeding waterfowl, herons & egrets). Reflects predation, disturbance, and flooding risk during breeding season. Management actions can affect predation rates and thus alter nest survival. Driver-outcome linkage is partly applicable to other species.
Sensitivity	Yes			Responds to changes in stressors, e. g., predation or flooding risk Indicator integrates outcomes over entire breeding season (i.e., not influenced by day to day variability). Good metric for evaluating restoration effectiveness.
Response time frame	Yes			Annual changes can be evaluated. Can look at change between years, as well as longer period.
Response spatial frame	Yes			Results calculated for individual marshes, but results for a single marsh may not be representative. Need 2 or more marsh sites per bay region. Need to distinguish bay region.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			CCMP goals for "recovery", "reversing declines" are non-quantitative. Quantitative target for this species is identified: 22 to 25% nest survival probability.
Meaningful to public/agencies	Yes			Very meaningful. Failure to rear young is easily understood problem; changes in nest survival easily understood.
Transferability				
Scalable	Yes			Very. Can scale down to sub-site within a marsh or to individual

				marsh. Best at watershed level. Can scale up to bay region.
Transferable to other watersheds	Yes			Absolute values can easily be compared to other areas, nationally and globally.

Biotic Condition-Birds

3. Heron and Egret Reproductive Success Indicator

Heron and Egret Reproductive Success Indicator

Description of Indicator:
Heron and Egret nest survival is a key indicator of annual reproductive success. Nest survival reflects variation in the ability of herons and egrets budget sufficient time for nest attendance relative to the competing demands of foraging. Therefore, it is associated with processes related to pressure from nest predators and local disturbance as well as foraging conditions in the surrounding landscape needed for successful nesting. Results are summed within and across major wetland subregions. Nesting performance of two species is included: Great Blue Heron and Great Egret.

Spatial Sampling and Estimation:
The indicator is expressed as the percent change in the proportion of nests that survive to fledge at least one young and is linked to process that affect nest success and operate over multiple spatial scales. Nest survival estimates for individual nesting colonies are aggregated metrics for each of three major wetland subregions (Central SF Bay, San Pablo Bay, and Suisun Bay) and regional estimates for the central and northern portion of the San Francisco Estuary.

Temporal Sampling:
Annual sampling during breeding season, based on approximately four (monthly) surveys at each nesting colony, March through June.

	Result (yes, no, or qualified)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1 and 2; Wildlife Goals #1 and 3; Wetlands Management Goals #2, 3, and 4.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend. Goal 3: Optimally manage and monitor the wildlife resources of the Estuary. Wetlands Management goals Goal 2: Restore and enhance the ecological productivity and habitat values of wetlands. Goal 3: Expedite a significant increase in the quantity and quality of wetlands. Goal 4: Educate the public about the values of wetland resources.
Data Availability and Adequacy				
Data available	Yes			Audubon Canyon Ranch Regional Heron and Egret studies: Ongoing monitoring of all known Great Blue Heron and Great Egret nesting colonies (40-50 sites, annually) in the northern San Francisco Bay area, based on repeated (monthly) visits during each breeding season from 1991 to 2010.
Data suitable quality	Yes			Field methods, data structure, and database management follow

				standardized protocols; intensive QA/QC is conducted annually. Data reflect intensive and extensive measurements of reproductive success at all known colony sites and are considered to be a vital rate in breeding population dynamics (Kelly et al. 2007).
Responsiveness				
Driver-outcome linkage	Yes, qualified			Heron and egret nest survival is closely associated with colony site stability, disturbance, and human activity near colony sites. It is al so a recognized indicator of biotic condition of surrounding estuarine and wetland ecosystems (Kushlan and Hancock 2005).
Sensitivity	Yes, qualified			This indicator is sensitive to process in the vicinity of the colony as well as in surrounding wetlands, especially within 3 km of nests.
Appropriate temporal and spatial time frames for response	Yes			Outcomes reflect annual responses to local wetland condition as well as broad responses to processes that operate at subregional and regional scales.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			CCMP Aquatic Resources Goals are not quantitative. However, using time series back to 1994; specific quantitative targets can be addressed.
Meaningful to public/agencies	Yes			Vital population rates in birds are compelling to policy makers. Herons and egrets are frequently used as symbols of wetland conservation (Parnell et al. 1988, Kushlan and Hancock 2005) and are recognized as indicators of wetland health (Kushlan 1993, Erwin and Custer 2000).
Transferability				
Scalable	Yes, qualified			Sampling of all known nesting colonies in the San Francisco Bay region facilitates analysis of vital population rates at multiple spatial scales.
Transferable to other watersheds	Yes, qualified			Monitoring methods are easily transferable. Trends can be compared to those in other estuaries, although results from other areas are typically limited to sporadic sampling.

Biotic Condition-Birds

4. Wintering Waterfowl Indicator

Wintering Waterfowl Indicator				
Description of Indicator: Annual Abundance Index (i.e., number of individuals detected during winter-time aerial surveys) for seven species of dabbling ducks and six species of diving ducks. Trends over time are estimated.				
Spatial Sampling and Estimation: Estimates determined for each of four regions: Central SF Bay, South SF Bay, San Pablo Bay, Suisun Bay				
Temporal Sampling: One survey per year in early January.				
	Result (yes, qualified yes, no, or partially)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (w/ regard to ecological function)	Yes	Biotic condition		
Fits with CCMP	Yes		Aquatic	Aquatic Resources Goals

(w/ regard to management objectives)			Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Data available since 1989 for all four regions; numbers compiled by USFWS and/or USGS.
Data suitable quality	Yes, qualified			Standardized protocols used. Only one survey-day per region. QA/QC not specified.
Responsiveness				
Driver-outcome linkage	Yes, qualified			Indicator metrics (abundance, change in abundance) are widely used as indicators of biotic condition in estuarine and wetland ecosystems. Differences in abundance reflect habitat condition, importance of surrounding land-use, hydrology, geomorphology, and specific vegetation characteristics. However, changes in abundance can reflect other factors that may be species-specific (e.g., influence of disease, invasive species, predation, breeding success). On the positive side, abundance or change in abundance can reflect management activity directly (e.g., predator control).
Sensitivity	Yes, qualified			Temporal variation is substantial, because surveys only conducted over one day. A single year's value is not reliable. Combining data (e.g., estimating trend) over years helps. All data are pooled over large regions, which are either good or bad (e.g., can't separate changes in one watershed from another).
Response time frame	Yes			Annual changes can be examined. However, better to evaluate over a multiple-year time frame (5 years or more).
Response spatial frame	Yes			Only resolved at bay region level.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			CCMP goals for "recovery", "reversing declines" are non-quantitative. Reference condition identified as numbers in 1989-1991 for SFBJV.
Meaningful to public/agencies	Yes			Metrics of bird populations are easily understood and feed into management activities/programs.
Transferability				
Scalable	Partially			Cannot scale down (to watersheds within a bay region), but can scale up to the entire SF Estuary, or even Pacific Flyway
Transferable to other watersheds	Yes, qualified			Trends in numbers can be compared to trends in other watersheds. Absolute numbers cannot be.

Biotic Condition-Birds

5. Heron and Egret Nest Density Indicator

Heron and Egret Nest Density Indicator
Description of Indicator:

Heron and Egret Nest Density is an indicator of annual breeding abundance, percent change in the peak number of active nests across nesting colonies within foraging range (10 km) of the San Francisco Estuary, summed within and across major wetland subregions. The indicator is expressed as percent change in nests per 100 km^2 of wetland habitat as an index of breeding abundance and population trends for two species: Great Blue Heron and Great Egret.				
Spatial Sampling and Estimation: Estimates for individual nesting colonies are aggregated to provide estimates for each of three major wetland subregions (Central SF Bay, San Pablo Bay, and Suisun Bay) and regional estimates for the central and northern portion of the San Francisco Estuary.				
Temporal Sampling: Annual sampling during breeding season, based on approximately four (monthly) surveys at each nesting colony, March through June.				

	Result (yes, no, or qualified)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3, and 4; Wildlife Goals #1 and 3; Wetlands Management Goals #2, 3, and 4.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend. Goal 3: Optimally manage and monitor the wildlife resources of the Estuary. Wetlands Management goals Goal 2: Restore and enhance the ecological productivity and habitat values of wetlands. Goal 3: Expedite a significant increase in the quantity and quality of wetlands. Goal 4: Educate the public about the values of wetland resources.
Data Availability and Adequacy				
Data available	Yes			Audubon Canyon Ranch Regional Heron and Egret studies: Ongoing monitoring of all known Great Blue Heron and Great Egret nesting colonies (40-50 sites, annually) in the northern San Francisco Bay area, based on repeated (monthly) visits during each breeding season from 1991 to 2010.
Data suitable quality	Yes			Field methods, data structure, and database management follow standardized protocols; intensive QA/QC is conducted annually. Data reflect intensive and extensive measurements of nest abundance at all known colony sites and are considered to provide an effective estimate of breeding population size (Kelly et al. 2007).
Responsiveness				
Driver-outcome linkage	Yes, qualified			Heron and egret nest density is widely used as indicators of biotic condition in estuarine and wetland ecosystems. Differences reflect wetland habitat conditions over spatial scales of 30-300 km^2, including the importance of surrounding land-use, hydrology, especially water circulation and depth, geomorphology, and vegetation characteristics. The linkage is well-documented (Kelly et al 2008, Kushlan 2000).
Sensitivity	Yes,			Spatial and temporal variation is substantial, but comprehensive

	qualified			regional monitoring, combined with detailed protocol and statistical procedures, reduces sampling error. Repeated sampling of each site within years ensures a sensitive measure of maximum abundance. The indicator can detect significant changes between years and provides a sensitive measure of regional population trends across spans of 5 or more years.
Appropriate temporal and spatial time frames for response	Yes			Outcomes reflect annual responses to wetland condition but are best evaluated over a multiple-year time frame (3 to 5 years). The indicator can reveal responses at multiple spatial scales, including variability among local conditions near heronries, major wetland systems related to wetland subregions, and variability in regional conditions.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			CCMP Aquatic Resources Goals are not quantitative. However, using time series back to 1991; specific quantitative targets relevant to each goal can be addressed by this indicator. The "recovery" of breeding abundances, at temporal scales of 3 or more years can be evaluated. Management of heron and egret abundances would target local colony site conditions as well as the extent of suitable feeding areas.
Meaningful to public/agencies	Yes			Bird population metrics are easily understood by policy makers. Herons and egrets are frequently used as symbols of wetland conservation (Parnell et al. 1988, Kushlan and Hancock 2005) and are recognized as indicators of wetland health (Kushlan 1993, Erwin and Custer 2000).
Transferability				
Scalable	Yes, qualified			Sampling of all known nesting colonies in the San Francisco Bay region facilitates analysis of indicator metrics at multiple spatial scales.
Transferable to other watersheds	Yes, qualified			Trends can be easily compared to those in other estuaries, although results from other areas are typically limited to sporadic sampling.

Biotic Condition-Birds

6. Wintering Shorebird Indicator

Wintering Shorebird Indicator

Description of Indicator:
Annual Abundance Index (i.e., number of individuals detected during early winter shore-based surveys) for multiple species (nine indicator species proposed.)

Spatial Sampling and Estimation:
Estimates determined for each of three regions: Central SF Bay, South SF Bay, San Pablo Bay (no Suisun Bay)

Temporal Sampling:
One survey per year in late November

	Result (yes, qualified yes, no, or partially)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (w/ regard to ecological function)	Yes	Biotic condition		
Fits with CCMP	Yes		Aquatic	Aquatic Resources Goals

(w/ regard to management objectives)			Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Partially			Data available for 1990-1992 and 2006-2008. Additional survey in 2010. Two of nine species are year-round resident; the others use SF Bay for wintering and migratory stop-over.
Data suitable quality	Yes, qualified			Standardized protocols used. Only one survey-day per region. QA/QC not specified.
Responsiveness				
Driver-outcome linkage	Yes, qualified			Indicator metric (change in abundance) is widely used as indicator of biotic condition in estuarine and wetland ecosystems. Differences in abundance reflect habitat condition, importance of surrounding land-use, etc. Not clear if change in indicator reveals changes in underlying population size or just shifts in distribution. Cannot resolve indicator at watershed level, so not tied as well to management.
Sensitivity	Yes, qualified			Temporal variation is substantial, because surveys only conducted over one day. A single year's value is not reliable. Combining data (e.g., estimating trend) over years helps. All data are pooled over bay regions, which are either good or bad (e.g., can't separate changes in one watershed from another). Changes in numbers may reflect shifts in spatial distribution, not biotic condition.
Response time frame	Yes			Annual changes can be examined. However, better to evaluate over a multiple-year time frame (5 years or more).
Response spatial frame	Yes			Only resolved at bay region level. Best to look at combined results over the three bay regions, as well as single regions.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			CCMP goals for "recovery", "reversing declines" are non-quantitative. Reference condition identified as numbers in 1991-1993. Target for SFBJV: no decline.
Meaningful to public/agencies	Yes, qualified			Metrics of bird populations are easily understood; interpretation can be difficult (shift in use, rather than population increase/decrease).
Transferability				
Scalable	Partially			Cannot scale down (to watersheds within a bay region), but can scale up to SF Bay/North Bay.
Transferable to other watersheds	Yes, qualified			Trends in numbers can be compared to trends in other watersheds. Absolute numbers cannot be.

Biotic Condition-Invertebrate Diversity & Abundance

7. Zooplankton Abundance: Not Selected

Zooplankton Abundance
(unit of measure: number of zooplanktons per unit volume sampled water)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	No			Long-term, consistently collected survey data for SF Estuary zooplankton survey are available for only the upstream portion of the estuary (Suisun Bay).
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Both seasonal and inter-annual patterns in zooplankton abundance known to be related to physical, chemical and biological conditions
Sensitivity	Yes			Indicator metric, abundance, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual or seasonal
Spatial sampling frame	No			Suitable data limited to upstream reaches of the SF Estuary
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Note: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of zooplankton or food organism abundance are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (abundance) can be consistently measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds) but, in the SF estuary, zooplankton abundance is consistently measured at only a few stations concentrated in the upstream reach of the estuary.
Transferable to other watershed	Yes			Indicator metric (abundance) is commonly used and easily derived from data from most comprehensive zooplankton survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition-Invertebrate Diversity and Abundance

8. Zooplankton Diversity: Not Selected

Zooplankton Diversity (unit of measure: number of zooplankton species present)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	No			Long-term, consistently collected survey data for SF Estuary zooplankton survey are available for only the upstream portion of the estuary (Suisun Bay).
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Both seasonal and inter-annual patterns in zooplankton diversity known to be related to physical, chemical and biological conditions
Sensitivity	Yes			Indicator metric, number of species, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual or seasonal
Spatial sampling frame	No			Suitable data limited to upstream reaches of the SF Estuary
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Note: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of zooplankton or food organism diversity are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (number of species) can be consistently measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds) but, in the SF estuary, consistent zooplankton surveys are conducted at only a few stations concentrated in the upstream reach of the estuary.
Transferable to other watershed	Yes			Indicator metric (number of species) is commonly used and easily derived from data from most comprehensive zooplankton survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition-Invertebrate Diversity and Abundance

9. Benthic Macrofauna Abundance: Not Selected

Benthic Macrofauna Abundance (unit of measure: numerical abundance)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			WEMAP, SFEI, DWR, USGS
Data suitable quality	Yes			Quality assurance protocols are available
Responsiveness				
Driver-outcome linkage	Yes			Responds to benthic pollution. There can be differences in benthic macrofauna abundance among habitats
Sensitivity	Yes			Calibration is needed since the indicator response is impact-and site-specific. In benthic process models, benthic macrofauna abundance is highly sensitive to predation rates.
Response time frame	Yes			Depends on impact. Instant (dredged sediment disposal) to years (climate change)
Spatial sampling frame	Yes			WEMAP used a regional sampling frame.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Sediment Quality Guidelines index thresholds and reference conditions. The Benthic Pilot Study has determined "ambient reference" conditions that provide a foundation for using benthic indicators to identify contaminant-impacted areas in the Estuary. An "ambient reference" benthic assemblage is defined as: "A sample of organisms that currently inhabit the least-contaminated areas of the Estuary that includes species known (from studies elsewhere) to inhabit uncontaminated sediments, but do not include very many species known to inhabit contaminated sediments. " These assemblages should exhibit natural fluctuations in species composition and abundance in response to changes in salinity and sediment-type.
Meaningful to public	No			Not in and by itself. Can be used effectively for informing the public if communicated as a cost-effective measure that is part of an estuarine health assessment (for example, as an integral part of the Water Quality Index)
Transferability				
Scalable	Yes			As part of SQG, this indicator is a component of a transparent and scalable weight-of-evidence framework
Transferable to other watershed	Yes			SQG provides a sediment assessment framework for all of California's estuaries

Biotic Condition-Invertebrate Diversity and Abundance

10. Benthic Macrofauna Diversity: Not Selected

Benthic Macrofauna Diversity (unit of measure: number of species/sample)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Benthic indicators database (SFEI/SCCWRP), USGS (historic)
Data suitable quality	Yes			Quality assurance protocols are available
Responsiveness				
Driver-outcome linkage	Yes			Two drivers of interest are sediment chemistry and biological invasions. Studies have documented relationships between species richness (number of species) and chemical stressors. The influence of *Spartina* and other habitat-modifying invasives appears to be conditional and depending on physical forcing. (e.g. desiccation).
Sensitivity	Yes			Benthic macrofauna diversity has been demonstrated as an indicator of metal contamination. In general, as the level of metals increase, diversity decreases and sensitive and indifferent species are substituted by tolerant or opportunistic species.
Response time frame	Yes			Instant (toxic spills) to decades (climate change)
Spatial sampling frame	Yes			Entire estuary
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal: biological integrity Thresholds: Benthic Response Index (BRI), Benthic Quality Index (BQI), Relative Benthic Index (RBI), River Invertebrate Prediction and Qualification System (RIVPACS), Index of Biotic Integrity (IBI) Reference conditions: A sample of organisms that currently inhabit the least-contaminated areas of the Estuary that includes species known (from studies elsewhere) to inhabit uncontaminated sediments, but do not include very many species known to inhabit contaminated sediments.
Meaningful to public	No			Meaningful only as an integrated part of the Water Quality Index
Transferability				
Scalable	Yes			As part of SQG, this indicator is a component of a transparent and scalable weight-of-evidence framework
Transferable to other watershed	Yes			Can be applied and calibrated to the benthic communities of other watersheds

Biotic Condition-Invertebrate Diversity and Abundance

11. Dungeness Crab Abundance: Not Selected

Dungeness Crab Abundance
(unit of measure: number of juvenile Dungeness crab per unit area sampled)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using an otter trawl survey one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	No			Dungeness crab abundance in the SF Estuary is largely a function of coastal ocean conditions, rather than watershed conditions or conditions within the estuary.
Sensitivity	No			Dungeness crab abundance in the SF Estuary is largely a function of coastal ocean conditions, rather than watershed conditions or conditions within the estuary.
Response time frame	Yes			Annual
Spatial response frame	Yes			Dungeness crabs are surveyed throughout the estuary and their abundance varies geographically within the estuary, however, their estuary-wide abundance is largely a function of coastal ocean conditions.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 1980-1989 average abundance Note: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of Dungeness crab abundance are compelling and easily understood.
Transferability				
Scalable	No			Indicator metric (Dungeness crab abundance) can be consistently measured over several scales (e.g., estuary-wide or estuary sub-regions) but because the indicator is most responsive to coastal ocean conditions rather than watershed or estuarine conditions, the indicator has limited scalability.
Transferable to other watershed	No			Indicator metric (Dungeness crab abundance) has limited relevance for watershed assessment and its transferability to other estuaries is limited by the species range and its stronger response to ocean conditions than estuarine conditions.

Biotic Condition-Invertebrate Diversity and Abundance

12. Rock Crab Abundance: Not Selected

Rock Crab Abundance (unit of measure: number of rock crab per unit area sampled)				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using an otter trawl survey one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	No			Rock crab abundance in the SF Estuary is largely a function of coastal ocean conditions, rather than watershed conditions or conditions within the estuary.
Sensitivity	No			Rock crab abundance in the SF Estuary is largely a function of coastal ocean conditions, rather than watershed conditions or conditions within the estuary.
Response time frame	Yes			Annual
Spatial sampling frame	Yes			Rock crabs are surveyed throughout the estuary and their abundance varies geographically within the estuary, however, their estuary-wide abundance is largely a function of coastal ocean conditions.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 1980-1989 average abundance Note: CCMP goals for “recovery”, “reversing declines” are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of rock crab abundance are compelling and easily understood.
Transferability				
Scalable	No			Indicator metric (rock crab abundance) can be consistently measured over several scales (e.g., estuary-wide or estuary sub-regions) but because the indicator is most responsive to coastal ocean conditions rather than watershed or estuarine conditions, the indicator has limited scalability.
Transferable to other watershed	No			Indicator metric (Dungeness crab abundance) has limited relevance for watershed assessment and its transferability to other estuaries is limited by the species range and its stronger response to ocean conditions than estuarine conditions.

Biotic Condition-Invertebrate Diversity & Abundance

13. Bay Shrimp Abundance: Selected but not calculated.

This candidate indicator was selected for calculation but was not calculated for this report because data were not made available within the scheduled timeframe.

Bay Shrimp Abundance (unit of measure: number of Bay shrimp per unit area sampled)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using an otter trawl survey one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Indicator metric, abundance: a) is commonly used indicator of biotic condition in aquatic ecosystems; and b) has statistically significant relationships with other WAF attribute categories (including landscape condition, hydrology and geomorphology).
Sensitivity	Yes			Indicator metric, abundance, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual
Spatial sampling frame				
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 1980-1989 average abundance Note: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of shrimp abundance are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (abundance) is consistently measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds).
Transferable to other watershed	Yes			Bay shrimp are common to Pacific coast estuaries but may not be a transferable indicator for other watershed. However, abundance measurements, which are commonly used and easily derived from data from most comprehensive survey programs, for other crustaceans or invertebrates may be useful substitutes.

Biotic Condition-Invertebrate Diversity & Abundance

14. *Macoma* Clam Abundance: Not Selected

Macoma Clam Abundance (unit of measure: individuals/m^2)				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	No			No regular quantitative sampling
Data suitable quality	No			N/a
Responsiveness				
Driver-outcome linkage	No			Not well established
Sensitivity	No			N/a
Response time frame	Yes			Long-term effects of pollution: months – years
Spatial sampling frame	Yes			N/a
Interpretation				
Goals, thresholds or reference conditions defined	No			None established
Meaningful to public	No			Not representing success measure of any particular management program. Since they are not well known, they don't represent an attribute of concern to the public.
Transferability				
Scalable	Yes			Can be scaled regionally, sub-regionally, or by habitat/feature
Transferable to other watershed	Yes			Macoma-type clams are important components of many estuarine ecosystems

Biotic Condition-Invertebrate Diversity & Abundance

15. *Mya* Clam Abundance: Not selected

Mya Clam Abundance (unit of measure: individuals/m^2)				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		

Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	No			No regular quantitative sampling
Data suitable quality	No			N/a
Responsiveness				
Driver-outcome linkage	Yes			Abundance of Potamocorbula amurensis is the main driver of Mya abundance. Like other clams, Mya arenaria are known to be effective moderators of eutrophication through their efficient filtration of phytoplankton and known to alter N and P cycling.
Sensitivity	Yes			Pollutants such as oil can measurably reduce abundance
Response time frame	No			n/a
Spatial sampling frame	No			n/a
Interpretation				
Goals, thresholds or reference conditions defined	No			None defined
Meaningful to public	No			Not representing success measure of any particular management program. Since they are not well known, they don't represent an attribute of concern to the public
Transferability				
Scalable	Yes			Can be scaled regionally, sub-regionally, or by habitat/feature
Transferable to other watershed	Yes			Has been introduced to other estuaries along the West Coast

Biotic Condition-Invertebrate Diversity & Abundance

16. Native Oyster Abundance

Native Oyster Abundance
(unit of measure: number of oysters)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.

Data Availability and Adequacy				
Data available	No			No regular quantitative sampling
Data suitable quality	No			n/a
Responsiveness				
Driver-outcome linkage	No			Not well established, no universal agreement
Sensitivity	No			No information found
Response time frame	No			Not enough information
Spatial sampling frame				N/a
Interpretation				
Goals, thresholds or reference conditions defined	No			None established
Meaningful to public	Yes			Native oysters represent a meaningful attribute of concern to the public and are well suited for educational purposes
Transferability				
Scalable	Yes			Provided data are collected based on a scalable framework and approach
Transferable to other watershed	Yes			There are restoration efforts underway in a number of estuaries along the West Coast

Biotic Condition: Fish Community

17. Fish Distribution: Not Selected

Fish Distribution (unit of measure: % of sample stations with selected species present)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using midwater and otter trawl surveys one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Distribution of fishes within the SF Estuary varies predictably on a seasonal basis and with estuarine environmental conditions. However, distribution patterns are generally species specific, therefore indicator response to environmental conditions also depends on species selected for calculation of the indicator.

Sensitivity	No			Although fish species distribution within the estuary varies in response to season and environmental conditions, using the available survey data, the indicator metric (% of stations with selected species present) has low resolution and is relatively insensitive.
Response time frame	Yes			Annual or seasonal
Spatial sampling frame	Yes			Fish distribution varies within the SF Estuary as a function of season and environmental conditions, therefore estuary-wide survey data are necessary for calculation of the indicator.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of fish distribution or presence/absence are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (% of stations with selected species present) is can be measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds). In the SF estuary, the large number of consistently measured stations allows for comparison of this measure of biotic condition across different regions within the estuary.
Transferable to other watershed	Yes			Indicator metric (% of stations with selected species present) is commonly used and easily derived from data from most comprehensive fish survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition: Fish Community

Fish Abundance: Selected and Calculated

This candidate indicator was refined and four indicators that assess abundance of different components of the San Francisco Estuary fish community were developed.

18. Pelagic Fish Abundance

Pelagic Fish Abundance
(unit of measure: number of native pelagic fish per 10,000 m^3)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35

				stations distributed throughout the SF estuary using a midwater trawl survey one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Pelagic fishes live in open water habitats, not closely associated with either the shore or bottom. Indicator metric, abundance: a) is commonly used indicator of biotic condition in aquatic ecosystems; and b) has statistically significant relationships with other WAF attribute categories (including landscape condition, hydrology and geomorphology).
Sensitivity	Yes			Indicator metric, abundance, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual
Spatial sampling frame				Pelagic fish abundance varies geographically within the SF Estuary as a function of season and environmental conditions, therefore estuary-wide survey data are necessary for calculation of the indicator.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 1980-1989 average abundance Note: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of fish abundance are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (abundance) is consistently measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds). In the SF estuary, the large number of consistently measured stations allows for comparison of this measure of biotic condition across different regions within the estuary.
Transferable to other watershed	Yes			Indicator metric (abundance) is commonly used and easily derived from data from most comprehensive fish survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition-Fish Abundance

19. Demersal Fish Abundance

Demersal Fish Abundance
(unit of measure: number of native demersal fish per 10,000 m^3)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability				

and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using an otter trawl survey one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Demersal fishes live at or near the bottom of a body of water. Indicator metric, abundance: a) is commonly used indicator of biotic condition in aquatic ecosystems; and b) has statistically significant relationships with other WAF attribute categories (including landscape condition, hydrology and geomorphology).
Sensitivity	Yes			Indicator metric, abundance, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual
Spatial sampling frame				Demersal fish abundance varies geographically within the SF Estuary as a function of season and environmental conditions, therefore estuary-wide survey data are necessary for calculation of the indicator.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 1980-1989 average abundance Note: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of fish abundance are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (abundance) is consistently measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds). In the SF estuary, the large number of consistently measured stations allows for comparison of this measure of biotic condition across different regions within the estuary.
Transferable to other watershed	Yes			Indicator metric (abundance) is commonly used and easily derived from data from most comprehensive fish survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition-Fish Abundance

20. Northern Anchovy Abundance

Northern Anchovy Abundance
(unit of measure: number of northern anchovy per 10,000 m^3)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife Goal #1.	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and

				the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using a midwater trawl survey one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Northern anchovy is the most common fish in the SF Estuary. Indicator metric, abundance: a) is commonly used indicator of biotic condition in aquatic ecosystems; and b) has statistically significant relationships with other WAF attribute categories (including landscape condition, hydrology and geomorphology).
Sensitivity	Yes			Indicator metric, abundance, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual
Spatial sampling frame				Northern anchovy abundance varies geographically within the SF Estuary as a function of season and environmental conditions, therefore estuary-wide survey data are necessary for calculation of the indicator.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 1980-1989 average abundance Note: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of fish abundance are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (abundance) is consistently measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds). In the SF estuary, the large number of consistently measured stations allows for comparison of this measure of biotic condition across different regions within the estuary.
Transferable to other watershed	Yes			Indicator metric (abundance) is commonly used and easily derived from data from most comprehensive fish survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition-Fish Abundance

21. Sensitive Fish Abundance

Sensitive Fish Species Abundance
(unit of measure: unweighted average of abundance of longfin smelt, Pacific herring, starry flounder and striped bass relative to their 1980-1989 average abundance)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2, 3 and 4; Wildlife	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into

			Goal #1.	consideration all beneficial uses of Bay-Delta resources. Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using midwater and otter trawl surveys one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Longfin smelt, Pacific herring, starry flounder and striped bass are the most common estuary-dependent fish species in the SF Estuary (except for northern anchovy). Indicator metric, abundance: a) is commonly used indicator of biotic condition in aquatic ecosystems; and b) has statistically significant relationships with other WAF attribute categories (including landscape condition, hydrology and geomorphology).
Sensitivity	Yes			Indicator metric, abundance, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual
Spatial sampling frame				Sensitive fish species abundance varies geographically within the SF Estuary as a function of season and environmental conditions, therefore estuary-wide survey data are necessary for calculation of the indicator.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 1980-1989 average abundance Note: CCMP goals for “recovery”, “reversing declines” are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of fish abundance are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (abundance) is consistently measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds). In the SF estuary, the large number of consistently measured stations allows for comparison of this measure of biotic condition across different regions within the estuary.
Transferable to other watershed	Yes			Indicator metric (abundance) is commonly used and easily derived from data from most comprehensive fish survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition: Fish Species Diversity: Selected and Calculated

This candidate indicator was refined and two indicators that assess diversity of different components of the San Francisco Estuary fish community were developed.

22. Native Fish Species Diversity

Native Fish Species Diversity (unit of measure: percentage of native fish species assemblage present)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using midwater and otter trawl surveys one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Indicator metric, diversity (or number of native species present, expressed as percentage of the maximum number of observed native species) is commonly used indicator of biotic condition in aquatic ecosystems.
Sensitivity	Yes			Indicator metric, diversity (or number of native species present, expressed as percentage of the maximum number of observed native species), exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual
Spatial sampling frame				Fish species assemblages vary geographically within the SF Estuary as a function of season and environmental conditions, therefore estuary-wide survey data are necessary for calculation of the indicator.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 50% of maximum observed species assemblage Note: CCMP goals for "recovery", "reversing declines" are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of fish diversity are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (number of native species present) is consistently measured over a range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds). In the SF estuary, the large number of consistently measured stations allows for comparison of this measure of biotic condition across different regions within the estuary.
Transferable to other watershed	Yes			Indicator metric (number of native species present) is commonly used and easily derived from data from most comprehensive fish survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition-Fish Species Diversity

23. Estuary-Dependent Fish Species Diversity

Estuary-dependent Fish Species Diversity (unit of measure: percentage of native estuary-dependent fish species assemblage present)				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2 and 4; Wildlife Goal #1.	Aquatic Resources Goals Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife Goals Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using midwater and otter trawl surveys one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Estuary-dependent fish species are those that reside in the SF Estuary or rely on the SF Estuary for some key part of their life cycle. Indicator metric, diversity of Bay-dependent fish species (or number of native estuary-dependent species present, expressed as percentage of the maximum number of observed native estuary-dependent species) is similar to commonly used diversity indicator of biotic condition in other aquatic ecosystems and has been refined to assess the diversity of the fish assemblage that depends on the SF Estuary.
Sensitivity	Yes			Indicator metric, diversity (or number of estuary-dependent species present, expressed as percentage of the maximum number of observed native species), exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual
Spatial sampling frame				Estuary-dependent fish species assemblages vary geographically within the SF Estuary as a function of season and environmental conditions, therefore estuary-wide survey data are necessary for calculation of the indicator.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 70% of maximum observed estuary-dependent species assemblage Note: CCMP goals for “recovery”, “reversing declines” are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of fish diversity are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (number of native estuary-dependent species present) is consistently measured over a range of scales (e.g., estuary-wide,

				regionally within estuary, individual watersheds). In the SF estuary, the large number of consistently measured stations allows for comparison of this measure of biotic condition across different regions within the estuary.
Transferable to other watershed	Yes			Indicator metric (number of native estuary-dependent species present) is commonly used and easily derived from data from most comprehensive fish survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

Biotic Condition-Fish Species Composition

24. Fish Species Composition: Selected and Calculated

Fish Species Composition (unit of measure: percentage of fish species that are native species)				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1, 2 and 4; Wildlife Goal #1.	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend.
Data Availability and Adequacy				
Data available	Yes			Interagency Ecological Program Bay Study Survey, 1980-2008, samples 35 stations distributed throughout the SF estuary using midwater and otter trawl surveys one time per month in most years.
Data suitable quality	Yes			Long-running survey program with standardized protocols, data are QA/QC checked by CA Department of Fish and Game.
Responsiveness				
Driver-outcome linkage	Yes			Indicator metric, species composition: a) is commonly used indicator of biotic condition in aquatic ecosystems; and b) has statistically significant relationships with other WAF attribute categories (including landscape condition, hydrology and geomorphology).
Sensitivity	Yes			Indicator metric, species composition, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables.
Response time frame	Yes			Annual
Spatial sampling frame				Fish species assemblages vary geographically within the SF Estuary as a function of season and environmental conditions, therefore estuary-wide survey data are necessary for calculation of the indicator.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: 85% of species are native species Note: CCMP goals for “recovery”, “reversing declines” are non-quantitative but the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions.
Meaningful to public	Yes			Measures of fish species composition are compelling and easily understood.
Transferability				

Scalable	Yes			Indicator metric (percentage of species that are native) is consistently measured over range of scales (e.g., estuary-wide, regionally within estuary, individual watersheds). In the SF estuary, the large number of consistently measured stations allows for comparison of this measure of biotic condition across different regions within the estuary.
Transferable to other watershed	Yes			Indicator metric (percentage of species that are native) is commonly used and easily derived from data from most comprehensive fish survey programs, but few estuaries or watershed are as extensively or as regularly surveyed as the SF estuary.

WAF Category: Chemical/Physical

The candidate indicator Bioaccumulation was subsumed by water quality.

25. Pollutant Loadings

Pollutant Loadings				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Chemical-physical		
Fits with CCMP (management objectives)	Yes		Aquatic Resources (CCMP Goals 1-4); Pollution Prevention and Reduction (CCMP Goals 13-17).	Aquatic Resources CCMP Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota, restoring healthy natural reproduction. CCMP Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. CCMP Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. CCMP Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Pollution Prevention and Reduction CCMP Goal 13: Promote mechanisms to prevent pollution at its source. CCMP Goal 14: Where pollution prevention is not possible, control and reduce pollutants entering the Estuary. CCMP Goal 15: Clean up toxic pollution throughout the Estuary. CCMP Goal 16: Protect against toxic effects, including bioaccumulation and toxic sediment accumulation. CCMP Goal 17: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			RMP Loading data, ABAG land use data, Co-op rain gauges, BASMAA studies, NPDES compliance monitoring data, BAAQMD data, Hg Deposition Network, USACE Dredged Material Disposal Dataset, DAYFLOW.
Data suitable quality	Yes			Data from RMP, NWS cooperative rain gauges, NPDES facilities, Hg Deposition Network, and DAYFLOW are quality-assured
Responsiveness				
Driver-outcome linkage	Yes			Pollutant sources (different human activities) are drivers, as are pollution prevention and reduction efforts. Pollutant loadings affect water quality outcomes.
Sensitivity	Yes			Highly sensitive at local scale near sources, low sensitivity farther away from sources (e.g., at the bottom of a watershed). Long term trends (indicators plotted over time) track effectiveness of regulations and efforts to reduce contamination. Associated uncertainties can be considerable due to effects of meteorological events, hydrological conditions, and other natural factors.

Response time frame	Yes			Annual – decadal
Spatial sampling frame	No			Some data sets cover the region (e.g. Hg Deposition Network), but tributary loading data are available only from "observation watersheds"
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goals: - Pollutant reduction goals: TMDLs - Pollutant discharge limits: NPDES permits Reference conditions: - Davis et al., 2000; Davis et al., 1992; Gunther et al., 1991
Meaningful to public	Yes			The concept of reducing pollutant loads is intuitive and of great public interest, and essential to improving water quality, which is also of great public interest.
Transferability				
Scalable	Yes			Analyses can be performed for a reach, waterbody, watershed, or region; for Bay features, segments, or the entire Bay.
Transferable to other watershed	Yes			The envisioned methodology will allow comparable pollutant loading estimates in different watersheds

Chemical-Physical Condition

26. Water Quality

Water Quality Index				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Chemical-physical		
Fits with CCMP (management objectives)	Yes		Aquatic Resources (CCMP Goals 1-4); Pollution Prevention and Reduction (CCMP Goals 13-17).	<u>Aquatic Resources</u> CCMP Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. CCMP Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. CCMP Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. CCMP Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Pollution Prevention and Reduction</u> CCMP Goal 13: Promote mechanisms to prevent pollution at its source. CCMP Goal 14: Where pollution prevention is not possible, control and reduce pollutants entering the Estuary. CCMP Goal 15: Clean up toxic pollution throughout the Estuary. CCMP Goal 16: Protect against toxic effects, including bioaccumulation and toxic sediment accumulation. CCMP Goal 17: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			RMP (water contaminants, nutrients, aquatic toxicity, sediment quality, bioaccumulation); USGS (nutrient, basic water quality, bioaccumulation); DWR (benthos); NOAA (NS&T); contaminated site data (CERCLA)
Data suitable quality	Yes			Data from above sources are quality-assured
Responsiveness				
Driver-outcome linkage	Yes			Land use, water management, and human activities are drivers of water quality, as are transport pathways such as atmospheric deposition. Economic and social drivers of water quality include commercial activity;

				structural features of the economic system (i.e. sectoral trends); demography and societal behavior patterns; patterns of resource use; and cultural and religious factors (e.g., faith-based environmental friendliness). In turn, water quality is a driver of ecological (biotic) condition
Sensitivity	Yes			Long term trends in water quality (indicators plotted over time) track effectiveness of regulations and efforts to reduce contamination.
Response time frame	Yes			Annual – decadal
Spatial sampling frame	Yes			RMP and USGS data are from a spatial sampling design for the Estuary
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goals: Water quality criteria (Region 2, CTR, site-specific objectives), sediment quality criteria, TMDL targets (fish, birds). Reference conditions: - Comparison to conditions in the past and to less impacted ecosystems
Meaningful to public	Yes			Water quality is one of the most common indicators
Transferability				
Scalable				Analyses can be performed for a specific location (e.g., a hotspot), reach, waterbody, watershed, or region; for Bay features, segments, or the entire Bay.
Transferable to other watershed	Yes			The Water Quality Index can be developed for the regional and/or state level. We anticipate that it will be transferrable to other watersheds.

WAF Category: ECOLOGICAL PROCESSES

27. Carbon Sequestration

Carbon Sequestration				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Ecological Processes		
Fits with CCMP (management objectives)	Yes		Expedite significant increase in wetlands; educate public about wetlands resources	No CCMP goal regarding carbon sequestration, but enhancing carbon sequestration from the atmosphere is consistent with state law and policy.
Data Availability and Adequacy				
Data available	No			No systematic data on greenhouse gas fluxes from various wetland habitats in the region
Data suitable quality	No			Limited experimental data for carbon dioxide, even less data available on methane and nitrous oxide evolution
Responsiveness				
Driver-outcome linkage	Yes			Carbon flux to the estuary (net of methane and nitrous oxide evolution) an important outcome
Sensitivity	Yes			This assumes flux of all greenhouse gases can be calculated
Response time frame	Yes			Recent research in Delta shows capacity for carbon accumulation on a meaningful time frame
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Existing carbon content of wetlands, and flux of greenhouse cases, can be reference condition (defined but not yet measured)
Meaningful to public	Yes			Taking greenhouse gases out of the atmosphere and storing them as carbon in wetlands easily understood
Transferability				
Scalable	Yes			Gas exchange will vary in different climates and habitats
Transferable to other watershed	Yes			Gas exchange will vary in different climates and habitats

Ecological Processes

28. Trophic Structure: Heron and Egret Brood Size Indicator

Heron and Egret Brood Size Indicator

Description of Indicator:
Heron and Egret brood size in successful nests is an indicator of annual population productivity. Brood size differences reflect variation in the productivity of wetland feeding areas across large spatial scales, as well as variation in foraging intensity by top wetland (piscivorous) predators. Results are summed within and across major wetland subregions. Nesting performance of two species is included: Great Blue Heron and Great Egret.

Spatial Sampling and Estimation:
The indicator is expressed as percent change in prefledging brood size across nesting colonies, and is directly linked to feeding conditions within a foraging range (10 km). Estimates for individual nesting colonies are aggregated to provide estimates for each of three major wetland subregions (Central SF Bay, San Pablo Bay, and Suisun Bay) and regional estimates for the central and northern portion of the San Francisco Estuary.

Temporal Sampling:
Annual sampling during breeding season, based on approximately four (monthly) surveys at each nesting colony, March through June.

	Result (yes, no, or qualified)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Biotic condition		
Fits with CCMP (management objectives)	Yes		Aquatic Resource Goals #1 and 2; Wildlife Goals #1 and 3; Wetlands Management Goals #2, 3, and 4.	<u>Aquatic Resources Goals</u> Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. <u>Wildlife Goals</u> Goal 1: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend. Goal 3: Optimally manage and monitor the wildlife resources of the Estuary. <u>Wetlands Management goals</u> Goal 2: Restore and enhance the ecological productivity and habitat values of wetlands. Goal 3: Expedite a significant increase in the quantity and quality of wetlands. Goal 4: Educate the public about the values of wetland resources.
Data Availability and Adequacy				
Data available	Yes			<u>Audubon Canyon Ranch Regional Heron and Egret studies:</u> Ongoing monitoring of all known Great Blue Heron and Great Egret nesting colonies (40-50 sites, annually) in the northern San Francisco Bay area, based on repeated (monthly) visits during each breeding season from 1991 to 2010.
Data suitable quality	Yes			Field methods, data structure, and database management follow standardized protocols; intensive QA/QC is conducted annually. Data reflect intensive and extensive measurements of productivity at all known colony sites and are considered to be a key vital rate in breeding population dynamics (Kelly et al. 2007).
Responsiveness				
Driver-outcome linkage	Yes,			Heron and egret brood size variation is recognized as an indicator

	qualified			of biotic condition in estuarine and wetland ecosystems Kushlan and Hancock 2005)... Differences reflect wetland habitat conditions over spatial scales of 30-300 km^2, including the importance of surrounding land-use, hydrology, especially water circulation and depth, geomorphology, and vegetation characteristics. The linkage is well-documented (Kelly et al 2008, Kushlan 2000).
Sensitivity	Yes, qualified			Variation is stronger among years than among wetland areas within the region, but comprehensive regional monitoring can also distinguish difference among wetland subregion.
Appropriate temporal and spatial time frames for response	Yes			Outcomes reflect annual responses to wetland condition. The indicator is best suited to reveal landscape responses to wetland systems associated with subregional and regional conditions.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			CCMP Aquatic Resources Goals are not quantitative. However, using time series back to 1991; specific quantitative targets can be addressed. Management of heron and egret abundances would target the quality and extent of suitable feeding areas.
Meaningful to public/agencies	Yes			Vital population rates in birds are compelling to policy makers. Herons and egrets are frequently used as symbols of wetland conservation (Parnell et al. 1988, Kushlan and Hancock 2005) and are recognized as indicators of wetland health (Kushlan 1993, Erwin and Custer 2000).
Transferability				
Scalable	Yes, qualified			Heron and egret brood size variation is most meaningful at regional and subregional scales (Kelly et al. 2008).
Transferable to other watersheds	Yes, qualified			Monitoring methods are easily transferable and can be compared to those in other estuaries

WAF Category: Hydro-Geomorphology

Spring Freshwater Inflow: Selected and Calculated

This candidate indicator was refined and four indicators that assess different aspects of freshwater inflow conditions to the San Francisco Estuary were developed.

29. Annual Freshwater Inflow

Annual Freshwater Inflow
(unit of measure: percentage of estimated unimpaired Sacramento-San Joaquin inflow that flows into the SF estuary/year)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Hydrology and geomorphology		
Fits with CCMP (management objectives)	Yes		Water Use, Aquatic Resources and Pollution Prevention and	Water Use Goal Goal 1: Develop and Implement aggressive water management measures to increase fresh water availability to the estuary. Aquatic Resources Goals Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Pollution Prevention and Reduction Goals

			reduction Goals (see comment at right).	Goal 5: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			Freshwater inflow to the SF estuary (aka net Delta outflow) data are compiled by the California Department of Water Resources (CDWR) in their Dayflow dataset (1930-2009). Estimates of unimpaired Delta outflow have been developed by CDWR (1921-2003) and, for recent years, estimates of "full natural flows" for the major rivers in the Sacramento-San Joaquin basin are available on the California Data Exchange Center (CDEC) website.
Data suitable quality	Yes			Long-running flow monitoring and Dayflow programs with standardized protocols, data are QA/QC checked by CA Department of Water Resources.
Responsiveness				
Driver-outcome linkage	Yes			The Sacramento-San Joaquin watershed provides more than 90% of the total freshwater inflow to the SF estuary. In this watershed, all but one of the major rivers are dammed and much of their water diverted for agricultural or urban use, never reaching the estuary. The amount of freshwater inflow determines the location and amount (volume or area) of low-salinity estuarine habitat used by many estuary-dependent species and, seasonally, it is a key driver for survival, movement and reproduction of many estuarine fish and wildlife species.
Sensitivity	Yes			Indicator metric, percentage of estimated unimpaired inflow that flows into the SF estuary per year, exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables and human activities. By incorporating unimpaired inflow as a component of the calculation, indicator has been normalized for natural year-to-year variations in hydrology.
Response time frame	Yes			Annual (indicator can also be measured and evaluated on a seasonal basis, e.g., spring)
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: Freshwater inflow $\geq$75% of unimpaired runoff, per flow criteria for protection of SF estuary public trust resources identified by the State Water Resources Control Board (SWRCB 2010).
Meaningful to public	Yes			Measures of flow reduction are compelling and easily understood.
Transferability				
Scalable	Yes			Indicator metric (% of unimpaired inflow) is based on two measures, actual inflow, which is regularly measured over a range of scales (e.g., estuary inflows, individual river flows); and unimpaired inflow, which is calculated for only some rivers and streams. Unimpaired flow data are available for most of the rivers in the SF estuary's Sacramento-San Joaquin watershed, but not for the many smaller watersheds that also flow into the estuary.
Transferable to other watershed	Yes			Indicator metric (% of unimpaired inflow) relies on data that may not be collected or calculated for some watersheds. However, an alternative calculation of the metric could be developed based on data for water diverted, which may be more commonly available.

Hydro-Geomorphology

30. Inter-annual Variation in Freshwater Inflow

Inter-annual Variation in Freshwater Inflow
(unit of measure: change in inter-annual variation between actual and unimpaired freshwater inflows)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Hydrology and geomorphology		
Fits with CCMP (management objectives)	Yes		Water Use, Aquatic Resources and Pollution Prevention and reduction Goals (see comment at right).	Water Use Goal Goal 1: Develop and Implement aggressive water management measures to increase fresh water availability to the estuary. Aquatic Resources Goals Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Pollution Prevention and Reduction Goals Goal 5: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			Freshwater inflow to the SF estuary (aka Delta outflow) data are compiled by the California Department of Water Resources (CDWR) in their Dayflow dataset (1930-2009). Estimates of unimpaired Delta outflow have been developed by CDWR (1921-2003) and, for recent years, estimates of "full natural flows" for the major rivers in the Sacramento-San Joaquin basin are available on the California Data Exchange Center (CDEC) website.
Data suitable quality	Yes			Long-running flow monitoring and Dayflow programs with standardized protocols, data are QA/QC checked by CA Department of Water Resources.
Responsiveness				
Driver-outcome linkage	Yes			The Sacramento-San Joaquin watershed provides more than 90% of the total freshwater inflow to the SF estuary. Annual runoff varies from year to year by as much as an order of magnitude. Dams on most of the major rivers in this watershed affect rivers flows and inflows to the estuary. Inter-annual variation in inflows creates dynamic habitat conditions, favors native species that have evolved in the system, and creates conditions that are unfavorable to non-native species adapted to more static environmental conditions.
Sensitivity	Yes			Indicator metric, the change in inter-annual freshwater inflow variation between actual and unimpaired conditions, is calculated using a 10-year running calculation but it exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables and human activities. By incorporating unimpaired inflow as a component of the calculation, indicator has been normalized for natural year-to-year variations in hydrology.
Response time frame	Yes			Annual
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: Change in inter-annual variation between actual and unimpaired flows >-1700, the estimated change in inter-annual variation for unimpaired inflows reduced by 15-25%, depending on water year type.
Meaningful to public	Yes			Value of year-to-year variations in flows is generally understood,

				although measures to quantify changes in inter-annual variation are more difficult to explain.
Transferability				
Scalable	Yes			Indicator metric (change in inter-annual variation in flows) is based on two measures, actual annual flow, which is regularly measured over a range of scales (e.g., estuary inflows, individual river flows); and annual unimpaired flow, which is calculated for only some rivers and streams. Unimpaired flow data are available for most of the rivers in the SF estuary's Sacramento-San Joaquin watershed, but not for the many smaller watersheds that also flow into the estuary.
Transferable to other watershed	Yes			Indicator metric (change in inter-annual variation in flows) relies on data that may not be collected or calculated for some watersheds. However, alternative metrics for assessing inter-annual variation status and trends could be developed using available flow data and other estimates of "natural" inter-annual variation, such as precipitation.

Hydro-Geomorphology

31. Peak Flows

Peak Flows
(unit of measure: change in number of days with freshwater inflows >50,000 cfs between actual and unimpaired inflow)

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Hydrology and geomorphology		
Fits with CCMP (management objectives)	Yes		Water Use, Aquatic Resources and Pollution Prevention and reduction Goals (see comment at right).	<u>Water Use Goal</u> Goal 1: Develop and Implement aggressive water management measures to increase fresh water availability to the estuary. <u>Aquatic Resources Goals</u> Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. <u>Pollution Prevention and Reduction Goals</u> Goal 5: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			Freshwater inflow to the SF estuary (aka Delta outflow) data are compiled by the California Department of Water Resources (CDWR) in their Dayflow dataset (1930-2009). Estimates of unimpaired Delta outflow have been developed by CDWR (1921-2003) and, for recent years, estimates of "full natural flows" for the major rivers in the Sacramento-San Joaquin basin are available on the California Data Exchange Center (CDEC) website. Daily unimpaired inflow data are not available for most years, therefore
Data suitable quality	Yes			Long-running flow monitoring and Dayflow program with standardized protocols, data are QA/QC checked by CA Department of Water Resources.
Responsiveness				
Driver-outcome linkage	Yes			High, or "peak", freshwater flows into the San Francisco Estuary following winter rainstorms and during the spring snowmelt transport sediment and nutrients to the estuary, increase mixing of estuarine waters, and create low salinity habitat conditions favorable for many estuary-dependent fish and invertebrate species. In rivers and

				estuaries, peak flows and the flood events they typically produce are also a form of "natural disturbance. The Sacramento-San Joaquin watershed provides more than 90% of the total freshwater inflow to the SF estuary.
Sensitivity	Yes			Indicator metric, the change in number of days with inflows>50,000 cfs between actual and unimpaired inflow conditions, is calculated as the difference between the actual number of days of peak flow per year and the expected number of days of peak flow per year based on estimated unimpaired inflow. By incorporating unimpaired inflow as a component of the calculation, indicator has been normalized for natural year-to-year variations in hydrology.
Response time frame	Yes			Annual
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: Change in number of days of peak flow >-30 days.
Meaningful to public	Yes			Change in high flow conditions is generally understood.
Transferability				
Scalable	Yes			Indicator metric (change in number of days of peak flow) is based on two measures, actual daily flows, which are regularly measured over a range of scales (e.g., estuary inflows, individual river flows); and annual unimpaired flow, which is calculated for only some rivers and streams. Unimpaired flow data are available for most of the rivers in the SF estuary's Sacramento-San Joaquin watershed, but not for the many smaller watersheds that also flow into the estuary.
Transferable to other watershed	Yes			Indicator metric (change in number of days of peak flow) relies on data that may not be collected or calculated for some watersheds. However, alternative metrics for assessing change in frequency of peak (or flood) flows could be developed using available flow data and other estimates of peak flow frequency (e.g., historical frequency).

Hydro-Geomorphology

32. Critical Dry Year Frequency

Critical Dry Year Frequency (unit of measure:)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Hydrology and geomorphology		
Fits with CCMP (management objectives)	Yes		Water Use, Aquatic Resources and Pollution Prevention and reduction Goals (see comment at right).	<u>Water Use Goal</u> Goal 1: Develop and Implement aggressive water management measures to increase fresh water availability to the estuary. <u>Aquatic Resources Goals</u> Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. <u>Pollution Prevention and Reduction Goals</u> Goal 5: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				

Data available	Yes			Freshwater inflow to the SF estuary (aka Delta outflow) data are compiled by the California Department of Water Resources (CDWR) in their Dayflow dataset (1930-2009). Estimates of unimpaired Delta outflow have been developed by CDWR (1921-2003) and, for recent years, estimates of "full natural flows" for the major rivers in the Sacramento-San Joaquin basin are available on the California Data Exchange Center (CDEC) website.
Data suitable quality	Yes			Long-running flow monitoring and Dayflow program with standardized protocols, data are QA/QC checked by CA Department of Water Resources.
Responsiveness				
Driver-outcome linkage	Yes			The Sacramento-San Joaquin watershed provides more than 90% of the total freshwater inflow to the SF estuary. Annual runoff varies from year to year by as much as an order of magnitude. Dams on most of the major rivers in this watershed affect rivers flows and inflows to the estuary. Inter-annual variation in inflows creates dynamic habitat conditions, favors native species that have evolved in the system, and creates conditions that are unfavorable to non-native species adapted to more static environmental conditions.
Sensitivity	Yes			Indicator metric, the change in inter-annual freshwater inflow variation between actual and unimpaired conditions, is calculated using a 10-year running calculation but it exhibits inter-annual variability that is generally interpretable relative to variations in other environmental variables and human activities. By incorporating unimpaired inflow as a component of the calculation, indicator has been normalized for natural year-to-year variations in hydrology.
Response time frame	Yes			Annual (indicator can also be evaluated and interpreted on a seasonal basis, e.g., spring)
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goal/Target/Reference Condition: Change in inter-annual variation between actual and unimpaired flows >-2000, the estimated change in variation for unimpaired inflows reduced by 15-25%, depending on water year type.
Meaningful to public	Yes			Value of year-to-year variations in flows is generally understood, although measures to quantify changes in inter-annual variation are more difficult to explain.
Transferability				
Scalable	Yes			Indicator metric (change in inter-annual variation in flows) is based on two measures, actual flow, which is regularly measured over a range of scales (e.g., estuary inflows, individual river flows); and unimpaired flow, which is calculated for only some rivers and streams. Unimpaired flow data are available for most of the rivers in the SF estuary's Sacramento-San Joaquin watershed, but not for the many smaller watersheds that also flow into the estuary.
Transferable to other watershed	Yes			Indicator metric (change in inter-annual variation in flows) relies on data that may not be collected or calculated for some watersheds.

Hydro-Geomorphology

33. Stream Alteration and Condition: Selected but Not Calculated

This candidate indicator, which was developed for San Francisco Estuary tributaries excluding the Central Valley Rivers, uses the two metrics to assess different aspects of stream alteration and condition.

Stream Alteration and Drainage Modification (unit of measure: % of natural creeks remaining)				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category	Yes	Landscape		

(ecological function)		Condition and Hydrology/ Geo-morphology		
Fits with CCMP (management objectives)	Yes		Dredging and Waterway Modification Goal #4; Pollution Prevention and Reduction Goals Goal #5	Dredging and Waterway Modification Goal 4**:** Manage modification of waterways to avoid or offset the adverse impacts of dredging, flood control, channelization, and shoreline development and protection projects. Pollution Prevention and Reduction Goal 5: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes with caveat			Consistent data set for streams south of Carquinez Strait and the Golden Gate (see SF Bay watershed reference map) compiled for Oakland Museum Creek and Watershed map series (Museum Maps). Streams mapped for watersheds larger than or equal to 0.2 km^2. The modern drainage network includes natural, buried, engineered, flood control channels and underground storm drains at least 24" in diameter. Information on stream and drainage alteration not covered by Museum maps in the North Bay, East Contra Costa, and Livermore can be developed from county and city public works and flood control agencies.
Data suitable quality	Yes but not for all watersheds			Data for the watersheds not covered by the Museum maps may not have the same QA/QC or level of detail.
Responsiveness				
Driver-outcome linkage	Yes with caveat			The metric characterizes stream and watershed alteration through a dimensionless ratio of current natural stream mileage to historic natural stream mileage. It does not necessarily represent stream or riparian habitat condition since some natural streams have diminished function and condition and some engineered channels may simulate natural stream conditions.
Sensitivity	Yes with caveat			This metric can be used to broadly distinguish watersheds by their degree of alteration – from relatively undisturbed to highly urbanized and altered watersheds but small differences in the percentage of alteration cannot be used to differentiate watersheds. Small changes in stream mileage may not necessarily translate to noticeable changes watershed or Bay condition.
Response time frame	No			It is expected that the stream channel lengths will change much more slowly in the future compared to past decades because creek daylighting is expensive, undergrounding is less likely to occur as most urbanized watersheds are built-out or will be in-filled, and development into undisturbed watersheds is discouraged or at least encouraged to preserve natural drainage. Change at the Bay watershed scale may be detectable at a decadal or longer time scale.
Spatial Sampling Frame	Yes with caveat			Consistently mapped data not yet available for the Bay Area (see data availability). Also only streams draining watersheds equal to or larger than 0.2 km^2 are covered in Museum maps. Smaller creeks and smaller storm drains are sampled in special studies for some watersheds but would be very expensive to assess for all Bay watersheds.
Interpretation				
Goals, thresholds or reference conditions	No			No agreed-upon goal but restoring natural stream channel length not a realistic goal or reference condition in highly urbanized watersheds. More realistic to use current stream

defined				lengths as a reference condition and to measure change from the current lengths. Thresholds of alteration not defined for stream length although thresholds for percent impervious cover have been defined for watershed and stream function.
Meaningful to public	Yes with caveat			The loss of natural stream length is easily understood as a way of characterizing watersheds. Since change will come slowly in future, may be best used to characterize watersheds and not necessarily as a way of assessing progress towards making watersheds and drainage function better. Recommend that drainage modification projects be tracked in a comprehensive and meaningful database that can be used to track change on a watershed basis
Transferability				
Scalable	Yes with caveat			Current mapping status at 1:24000 scale, which is suitable for watershed assessments and large regional assessments if consistent mapping effort is made. Data not appropriate for assessing stream alteration at a larger scale (1: 12,000).
Transferable to other watershed	Yes			Mapping streams and drainage and calculating changes in length is easily transferable to other watersheds.

Stream Alteration and Drainage Modification (unit of measure: drainage length change)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Landscape Condition and Hydrology/ Geo-morphology		
Fits with CCMP (management objectives)	Yes		Dredging and Waterway Modification Goal #4; Pollution Prevention and Reduction Goals Goal #5	Dredging and Waterway Modification Goal 4: Manage modification of waterways to avoid or offset the adverse impacts of dredging, flood control, channelization, and shoreline development and protection projects. Pollution Prevention and Reduction Goal 5: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes with caveat			Consistent data set for streams south of Carquinez Strait and the Golden Gate (see SF Bay watershed reference map) compiled for Oakland Museum Creek and Watershed map series (Museum Maps). Streams mapped for watersheds larger than or equal to 0.2 km^2. The modern drainage network includes natural, buried, engineered, flood control channels and underground storm drains at least 24" in diameter. Information on stream and drainage alteration not covered by Museum maps in the North Bay, East Contra Costa, and Livermore can be developed from county and city public works and flood control

				agencies.
Data suitable quality	Yes but not for all watersheds			Data for North Bay streams will not have the same QA/QC or level of detail that the Oakland Museum series has.
Responsiveness				
Driver-outcome linkage	Yes with caveat			The metric characterizes stream and watershed alteration through a dimensionless ratio of the length of the modern drainage network to the length of historic streams. Because mapping is for watersheds larger than 0.2 km^2 and storm drains at least 24" in diameter, metric may not represent full extent of drainage alteration.
Sensitivity	Yes with caveat			This metric can be used to broadly distinguish watersheds by their degree of alteration – from relatively undisturbed to highly urbanized and altered watersheds but small differences in the percentage of alteration cannot be used to differentiate watersheds. Small changes in drainage length may not necessarily translate to noticeable changes watershed or Bay condition.
Response time frame	No			It is expected that the stream channel lengths will change much more slowly in the future compared to past decades because creek daylighting is expensive, undergrounding is less likely to occur as most urbanized watersheds are built-out or will be in-filled, and development into undisturbed watersheds is discouraged or at least encouraged to preserve natural drainage. Change at the Bay watershed scale may be detectable at a decadal or longer time scale.
Spatial Sampling Frame	Yes with caveat			Consistently mapped data not yet available for the Bay Area (see data availability). Also only underground storm drains equal to or larger than 24" in diameter are covered in Museum maps. Smaller creeks and smaller storm drains are sampled in special studies for some watersheds but would be very expensive to assess for all Bay draining watersheds.
Interpretation				
Goals, thresholds or reference conditions defined	No			No agreed-upon goal but restoring historic natural stream channel length not a realistic goal or reference condition in highly urbanized watersheds. More realistic to use current drainage length as a reference condition and to measure change from the current length. Thresholds of alteration not defined for drainage length although thresholds for percent impervious cover have been defined for watershed and stream function.
Meaningful to public	Yes with caveat			The drainage length change may not be as intuitive as loss of natural stream channel but can be easily explained and understood by public. Since change will come slowly in future, may be best used to characterize watersheds and not necessarily as a way of assessing progress towards making watersheds and drainage function better. Recommend that drainage modification projects be tracked in a comprehensive and meaningful database that can be used to track change on a watershed basis.

Transferability				
Scalable	Yes with caveat			Current mapping status at 1:24000 scale, which is suitable for watershed assessments and large regional assessments if consistent mapping effort is made. Data not appropriate for assessing stream alteration at a larger scale (1: 12,000).
Transferable to other watershed	Yes			Mapping streams and drainage and calculating changes in length is easily transferable to other watersheds.

WAF Category: Landscape Condition

34. Distribution of Salt-tolerant Intertidal Vegetation

Distribution of salt-tolerant intertidal vegetation				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Landscape		
Fits with CCMP (management objectives)	Yes		Aquatic Resources (CCMP Goal 2); Wildlife Goal (CCMP Goal 5); Wetlands (CCMP Goals 8-11)	Aquatic Resources CCMP Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Wildlife CCMP Goal 5: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend. Wetlands CCMP Goal 8: Protect and manage existing wetlands. CCMP Goal 9: Restore and enhance the ecological productivity and habitat values of wetlands. CCMP Goal 10: Expedite a significant increase in the quantity and quality of wetlands. CCMP Goal 11: Educate the public about the values of wetland resources.
Data Availability and Adequacy				
Data available	Yes			Monitoring data for the San Jose Sewage Treatment Facility
Data suitable quality	No			Data gaps are undefined.
Responsiveness				
Driver-outcome linkage	Yes			The distribution of salt-tolerant plants is driven by differential tolerance to salt stress across estuarine species and plant competition. Changes in their distribution reflect changes in salinity regime.
Sensitivity	Yes			Responsive to large-scale environmental conditions such as sea level rise (inundation) and climate change
Response time frame	Yes			Decadal
Spatial sampling frame	No			Only one location monitored
Interpretation				
Goals, thresholds or reference conditions defined	No			Goals: - none established Reference conditions: - no data
Meaningful to public	No			Finding meaning in this indicator requires some basic understanding and appreciation of vegetation in the tidal marsh ecosystem. Mapped, this indicator could be used effectively to visually climate change and sea level rise impacts, but it probably won't stir much interest in itself.

Transferability				
Scalable	Yes			Spatial and temporal
Transferable to other watershed	Yes			*Spartina foliosa* are endemic to tidal marshes of the San Francisco Estuary, but *Salicornia virginica* are found in other CA estuaries

Landscape Condition

35. Quality of Tidal Habitat

Quality of tidal habitat				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Landscape		
Fits with CCMP (management objectives)	Yes		Aquatic Resources (CCMP Goals 1-4); Wildlife (CCMP Goal 5); Wetlands (CCMP Goals 8-10); Pollution Prevention and Reduction (CCMP Goal 17).	<u>Aquatic Resources</u> CCMP Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. CCMP Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. CCMP Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. CCMP Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. <u>Wildlife</u> CCMP Goal 5: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend. <u>Wetlands</u> CCMP Goal 8: Protect and manage existing wetlands. CCMP Goal 9: Restore and enhance the ecological productivity and habitat values of wetlands. CCMP Goal 10: Expedite a significant increase in the quantity and quality of wetlands. <u>Pollution Prevention and Reduction</u> CCMP Goal 17: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			Regional and statewide ambient surveys and project assessments.
Data suitable quality	Yes			The California Rapid Assessment Method (CRAM) provides consistent, scientifically defensible information about wetland condition.
Responsiveness				
Driver-outcome linkage	Yes			Sea level rise, no-net-loss policy
Sensitivity	Yes			Sea level rise, restoration efforts
Response time frame	Yes			5 – 10 years
Spatial sampling frame	Yes			Objective, probabilistic ambient sample frames were designed to support regional and statewide assessments of wetland condition
Interpretation				
Goals, thresholds or reference conditions defined	Yes			<u>Goals:</u> - anti-degradation (no decrease from baseline). <u>Reference conditions:</u> - CRAM reference sites have 90th percentile scores for the overall CRAM index, the four different attributes, or the metric scores (within the attributes)
Meaningful to public	Yes			High quality habitat is a widely accepted, intuitive public value.

Transferability				
Scalable	Yes			Results are relevant across a wide range of scales (project/wetland, watershed, regional)
Transferable to other watershed	Yes			Can be applied to any watershed in CA.

Landscape Condition

36. Percent Historical Wetlands, Tidal Flats, and Riparian Areas

Percent historical wetlands, tidal flats, and riparian areas

	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Landscape		
Fits with CCMP (management objectives)	Yes		Aquatic Resources (CCMP Goal 2); Wildlife (CCMP Goal 5); Wetlands (CCMP Goals 8-11).	Aquatic Resources CCMP Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. Wildlife CCMP Goal 5: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend. Wetlands CCMP Goal 8: Protect and manage existing wetlands. CCMP Goal 9: Restore and enhance the ecological productivity and habitat values of wetlands. CCMP Goal 10: Expedite a significant increase in the quantity and quality of wetlands. CCMP Goal 11: Educate the public about the values of wetland resources.
Data Availability and Adequacy				
Data available	Yes			Current conditions: Bay Area Aquatic Habitat Basemap. Historical data are available for tidal wetlands and flats.
Data suitable quality				Data QA/QC according to proposed state mapping standards
Responsiveness				
Driver-outcome linkage	Yes			Sensitive to changes in climate or land use
Sensitivity	Yes			Long-term
Response time frame	Yes			Decadal
Spatial sampling frame	Yes			Regional standard basemap of aquatic habitats
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goals: - California: "no-net loss" policy for wetlands - Safe the Bay: re-establish 100,000 acres of wetlands Reference conditions: - CCMP benchmark (approximate): Modern Baylands 1998 map (EcoAtlas) - Historical conditions: Historical Baylands map (EcoAtlas)
Meaningful to public	Yes			Easily understood measure of habitat loss or gain and of the success of restoration and protection efforts
Transferability				
Scalable	Yes			Spatial (basin, region, watershed) + time
Transferable to other watershed	Yes			Consistent statewide methodology

Landscape Condition

37. Landcover

Landcover				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Landscape		
Fits with CCMP (management objectives)	Yes		Land Use Chapter Goals	All of the land use chapter goals require the calculation of changing land use as a means to predict changing condition of aquatic habitat. The goals also advocate for "smarter planning" including integrating transportation and housing, which can be analyzed with the use of landcover data.
Data Availability and Adequacy				
Data available	Yes			ABAG has the most recent data for the Bay Area. Additional data: wildland/urban interface information (Radeloff et al, 2005); development of "wildlands" in the Bay-Delta region (FRAP); Census data. Historical data (reference conditions): land cover (ABAG; 1962, 1990); land use (SFEI's historical ecology work for some areas); UC Berkeley vegetation maps (Weislander et al, 1945); T-sheet maps (1860s, reference condition for coastal development)
Data suitable quality	Yes			Standardized land-use types (USGS NLCD)
Responsiveness				
Driver-outcome linkage	Yes			Peoples' responses to economic opportunities, as mediated by institutional factors, drive land-cover changes. Statistical relationships of land cover metrics have been documented for variables such as human/household characteristics, institutions, economic forces (incl. poverty or well-being), and habitat condition
Sensitivity	Yes			Respond to economy and regulation
Response time frame	Yes			Variable, scalable; decadal would be recommended
Spatial sampling frame	Yes			Part of National Land Cover Dataset
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goals: - General plans, "slow-growth" initiatives Reference conditions: - historical landcover estimates
Meaningful to public	Yes			Land cover maps are an easily understood representation for the extent of human-induced pressures in a watershed
Transferability				
Scalable	No			Scalable remote sensing applications for understanding land cover dynamics are in development. However, spatially averaged measures of land cover dynamics bring along statistical issues that haven't been fully resolved, such as spatial variation in misclassification and problems with quantifying error margins in derivatives, such as the areal extents of different land cover types and the land cover change statistics.
Transferable to other watershed	Yes			For comparison between different watersheds, land cover characteristics could be expressed as standardized values stored as raster data sets.

Landscape Condition

38. Open Water Estuarine Habitat

Open water estuarine habitat				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Landscape		
Fits with CCMP (management objectives)	Yes		Aquatic Resources (CCMP Goals 1-4); Wildlife (CCMP Goal 5); Wetlands (CCMP Goals 8-10); Water Use (CCMP Goal 12); Pollution Prevention and Reduction (CCMP Goal 17).	Aquatic Resources CCMP Goal 1: Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction. CCMP Goal 2: Restore healthy estuarine habitat to the Bay-Delta, taking into consideration all beneficial uses of Bay-Delta resources. CCMP Goal 3: Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline. CCMP Goal 4: Manage the fish and wildlife resources of the Estuary to achieve the goals stated above. Wildlife CCMP Goal 5: Stem and reverse the decline of estuarine plants and animals and the habitats on which they depend. Wetlands CCMP Goal 8: Protect and manage existing wetlands. CCMP Goal 9: Restore and enhance the ecological productivity and habitat values of wetlands. CCMP Goal 10: Expedite a significant increase in the quantity and quality of wetlands. Water Use CCMP Goal 12: Develop and implement aggressive water management measures to increase freshwater availability to the Estuary. Pollution Prevention and Reduction CCMP Goal 17: Promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			DWR dayflow dataset
Data suitable quality	Yes			Data are of consistent and generally high quality.
Responsiveness				
Driver-outcome linkage	Yes			Extent and seasonal variation in low-salinity open water habitat is a well-documented physical and ecological driver. See DRERIP fish habitat linkage conceptual model
Sensitivity	Yes			Responsive to large-scale uncontrolled environmental conditions
Response time frame	Yes			Annual - decadal
Spatial sampling frame	No			Limited to North Bay
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goals: - Bay-Delta Water Quality Standards for X2 Reference conditions: - historical Bay surface area - CCMP benchmark (approximate): % of compliance with X2 goals (Suisun March salinity) 1995 and now
Meaningful to public	Yes			X2 has been established as a policy variable to set standards for managing freshwater inflow
Transferability				
Scalable	No			This indicator may have little utility at smaller geographic scales or in

				other estuaries where the relationship between flow and the extent of low-salinity habitat may not have been developed.
Transferable to other watershed	No			Not in and by itself. Some analogous measurement of in-stream flow levels in California rivers and streams can be used at a wide range of geographic scales and in a diversity of aquatic habitat types

WAF Category: Natural Disturbance Regimes

39. Deviation of Wildfire Regimes

Deviation of Wildfire Regimes				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Natural Disturbance		
Fits with CCMP (management objectives)	No			No direct links to CCMP goals exist.
Data Availability and Adequacy				
Data available	Yes			CalFire
Data suitable quality	Yes			The CalFire wildfire database represents the best available fire data for California, and its quality is considered very high relative to that of similar databases worldwide
Responsiveness				
Driver-outcome linkage	Yes			The fire regime of an ecosystem is the collective outcome of multiple drivers, such as ignition patterns, climate, and vegetation characteristics. The influence of fire then feeds back to affect vegetation distributions.
Sensitivity	Yes			Wildfire regimes respond to fuel availability and flammability
Response time frame	No			Decades to centuries
Spatial sampling frame	No			Fire maps do not accurately portrait the high spatial variability of wildfires
Interpretation				
Goals, thresholds or reference conditions defined	No			<u>Goals:</u> - none established <u>Reference conditions:</u> 1993 fuel rank data (if available)
Meaningful to public	Yes			Fire prevention is a universal concern, but there's probably limited interest by the public in consulting scientific sources that are difficult to interpret an d have no short-term benefits for reducing wildfire risks
Transferability				
Scalable	Yes			Analyses become more meaningful on the regional or statewide scale. There are accuracy and resolution issues with smaller fires because of inconsistent reporting (i.e.,121 ha or 300 acres for same fire) and generalized perimeter mapping such that outlines are often approximated, and unburned islands, which can be numerous, are not included.
Transferable to other watershed	Yes			The envisioned methodology will allow the assessment of wildfire-environment relationships for the entire State of California

WAF Category: Socio-Economic

40. Consumptive Water Use

Consumptive Water Use				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Socio-economic		
Fits with CCMP (management objectives)	No			This indicator has only indirect links to CCMP goals
Data Availability and Adequacy				
Data available	Yes			DWR, CA Land and Water Use, Conservation Scorecard
Data suitable quality	Yes			Data provided by DWR are quality-assured
Responsiveness				
Driver-outcome linkage	Yes			The most important drivers of water use include population, economic development and output, technological conditions, and natural and climatic conditions; but also societal views on the value of water (water pricing, water use practices). Consumptive water use impacts the natural water cycle.
Sensitivity	Yes			Water demands for gardening, lawn sprinkling, and showering are sensitive to climate changes (increase!). Aggregated domestic water use is not sensitive to climate variables (precipitation, temperature)
Response time frame	Yes			Annual - centuries
Spatial sampling frame	No			Aggregate data reported by water districts are not suitable for watershed-based analyses
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goals: - Conservation Potential (2030 CA Water High Efficiency Scenarios, Pacific Institute, 2005) - 20% reduction in per capita by 2020 (Governor's letter of February 28, 2008) Reference condition: 1993
Meaningful to public	Yes			Consumptive water use is a common issue of public debate
Transferability				
Scalable	Yes			The indicator is scalable to the area and time-frame of interest.
Transferable to other watershed	No			The envisioned indicators can be readily transferred to any region of interest. It should be noted that this indicator is more meaningful at a regional scale. It is very difficult to aggregate the data by watershed. Because data are reported by water districts with boundaries that are different from watershed boundaries, assigning values to specific watersheds or other hydrologic units will always be arbitrary.

Socio-Economic

41. Green Jobs

Green Jobs				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Socio-economic		
Fits with CCMP (management objectives)	No			The CCMP has no explicit goals related to economic issues.
Data Availability and Adequacy				
Data available	No			unknown
Data suitable quality	No			n/a
Responsiveness				
Driver-outcome linkage	Yes			Drivers for green jobs include climate change, demand-side factors (such as policy, regulation and investment), and supply-side factors (availability of skilled labor and investing in human capital). Green jobs link climate change-adaptation to reconciled social and natural criteria ("decent work in a sustainable, low-carbon world").
Sensitivity	Yes			Presumably respond to public investments
Response time frame	Yes			Annual/biannual
Spatial sampling frame	No			n/a
Interpretation				
Goals, thresholds or reference conditions defined	No			Goals: - none established Reference conditions could include (a) the percentage of conservation/recreation/eco-tourism jobs in the total workforce prior to recent large-scale public investments starting with Proposition 208; (b) the highest ratio of job/wage creation to public and private investment of any job sector
Meaningful to public	Yes			Large public interest in green sector developments, including jobs
Transferability				
Scalable	Yes			The indicator is scalable to the area and time-frame of interest.
Transferable to other watershed	Yes			The envisioned indicators can be readily transferred to any region of interest.

Socio-Economic

42. Quality of Life

Quality of Life				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Socio-economic		
Fits with CCMP (management objectives)	No			The CCMP has no explicit goals related to quality of life .
Data Availability and Adequacy				
Data available	Yes			A) Bay Area Metropolitan Transit Commission database (vehicle miles of travel, population, and employment statistics) B) Bay Area Open Space Council (database on preserved lands), individual land use jurisdictions (protected viewshed), CDF (census data by tract); C) Green Info Network D) ABAG
Data suitable quality	Yes			U.S. census data are quality-assured
Responsiveness				
Driver-outcome linkage	Yes			Quality of life is a main driver for national, state, and local policies. Drivers for quality of live include subjective aspects of well-being (self-esteem, autonomy, relations, etc.) and objective, external conditions (economy, governance, culture). From the individual perspective, quality of life outcomes include physical and mental health, knowledge and understanding, work, material well-being, freedom and self-determination, and interpersonal relationships. There are strong linkages between ecosystem services (provisioning, regulating) and constituents of well-being (security, material, health). There is also a linkage between environmental experiences (stressors, e.g. noise vs. leisure and aesthetics) and human well-being.
Sensitivity	Yes			QOL measurements are highly sensitive to their respective domains. This includes family and friends, emotional well-being, health, work and productivity, material well-being, feeling part of one's community, personal safety, but also quality of the environment.
Response time frame	No			unknown
Spatial sampling frame	Yes			A) Bay Area Transit Survey database contains daily information for members of randomly selected households in the nine-county San Francisco Bay Area, including longitudinal- latitudinal coordinates of journey origins and destinations. B) Regional geospatial database of protected lands C) U.S. Census uses the national Master Address File
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goals: - none established Reference conditions - extent of per-capita preserved open space in (a) 1993, (b) those cities consistently scoring in the top five “most livable cities”
Meaningful to public	Yes			Quality of life is everybody’s main concern

Transferability				
Scalable	Yes			The indicator is scalable to the area and time-frame of interest.
Transferable to other watershed	Yes			The envisioned indicators can be readily transferred to any region of interest.

Socio-Economic

43. Ratio of Infill to Green Development

Ratio of Infill to Greenfield Development				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Socio-economic		
Fits with CCMP (management objectives)	Yes		Land Use and Watershed Management (CCMP Goals 23-25)	Land Use and Watershed Management CCMP Goal 23: Establish and implement land use and transportation patterns and practices that protect, restore, and enhance watershed processes and functions, the Estuary's open waters, wetlands, tributary waterways, and essential upland habitats. CCMP Goal 24: Coordinate and improve planning, regulatory, and development programs of local, regional, state, and federal agencies to protect natural resources and improve the health of the Estuary and its watersheds. CCMP Goal 25: Adopt and utilize land use policies, including transportation patterns that provide incentives for more active participation by the public and private sectors in cooperative efforts that protect and improve the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			ABAG
Data suitable quality	Yes			ABAG serves as the regional Census Data Center. Census data are quality-assured.
Responsiveness				
Driver-outcome linkage	Yes			An important driver for changing development patterns is oil vulnerability. Specific drivers for infill development are the community context (perceptions, attitudes, and resources), municipal context (perceptions, attitudes, resources, policies, practices, and goals), and market context (composite perception of local real estate supply and demand trends). Increased infill development results in lower emissions of hydrocarbons (VOCs), nitrogen oxides (NOx), and carbon monoxide (CO). Increased greenfield development results in landscape fragmentation; loss of habitat and migration corridors; loss of biodiversity; increase in impervious surfaces and the resulting changes in the hydrograph, including increased peak flows/risk of flooding; and increase in pollutants associated with runoff.
Sensitivity	Yes			Responds to land use decisions.
Response time frame	Yes			Real-time to annual
Spatial sampling frame	Yes			U.S. Census uses the national Master Address File
Interpretation				

Goals, thresholds or reference conditions defined	Yes			Goals: - to be established in Smart Growth Vision (ABAG) - Green Alliance goals Reference conditions: - 1993
Meaningful to public	Yes			Infill density is a public concern
Transferability				
Scalable	Yes			The indicator is scalable to the area and time-frame of interest.
Transferable to other watershed	Yes			The envisioned indicators can be readily transferred to any region of interest.

Socio-Economic

44. Stewardship, Public Awareness, Social Justice

Stewardship, Public Awareness, Social Justice (incl. Watershed Restoration)				
	Result (yes or no)	**WAF category**	**CCMP Goal**	**Comments**
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Socio-economic		
Fits with CCMP (management objectives)	Yes		All	Supports all CCMP goals
Data Availability and Adequacy				
Data available	No			unknown
Data suitable quality	No			n/a
Responsiveness				
Driver-outcome linkage	Yes			The concept of ecosystem health is appropriate for evaluating the social and ecological outcomes of ecosystem management, because it bridges social and natural criteria. Key socio-ecological linkages are represented by land use practices, management decisions, and public engagement.
Sensitivity	No			Unknown if trends between management actions and indicators of ecological and socioeconomic outcomes are persuasive.
Response time frame	No			Unknown
Spatial sampling frame	No			Unknown
Interpretation				
Goals, thresholds or reference conditions defined	Yes			Goals: - none established Reference conditions: - 1993; other NEP watersheds or areas of comparable size and population.
Meaningful to public	Yes			Stewardship, public awareness, and social justice are meaningful principles
Transferability				
Scalable	No			Unknown
Transferable to other watershed	Yes			The envisioned indicators can be readily transferred

Socio-Economic

45. No. Households in 50 Year Floodplain

# Households in 50-year Floodplain				
	Result (yes or no)	WAF category	CCMP Goal	Comments
Conceptual Relevance				
Fits with WAF category (ecological function)	Yes	Socio-economic		
Fits with CCMP (management objectives)	Yes		Wildlife (CCMP Goal 6); Land Use and Watershed Management (CCMP Goals 23, 24).	<u>Wildlife</u> CCMP Goal 6: Ensure the survival and recovery of listed and candidate threatened and endangered species, as well as special-status species. <u>Land Use and Watershed Management</u> CCMP Goal 23: Establish and implement land use and transportation patterns and practices that protect, restore, and enhance watershed processes and functions, the Estuary's open waters, wetlands, tributary waterways, and essential upland habitats. CCMP Goal 24: Coordinate and improve planning, regulatory, and development programs of local, regional, state, and federal agencies to protect natural resources and improve the health of the Estuary and its watersheds.
Data Availability and Adequacy				
Data available	Yes			ABAG, cities, counties, FEMA maps, UC Berkeley, UC Davis
Data suitable quality	Yes			ABAG serves as the regional Census Data Center. Census and FEMA map data are quality-assured.
Responsiveness				
Driver-outcome linkage	No			Unknown
Sensitivity	No			Land acquisition programs; homeowner decision-making
Response time frame	No			Decades
Spatial sampling frame	Yes			U.S. Census uses the national Master Address File. FEMA maps can be used to stratify the sample frame.
Interpretation				
Goals, thresholds or reference conditions defined	Yes			<u>Goals:</u> - none established <u>Reference conditions:</u> - 1993
Meaningful to public	No			Less meaningful except for those who are already sensitized and therefore expert in the issues or became expert because they are directly affected by zoning policies or risk of flooding
Transferability				
Scalable	Yes			The indicator is scalable to the area of interest.
Transferable to other watershed	Yes			The envisioned indicators can be readily transferred

Summary

Indicators to be taken to next step (calculations):

WAF Category	Not Selected	Selected Not Calculated	Selected/Calculated
Candidate Indicators			
Biotic Condition			
Biotic Condition of Birds			Yes
*Tidal Marsh Bird Populations Indicator			Yes
*Marsh Bird Reproductive Success Indicator			Yes
*Heron and Egret Reproductive Success Indicator			Yes
*Wintering Waterfowl Indicator			Yes
*Heron and Egret Nest Density Indicator			Yes
*Wintering Shorebird Indicator	X		
Fish Community Index			Yes
*Pelagic Fish Abundance			Yes
*Demersal Fish Abundance			Yes
*Northern Anchovy Abundance			Yes
*Sensitive Fish Species Abundance			Yes
*Native Fish Species Diversity			Yes
*Estuary-dependent Fish Species Diversity			Yes
*Fish Species Composition			Yes
Invertebrate Diversity & Abundance			
*Zooplankton Abundance/Diversity	X		
*Benthic Macrofauna Abundance/Diversity	X		
*Dungeness Crab Abundance	X		
*Rock Crab Abundance	X		
*Bay Shrimp Abundance		X	
* Macoma (clam)	X		
*Mya (clam)	X		
*Native Oysters	X		
Chemical/Physical			
Pollutant Loadings	X		
Sediment Quality Index	X		
Water Quality Index			Yes
Ecological Processes			
Carbon Sequestration	X		
Trophic Structure-Heron & Egret Brood Size	X		
Hydro-Geomorphology			
Annual Freshwater Inflow			Yes
Inter-annual Variation in Freshwater Inflow			Yes
Peak Flows			Yes

Critical Dry Year Frequency			Yes
Stream Alteration & Condition			Yes
Landscape			
Distribution of Salt Tolerant Tidal Vegetation	X		
Quality of Estuarine Tidal Habitat			Yes
Percent Historical Wetlands, Tidal Flats, Riparian			Yes
Landcover	X		
Open Water Estuarine Habitat	X		
Natural Disturbance			
Deviation of Wildfire Regimes from Natural Variation	X		
Trends in Flood Peaks	X		
Socio-Economic			
Consumptive Water Use by Sector	X		
Green Jobs	X		
Quality of Life	X		
Ratio of Infill to Greenfield Development		X	
Stewardship, Public Awareness, Env Justice			
No. of Households in 50 Year Floodplain	X		

Screened out and (main) reason why: Indicators were “disqualified” for various reasons by rigidly applying the indicator selection criteria. Several indicators were screened out because they have no direct links to CCMP goals, including Deviation of Wildfire Regimes (Natural Disturbance); and Green Jobs, Quality of Life, and Consumptive Water Use[1] (Socio Economic). Two Landscape indicators were screened out based on the scalability criterion: Landcover and Open Water Estuarine Habitat. Landcover was screened out due to statistical issues that have not been resolved for spatially averaged measures. Open Water Estuarine Habitat (Landscape) was screened out since it has little use at smaller geographic scales or in other estuaries, even though the metric of choice, X2, is a significant variable for managing flow regionally. Pollutant Loadings (Chemical/Physical) was screened out based on the spatial sampling frame: for pollutant with data, loading estimates would need to be extrapolated and estimated based on monitoring data from “observation watersheds”. Invertebrates (Biota) and Distribution of Salt-Tolerant Vegetation were screened out because they appear to be less meaningful for communicating Estuary health to the general public. Number of Households in the 50-year Floodplain (Socio-Economic) was screened out mainly because there are no clearly defined conceptual driver-outcome linkages to indicators of ecological health. Indicators of Stewardship, Public Awareness, and Social Justice (Socio-Economic) were screened out because of a lack of data or because the Indicator Development Team felt that there are other groups with different expertise that may be more appropriate to develop and evaluate them.

[1] The CCMP has a Water Use goal: CCMP Goal 12. *Develop and implement aggressive water management measures to increase freshwater availability to the Estuary.* However, there is no clear-cut cause-effect relationship between reducing consumptive water use in the nine Bay Area counties and increasing freshwater availability to the Estuary. The relationship is complex, because 1) not all source water consumed in the Bay Area originates in the watershed, and 2) increasing freshwater availability to the Estuary largely depends on reducing water diversions from the Delta. About 83 percent of diverted Delta water is used for agriculture in the Central Valley

IV. Quantified Indicators: Calculation and Evaluation of Selected Indicators

WAF Category: Biotic Condition

Biotic Condition 1. Tidal Marsh Bird Population Indicator

By Nadav Nur and John Kelly

Background and Rationale:
San Francisco Estuary tidal marsh habitat has been dramatically altered in the past one hundred and sixty years. Approximately 85% of the original tidal marsh habitat in the region has been lost due to creation of salt ponds, conversion to agricultural and industrial/urban use, and water diversion and management (Marshall & Dedrick 1994, Goals Project 1999). The reduction in area, fragmentation of remaining habitat, degradation in habitat quality, and spread of invasive species have all contributed to reductions in the population size and viability of tidal marsh obligate species (Takekawa et al. 2006). For these reasons, many of the species that depend on tidal marsh habitat are currently listed as Federally- or State- threatened or endangered, in particular Clapper Rail and Black Rail, or are of conservation concern (e.g., California Species of Special Concern, Shuford & Gardali 2008). It is for these reasons that the first-listed “Aquatic Resources Goal” of the CCMP is

- “Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction.”

The indicator presented here, **Tidal Marsh Bird Population Indicator**, assesses abundance of target species of concern and provides information on health of these populations by determining changes in abundance metrics. This indicator also provides information regarding progress towards the second and third stated goals for Aquatic Resources, i.e.,

- “Restore healthy estuarine habitat to the Bay-Delta” and
- “Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline.”

This indicator does not assess healthy estuarine **habitat** directly, but instead allows for inference to be made, based on bird populations that depend on healthy estuarine habitat. The indicator also allows assessment of progress made with respect to the recovery of threatened and endangered species, as well as additional species that are known or presumed to have reduced abundance compared with earlier time periods, especially the period before 1800.

The proposed indicator draws primarily on PRBO’s tidal marsh bird monitoring project begun in 1996 (Nur et al. 1997, Spautz et al. 2006). This program has been studying tidal marsh-dependent species throughout the San Francisco Estuary, utilizing an extensive array of breeding-season point count surveys (about 10 point count locations per mash), conducted twice per breeding season, between 1996 and 2010. Until 2007, surveys were conducted at about 20 to 40 marshes per year; from 2008 to the present, surveys have been conducted at about 8 marshes per year. The indicator is calculated for three identified regions: Suisun Bay, San Pablo Bay, and San Francisco Bay. The San Francisco Bay region includes both Central and South San Francisco Bay, combined.

Four species are included in this indicator. Each is year-round resident (or primarily resident) and **is dependent on, or strongly associated with, tidal marsh habitat** (Goals Project 2000). Two species are rails, **Clapper Rail** and **Black Rail** (family Rallidae); the indicator is restricted to the California Clapper Rail subspecies (*Rallus longirostris obsoletus*) and the California Black Rail subspecies (*Laterallus jamaicensis coturniculus*). The other two species are songbirds, **Song Sparrow** (*Melospiza melodia*) and **Common Yellowthroat** (*Geothlypis trichas*, a North American warbler). The proposed indicator (and data available) is specific to the tidal marsh-dependent subspecies of the Song Sparrow and Common Yellowthroat (Marshall and Dedrick 1994, Nur et al. 1997).

Data Sources:
For Black Rails, Song Sparrows, and Common Yellowthroats, data are from PRBO tidal marsh bird project (www.prbo.org/cms/135; Nur et al. 1997, Spautz et al. 2006). Survey results for these three species are available for 1996 to 2008, and presented here. Information from 2009 and 2010 will soon be available for inclusion in the next iteration of the indicator (in early 2011).

Survey results for Clapper Rail are only available for 2005 to the present, though there is partial information, at the regional scale, for the 1990's (Albertson and Evens 2000). Clapper Rail data are from a consortium of organizations studying this species, led by PRBO (Liu et al. 2009; www.prbo.org/cms/135). For this species, only data from 2005 through 2008 have been analyzed (see Liu et al. 2009). For 2009 and 2010, data have been compiled and will be used to update the indicator in early 2011. However, with Clapper Rail data currently available only from 2005 to 2008, we have not subjected these data to the quantitative analysis presented for the other three species. We maintain that at least a five-year span is required for an informative analysis of trends for any bird species of the San Francisco Estuary. In early 2011, data from the requisite time period will be available for the appropriate analysis.

Methods and Calculations:
Abundance data were collected regarding Black Rails, Song Sparrows, and Common Yellowthroats, using point count surveys conducted at multiple marshes per region per year (usually 5 to 8 marshes per region per year) during the breeding season (March to end of May). Generally, 6 to 10 point count stations were established per marsh survey (Liu et al. 2007). For each species and each region, we estimated mean number of individuals detected per hectare of surveyed marsh per survey (usually, two surveys per year per marsh). These surveys did not use tape playback. Statistical analysis was conducted on densities per marsh per year, averaged over the number of survey visits. "Density" for this indicator refers to the number of birds detected per hectare surveyed, and is more properly termed "apparent density" since we did not correct for detectability (but see Nur et al. 1997; Thomas et al. 2010). All analyses were conducted on log-transformed values (with a constant added so that all densities were > 0; Nur et al. 1999).

Between 1996 and 2008, many marsh sites were surveyed, but the same sites were not surveyed in each year. To control for site-to-site differences in abundance, "site" was included as a categorical variable in the analyses. The statistical analysis was carried out separately for each region (SF Bay, San Pablo Bay, Suisun Bay), and for each species. Finally, a multiple-species metric was calculated based on the single species densities, while controlling for site differences.

The multiple-species metric was calculated on log-densities, controlling for differences in apparent density among the three species. Note: (1) The statistical control for site effects was carried out separately for each species. (2) Black Rail density was not estimated for SF Bay region, due to lack of detections of individuals in that region (see Evens and Nur 2002).

In addition to presenting year-by-year results for 1996 to 2008, we calculated trends for two time periods: 1996 to 2008 (i.e., the most recent 13 years of survey data), and 2004 to 2008 (i.e., the most recent 5 years). We also compare the most recent three year-mean values (for 2006-2008) to the benchmark 5-year values (for 1996-2000). Trends were calculated for each of the three species and for all species combined in a multi-species statistical model that fit a single slope, common to the three species, but allowed species log (density) to differ among the three species. See Pyle et al. (1994) for similar example. Because these analyses were conducted on log-densities, the coefficients obtained (i.e., slopes) represent the constant proportional increase or decrease for each species or for the three combined species (Nur et al. 1999).

Clapper Rail density for 2005-2008 was estimated by Liu et al. (2009), for each year and for each region of the SF Estuary. We will present and evaluate this metric for the period 2005-2010 when additional data are available in early 2011 (see above).

Goals, Targets, and Reference Conditions:
There are no agreed upon, explicitly stated goals, targets or reference conditions for any of the four main focal species (Black Rail, Song Sparrow, Common Yellowthroat, and Clapper Rail). Because of loss of habitat, population size has been reduced from historical levels (e.g., since c. 1800). Therefore, one means of assessment is to evaluate trends since 1996 (the earliest year for which annual survey data are available for Black Rail, Song Sparrow, and Common Yellowthroat). To assist in evaluation of the "longer-term" trends (in this case, 1996 to 2008), we also consider more recent "short-term" trends (in this case from 2004 to 2008). Finally, we compare mean densities observed in 1996 to 2000 (best available 5-year benchmark) to the period 2006 to 2008 (most recent 3 years of data).

The goal (target) is for trends to be positive (indicating recovery of tidal marsh species), or at least to be non-negative. For all species considered, evaluations are carried out for each region within the Estuary.

Results:
For this indicator, results differed strikingly from one region of the SF Estuary to another. In addition, each species displayed a distinctive pattern.

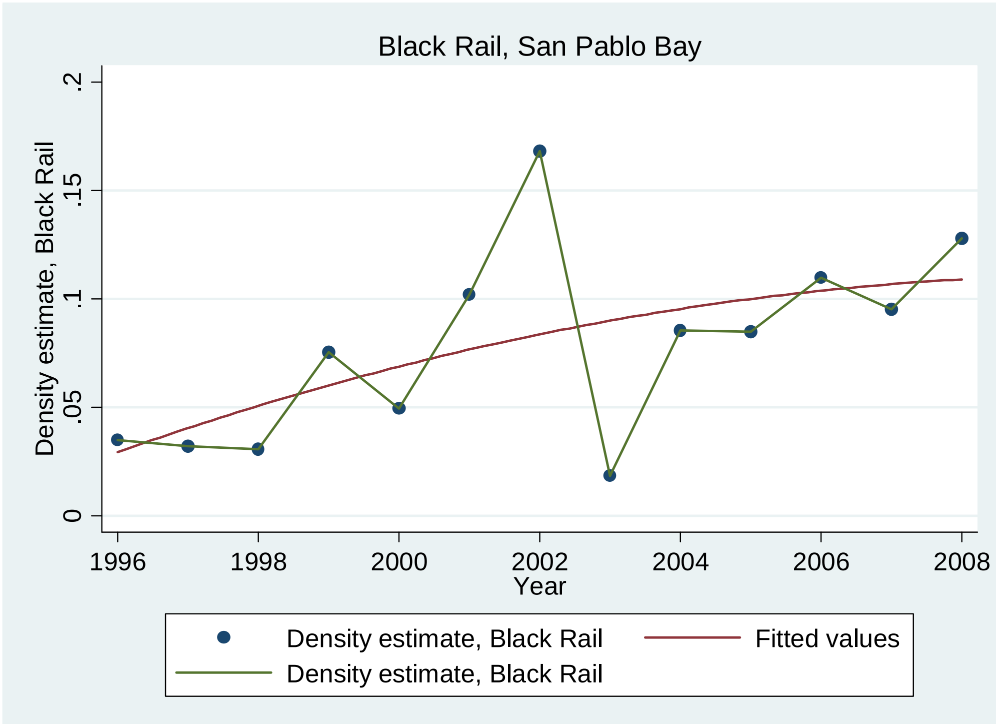
For **Black Rail**, the trend in both San Pablo Bay and Suisun Bay has been positive (Figure T1 A, B). In San Pablo Bay the positive trend is exemplified in the longer-term (since 1996) and shorter-term (Table T1). In Suisun Bay, the positive trend is only evident in the last 5 years; in fact, the highest density values for Black Rails are all in the most recent 5 years of surveys (2004-2008; Table T1). The overall increase in density of Black Rails for San Pablo and Suisun is confirmed when one compares the most recent 3-year period with the earlier 5-year benchmark period (Table T2).

For **Common Yellowthroat**, there has been little increase in San Francisco Bay over the 13-year period, except that the most recent 10 years have higher densities than the first three years (Figure T1C). Nevertheless, the overall trends for the longer-time period and the shorter-time period are non-significant, nor does the most recent three-year period differ significantly from the five-year benchmark period (Table T1, T2). In contrast, in both San Pablo Bay and Suisun Bay, there have been significant increases over the long-term, but this trend has abated in recent years in San Pablo Bay (Figure T1 D, E). In Suisun Bay, it is less clear whether the increasing trend is evident, but the overall pattern is of higher densities in recent years compared to earlier years. Note that the density index for Suisun Bay Common Yellowthroats has remained about 10-fold greater than the comparable density index for San Francisco Bay or San Pablo Bay Common Yellowthroats (Figure T1 C, D, E). This consistent regional difference is likely due to habitat affinities: Common Yellowthroats prefer brackish marsh to saline marsh (Spautz et al. 2006, Stralberg et al. 2010).

For **Song Sparrows**, only the San Francisco Bay region shows an increase, and even then the increase has reversed, i.e., this region demonstrates a recent decline (Figure T1 F, Table T1). In contrast to the overall-increase for the San Francisco Bay region, Suisun and San Pablo Bay regions show overall decreases (Figure T1 G, H; Table T1). Moreover, all three regions demonstrate recent, short-term declines. As a result of these divergent trends, San Francisco Bay Song Sparrows no longer demonstrate the lowest density of the three regions, instead Suisun Song Sparrows evidence the lowest density, and San Francisco Bay Song Sparrows the middle level of density. For this species, there are no significant differences between the 3 most recent years and the 5-year benchmark period for any of the three regions (Table T2).

The **combined species** analysis demonstrates a different pattern for each region, though the overall-result is a net increase. In San Francisco Bay, the increase is evident earlier in the period but more recently demonstrates a decrease (Figure T1 I). In San Pablo Bay, the overall increase in density is evident during the entire period (Figure T1 J). In Suisun, an initial decrease has been followed by a more recent increase in density (Figure T1 K).

Figure T1. Population Trends for Three Tidal Marsh Species (Black Rail, Common Yellowthroat, and Song Sparrow) and Combined Trend for all 3 species. Shown is density index (birds detected per hectare per survey) by SF Estuary region, controlling for site-to-site differences in density within a region. Note: There are no breeding Black Rails in San Francisco Bay. Combined species trend depicts geometric mean across the three species (see text). Each species-region graph shows the best linear fit (Figures T1-E and T1-G) or quadratic fit (Figures T1-A to T1-D, T1-F, and T1-H to T1-K) as appropriate; choice of fit (linear vs. quadratic) determined by maximization of adjusted R^2 (Nur et al. 1999).
A)


Black Rail, San Pablo Bay
Density estimate, Black Rail
0
.05
.1
.15
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1996
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2000
2002
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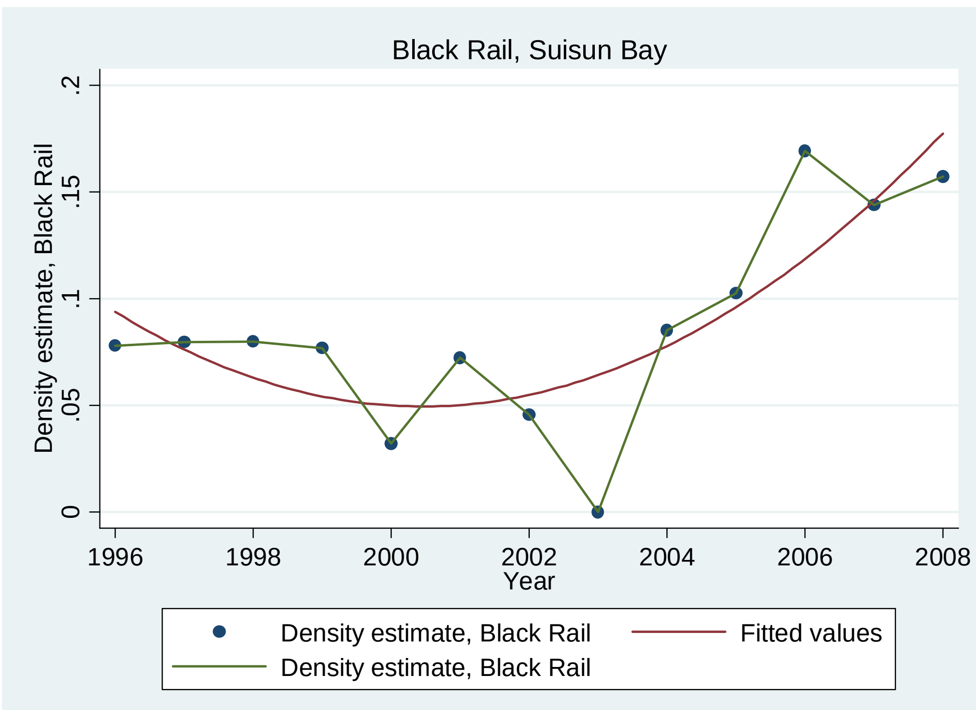
2006
2008
Year
Density estimate, Black Rail
Fitted values
Density estimate, Black Rail

B)


Black Rail, Suisun Bay
Density estimate, Black Rail
0
.05
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2006
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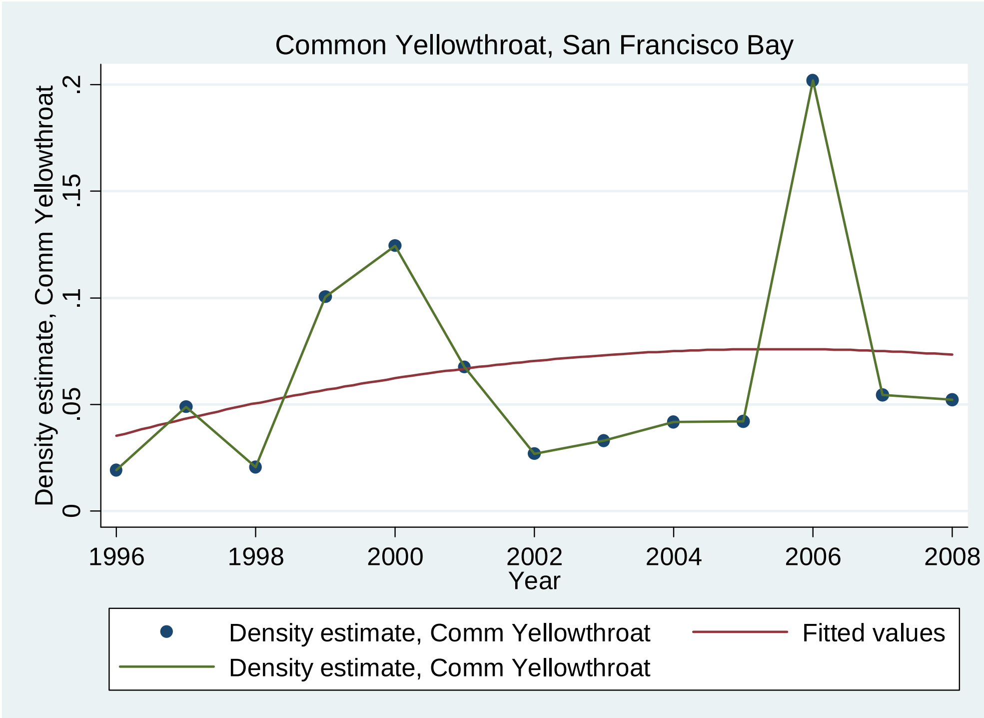
Density estimate, Black Rail
Fitted values
Density estimate, Black Rail

C)



Common Yellowthroat, San Francisco Bay
Density estimate, Comm Yellowthroat
0
.05
.1
.15
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1996
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2000
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2004
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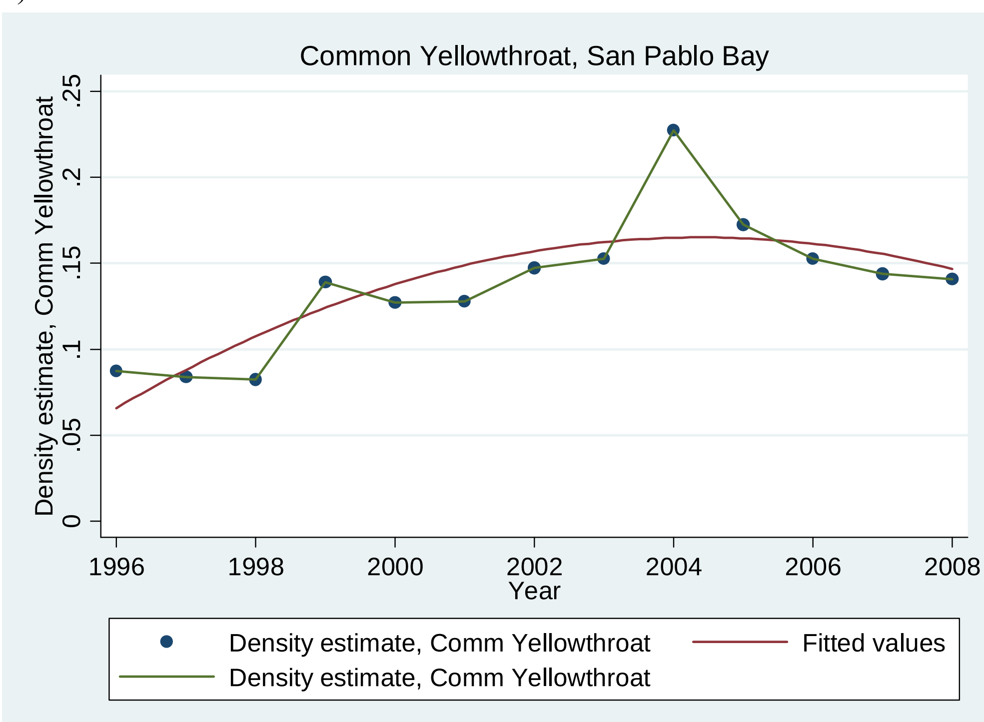
2008
Year
Density estimate, Comm Yellowthroat
Fitted values
Density estimate, Comm Yellowthroat

D)



Common Yellowthroat, San Pablo Bay
Density estimate, Comm Yellowthroat
0
.05
.1
.15
.2
.25
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1998
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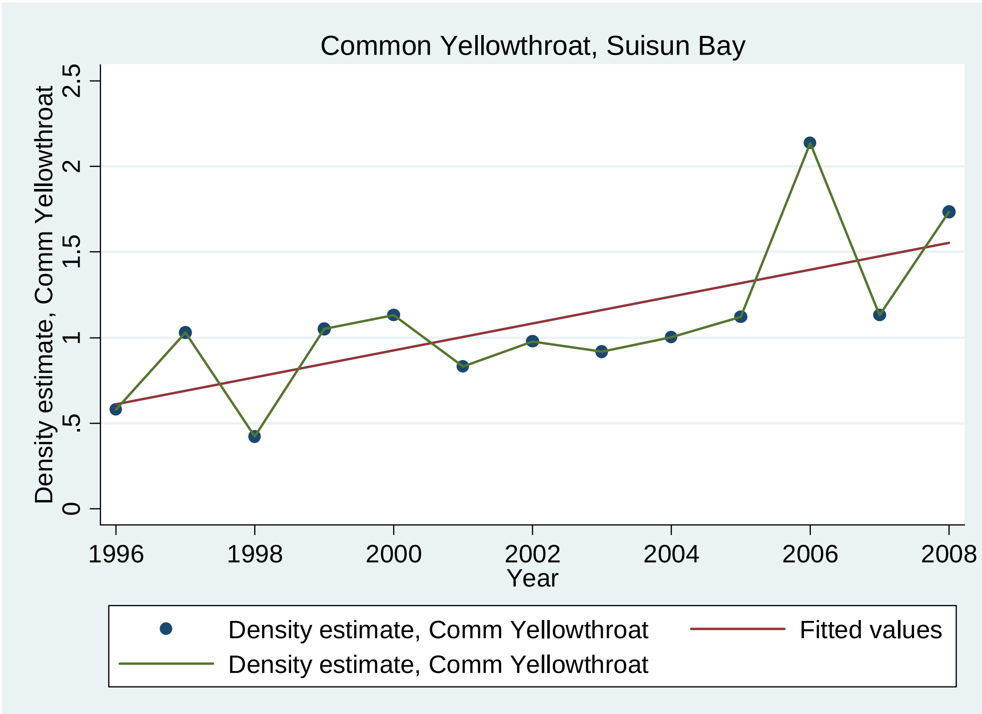
2006
2008
Year
Density estimate, Comm Yellowthroat
Fitted values
Density estimate, Comm Yellowthroat

E)


Common Yellowthroat, Suisun Bay
Density estimate, Comm Yellowthroat
0
.5
1
1.5
2
2.5
1996
1998
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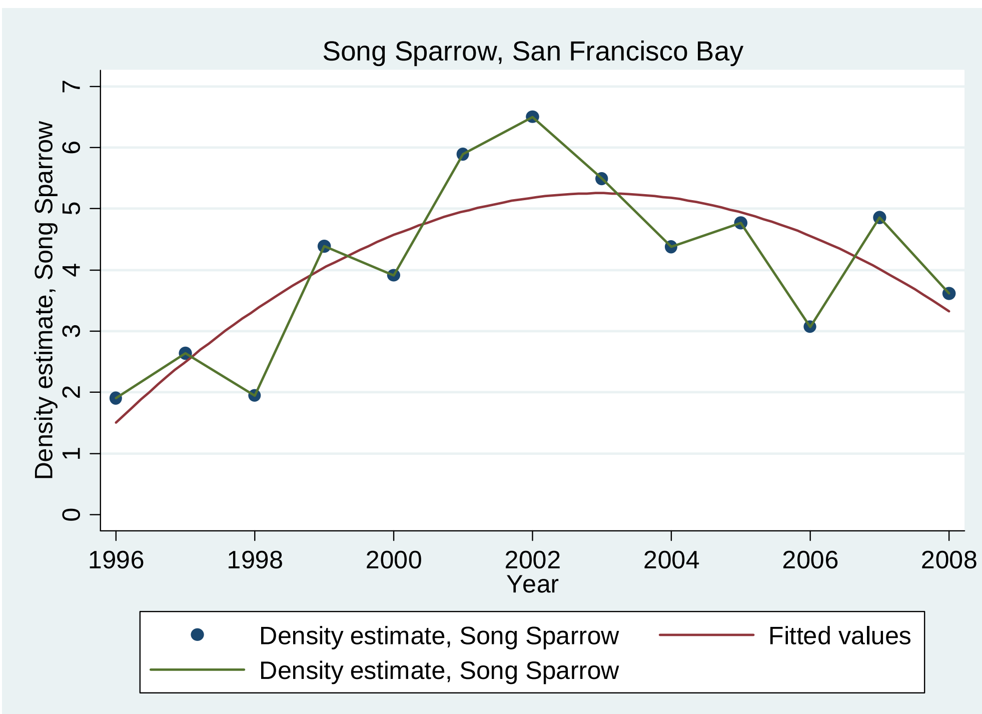
2002
2004
2006
2008
Year
Density estimate, Comm Yellowthroat
Fitted values
Density estimate, Comm Yellowthroat

F)


Song Sparrow, San Francisco Bay
Density estimate, Song Sparrow
0
1
2
3
4
5
6
7
1996
1998
2000
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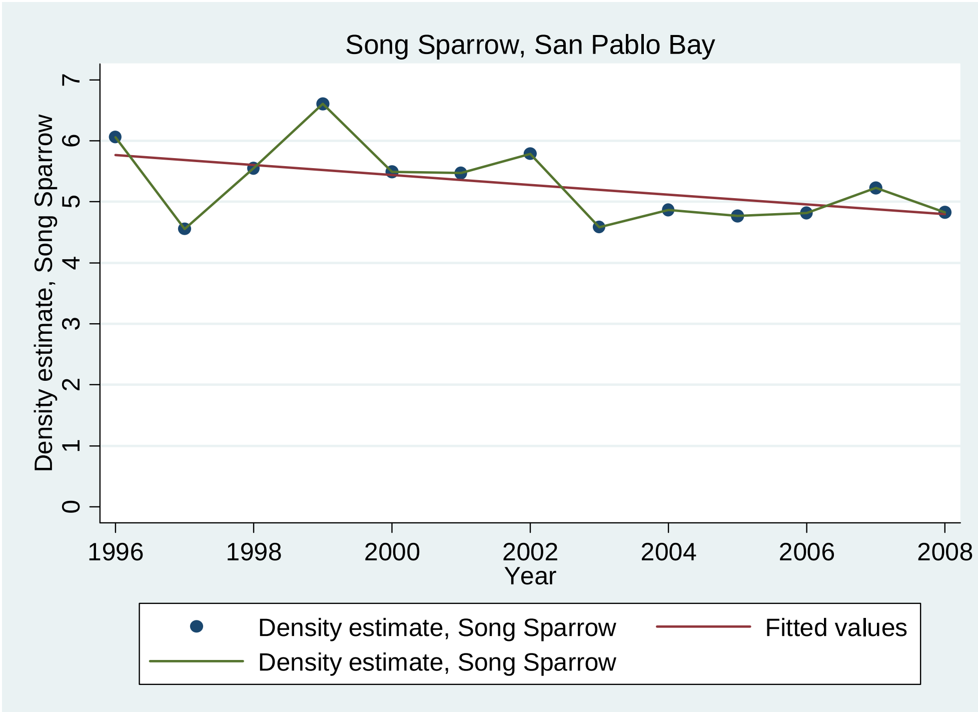
2004
2006
2008
Year
Density estimate, Song Sparrow
Fitted values
Density estimate, Song Sparrow

G)


Song Sparrow, San Pablo Bay
Density estimate, Song Sparrow
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1996
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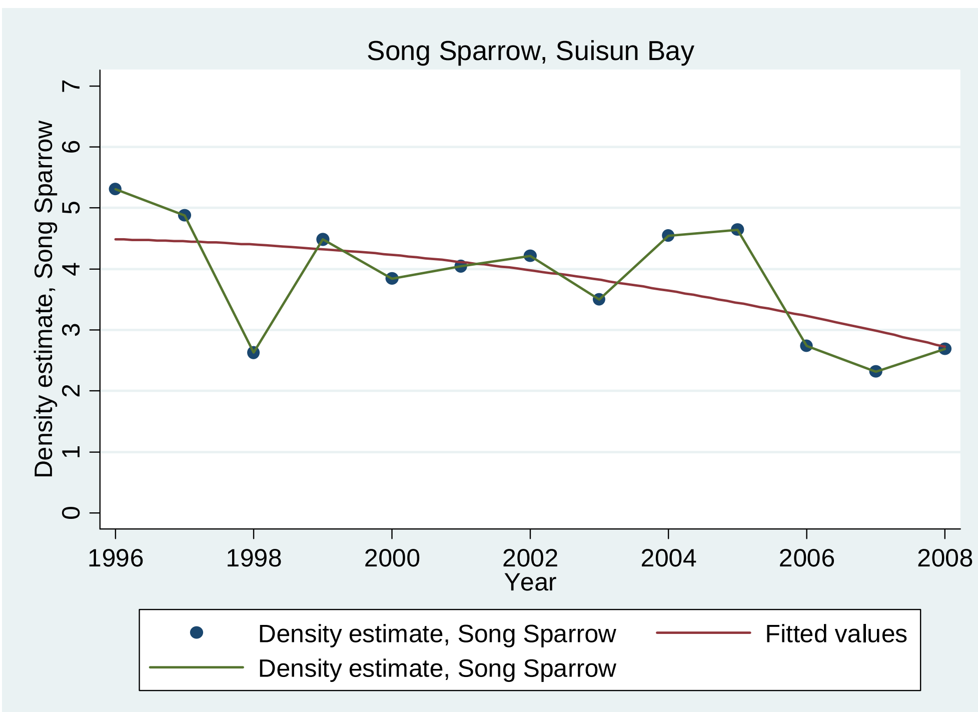
2008
Year
Density estimate, Song Sparrow
Fitted values
Density estimate, Song Sparrow

H)


Song Sparrow, Suisun Bay
Density estimate, Song Sparrow
0
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1996
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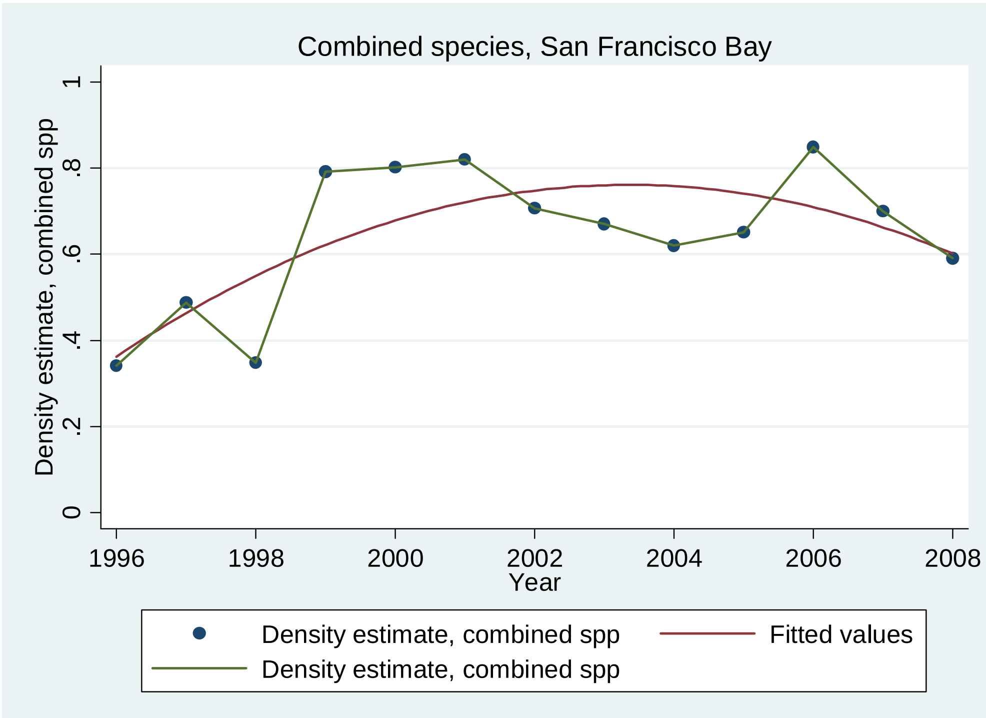
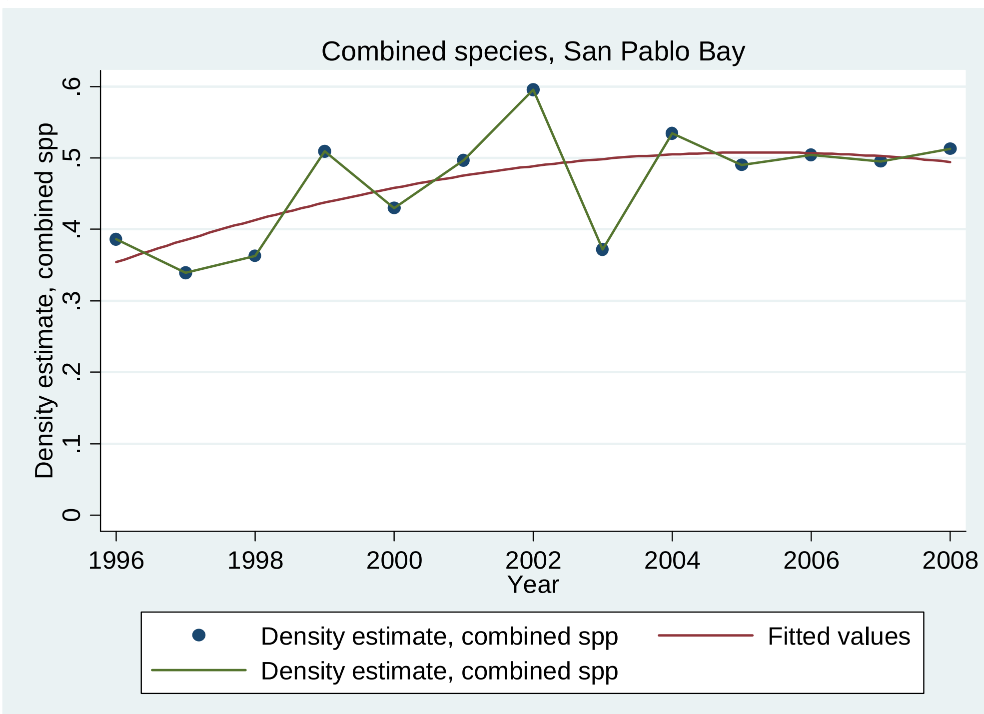
2006
2008
Year
Density estimate, Song Sparrow
Fitted values
Density estimate, Song Sparrow

I)


Combined species, San Francisco Bay
Density estimate, combined spp
0
.2
.4
.6
.8
1
1996
1998
2000
2002
2004
2006
2008
Year
Density estimate, combined spp
Fitted values
Density estimate, combined spp

J)


Combined species, San Pablo Bay
Density estimate, combined spp
0
.1
.2
.3
.4
.5
.6
1996
1998
2000
2002
2004
2006
2008
Year
Density estimate, combined spp
Fitted values
Density estimate, combined spp

K)

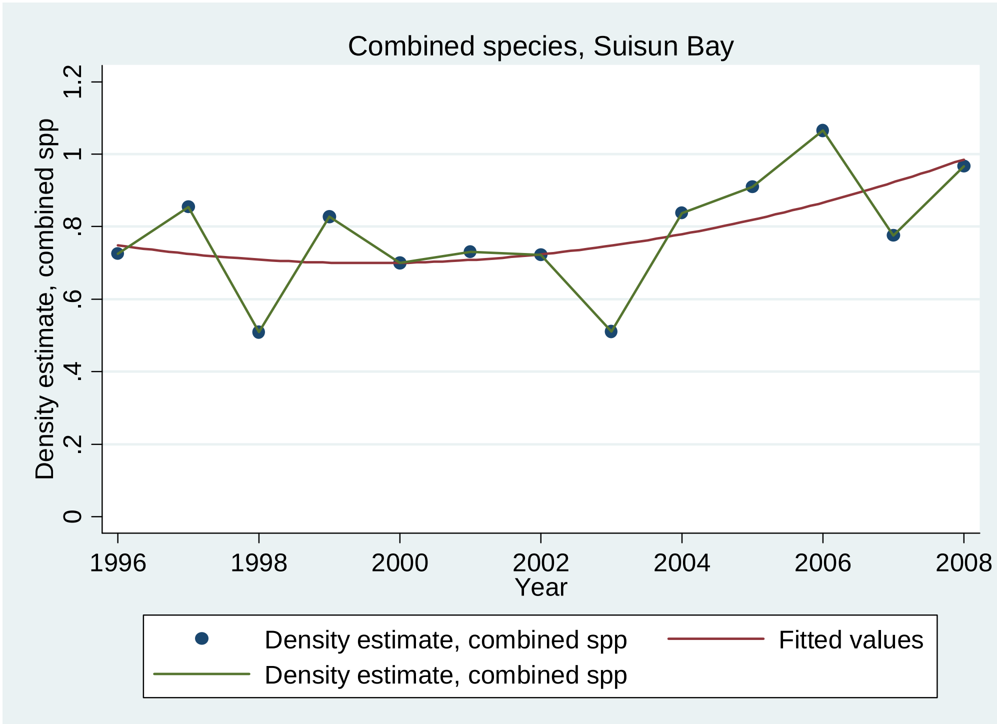


Table T1.

Long-term (1996 to 2008) and Short-term (2004 to 2008) trends for tidal marsh bird species

Shown are estimated annual percent changes per year in density index. Highlighting indicates significant ($P < 0.05$) differences (bright yellow) or marginally significant ($0.05 \leq P < 0.10$)

	San Francisco B		**San Pablo B**		**Suisun & W. Delta**	
Song Sparrow	Ann Pct	P-val	Ann Pct	P-val	Ann Pct	P-val
Long-term	5.77%	P = 0.008	-1.54%	P = 0.16	-2.63%	P > 0.2
Short-term	-0.67%	P > 0.9	-2.81%	P > 0.3	-14.7%	P = 0.19
Common Yellowthroat						
Long-term	-0.45%	P > 0.8	4.33%	P = 0.019	7.10%	P = 0.019
Short-term	1.37%	P > 0.8	-10.3%	P = 0.083	14.7%	P > 0.3
Black Rail						
Long-term	ND		4.08%	P = 0.034	2.18%	P > 0.4
Short-term	ND		5.19%	P > 0.5	7.37%	P > 0.4
Combined species						
Long-term	2.61%	P = 0.14	2.26%	P = 0.018	2.14%	P = 0.15

Short-term	0.34%	P > 0.9	-2.83%	P > 0.4	1.65%	P > 0.8

Table T2.
Comparison of 3-year Current (2006-2008) vs. 5-year Benchmark (1996 to 2000)
Shown are estimated percent differences in density index for two time periods. Highlighting indicates significant (P < 0.05) differences (bright yellow) or marginally significant (0.05 ≤ P < 0.10)

	San Francisco Bay		**San Pablo Bay**		**Suisun Bay**	
	Percent	P-val	Percent	P-val	Percent	P-val
Song Sparrow						
Comparison	2.70%	P > 0.9	-11.7%	P > 0.2	-33.8%	P = 0.18
Common Yellowthroat						
Comparison	20.0%	P > 0.4	38.7%	P = 0.073	74.3%	P = 0.15
Black Rail						
Comparison	ND		49.5%	P = 0.034	83.0%	P = 0.041
Combined species						
Comparison	11.0%	P > 0.5	22.3%	P = 0.033	28.3%	P = 0.19

In addition, we note that Clapper Rail population trends will be added to this indicator once the 2009 and 2010 data are available in early 2011. We feel that a minimum of 5 years of indicator data are required and as of now only four years (2005-2008) are available.

We conclude that the tidal marsh bird population indicator reveals a mixed picture: The combined species index shows overall increases in marsh bird population density since 1996, which **indicates some success in meeting the CCMP's first stated Aquatic Resources goal**: "Stem and reverse the decline in the health and abundance of estuarine biota." In San Pablo and San Francisco Bay regions, the increase for the combined species index is evident comparing 1999-2008 with 1996-1998, but recent years have not demonstrated further increases. For Suisun, the increase is evident comparing 2004-2008 to earlier years. Black Rails, a State-threatened species, clearly show a population-level increase which suggest that progress is also being made with regard to the third stated Aquatic Resources goal: "Ensure the survival and recovery of listed (and candidate) threatened and endangered species...." Song Sparrows reveal the other side of the story: this species demonstrates declines in density in San Pablo and Suisun Bays. Song Sparrows in San Francisco Bay show a recent decline (2002 to 2008) which partly counteracts the early improvements seen, from 1996 to 2002. The declines observed for this species are a cause for concern.

The overall declines in the Song Sparrow population index are consistent with the low levels of reproductive success that are apparent (see Biotic Indicator 4. *Marsh bird reproductive success*, below). The increase in density seen since 1996 reflects an improvement in habitat quality, at minimum increased habitat quality in restored tidal marshes. It is less clear whether mature marshes (those over 100 years of age) are showing increases in habitat quality.

Biotic Condition 2. Heron and Egret Nest Density Indicator

By Nadav Nur and John Kelly

Background and Rationale:

Audubon Canyon Ranch has monitored Great Blue Heron and Great Egret nest abundance at all known nesting colonies (40-50 sites) in the northern San Francisco Estuary, annually, since 1991. The conspicuousness of heron and egret nesting colonies facilitates the use of nest abundance as an effective index of breeding population abundance and distribution. Heron and egret nest abundance is recognized as a valuable metric for assessing biotic condition in estuarine and wetland ecosystems (Fasola et al. 2010, Kelly et al. 2008, Erwin and Custer 2000). Energetic limits on the foraging ranges of these species are associated with interannual shifts among nesting colony sites that in turn lead to dynamic variation in nest density which reflects suitability of surrounding feeding areas (Gibbs 1991, Wittenberger and Hunt 1985, Kelly et al. 2008). The two target species are used to indicate population responses to different habitat conditions: Great Egrets preferentially forage in small ponds in emergent wetlands and in areas with shallow, fluctuating water depths for foraging. In contrast, Great Blue Herons forage along the edges of larger bodies of water and creeks and are less sensitive to water depth (Custer and Galli 2002, Gawlik 2002). This indicator is sensitive to changes in land-use, hydrology (especially water circulation and depth), geomorphology, environmental contamination, vegetation characteristics, and the availability of suitable prey (Kushlan 2000).

Differences in breeding abundance reflect responses to habitat conditions within 30-300 km^2 (Custer et al. 2004, Kelly et al. 2008) and can be used to evaluate differences in habitat use between or across years at multiple spatial scales (colony sites, major wetland subregions, region-wide). Linkage between nest abundance and the landscape distribution of wetland habitat types is well-documented in the San Francisco Estuary (Kelly et al 2008) and in the Sacramento Valley (Elphick 2008). At the local scale of colony sites and adjacent marshes, changes in heron and egret nest abundance reflect variation in other factors, such as disease, nest predation, especially by human commensal species such as raccoons or ravens, and direct human disturbance to colony sites (Kelly et al. 2007).

Herons and egrets are frequently used as symbols of wetland conservation (Parnell et al. 1988, Kushlan and Hancock 2005) and are widely recognized as indicators of wetland health (Kushlan 1993, Erwin and Custer 2000). These values lead to compelling interest by policy makers, resource managers, and the public, in metrics related to the ecological status of herons and egrets.

Data Source:

The Heron and Egret Nest Density Indicator was calculated using data from ongoing regional heron and egret studies by Audubon Canyon Ranch (Kelly et al. 1993, 2007). The data, which reflect repeated annual nest counts at all known colony sites, provide intensive and extensive measurements of nest abundance and an effective index of regional breeding population sizes. Additional data on nest abundances in the southern San Francisco Bay (not presented here) are available from partners at the San Francisco Bay Bird Observatory.

Methods and Calculations:

The Heron and Egret Nest Density Indicator includes metrics calculated for Great Egrets and Great Blue Herons. Results are provided for each year (1991-2008; updated results to 2010 are pending), for each colony within each of three northern subregions (Central San Francisco Bay, San Pablo Bay, and Suisun Bay). Nest density estimates are based on the peak number of active nests among four (monthly) visits to at each colony site (40-50 sites) within foraging range (10 km) of the historic tidal wetland boundary (ca.1770–1820; San Francisco Estuary Institute 1999; Figure H1), summed annually within and across subregions. Density is calculated based on the estimated peak nest abundance within 10 km of the historic tidal-marsh boundary of Suisun Bay, San Pablo Bay, and Central San Francisco Bay, and within the combined area of the three subregions, excluding the extensive open water areas of the San Francisco Estuary (Figure H1). The detection of new colony sites is achieved through ongoing communications with state, regional and local natural resource managers, county breeding bird atlas efforts, local birding networks, and occasional ground-based and aerial searches of the region. The Nest Density Indicator is calculated as the geometric mean percent change in nest density for the two species, in comparison to the 1991-1995 average (Great Blue Heron: 181±15 nests [S. E.], 5.1±0.43 100 km^{-2}; Great Egret: 535±47 nests, 15.1±1.33 100 km^{-2}). That is, the proportional change was calculated for each species for the specified time period and then the geometric mean was calculated; finally, the mean proportional change was converted to percent change.

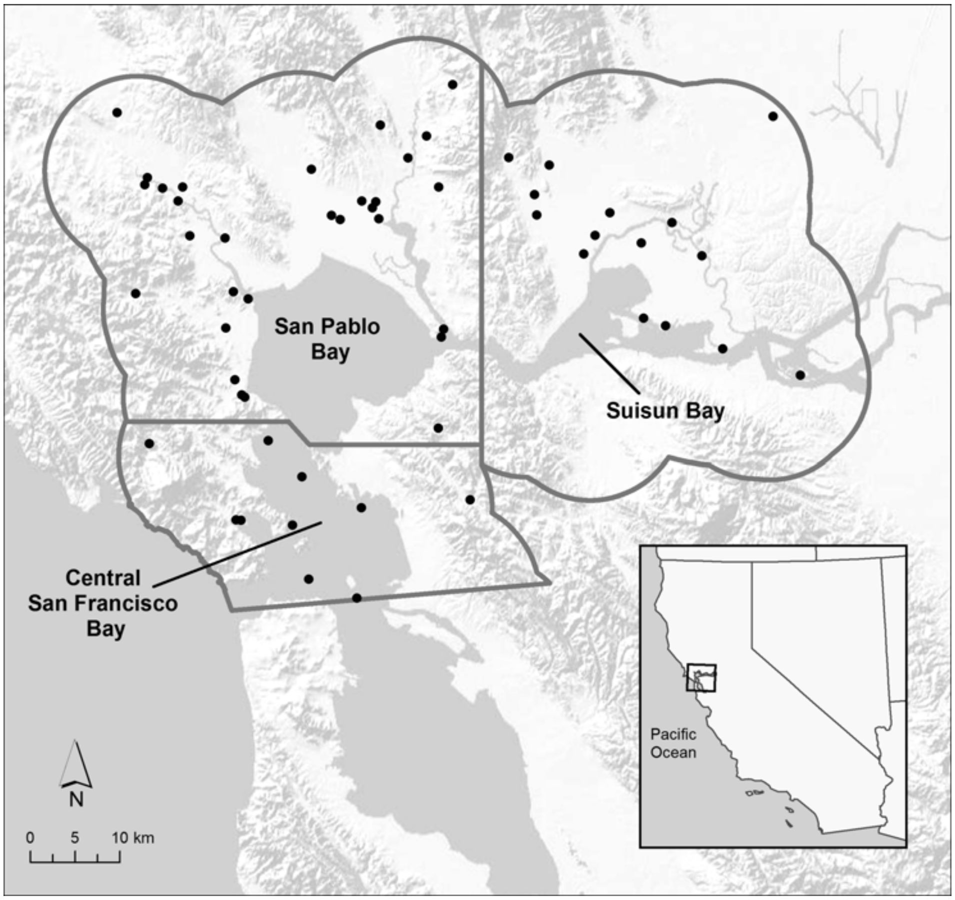


Figure H1. Heron and egret nesting colonies within 10 km of historic tidal wetlands in northern San Francisco Estuary, 1991-2008. Areas indicated by boundary lines, excluding the open waters of Suisun Bay, San Pablo Bay, and the Central Bay, were used to determine heron and egret nest density.

Goals, Targets and Reference Conditions:
CCMP goals to "restore" and "enhance" the ecological productivity and habitat values of wetlands are non-quantitative in nature. However, the use of time series back to 1991 allows the specification of appropriate quantitative reference conditions. Differences or trends in nest density can be quantified and used for assessment.

Maintenance of current regional or subregional breeding densities

- Target: current 5-year trend (linear) ≥ 0, i.e., stable or increasing
- Target: current 15-year trend ≥ 0, i.e., stable or increasing
- Target: current 3-year mean ≥ 5-year reference mean (1991-1995), i.e., current levels equal to or greater than reference.

Enhancement of regional or subregional breeding densities with wetland restoration

- Target: current 5-year trend (linear) ≥ current 15-year reference trend
- Target: current 3-year mean ≥ highest 5-year *subregional* reference mean (1991-1995)

Results: Annual results of the Heron and Egret Nest Density Indicator are shown in Figure H2.

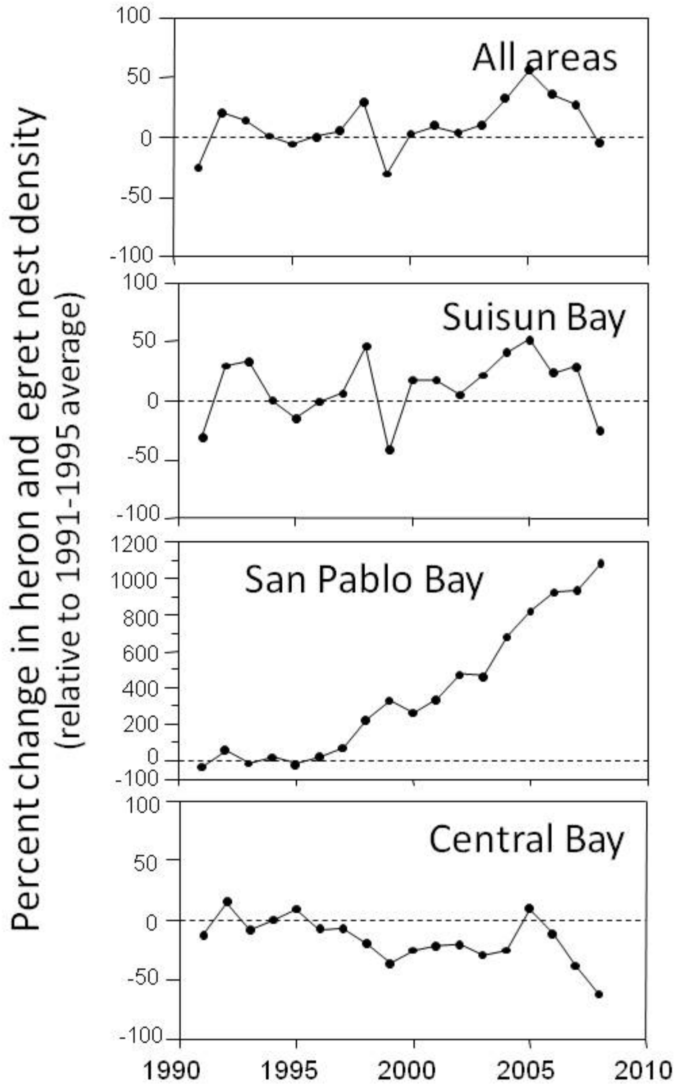


Figure H2. Annual percent change in heron and egret nest density, 1991-2008, relative to the average nest density (dashed line), 1991-1995, in the northern San Francisco Estuary.

Regional nest densities are stable for both species but 5-year trends provide evidence suggesting recent declines.

Recent (2006-2008), regional nest densities of herons and egrets did not differ significantly over 1991-1995 reference levels (t-tests, $P > 0.05$). Recent 15-year (1994-2008) linear trends in percent change in (log-transformed) nest density are > 0, but are marginally or not statistically significant for the combined species index (Indicator: $F_{1,13} = 3.3$, $P < 0.10$) and for individual species (Great Blue Heron: $P < 0.08$; Great Egret: $P < 0.18$). In contrast, the recent 5-year regional trends (2004-2008) are declining, although not significantly ($P > 0.05$), for both species, and trends are significantly less than the *current* 15-year trends, for the Indicator ($t_{18} = 4.2$, $P < 0.001$, Figure H2) and for each species (Great Blue Heron: $P = 0.02$; Great Egret: $P < 0.01$). This suggests recent, relative regional declines in breeding densities. Trends within subregions were similar to regional trends, with one exception: trends in San Pablo Bay were dominated by a small but dramatic increase in Great Egrets nest abundance, from less than 5 nests, in the early 1990s, to 163 in 2008 (Figure H2).

Nest densities were lower in San Pablo Bay than in other subregions, with some evidence of relative increases and a reduced variation among subregions.
During the reference period (1991-1995), Great Egret nest density was significantly lower in San Pablo Bay than in both other subregions, for Great Egret and, marginally, for Great Blue Heron (multiple comparisons, $P < 0.001$ and $P \leq 0.08$, respectively). The nest density indicator revealed a dramatic percent increase in San Pablo Bay in recent years (2006-2008) relative to the reference period (981±51%), that which was significantly greater than in other subregions (multiple comparisons, $P = 0.001$). As a result, Great Egret nest density in San Pablo Bay during the response period (2006-2008) was significantly lower only in comparison with Suisun Bay (multiple comparisons, $P < 0.05$), and Great Blue Heron density did not differ significantly among subregions ($F_{4,4} = 2.4$, $P = 0.21$).

Based on nest densities of Great Blue Herons and Great Egrets, CCMP goals of restoring or enhancing wetland productivity and associated wetland habitat values have not been generally met, but possible responses to habitat enhancement are suggested.
Nest densities in most of northern San Francisco Bay are stable, with some suggestion of gradual, long-term, subregional increases in San Pablo Bay wetlands. In that subregion, evidence of increasing nest density, especially for Great Egrets, suggests possible responses to continuing habitat restoration and enhancement. However, regional trends in recent years provide evidence of possible declines across northern San Francisco Bay.

Biotic Condition 3. Wintering Waterfowl Population Indicator

By Nadav Nur and John Kelly

Background and Rationale:
San Francisco Estuary provides important wintering habitat for waterfowl (Goals Project 2000, Steere & Schaefer 2001), one of the most important such areas in North America. For some species, during the winter, San Francisco Estuary hosts a majority of the entire Pacific Flyway population (Steere & Schaefer 2001). This is in addition to the estuary's value to waterfowl during the breeding season (especially in Suisun Bay region) and during the spring and fall migratory periods. More than 30 species of waterfowl are commonly observed in the San Francisco Bay region (Goals Project 2000).

The importance of the estuary for waterfowl has long been recognized. The San Francisco Bay region is identified as a waterfowl habitat area of major concern in the North American Waterfowl Management Plan (NAWMP; U.S. Fish and Wildlife Service 1998). NAWMP is implemented and financed through joint venture partnerships involving federal and state agencies, along with non-government organizations, and the private sector. The San Francisco Bay Joint Venture is one such partnership, playing an active role in conservation throughout the Bay area (Steere and Schaefer 2001).

Because of the long-recognized importance of waterfowl to the mission of the U. S. Fish and Wildlife Service, the "Mid-Winter Waterfowl Surveys" have been conducted by this agency, throughout the United States since 1955, in cooperation with state agencies (Eggeman and Johnson 1989). The biotic indicator used here for the San Francisco Estuary, therefore, is just a subset of the nation-wide effort. The survey attempts to enumerate all waterfowl, by species, for the entire estuary. Survey efforts target three habitats or areas: open bay throughout the estuary; salt ponds in the estuary (San Pablo Bay and South San Francisco Bay); and Suisun Marsh (including Grizzly Island Wildlife Area). The principal objective of the MWW Surveys is to provide information on population trends.

Waterfowl include **dabbling ducks**, which feed at the surface or in shallow water, **diving ducks**, which forage underwater, **swans**, and **geese**, which feed on plants in wetlands and fields. For the "winter waterfowl population indicator" we focus just on the two most abundant (and species-rich) groups of waterfowl, **dabbling ducks** and **diving ducks**. Swans and geese are not currently a primary component of San Francisco Bay waterfowl, with the exception of the Canada Goose which has become a pest species recently. In addition to the four waterfowl groups listed above (dabbling ducks, diving ducks, swans, and geese) the Mid-Winter Waterfowl surveys identify a fifth group: **sea ducks**. We have chosen not to include in this indicator the sea ducks, which are considered a distinct group of waterfowl and have their own joint venture (www.seaduckjv.org). Sea ducks are most commonly found in coastal and off-shore areas of the Bay region. In San Francisco Bay, sea ducks are almost entirely represented by scoters (*Melanitta* spp.; Surf Scoter, Black Scoter, and White-winged Scoter). However, this indicator could be re-calculated to include scoter species as well.

Data Source:
USFWS and CDFG jointly conduct surveys in the San Francisco Estuary in January of each year. Joelle Buffa (USFWS) and Michael Wolder (USWFS) kindly provided the data used here. Data are summarized by survey area and then compiled into regional summaries.

Methods and Calculations:
Surveys are conducted on a single day per survey area per year; sometimes several areas are surveyed in a single day. Surveys are conducted mainly from fixed-wing aircraft, but sometimes from the ground or by boat. Open bay and salt ponds are the target of surveys by USFWS observers throughout the estuary. Survey numbers are summarized by bay region: Suisun Bay, North Bay (San Pablo Bay and the northern portion of San Francisco Bay), Central San Francisco Bay, and South San Francisco Bay. Suisun marsh, including Grizzly Island Wildlife Area, is the target of surveys by CDFG, which also surveys the Delta. Thus, Bayland habitat in the estuary, other than the Suisun region, is not adequately surveyed in the Mid-Winter Waterfowl Survey (Takekawa 2002).

As noted on the USFWS website for Mid-Winter Waterfowl Surveys, "[S]pecific sampling procedures are not defined. Instead, an aerial crew determines the best and most practical means to conduct a complete count of all waterfowl within a predefined unit area." Surveys are not standardized with respect to tide. Weather and other physical conditions during the survey period are noted but analyses do not statistically adjust for weather conditions. Survey effort may be noted, but numbers are not adjusted by effort. In theory, one could convert counts into densities by dividing by the area surveyed, but this has not yet been implemented.

The analysis presented here uses the regional totals in each year, broken out by species, where region is Suisun Bay, North Bay, Central San Francisco Bay, and South San Francisco Bay. Here "Suisun Bay" refers to the open water of the bay. Suisun Marsh is not currently included, but we are working to include these counts in the metric as well. The indicator will be re-analyzed when such data are available. We analyzed changes in the natural log-transformed counts per region and per species in a linear model that included species main effects, similar to the analysis used for combined species Tidal Marsh Bird Population indicator. Dabbling and diving duck species were excluded if the majority of years had zero counts for that species. This left twelve species for analysis: six species of dabblers (American Wigeon, Gadwall, Green-winged Teal, Mallard, Northern Pintail, Northern Shoveler) and six species of diving ducks (Bufflehead, Canvasback, Goldeneye, Redhead, Ruddy Duck, Scaup). The analyses of change over time were carried out separately for dabbling ducks and for diving ducks. The result was an overall estimate of change over time for each waterfowl group (dabblers and divers), while adjusting for differences in abundance among species within a group. The approach used was similar to that used for the "combined-species" index of tidal marsh bird populations (described above, Biotic Condition 1).

We used three methods to evaluate change over time: (1) long-term trends over time, for the period 1989 to 2006 (except 1988 to 2006 for South San Francisco Bay), (2) short-term trends over time, for the most recent 5-year period, which was 2002-2006 (except 2001-2006 for Suisun because surveys were not conducted there in 2005), and (3) comparison of the period 2004-2006 with the 5-year benchmark period, 1989 to 1993 (except 1988 to 1992 for South San Francisco Bay; only South San Francisco Bay had data available for 1988).

Goals, Targets, and Reference Conditions:

The San Francisco Bay Joint Venture (Steere and Schaefer 2001) has determined that values for estimated waterfowl abundance in the period 1988 to 1990 should be used as a baseline for comparison, and furthermore these estimated abundances should also provide goals for individual species. Table W1 provides estimates of the "long-term trends" by waterfowl group since 1988 or 1989, which facilitates evaluation. In addition, survey estimates of current numbers can be compared directly with the earlier period. Because of the high year to year variation in number, primarily due to the fact that the survey is conducted only on a single day, and that some important influences on counts are not statistically controlled for, we feel it most appropriate to use the most recent three-year period (2002-2006) for assessing "current" numbers and the five-year period that includes 1988 to 1990 as the benchmark value.

Results:

In **Suisun Bay**, dabbling ducks demonstrate an increase, but only in recent years (since 2001; Figure W1 A; Table W1). As a result, their numbers show a significant increase in recent years, compared with the 5-year benchmark period (Table W2). Diving ducks in Suisun Bay demonstrate a weak (non-significant) decline, with an estimated decline of 18.4%/year in the most recent 5 years (Figure W1 B; Table W1). Note that these population changes only refer to numbers as assessed in open water of the Bay. Suisun Marsh data will be added at a later time.

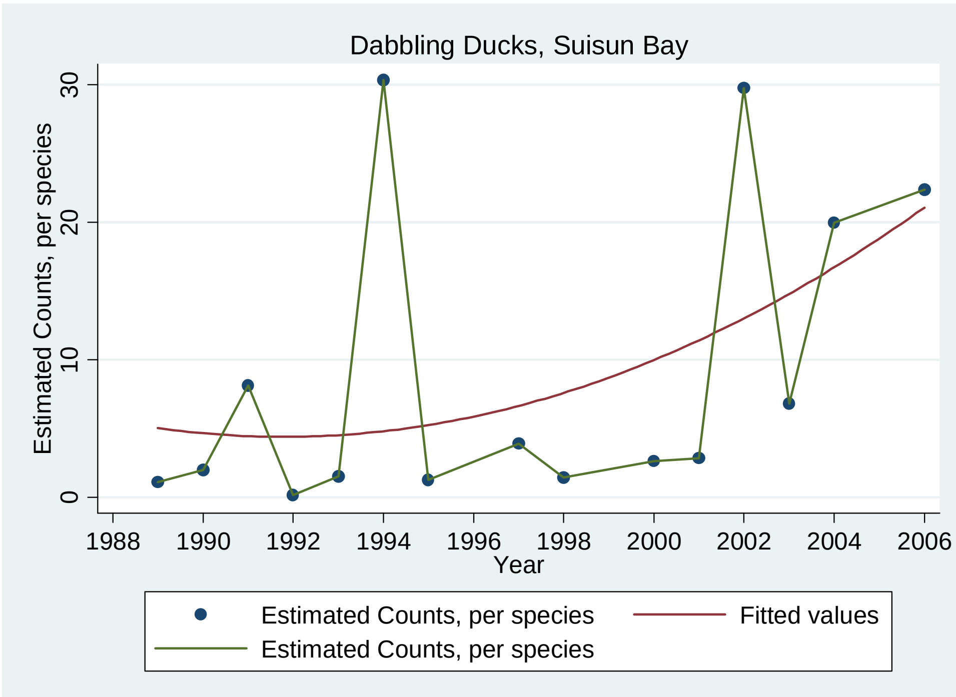
In the **North Bay**, dabbling ducks also demonstrate an increase, over a sustained period of time, 1995 to 2006 (Figure W1 C). However, the most recent 5-year period evidences a decrease, not an increase, for this group. Nevertheless, the result, when comparing the most recent 3-years with the 5-year benchmark is a significant increase (Table W2). Diving ducks, in contrast, have shown an overall decrease, and in the most recent years, this decline is significant (Figure W1 D, Table W1). The result is that counts for the most recent 3-year period are significantly lower for diving ducks in the North Bay compared to the 5-year benchmark period (Table W2).

In the **Central San Francisco Bay**, dabbling duck numbers have been low in every year except 1999. As a result, there are no significant trends or differences for this group, though the tendency has been for decreases in number (Figure W1 E, Tables W1 and W2). Compared to historical numbers, there is likely cause for concern. Diving ducks in this region have demonstrated no significant trends for the long-term or short-term, though since 1999 the trend has clearly been negative (Figure W1 F). That is, a decrease from 1989 to 1997 was followed by an increase from 1997 to 2001, followed by another drop.

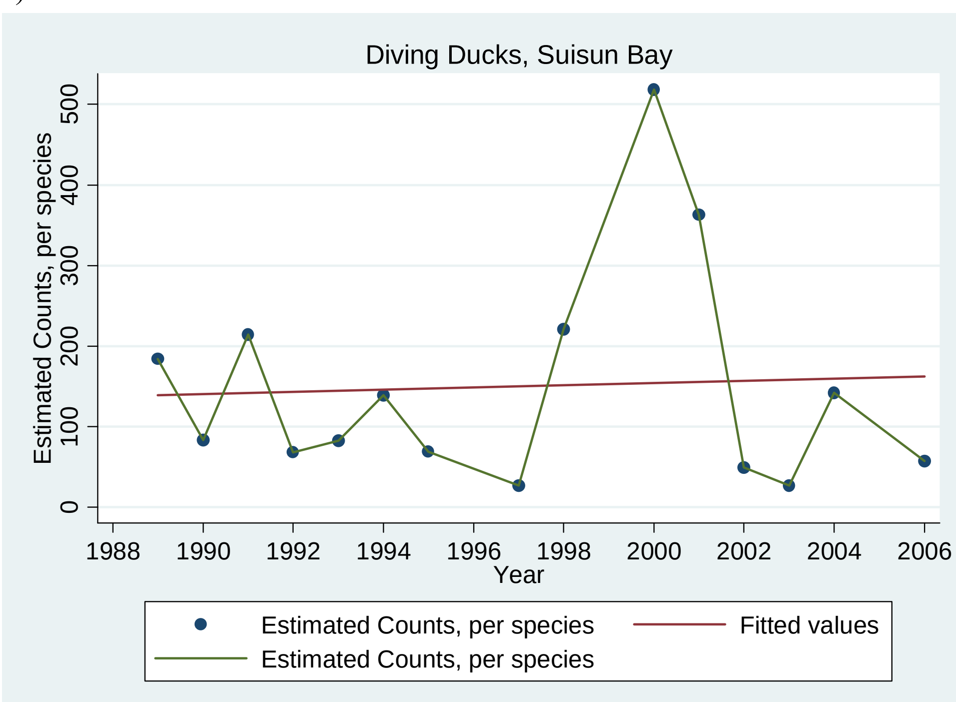
In **South San Francisco Bay**, dabbling ducks demonstrate a slight increase overall (Figure W1 G). Numbers in the most recent 3-year period are greater than they were in 1992-1995, and marginally significantly greater in the most recent 3 years compared to the 5-year benchmark period ($P = 0.096$, Table W2). Diving ducks show an increase from 1988 to 2001, resulting in a significant increase over the long-term (Figure W1 H), with a non-significantly higher numbers in the most recent 3 years compared to the benchmark period (Table W2). However, since the peak in 2001-2002, there has been an overall decline, which in the last 5 years is marginally significant ($P = 0.083$).

Figure W1. Population Trends for Waterfowl in San Francisco Estuary, 1988 to 2006. Results are from USFWS Midwinter Waterfowl Surveys. Shown are mean counts per species per year for two groups of waterfowl: Dabbling Ducks (6 species included: American Wigeon, Gadwall, Green-winged Teal, Mallard, Northern Pintail, Northern Shoveler) and Diving Ducks (6 species included: Bufflehead, Canvasback, Goldeneye, Redhead, Ruddy Duck, Scaup). Results shown for Suisun Bay, North Bay, Central San Francisco Bay, and South San Francisco Bay. Analyses controlled for species differences in log-transformed counts. Trend lines are shown as quadratic fits (Figure W1-A) or linear fits (Figure W1-B to W1-H); choice of fit (linear vs. quadratic) determined by maximization of adjusted R^2 (Nur et al. 1999).

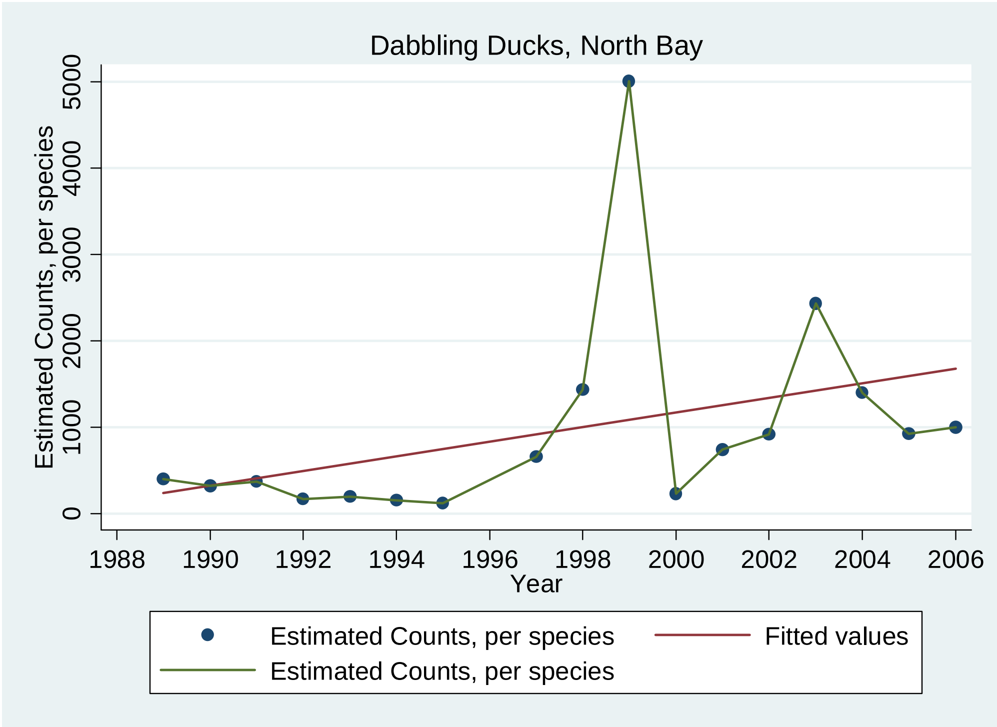
A)


Dabbling Ducks, Suisun Bay
Estimated Counts, per species
0
10
20
30
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

B)

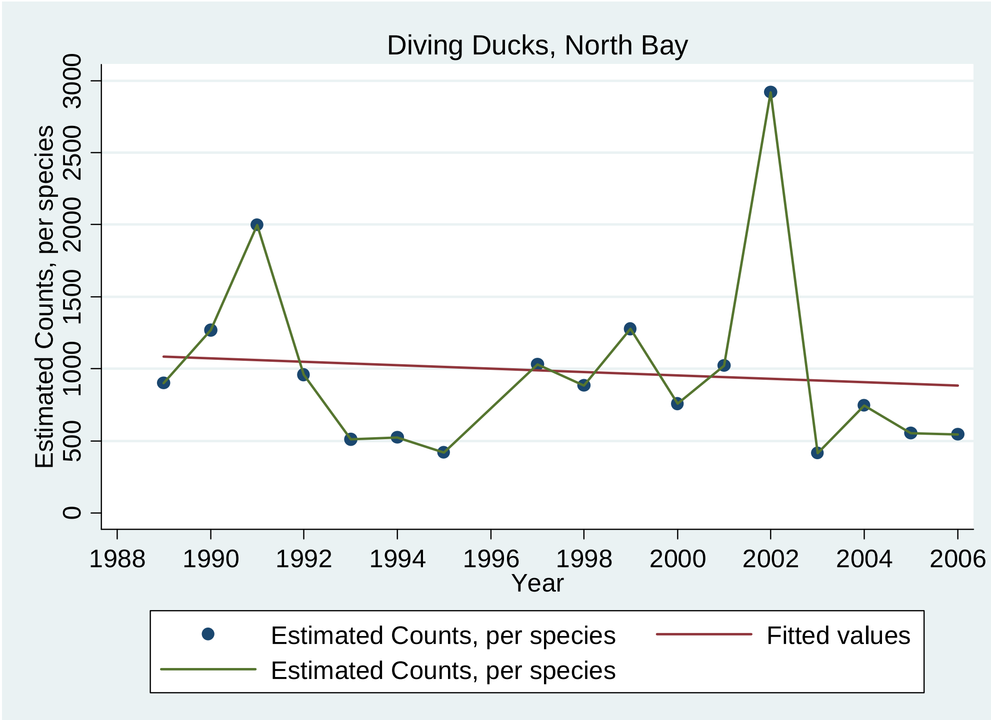

Diving Ducks, Suisun Bay
Estimated Counts, per species
0
100
200
300
400
500
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

C)

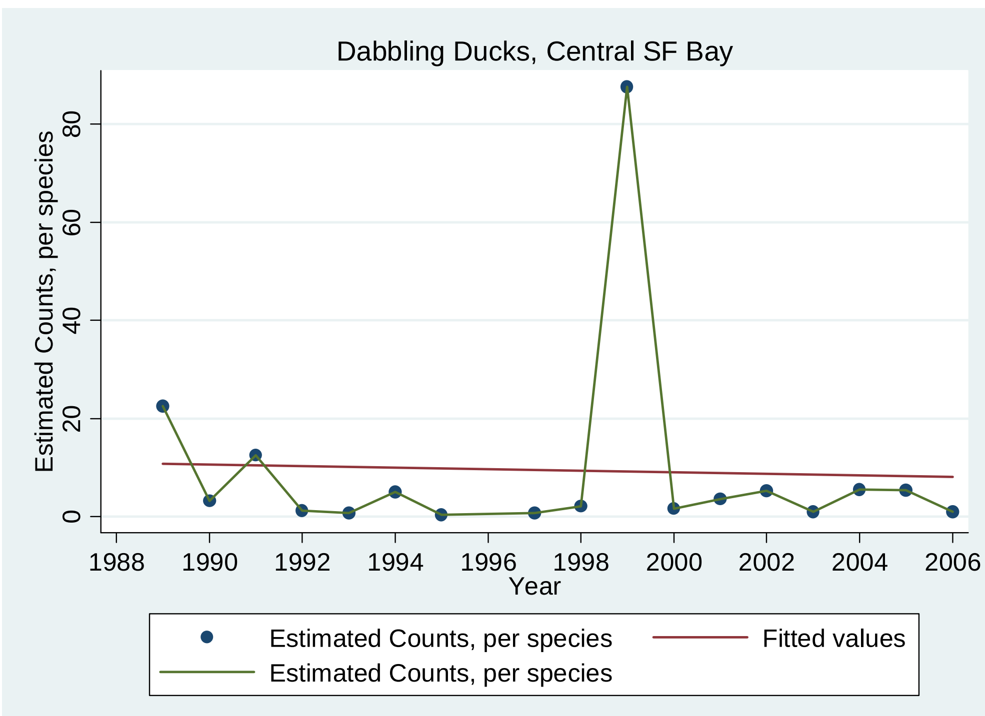


Dabbling Ducks, North Bay
Estimated Counts, per species
0
1000
2000
3000
4000
5000
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

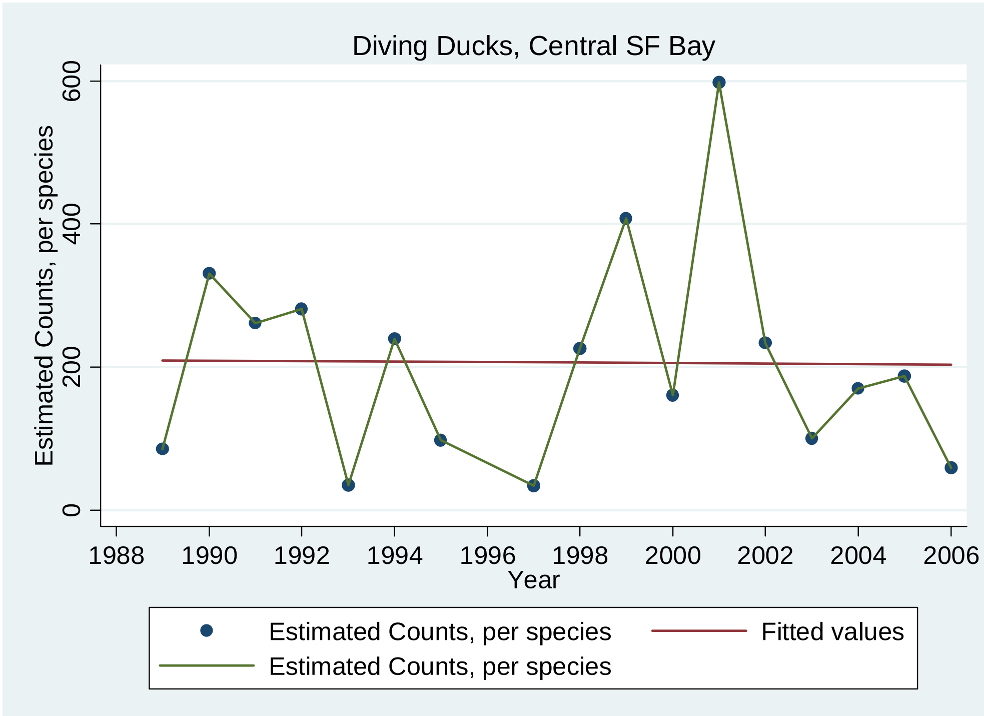
D)


Diving Ducks, North Bay
Estimated Counts, per species
0
500
1000
1500
2000
2500
3000
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

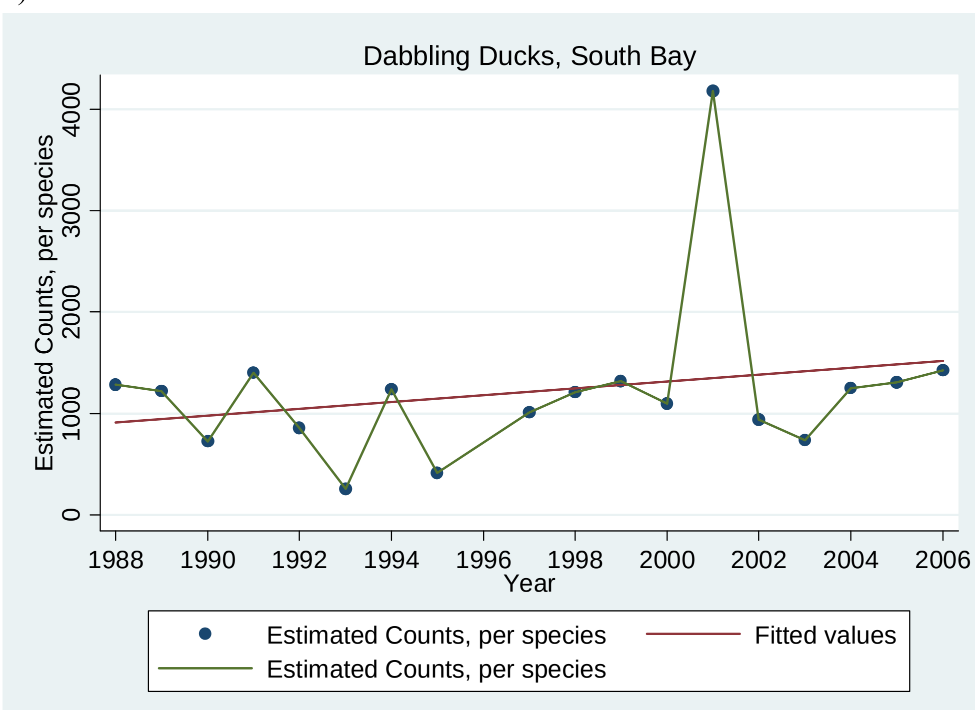
E)


Dabbling Ducks, Central SF Bay
Estimated Counts, per species
0
20
40
60
80
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

F)


Diving Ducks, Central SF Bay
Estimated Counts, per species
0
200
400
600
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

G)


Dabbling Ducks, South Bay
Estimated Counts, per species
0
1000
2000
3000
4000
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

H)

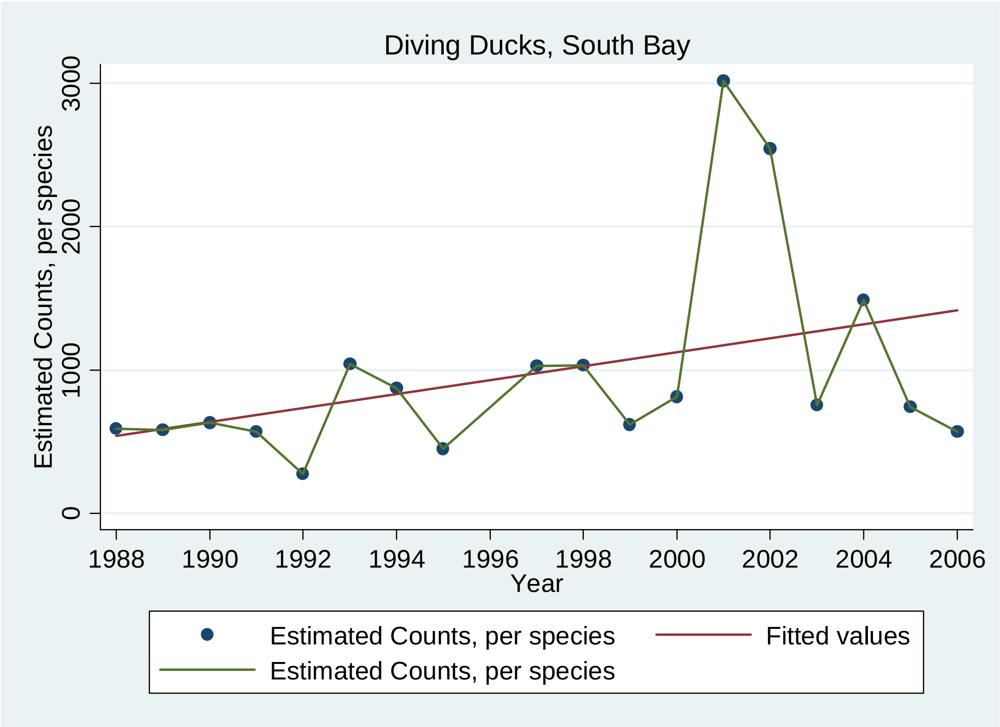

Diving Ducks, South Bay
Estimated Counts, per species
0
1000
2000
3000
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Estimated Counts, per species
Fitted values
Estimated Counts, per species

Table W1. San Francisco Estuary Waterfowl: Long-term (1988 or 1989 to 2006) and Short-term (2002 to 2006) trends for two groups of waterfowl. Shown are estimated annual percent changes per year in population index. (Mid-winter waterfowl surveys, USFWS).

		Dabbling Ducks		Diving Ducks	
	number of years	Ann Pct	P-val	Ann Pct	P-val
Suisun Bay					
Long-term	15	11.5%	P = 0.001	-2.04%	P > 0.5
Short-term	5	29.0%	P = 0.19	-18.4%	P > 0.3
North Bay					
Long-term	18	12.5%	P < 0.001	-1.91%	P > 0.3
Short-term	5	-7.63%	P > 0.5	-26.5%	P = 0.033
Central SF Bay					
Long-term	18	-2.44%	P > 0.4	-0.09%	P > 0.9
Short-term	5	-10.3%	P > 0.5	-18.8%	P > 0.2
South SF Bay					
Long-term	19	2.70%	P = 0.14	4.54%	P = 0.037
Short-term	5	15.1%	P > 0.2	-26.0%	P = 0.083

Highlighting indicates significant (P < 0.05) differences (bright yellow) or marginally significant (light yellow; 0.05 ≤ P < 0.10)

Note: Suisun, North Bay, Central SF Bay long-term is for 1989 to 2006; South Bay long-term is for 1988 to 2006.

Short-term is 2002 to 2006, except for Suisun Bay, which is 2001 to 2006 (no survey data in 2005)

Table W2. San Francisco Estuary Waterfowl: Comparison of 3-year Current (2004-2006) vs. 5-year Benchmark (1989 to 1993). Shown are percent differences in standardized count index for the two time periods (Mid-winter waterfowl surveys, USFWS).

	Dabbling Ducks		**Diving Ducks**	
	Percent	P-val	Percent	P-val
Suisun				
Comparison	683%	P < 0.001	-20%	P > 0.5
North Bay				
Comparison	295%	P < 0.001	-41%	P = 0.021
Central SF Bay				
Comparison	-21%	P > 0.6	-17%	P > 0.6
South SF Bay				
Comparison	58%	P = 0.096	49%	P = 0.17

Highlighting indicates significant (P < 0.05) differences (bright yellow) or marginally significant (light yellow; 0.05 ≤ P < 0.10)

Note: South SF Bay benchmark is for 1988 to 1992

Scoters, since they are usually considered sea ducks were not included, but it is interesting to compare their trends to dabblers and divers. There were no significant (P > 0.1) long-term or short-term trends evident for scoters in any region. However, numbers in the most recent 3-year period were lower in the North Bay than they were in the 5-year benchmark period (P = 0.072).

To summarize, the patterns are very different comparing dabbling ducks to diving ducks: Dabbling ducks have increased in Suisun and the North Bay, and there is the suggestion of an increase in the South Bay, too. Diving ducks have decreased in the North Bay and they demonstrate recent, short-term declines in all bay regions, though the declines are not significant in every case. Still, the magnitude of decline for diving ducks is of concern: for each bay region, recent declines exceeded 18% per year between 2002 and 2006. Thus, **CCMP Aquatic Resources Goal 1, to stem and reverse the decline in abundance of estuarine biota, has not been met for diving ducks, but the situation is encouraging for dabbling ducks.** Furthermore, current tidal marsh habitat restoration efforts are likely benefitting dabbling ducks, but not diving ducks, since the former utilize the shallow water habitat found in tidal marshes, but the latter group does not (Stralberg et al. 2009). The discrepancy for the two groups of waterfowl will only be enhanced in the future as more restoration projects come to fruition.

Biotic Condition 4. Marsh Bird Reproductive Success

By Nadav Nur and John Kelly

Background and Rationale:

San Francisco Estuary tidal marsh habitat has been dramatically altered in the past one hundred and sixty years. Approximately 85% of the original tidal marsh habitat in the region has been lost due to creation of salt ponds, conversion to agricultural and industrial/urban use, and water diversion and management (Marshall & Dedrick 1994). The reduction in area, fragmentation of remaining habitat, degradation in habitat quality, and spread of invasive species have all contributed to reductions in the population size and viability of tidal marsh obligate species. Future threats such as climate change will also alter the area and distribution of marshes and may lead to increased risk of mortality due to flooding, as a result of sea level rise and increased frequency of storm surges (Takekawa et al. 2006). For these reasons, many of the species that depend on tidal marsh habitat are currently listed as Federally- or State- threatened or endangered, in particular Clapper Rail and Black Rail, or are of conservation concern (e.g., California Species of Special Concern, Shuford & Gardali 2008). It is for these reasons that the first-listed "Aquatic Resources Goal" of the CCMP is

- "Stem and reverse the decline in the health and abundance of estuarine biota (indigenous and desirable non-indigenous), restoring healthy natural reproduction."

The indicator presented here, **Marsh Bird Reproductive Success**, provides for informative assessment of progress in meeting this goal, as well as providing information regarding progress towards the second and third stated goals for Aquatic Resources, i.e.,

- "Restore healthy estuarine habitat to the Bay-Delta" and
- "Ensure the survival and recovery of listed (and candidate) threatened and endangered species, as well as other species in decline."

Successful reproduction involves several components, for which we focus on one, **nest survival**. Other components of reproductive success include number of young reared per successful breeding attempt and number of breeding attempts per breeding pair (Chase et al. 2005). Nest survival in avian species is a parameter that is monitored and evaluated on the national and international levels (Greenberg et al. 2006, Jones and Geupel 2007).

Nest survival refers to the probability that a nesting attempt survives to fledge one or more young. Nest survival of tidal marsh **Song Sparrows** reflects two principal mortality pressures: predation on nests and flooding of nests (Greenberg et al. 2006, Nordby et al. 2008). For tidal marsh Song Sparrows, this indicator reflects primarily nest-predation (either predation on eggs or nestlings). Principal predators are birds (especially corvids), mammals (especially raccoons), and snakes. Secondarily, the indicator reflects inundation, and thus flooding due to high tides. Flooding is the second-leading cause of nest failure for tidal marsh Song Sparrows (Greenberg et al. 2006, Nordby et al. 2009).

Between 1996 and 2006, PRBO conducted systematic nest monitoring at up to five sites per year for two regions: San Pablo Bay and Suisun Bay. In addition, there is partial information from San Francisco Bay for 2002 and 2003 (Nordby et al. 2009).

Data Source:
PRBO biologists conducted nest-monitoring in tidal marsh habitat for Song Sparrows at three to five sites in each year, distributed between San Pablo and Suisun Bays, between 1996 and 2006. In 9 out of 11 years, there were at least two sites monitored per bay per year.

Methods and Calculations:
Nest monitoring was conducted following methods outlined in Martin and Geupel (1993) and Liu et al. (2007). At each site, two to four study plots were established. For each breeding pair, nests were intensively searched for and then monitored, from nest discovery to the fledging or failure of a nesting attempt. Nests were usually visited every 2-4 days in order to accurately estimate dates of nest failure, dates of egg laying, hatching of eggs, and fledging of young. The ultimate outcome of each nest (success or failure) was determined based on nest condition and behavior of the breeding pair (Martin and Geupel 1993). For each breeding season, we calculated daily nest survival of a specific site using the Mayfield method (Mayfield 1975). We then converted daily nest survival (calculated separately for each stage of the nesting cycle) into overall survival, from laying of the first egg until fledging following Nur et al. (1999).
Not every site was monitored in every year. Therefore, in order to adjust for site-specific differences in nest survival, which may confound differences among years, we included "site" as a categorical variable to be controlled for, when analyzing sites and years. This "standardization" of nest survival was carried out separately for each region, i.e., for San Pablo Bay sites and Suisun Bay sites. The statistical analysis was similar to that presented for the Tidal Marsh Bird Population Indicator (above). Note: no PRBO monitoring was carried out in Central or South San Francisco Bay (but see Nordby et al. 2009 for two years of results for that region).

Goals, Targets, and Reference Conditions:
This indicator focuses on a single species, the Song Sparrow; specifically, the subspecies that are endemic to tidal marsh habitat (Spautz and Nur 2008a, 2008b). For this indicator, it is possible and desirable to identify an absolute benchmark that will provide insight regarding success at meeting the first stated goal, "restoring healthy natural reproduction" for this species. On the basis of demographic modeling of this species, drawing on PRBO studies and the literature, it appears that a stable population of tidal marsh Song Sparrows requires nest survival probability of 20% or greater, and more likely 25% or greater, to achieve "source" status rather than "sink" status (Nur et al. 2007), where "source" refers to a population which can sustain itself without net immigration (Nur and Sydeman 1999). There is some uncertainty here, due to uncertainty with regard to other demographic parameter value. Our best estimate is 22 to 25%, but, we recognize that values as low as 20% may be sufficient.

Results:
Nest survival probabilities, standardized for site-to-site variation are shown for San Pablo Bay and Suisun Song Sparrows (Fig T-2). In 7 years out of 11, Suisun values were below 15%. This

is a serious concern, given that at least 20% survival probability is needed for sustainability of the population. For San Pablo, the situation is less grave: only 3 out of 10 years were below 15%, but, nevertheless, in 7 years out of 11, nest survival was below 20%. A key point of this analysis is that absolute values are meaningful and not just the trend. The longer-term trend (1996 to 2006) is for nest survival to demonstrate a weak negative trend (5.5% decline per year, P = 0.093) for San Pablo Song Sparrows, and a slight increase (6.6% per year, P > 0.1) for Suisun Song Sparrows.

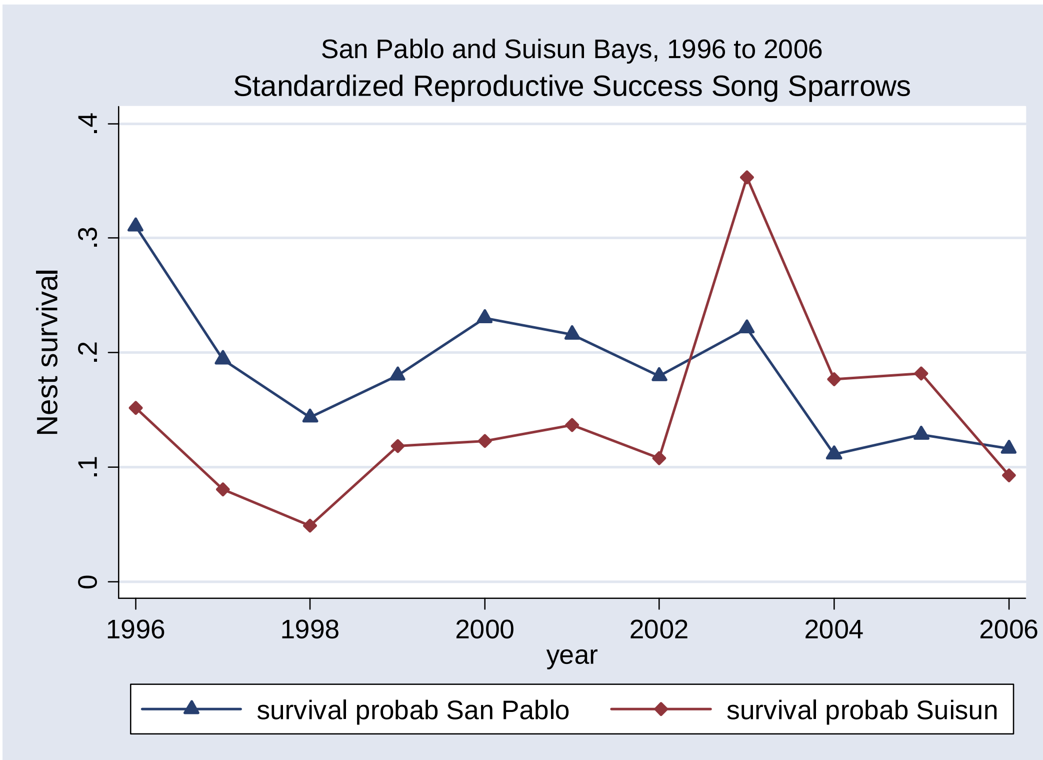


Figure T-2. Nest survival (standardized, see text) for San Pablo and Suisun Song Sparrows (based on PRBO unpublished studies; Liu et al. 2007).

Reproductive Success in tidal marsh songbirds appears to be insufficient to maintain population levels. Substantial improvement is needed to meet the goal of "restoring healthy natural reproduction." Suisun Song Sparrows have shown a slight increase in nest survival, between 1996 and 2006, but nevertheless in every year except one, nest survival was below the 20% threshold. Low reproductive success may account for the decline in Suisun Song Sparrow population density observed since 2000 (see Biotic Condition 1, above). San Pablo Song Sparrow nest survival rates are closer to meeting the minimum threshold of 20%, but at the same time this subspecies has demonstrated an apparent decline in nest survival, especially since 2000. The Alameda subspecies of tidal-marsh Song Sparrow appears to have low nest survival rates as well (Nordby et al. 2009), though no trend information is available.

The causes of low nest survival probability are likely two-fold: high levels of predation on nests and nest failure due to flooding (i.e., tidal inundation; Greenberg et al. 2006, Nordby et al. 2009). Nest-predators are not well identified for tidal marsh Song Sparrows (Spautz and Nur 2008a, Spautz and Nur 2008b), but certainly include non-native predators, such as feral cats (*Felix catus*), red fox (*Vulpes fulva*), and Norway rats (*Rattus norvegicus*), as well as native predators, such as corvids (American Crow [*Corvus brachyrynchos*] and Common Raven [*Corvus corax*]) that thrive in proximity to humans.

Nordby et al. (2009) also identified a specific threat associated with the invasive cordgrass, *Spartina alterniflora* and its hybrids: nests in this type of plant were more likely to fail due to flooding, possibly because of the low elevation of the invasive *Spartina*, relative to high tides.

Biotic Condition 5. Heron and Egret Nest Survival Indicator

By Nadav Nur and John Kelly

Background and Rationale:

Audubon Canyon Ranch has monitored the survival of focal Great Blue Heron and Great Egret nests (proportion of nests that fledge at least one young) across nesting colonies throughout the northern San Francisco Estuary, annually, since 1994 (Kelly et al. 2007). (Here we use "nest survival" as a term that also encompasses "nest survivorship"; the latter refers to the proportion of nests that survive from initiation to a specified point in time, whereas the former can refer to the probability of survival during any relevant time period. An extensive literature has developed regarding nest survival and its analysis, see Jones and Geupel 2007.)

The conspicuousness of heron and egret nesting colonies and the visibility of nests facilitates the monitoring of nesting activity and the use of nest survival as an effective index of overall nest success. This indicator is sensitive to nest predation and colony disturbance by native and introduced nest predators (especially by human commensal species such as raccoons and ravens), land development and human activity near heronries, and severe weather (Pratt and Winkler 1985, Frederick and Spalding 1994, Kelly et al. 2005 and 2007). Such ecological processes can vary over space and time in response to landscape patterns of habitat change, dynamics of predator populations, and changes in human land use, and are therefore likely to differentially affect nesting colonies of herons and egrets. Note that heron and egret nest survival is not a particularly strong indicator of food availability. Rather, food availability (and more generally, the food web) for piscivorous birds is reflected in the "Heron and Egret Brood Size Indicator", see Ecological Processes Indicator 1, below.

Data Source:

The Heron and Egret Nest Survival Indicator was calculated using data from ongoing regional heron and egret studies by Audubon Canyon Ranch (Kelly 1993, 2007). The data, which reflect the survival of focal nests followed through the entire nesting cycle on repeated visits to colony sites throughout the northern San Francisco Estuary, provide an effective index of regional and subregional nest success.

Methods and Calculations:

The Heron and Egret Nest Survival Indicator, calculated as the apparent nest success of Great Egrets and Great Blue Herons, is based on the proportion of focal nests that remain active through the nesting cycle, from nest initiation or early in the incubation period, at 40-50 colony sites within 10 km of the historic tidal wetland boundary (ca.1770–1820; San Francisco Estuary Institute 1999; Figure H1). Great Egret and Great Blue Heron nests are considered successful if at least one young survives to minimum fledging age of seven or eight weeks, respectively (Pratt 1970, Pratt and Winkler 1985). Nest are sampled I approximate proportion to colony size. In colonies with fewer than 15 active nests, all nests initiated before the colony reaches peak nest abundance are treated as focal nests. At larger colonies, random samples of at least 10-15 focal nests are selected. Nest survival is calculated as the geometric mean, between species, of percent deviation of the proportion of focal nests that are successful from average nest survival during a five year reference period (1995-1998).

Goals, Targets and Reference Conditions:
CCMP goals to "restore" and "enhance" the ecological productivity and habitat values of wetlands are non-quantitative. However, the use of time series back to 1994, allows the specification of appropriate quantitative reference conditions. Differences or trends in nest survival can be quantified and used for assessment.

<u>Maintenance of current resource levels</u>

- Target: current 3-year mean (2006-2008) ≥ 5-year reference mean (1994-1998)

<u>Enhancement of resources with wetland restoration</u>

- Target: *current* 3-year mean (2006-2008) ≥ highest 5-year *subregional* reference mean (1994-1998).

Results: Results of the Heron and Egret Nest Survival are shown in Figure H3.

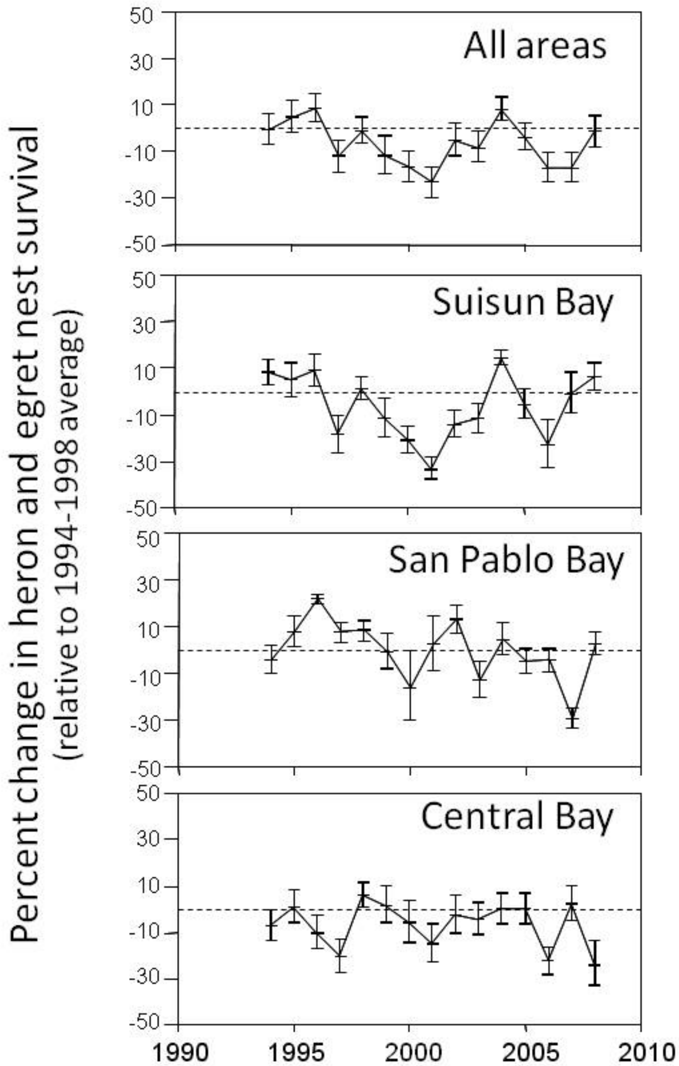


Figure H3. Annual percent change in heron and egret nest survival, 1994-2008, relative to the average nest survival (dashed line), 1994-1998, in the northern San Francisco Estuary.

Recent rates of nest survival (2006-2008) were generally lower than reference levels (1994-1998).

A marginally significant regional decline in nest survival (12.7%, $t_{272} = 1.97$, $P = 0.05$) reflected primarily a 16.8% decline in the survival of Great Egret nests. Within subregions, overall nest survival was significantly lower than the 1994-1998 regional level only in San Pablo Bay, which was lower, primarily because of an 18.1% decline in the survival in Great Egret nests ($t_{445} = 2.3$, $P < 0.02$; Figure H3). However, in the Central Bay, Great Blue Heron nest survival was 21.6% lower ($t_{75} = 2.6$, $P < 0.05$) than in reference period and, in Suisun Bay, survival of Great Egret nests was 27.5% lower (t_{146} = 4.1, P < 0.001). Reference nest success rates (1994-1998) are 80.5% for Great Blue Heron and 81.8% for Great Egret.

Nest Survival differs among subregions, with differential ranking between species.
The Nest Survival Indicator differed significantly among subregions ($F_{2, 817}$ = 3.6, P < 0.05). Suisun Bay exhibited significantly higher Great Blue Heron nest survival (10.0% increase over the regional reference level) and significantly lower Great Egret nest survival (32.0% decline) than other subregions (multiple comparisons, P < 0.05).

Based on the survival of Great Blue Heron and Great Egret nests, CCMP goals of restoring or enhancing wetland productivity and associated wetland habitat values have not been met in the region, although evidence suggests some subregional enhancement in nest survival.
Recent survival rates of Great Blue Heron and Great Egret nests are generally lower than rates measured during the 1994-1998 reference period. However, possible enhancement of Great Blue Heron nest success was suggested by the results for Suisun Bay. Differences in the survival of heron and egret nests among the subregions suggest that breeding performance in these species may contribute to informed comparisons of biotic condition among regions within the San Francisco Estuary.

Biotic Condition Indicator 6. Pelagic Fish Abundance

By Christina Swanson

Background and Rationale: Abundance (or population size) of native fish species within an ecosystem can be a useful indicator of aquatic ecosystem health, particularly in urbanized watersheds (Wang and Lyons, 2003; Harrison and Whitfield, 2004). Native fishes are more abundant in a healthy aquatic ecosystem than in one impaired by altered flow regimes, toxic urban runoff and reduced nearshore habitat, the usual consequences of urbanization. In addition, in San Francisco Estuary, the population abundances of a number of fish (and invertebrate) species are strongly correlated with specific environmental conditions associated with freshwater inflow from the Sacramento and San Joaquin Rivers (Jassby et al., 1995; Kimmerer, 2002), watersheds that have also been impaired by water development, flood control efforts, agriculture and urbanization. More than 100 native fish species[2] use the San Francisco Estuary for spawning, nursery and rearing habitat, and as a migration pathway between the Pacific Ocean and the rivers of the estuary's watersheds. Pelagic fish species are those that live and feed in the open waters of the estuary.

Data Source: The Pelagic Fish Abundance indicator was calculated using data from the California Department of Fish and Game (CDFG) Bay Study Midwater Trawl survey, conducted every year since 1980.[3] The midwater trawl is towed through the middle of the water column and selectively captures pelagic fishes that utilize open water habitats and tends to collect smaller and/or younger fish (e.g., "young-of-the-year" fish) that are too slow to evade the net. Each year, the survey samples the same 35 fixed stations in the estuary, which are relatively evenly distributed among the four sub-regions of the estuary and among channel and shoal habitats, once per month for most months of the year.[4] In one year, 1994, the Midwater Trawl survey was conducted during only two months, compared to the usual 8-12 months per year. Because the sampling period was limited, data from this year were not included in calculation of the indicator. Information on sampling stations, locations and total number of surveys conducted each year in each of the four sub-regions is shown in Figure 1 and Table 1.

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[2] Native species are those that have evolved in the Bay and/or adjacent coastal or upstream waters. Non-native species are those that have evolved in other geographically distant systems and have been subsequently transported to the Bay and established self-sustaining populations in the estuary.
[3] Information on the CDFG Bay Study is available at www.delta.dfg.ca.gov/baydelta/monitoring/baystudy.asp.
[4] The Bay Study samples more than four dozen stations but the 35 sampling stations used to calculate the indicators are the original sampling sites for which data are available for the entire 1980-2006 period.

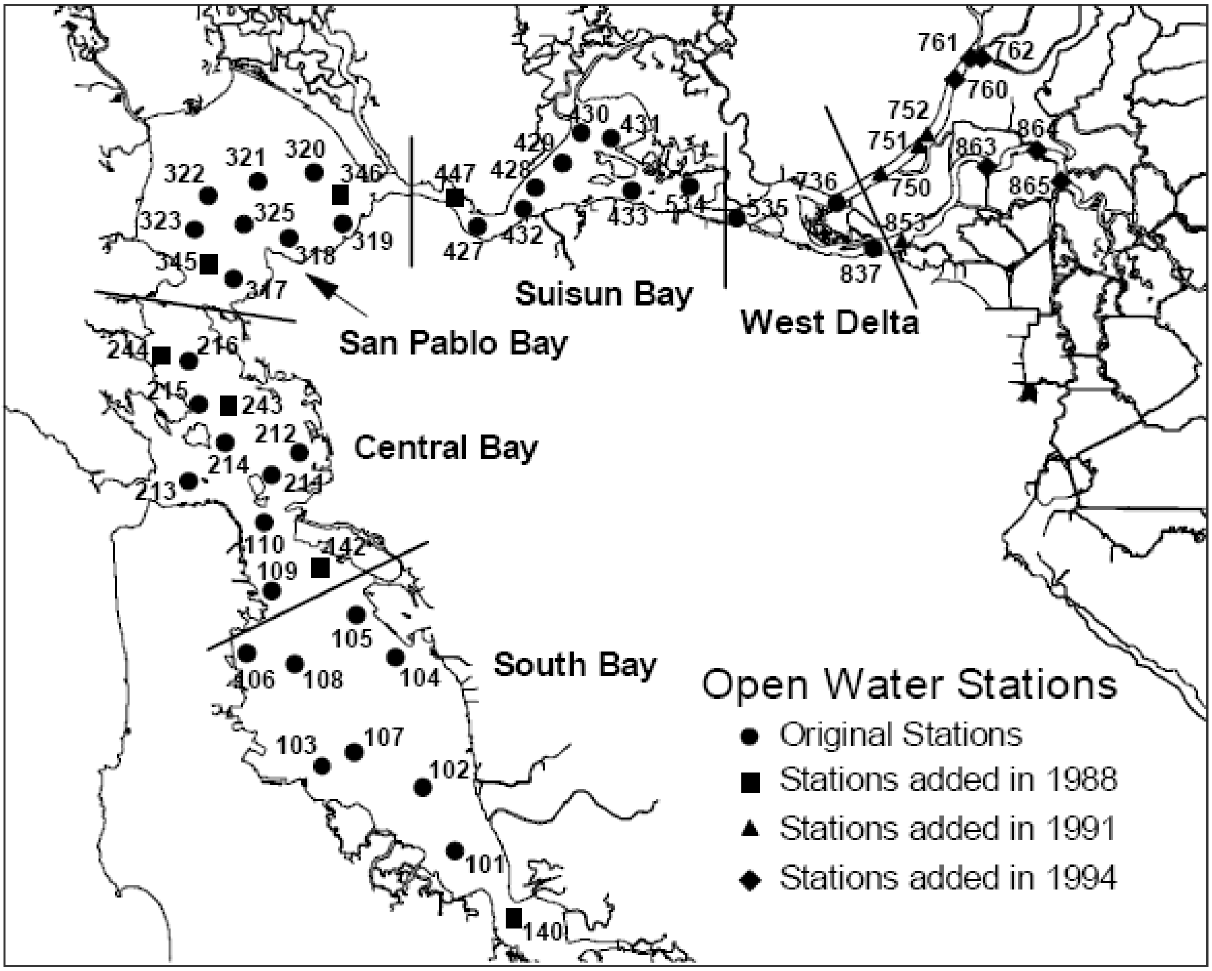

Figure 1. Locations of the sampling stations for the CDFG Bay Study Midwater Trawl and Otter Trawl surveys in different sub-regions of the San Francisco Bay. For the 2007 Fish Index, only data from the "original stations" (sampled continuously for 1980-2006 period) were used to calculated indicators for four sub-regions: South Bay, Central Bay, San Pablo Bay, and Suisun Bay (which for this study includes the West Delta sub-region).

Table 1. Sampling stations and total numbers of surveys conducted per year (range for the 1980-2006 period, excludes 1994) by the CDFG Bay Study Survey in each of four sub-regions of San Francisco Bay. MWT=Midwater Trawl survey; OT= Otter Trawl survey. See Figure 1 for station locations.

Sub-region	Sampling stations	Number of surveys (range for 1980-2005 period)
South Bay	101, 102, 103, 104, 105, 106, 107, and 108	64-96 (MWT) 64-96 (OT)
Central Bay	109, 110, 211, 212, 213, 214, 215, and 216	64-96 (MWT) 64-96 (OT)
San Pablo Bay	317, 318, 319, 320, 321, 322, 323, and 325	64-96 (MWT) 64-96 (OT)
Suisun Bay (includes West Delta sub-region shown in Figure 1)	425, 427, 428, 429, 430, 431, 432, 433, 534, 535, 736, and 837	87-132 (MWT) 88-132 (OT)

Methods and Calculations: The Pelagic Fish Abundance indicator was calculated for each year (1980-2008) for each of four sub-regions of the estuary (South, Central, San Pablo and Suisun Bays; see Table 1) using catch data for all native species except northern anchovy from the Bay Study Midwater Trawl survey. Catch data for northern anchovy were not included in this indicator because results for this single species obscured results for all other species. In most years of the Bay Study survey and in most sub-regions of the estuary, northern anchovy comprised >80% of all fish collected in the Bay. The indicator was calculated as:

$$\text{\# fish}/10{,}000\ m^3 = [(\text{\# of fish})/(\text{\# of trawls x av. trawl volume}, m^3)] \times (10{,}000)$$

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT, 2008) for "recovery", "reversing declines" of estuarine fish and wildlife are non-quantitative. However, the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions. For the Pelagic Fish Abundance indicator, the reference condition was established as the average pelagic fish abundance for the first ten years of the study, 1980-1989.

Results: Results of the Pelagic Fish Abundance indicator are show in Figure PF1.

Abundance of pelagic fishes differs among the estuary's sub-regions. Pelagic fishes are significantly more abundant in Central Bay than in all other sub-regions of the estuary (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$). Abundance of pelagic fishes in South Bay is greater than that in Suisun Bay ($p<0.05$) but comparable to that in San Pablo Bay. In 2008, pelagic fishes were three times more abundant in Central Bay (89 fish/10,000m^3) than either South (30 fish/10,000m^3) or San Pablo Bays (32 fish/10,000m^3) and nearly 30 times more abundant than in Suisun Bay (3 fish/10,000m^3).

Abundance of pelagic fishes has declined in most sub-regions of the estuary. Pelagic fish abundance declined significantly over time in all sub-regions of the estuary except Central Bay (regression: $p<0.05$ for South and San Pablo Bays, $p<0.001$ for Suisun Bay).

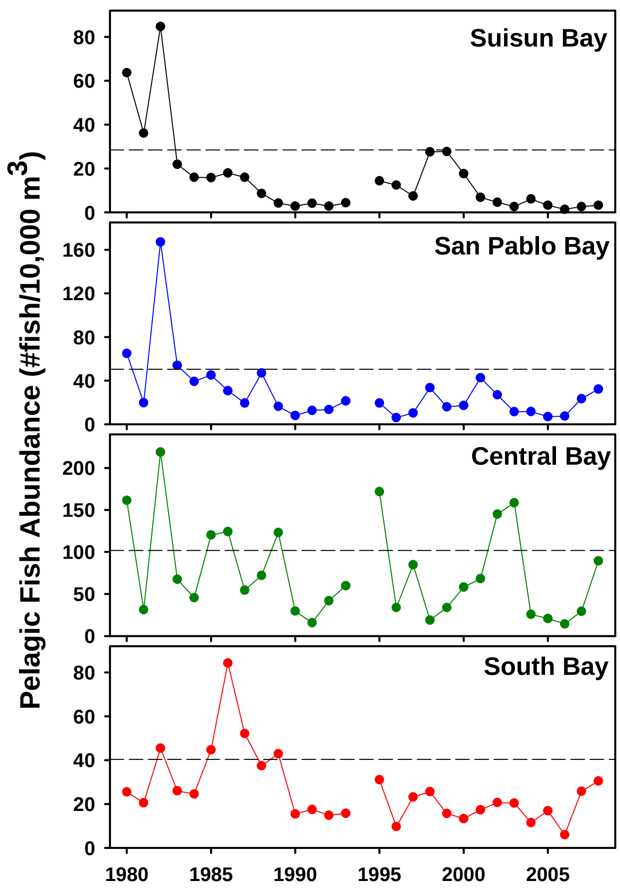

Figure PF1.Changes in the Pelagic Fish Abundance indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1980-1989 average).

Abundance of pelagic fishes in Central Bay showed no long-term trend and its high inter-annual variability reflects the periodic presence of large numbers of marine species such as Pacific sardine. However, for the most recent five years (2004-2008) compared to 1980-1989 levels, average abundance of native pelagic fishes was significantly lower in all regions: 55% lower in South Bay, 65% lower in Central Bay, 68% lower in San Pablo Bay and 88% lower in Suisun Bay.

Based on the abundance of pelagic fishes, CCMP goals to "recover" and "reverse declines" of estuarine fishes have not been met.
Both current levels (expressed as the 2004-2008 average) and trends in pelagic fish abundance are below the 1980-1989 reference period for all sub-regions of the estuary (t-test or Mann-Whitney, $p<0.05$, all regions). However, in the most recent two years there is some evidence of increases in pelagic fish abundance in all sub-regions of the San Francisco Estuary except Suisun Bay.

Biotic Condition Indicator 7. Demersal Fish Abundance

By: Christina Swanson

Background and Rationale: Demersal fish species are those live at or near the bottom. As for pelagic fish species, abundance of native fish species is a commonly used indicator of aquatic ecosystem health (for more information, see Background and Rationale section for the Pelagic Fish Abundance indicator, above).

Data Source: The Demersal Fish Abundance indicator was calculated using data from the CDFG Bay Study Otter Trawl survey, conducted every year since 1980. The otter trawl is towed near the bottom and selectively captures demersal fishes that utilize bottom and near-bottom habitats and tends to collect smaller and/or younger fish (e.g., "young-of-the-year" fish) that are too slow to evade the net. Each year, the survey samples the same 35 fixed stations in the estuary as the Midwater Trawl survey (see Data Source section for the Pelagic Fish Abundance indicator, Figure 1 and Table 1, above).

Methods and Calculations: The Demersal Fish Abundance indicator was calculated for each year (1980-2008) for each of four sub-regions of the estuary (South, Central, San Pablo and Suisun Bays; see Table 1) using catch data for all native species from the Bay Study Otter Trawl survey. The indicator was calculated as:

$$\text{\# fish/10,000 m}^2 = [(\text{\# of fish})/(\text{\# of trawls x av. trawl volume, m}^2)] \times (10{,}000)$$

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT, 2008) for "recovery", "reversing declines" of estuarine fish and wildlife are non-quantitative. However, the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions. For the Demersal Fish Abundance indicator, the reference condition was established as the average demersal fish abundance for the first ten years of the study, 1980-1989.

Results: Results of the Demersal Fish Abundance indicator are show in Figure DF1.

Abundance of demersal fish species differs among the estuary's sub-regions. Demersal fishes are more abundant in Central Bay (942 fish/10,000m^2) than in all other sub-regions of the estuary and least abundant in Suisun Bay (50 fish/10,000m^2) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$). Demersal fish abundance in South (288 fish/10,000m^2) and San Pablo Bays (277 fish/10,000m^2) are comparable. In 2008, demersal fishes were nearly ten times more abundance in Central Bay (2093 fish/10,000m^2) than either South (231 fish/10,000m^2) or San Pablo Bays (335 fish/10,000m^2) and nearly 40 times more abundant than in Suisun Bay (54 fish/10,000m^2).

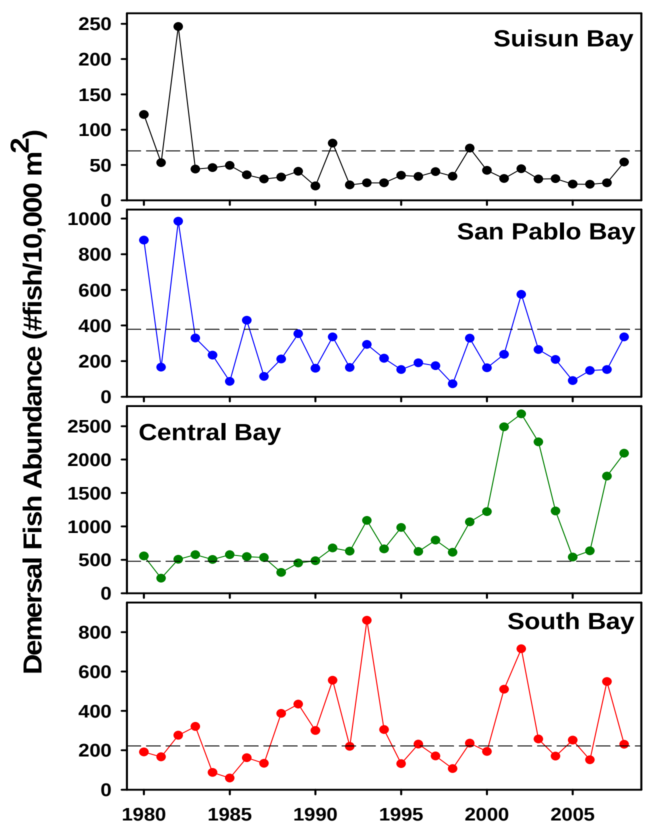

Figure DF1. Changes in the Demersal Fish Abundance indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1980-1989 average).

Abundance of demersal fishes has increased in Central Bay and declined in Suisun Bay.
During the past 29 years, abundance of native demersal fishes increased in Central Bay (regression: $p<0.05$) but declined in Suisun Bay (regression: $p<0.05$). In South and San Pablo Bays, demersal fish abundance has fluctuated widely. Compared to 1980-1989 levels, recent average abundances (2004-2008) were 56% and 51% lower in Suisun and San Pablo Bays, respectively, and 22% and 161% higher in South and Central Bays, respectively.

Increases in demersal fish abundance in Central and South Bays were driven by multiple species.
In South Bay, increases in demersal fish abundance were largely attributable to high catches of Bay goby, a Bay resident species. In contrast, demersal fish abundance increases in Central Bay in the late 1990s and early 2000s were largely driven by two species of flatfishes, seasonal species that use the estuary as nursery habitat but which maintain substantial populations outside the Golden Gate. It is likely that increases in the abundance of these species reflected improved ocean conditions.

Based on the abundance of demersal fishes, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions except Suisun Bay, the upstream reach of the estuary.

Both current levels (expressed as the 2004-2008 average) and trends in demersal fish abundance were comparable to the 1980-1989 reference period for all sub-regions of the estuary except Central Bay, where demersal fish abundance increased (t-test or Mann-Whitney, $p>0.05$, South, San Pablo and Suisun Bays; $p=0.012$ for Central Bay). However, demersal fish abundance fluctuates widely in all sub-regions of the San Francisco Estuary, suggesting that this indicator may be inadequately responsive to watershed conditions. In addition, the different trends between the upstream sub-regions (Suisun and San Pablo Bays) and downstream sub-regions (Central and South Bays) suggest that different environmental drivers are influencing demersal fish abundance in the different sub-regions of the estuary: ocean conditions in the downstream sub-regions and watershed conditions, in particular hydrological conditions, in the upstream sub-regions.

Biotic Condition Indicator 8. Northern Anchovy Abundance

By Christina Swanson

Background and Rationale: Northern anchovy is the most common native fish species collected in the Bay. It is consistently collected in all sub-regions of the estuary in numbers that are often orders of magnitude greater than for all other species. The abundance of common and broadly distributed species is a commonly used indicator of aquatic ecosystem health (for more information, see Background and Rationale section for the Pelagic Fish Abundance indicator, above). The abundance of northern anchovy was not included in calculation of the Pelagic Fish Abundance indicator (see Methods and Calculations section for Pelagic Fish Abundance indicator, above).

Data Source: The Northern Anchovy Abundance indicator was calculated using data from the CDFG Bay Study Midwater Trawl survey, conducted every year since 1980 (except 1994; see Data Source section for Pelagic Fish Abundance indicator, Figure 1 and Table 1, above).

Methods and Calculations: The Northern Anchovy Abundance indicator was calculated for each year (1980-2008, excluding 1994) for each of four sub-regions of the estuary (South, Central, San Pablo and Suisun Bays; see Table 1) using catch data for northern anchovy from the Bay Study Midwater Trawl survey. The indicator was calculated as:

$$\text{\# fish}/10{,}000\ m^3 = [(\text{\# of fish})/(\text{\# of trawls x av. trawl volume, } m^3)] \times (10{,}000)$$

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT, 2008) for "recovery", "reversing declines" of estuarine fish and wildlife are non-quantitative. However, the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions. For the Northern Anchovy Abundance indicator, the reference condition was established as the average northern anchovy abundance for the first ten years of the study, 1980-1989.

Results: Results of the Northern Anchovy Abundance indicator are show in Figure NA1.

Abundance of northern anchovy differs among the estuary's sub-regions.
Although northern anchovy are always found in all sub-regions of the estuary, their abundance differs markedly. For the past 29 years, northern anchovy have been more abundant in Central Bay (mean: 304 fish/10,000m^3) than all other sub-regions, least abundant in Suisun Bay (18 fish/10,000m^3), and present at intermediate abundance levels in San Pablo (147 fish/10,000m^3) and South Bays (304 fish/10,000m^3) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$).

Trends in abundance of Northern anchovy differ in different sub-regions of the estuary.
During the past 29 years, abundance of northern anchovy has been variable but roughly stable in South and Central Bays although, in most recent years, Central Bay abundance has averaged about 45% lower than 1980-1989 levels. Northern anchovy abundance has steadily declined in San Pablo Bay (regression: $p<0.01$), falling to 41% of 1980-1989 levels during the most recent five years (2004-2008). The decline was more abrupt in Suisun Bay (regression: $p<0.05$), with northern anchovy virtually disappearing from this upstream portion of the estuary: since 1995, northern anchovy population levels in this region of the estuary averaged less than 6% of 1980-1989 levels and less than 2% of populations in adjacent San Pablo Bay.

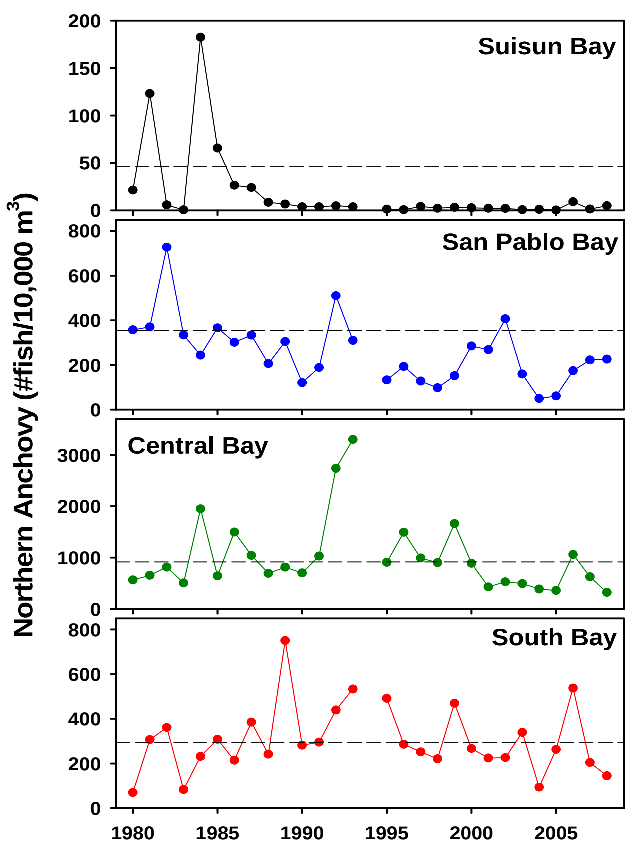

Figure NA1. Changes in the Northern Anchovy Abundance indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1980-1989 average).

Based on the abundance of northern anchovy, CCMP goals to "recover" and "reverse declines" of estuarine fishes have not been met in the upstream sub-regions of the estuary.
The abundance of northern anchovy, the most common fish in the San Francisco Estuary, has declined throughout the upstream regions of the estuary to levels that significantly below the 1980-1989 average reference conditions (t-test or Mann0Whitney, $p<0.05$ for San Pablo and Suisun Bays). In contrast, in Central and San Pablo Bays, recent northern anchovy abundance levels are comparable to levels measured in the 1980s (t-test or Mann-Whitney, $p>0.05$, both regions). As with demersal fishes, the markedly different trends between the upstream sub-regions (Suisun and San Pablo Bays) and downstream sub-regions (Central and South Bays) suggest that different environmental drivers are

influencing northern anchovy in different sub-regions of the estuary: ocean conditions in the downstream sub-regions and watershed conditions, in particular hydrological conditions and planktonic food availability, in the upstream sub-regions.

Biotic Condition Indicator 9. Sensitive Fish Species Abundance

By Christina Swanson

Background and Rationale: The San Francisco Estuary is essential habitat for diverse assemblages of marine, estuarine, and anadromous fish species. Marine species tend to use the estuary as spawning and nursery habitat while estuarine species reside in the estuary throughout their life cycle. For anadromous fishes, the estuary is an important segment of their migration route between upstream spawning areas and the ocean. Abundance of representative species that rely on the estuary in different ways is a useful indicator of the health of the Bay as a "multi-purpose" habitat. Four species were selected for the indicator: longfin smelt, Pacific herring, starry flounder and striped bass.[5] Each is relatively common and consistently present in all four sub-regions of the estuary, and all except starry flounder are targets of environmental or fishery management in the estuary. In addition, the population abundance of each of these species is influenced by a key ecological driver for the estuary, seasonal freshwater inflows (Jassby et al. 1995; Kimmerer 2002). Key characteristics of each of the four species are briefly described below.

- **Longfin smelt** are found in open waters of large estuaries on the west coast of North America.[6] The San Francisco Estuary population spawns in upper estuary (Suisun Bay and Marsh and the Delta) and rears downstream in brackish estuarine and, occasionally, coastal waters (Moyle, 2002). The species is listed as “threatened” under the California Endangered Species Act in 2008.

- **Pacific herring** is a coastal marine fish that uses large estuaries for spawning and early rearing habitat. On the basis of spawning biomass, the San Francisco Estuary is the most important spawning area for eastern Pacific populations of the species (CDFG, 2002). Pacific herring supports a commercial fishery, primarily for roe (herring eggs) but also for fresh fish, bait and pet food. In the San Francisco Estuary, the Pacific herring fishery is the last remaining commercial finfish fishery.

- **Starry flounder** is an estuary-dependent, demersal fish that can be found over sand, mud or gravel bottoms in coastal ocean areas, estuaries, sloughs and even fresh water. The species, whose eastern Pacific range extends from Santa Barbara to arctic Alaska, spawns near river mouths and sloughs; juveniles are found exclusively in estuaries. Starry flounder is one of the most consistently collected flatfishes in the San Francisco Estuary.

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[5] Although striped bass is not native to the Pacific coast, the species was introduced to San Francisco Bay more than 100 years ago and, since then, has been an important component of the Bay fish community. On the north American west coast, the main breeding population of the species is in the San Francisco estuary (Moyle, 2002).

[6] In California, longfin smelt are found in San Francisco Bay, Humbolt Bay, and the estuaries of the Russian, Eel, and Klamath Rivers.

- **Striped bass** was introduced into San Francisco Bay in 1879 and by 1888 the population had grown large enough to support a commercial fishery (Moyle, 2002). That fishery was closed in 1935 in favor of the sport fishery, which remains popular today although at reduced levels. Striped bass are anadromous, spawning in large rivers and rearing in downstream estuarine and coastal waters. Declines in the striped bass population were the driving force for changes in water management operations in Sacramento and San Joaquin Rivers and the Delta in the 1980s. Until the mid-1990s, State Water Resources Control Board-mandated standards for the estuary were aimed at protecting larval and juvenile striped bass.

Data Source: The Sensitive Fish Species Abundance indicator was calculated using data from the CDFG Bay Study Midwater and Otter Trawl surveys, conducted every year since 1980 (except 1994 for the Midwater trawl survey; see Data Source section for Pelagic Fish Abundance indicator, Figure 1 and Table 1, above).

Methods and Calculations: For the Sensitive Fish Species Abundance indicator, the abundance of each of the four species was calculated for each year (1980-2008, excluding 1994) for each of four sub-regions of the estuary (South, Central, San Pablo and Suisun Bays; see Table 1) as the sum of the abundances from each of the two Bay Study surveys using the equation below.

$$\text{\# fish}/10{,}000\ m^3 = [(\text{\# of fish})/(\text{\# of trawls} \times \text{av. trawl volume, } m^3)] \times (10{,}000)$$

The summed abundance for each species was then expressed as a percentage of the average 1980-1989 for that species. The indicator was calculated as the average of the percentages for the four species. Each species was given equal weight in this calculation.

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT, 2008) for "recovery", "reversing declines" of estuarine fish and wildlife are non-quantitative. However, the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions. For the Sensitive Species Abundance indicator, the reference condition was established as the average abundance for the first ten years of the study, 1980-1989.

Results: Results of the Sensitive Fish Species Abundance indicator are show in Figure SF1.

Abundances of longfin smelt, Pacific herring, starry flounder and striped bass differ among the different sub-regions of the estuary.

The Bay-wide abundance of the four species was roughly comparable (although starry flounder densities are generally lower than those of the pelagic species), but different species use different sub-regions within the estuary. Longfin smelt and starry flounder are most abundant in San Pablo, Suisun and Central Bays and rare in South Bay. Pacific herring are most commonly found in Central, South and San Pablo Bays and rarely collected in Suisun Bay. Striped bass are mostly collected in Suisun Bay and, to a lesser extent, San Pablo Bay and rarely found in Central and South Bays.

Abundance of sensitive fish species has declined in all sub-regions of the estuary.
During the past 29 years, combined abundance of the four sensitive fish species has declined in all sub-regions of the estuary (regression: $p<0.05$ all sub-regions). For the most recent five-year period (2004-2008), abundance of sensitive fish species abundance Central Bay is just 20% of that sub-region's 1980-1989 average, 32% in San Pablo Bay, 35% in South Bay and 51% in Suisun Bay. The higher abundances measured in Suisun Bay in 2008 reflect increases in Pacific herring and starry flounder, species that are relatively uncommon in that sub-region. In each sub-regions, most of the decline occurred during the late 1980s and early 1990s and, with the exceptions of a few single years in different sub-regions, the abundance of the four sensitive fish species has remained below 50% of the 1980-1989 since then.

Abundance declines were measured for most of the species in most sub-regions of the estuary.
All of the species except Pacific herring declined significantly in the sub-region in which they were most prevalent (regression: $p<0.05$ for all species except Pacific herring in Central Bay). Longfin smelt declined in both San Pablo and Suisun Bays (regression: $p<0.05$ both tests), starry flounder declined in Central and San Pablo Bays (regression: $p<0.05$ both tests), striped bass declined in all sub-regions (regression: $p<0.05$ in all sub-regions except South Bay, where $p=0.051$), and Pacific herring declined in South Bay (regression: $p<0.05$).

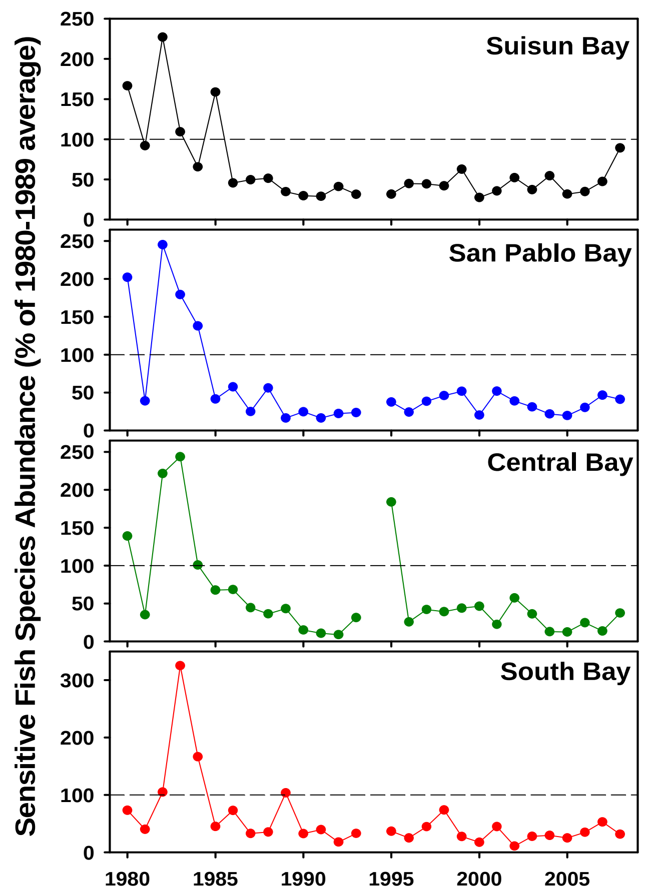


Figure SF1. Changes in the Sensitive Fish Species Abundance indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1980-1989 average).

Based on the abundance of sensitive fish species, CCMP goals to "recover" and "reverse declines" of estuarine fishes have not been met in any sub-region of the estuary.
The combined abundance of the four estuary-dependent species assessed with this indicator have fallen to levels that are consistently 50% or less than the 1980-1989 average abundance reference condition. However, sensitive species abundance exhibited high variability during the 1980s, thus recent levels (2004-2008) were significantly lower in only South and Central Bay (t-test or Mann-Whitney, $p<0.05$). Although recent abundance levels in San Pablo and Suisun Bay were markedly lower than during the 1980-1989 reference, the differences were not statistically significant due to high variability during the 1980s. The significant declines measured for three of the four individual species

indicates that population declines of estuary-dependent species span multiple species and all geographic regions of the estuary.

Biotic Condition Indicator 10. Native Fish Species Diversity

By Christina Swanson

Background and Rationale: Diversity, or the number of species present in the native biota that inhabit the ecosystem, is one of the most commonly used indicators of ecological health of aquatic ecosystems (Karr et al., 2000; Wang and Lyons, 2003; Harrison and Whitfield, 2004). Diversity tends to be highest in healthy ecosystems and to decline in those impaired by urbanization, alteration of natural flow patterns, pollution, and loss of habitat area. More than 100 native fish species have been collected in the San Francisco Estuary by the Bay Study surveys. Some are transients, short-term visitors from nearby ocean or freshwater habitats where they spend the majority of their life cycles, or anadromous migrants, such as Chinook salmon and sturgeon, transiting the Bay between freshwater spawning grounds in the Bay's tributary rivers and the ocean. Other species are dependent on the Bay as critical habitat, using it for spawning and/or rearing, spending a large portion or all of their life cycles in Bay waters.

Data Source: The Native Fish Species Diversity indicator was calculated using data from the CDFG Bay Study Midwater and Otter Trawl surveys, conducted every year since 1980 (except 1994 for the Midwater trawl survey; see Data Source section for Pelagic Fish Abundance indicator, Figure 1 and Table 1, above).

Methods and Calculations: The Native Fish Species Diversity indicator was calculated for each year and for each of four sub-regions of the estuary (South, Central, San Pablo and Suisun Bays; see Table 1) as the number of species collected, expressed as the percentage of the maximum number of species ever collected in that sub-region, using catch data for all native species from the Bay Study Midwater and Otter Trawl surveys. The indicator was calculated as:

% of species assemblage = (# native species/maximum # of native species reported) x 100

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT, 2008) for "recovery", "reversing declines" of estuarine fish and wildlife are non-quantitative. However, the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions. For the Native Fish Species Diversity indicator, the average native fish species diversity differed slightly among the four sub-regions (Suisun Bay diversity was lower than that in the other three sub-regions; see Results, below). However, given the smaller magnitude difference, the reference condition for all four sub-regions was set at 50%, roughly the average of the average native fish species diversity of each of the four sub-regions (49%) for the first ten years of the study, 1980-1989.

Results: Results of the Native Fish Species Diversity indicator are show in Figure NF1.

Maximum native species diversity differs among the four sub-regions of the estuary.

The greatest numbers of native fish species are found in Central Bay (94 species) and the fewest are in Suisun Bay (48 species). A maximum of 73 native species have been collected in South Bay and 66 native species have been found in San Pablo Bay.

The percentage of the native fish species assemblage present differs among the sub-regions. In addition to having a smaller native fish species assemblage, Suisun Bay has a significantly lower percentage (44%) of that assemblage present each year compared to all other sub-regions (48% in Central Bay; 49% in South Bay and 51% in San Pablo Bay) (ANOVA: $p<0.001$, all pairwise comparisons: $p<0.01$). In recent years (2004-2008), native fish diversity has been highest in Central Bay (ANOVA: $p<0.05$ for Central Bay compared to Suisun Bay).

Trends in native species diversity differ among the sub-regions. Native species diversity has increased significantly in Central Bay (regression: $p<0.01$) with an average of six more species in the most recent five-year period compared to the 1980-1989 reference period. Native fish species diversity decreased significantly in San Pablo Bay (regression: $p=0.05$), with an average of four fewer species in the 2005-2008 period compared to the 1980-1989 period. Native fish species diversity fluctuated in both South and Suisun Bays.

Based on the diversity of the native fish community, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions of the estuary. Comparison of average native fish species diversity in the most recent five years (2004-2008) to that measured during the 1980-1989 period shows no significant differences except for Central Bay, where diversity is significantly higher (t-test: $p<0.05$).

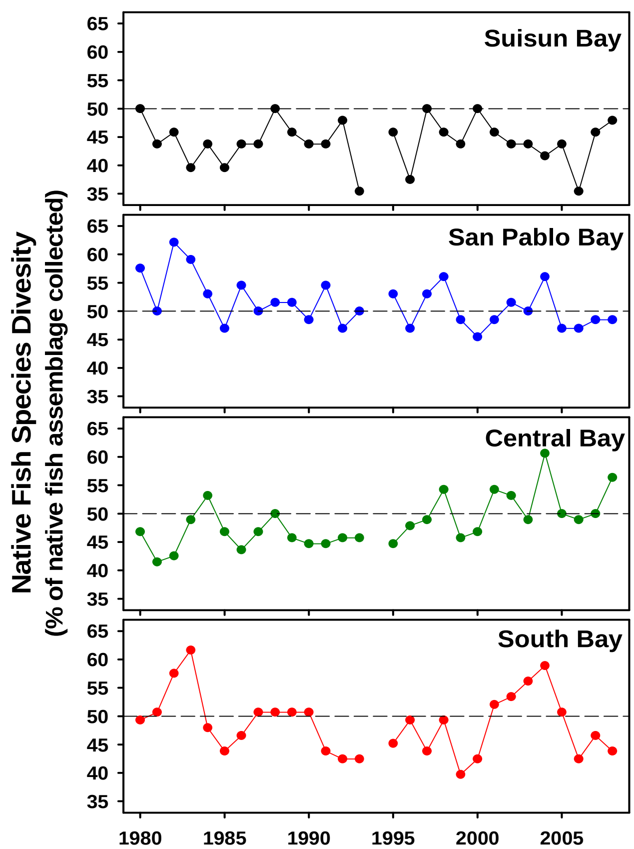


Figure NF1. Changes in the Native Fish Species Diversity indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition.

Biotic Condition Indicator 11. Estuary-dependent Fish Species Diversity

By Christina Swanson

Background and Rationale: Of the more than 100 fish species collected by the Bay Study since 1980, 39 species can be considered "estuary-dependent" species (Table 2 below). These species may be resident species that spend their entire life-cycle in the estuary, marine or freshwater species that depend on the San Francisco Estuary for some key part of their life cycle (usually spawning or early rearing), or local species that spend a large portion of their life cycle in the San Francisco Estuary. Just as diversity, or species richness, of the native fish assemblage is a useful indicator of the ecological health of aquatic ecosystems (Karr et al., 2000; Wang and Lyons, 2003; Harrison and Whitfield, 2004), diversity of the estuary-dependent fish assemblage is a useful indicator for the ecological health of the San Francisco Estuary.

Data Source: The Estuary-dependent Fish Species Diversity indicator was calculated using catch data for the 39 estuary-dependent species listed in Table 2 from the CDFG Bay Study Midwater and Otter Trawl surveys, conducted every year since 1980 (except 1994 for the Midwater trawl survey; see Data Source section for Pelagic Fish Abundance indicator, Figure 1 and Table 1, above).

Methods and Calculations: The Estuary-dependent Fish Species Diversity indicator was calculated for each year and for each of four sub-regions of the estuary (South, Central, San Pablo and Suisun Bays; see Table 1) as the number of estuary-dependent species collected, expressed as the percentage of the maximum number of estuary-dependent species ever collected in that sub-region, using catch data from the Bay Study Midwater and Otter Trawl surveys. The indicator was calculated as:

% of species assemblage
= (# estuary-dependent species/maximum # of estuary-dependent species reported) x 100

Table 2. San Francisco Estuary-dependent fish species collected in the CDFG Bay Study Midwater Trawl and Otter Trawl surveys.

Estuary-dependent fish species (common names)	
Estuary resident species Species with resident populations in the estuary and/or estuary-obligate species that use the estuary as nursery habitat	**Seasonal species** Species regularly use the estuary for part of their life cycle but also have substantial connected populations outside the estuary
Arrow goby	Barred surfperch
Bat ray	Black perch
Bay goby	Bonehead sculpin
Bay pipefish	California halibut
Brown rockfish	California tonguefish
Brown smoothhound	Diamond turbot
Cheekspot goby	English sole
Delta smelt	Northern anchovy
Dwarf surfperch	Pacific sandab
Jack smelt	Pacific tomcod

Leopard shark	Plainfin midshipman
Longfin smelt	Sand sole
Pacific herring	Speckled sanddab
Pacific staghorn sculpin	Spiny dogfish
Pile perch	Splittail
Shiner perch	Starry flounder
Threespine stickleback	Surfsmelt
Topsmelt,	Walleye surfperch
Tule perch	
White croaker	
White surfperch	

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT, 2008) for “recovery”, “reversing declines” of estuarine fish and wildlife are non-quantitative. However, the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions. For the Estuary-dependent Fish Species Diversity indicator, average estuary-dependent fish species diversity differs significantly among the four sub-regions: therefore a reference condition was set for each sub-region as the 1980-1989 average (84% for south Bay; 85% for Central Bay; 71% for San Pablo Bay; and 49% for Suisun Bay.

Results: Results of the Estuary-dependent Fish Species Diversity indicator are show in Figure FSD1.

The diversity of estuary-dependent species is lower in Suisun Bay than in other sub-regions of the estuary.

Although roughly the same number of estuary-dependent species are found in each sub-region (38 species in San Pablo Bay; 36 species in Central and South Bays; and 31 species in Suisun Bay), a significantly smaller percentage of the estuary-dependent fish assemblage occurs in Suisun Bay (49% of the assemblage) than in all other regions of the San Francisco Estuary (84% in Central Bay; 80% in South Bay; and 69% in San Pablo Bay) (ANOVA: $p<0.001$, all pairwise comparisons, $p<0.05$).

Diversity of Bay-dependent species is generally stable in most sub-regions of the estuary.

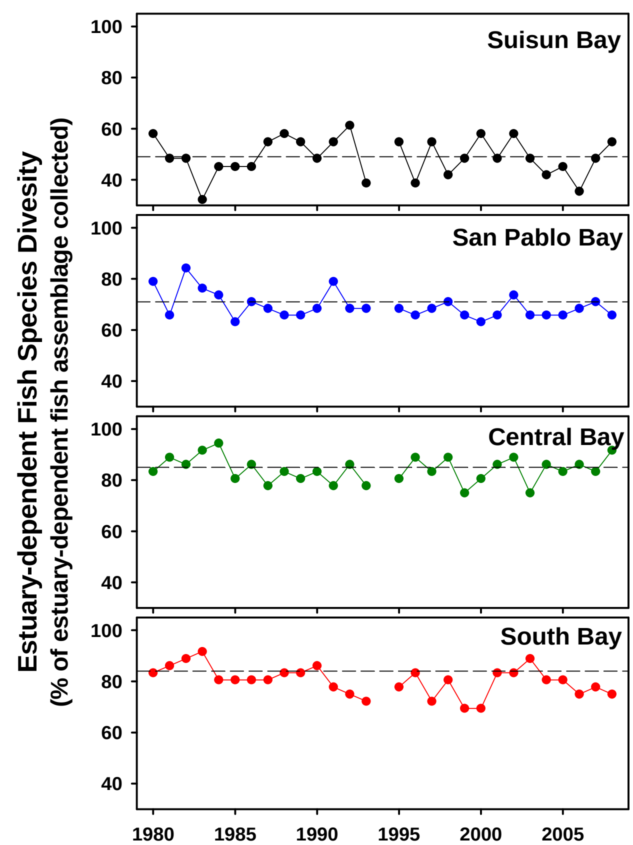


Figure FSD1. Changes in the Estuary-dependent Fish Species Diversity indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1989-1989 average).

Estuary-dependent species diversity has declined slightly in San Pablo Bay (regression: $p<0.05$, for a decrease of 2 species from the 1980-1989 period to the 2004-2008 period) and South Bay (regression: $p<0.05$, for an average decrease of 1.5 species). In all other regions, estuary-dependent diversity has fluctuated but remained relatively stable over the 29-year period.

Based on the diversity of the estuary-dependent fish community, CCMP goals to "recover" and "reverse declines" of estuarine fishes have been met in all sub-regions of the estuary except South Bay.
Comparison of average estuary-dependent fish species diversity in the most recent five years (2004-2008) to that measured during the 1980-1989 period shows no significant differences, except for South Bay, where diversity of estuary-dependent fishes was significantly lower (Mann-Whitney Rank Sum test: $p<0.05$).

Biotic Condition Indicator 12. Fish Species Composition

By Christina Swanson

Background and Rationale: The relative proportions of native and non-native species found in an ecosystem is an important indicator of ecosystem health (May and Brown, 2002; Meador et al., 2003). Non-native species are most prevalent in ecosystems that have been modified or degraded with resultant changes in environmental conditions (e.g., elevated temperature, reduced flood frequency), pollution, or reduction in area or access to key habitats (e.g., tidal marsh, seasonal floodplain). The San Francisco Estuary has been invaded by a number of non-native fish species. Some species, such as striped bass, were intentionally introduced into the estuary; others have arrived in ballast water or from upstream habitats, usually reservoirs.

Data Source: The Fish Species Composition indicator was calculated using data from the CDFG Bay Study Midwater and Otter Trawl surveys, conducted every year since 1980 (except 1994 for the Midwater trawl survey; see Data Source section for Pelagic Fish Abundance indicator, Figure 1 and Table 1, above).

Methods and Calculations: The Fish Species Composition indicator was calculated for each year and for each of four sub-regions of the estuary (South, Central, San Pablo and Suisun Bays; see Table 1) as the percentage of fish species collected in the estuary that are native to the estuary and its adjacent ocean and upstream habitats using the equation below.

$$\% \text{ native species} = [\# \text{ native species}/(\# \text{ native species} + \# \text{ non-native species})] \times 100$$

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT, 2008) for "recovery", "reversing declines" of estuarine fish and wildlife are non-quantitative. However, the length of the available data record allows for use of historical data to establish and provide targets and/or reference conditions. Non-native fish species have been present in the San Francisco Estuary Bay for more than 100 years; therefore, 100% native fish species is unrealistic. However, there is an extensive literature on the relationship between the presence and abundance of non-native species and ecosystem conditions (see Background and Rationale, above); in general, ecosystems with high proportions of non-natives (e.g., >50%) are considered to be seriously degraded. For the Species Composition indicator, the reference conditions as set at average estuary-dependent fish species diversity differs significantly among the four sub-regions: therefore a reference condition was set at 90% (which is also the 1980-1989 average for the South, Central and San Pablo Bay sub-regions).

Results: Results of the Fish Species Composition indicator are show in Figure FSC1.

The percentage of native species in the fish community differs among the four sub-regions of the estuary.

For the past 29 years, non-native species have been most prevalent in Suisun Bay, where in most years less than 75% of species are natives, intermediate in South and San Pablo Bays (88% and 86% native, respectively), and the least prevalent in Central Bay (92%) (Kruskal Wallis One-way ANOVA of Ranks: $p<0.001$, all pairwise comparisons: $p<0.05$).

Trends in the percentage of native species differ among the sub-regions.

The percentage of native species is declining in all sub-region of the estuary except Central Bay. In San Pablo Bay, the percent native species declined significantly (regression: $p<0.001$) from 90% in the 1980-1989 period to 81% in the most recent five-year period. Percent native species declined in Suisun Bay from 77% to 69% (regression: $p<0.01$) and in South Bay the percentage of native species declined from 89% to 85% (regression: $p<0.05$).

Trends in the percentage of native species in Bay fish assemblages are driven by declines in the numbers of native species and increases in non-native species.

During the past 29 years, the number of native species in San Pablo Bay declined by three species and the number of non-native species increased by three, to an average of seven non-native species of the 2004-2008 period. The number of non-native species collected in Suisun Bay increased by an average of three species, from six species in the 1980-1989 period to nine species in the most recent five years. In South Bay, native species declined by one and non-natives increased by one. In Central, the total number of native species collected increased by six species.

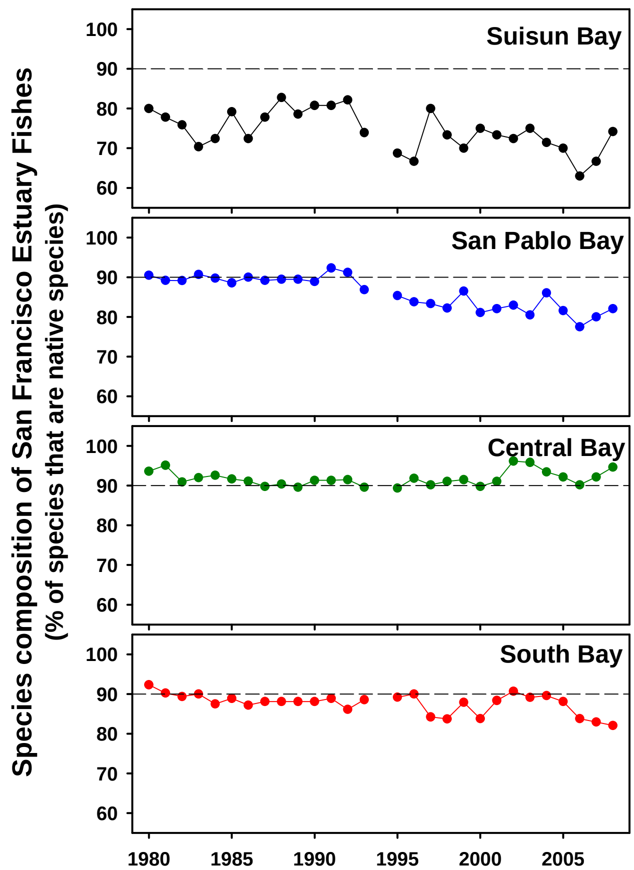


Figure FSC1. Changes in the Fish Species Composition indicator in each of four sub-regions of the San Francisco Estuary from 1980-2008. Horizontal dashed line shows the reference condition (1989-1989 average for South, Central and San Pablo Bays).

Based on fish species composition, CCMP goals to "recover" and "reverse declines" of estuarine fishes have not been met in all sub-regions of the estuary except Central Bay and South Bay.
Compared to the 1980-1989 period and the biologically based 90% native species reference condition, recent measurements (2004-2008) of the fish species composition indicate significantly poorer condition for San Pablo Bay (Mann-Whitney Rank Sum test: $p<0.01$) and Suisun Bay (t-test: $p<0.01$). Although both a long-term (1980-2008) and recent (2004-2008) decline were evident in South Bay, the average percentage of native species for the most recent five year period was not significantly different than that for the 1980-1989 reference period.

Summary of Results for Fish Indicators of Biotic Condition

Collectively, the seven indicators of biotic condition developed using fish survey data provide comprehensive assessment of status and trends San Francisco Estuary fish community. Calculation of indicator results for different sub-region of the San Francisco Estuary, which was possible because the long-running Bay Study survey covered a broad geographic range and utilized multiple sampling stations distributed relatively evenly and comprehensively throughout the large and complex estuary, showed substantial geographic variation in both the composition and condition of the fish community within the estuary and in the response of the indicators over time. Table 3 below summarizes the indicator results by sub-region. In addition, the following general conclusions can be made:

1. The San Francisco Estuary fish community differs geographically within the estuary in fish community composition, fish abundance, and trends in various aspects of biotic condition over time.
2. Different indicators show different responses over time, some demonstrating clear declines in condition over time, others no change and few increases. In some cases, the same indicators measured in different sub-regions of the estuary show different responses over time. These results suggest that different physical, chemical or biological environmental variables (or combinations of these variables) influence the fish community response in different sub-regions.
3. Overall biotic condition, as measured individually the fish indicators and collective by the fish community response, is poorest in upstream reaches of estuary, Suisun and San Pablo Bays, the best in Central Bay, the region most strongly influenced by ocean conditions and with a predominantly marine fish fauna, and intermediate in South Bay.
4. The abundance of pelagic fishes in the estuary (and in the upper estuary, in particular) has shown the greatest changes over time, indicating this component of the fish community has low resilience and/or is tightly linked to just one or a few environmental drivers that have also experienced substantial change in conditions during the sampling period.
5. Based on indicator response over the 29-year period and relative to the other indicators, demersal fish abundance and the diversity indicators appear to have low sensitivity.

Table 3. Summary of results, relative to the CCMP goals to “recover” and “reverse declines” of estuarine fishes, of the seven fish indicators for each of the four sub-regions of the San Francisco Estuary.

Indicator	Sub-region	CCMP Goal Met (yes or no)	Trend long-term (29 yrs)	Trend short-term (last 5 yrs)
Pelagic Fish Abundance	Suisun	No	Decline	Stable
	San Pablo	No	Decline	Stable
	Central	No	Stable	Stable
	South	No	Decline	Stable
Demersal Fish Abundance	Suisun	Yes	Decline	Stable
	San Pablo	Yes	Stable	Stable
	Central	Yes	Increase	Stable
	South	Yes	Stable	Stable
Northern Anchovy Abundance	Suisun	No	Decline	Stable
	San Pablo	No	Decline	Increase
	Central	Yes	Stable	Stable
	South	Yes	Stable	Stable
Sensitive Fish Species Abundance	Suisun	Yes	Decline	Stable
	San Pablo	Yes	Decline	Stable
	Central	No	Decline	Stable
	South	No	Decline	Stable
Native Fish Species Diversity	Suisun	Yes	Stable	Stable
	San Pablo	Yes	Decline	Stable
	Central	Yes	Increase	Stable
	South	Yes	Stable	Stable
Estuary-dependent Fish Species Diversity	Suisun	Yes	Stable	Stable
	San Pablo	Yes	Decline	Stable
	Central	Yes	Stable	Stable
	South	No	Decline	Stable
Fish Species Composition	Suisun	No	Decline	Stable
	San Pablo	No	Decline	Stable
	Central	Yes	Stable	Stable
	South	Yes	Decline	Decline

WAF Category: Chemical Physical

Chemical-Physical Indicator 1: Water Quality

By Jay Davis

General Considerations

Clean water is essential to the health of the San Francisco Bay ecosystem and to many of the beneficial uses of the Bay that Bay Area residents enjoy and depend on. Billions of dollars have been invested in management of the wastewater and other pollutant sources that impact Bay water quality, and as a result the Bay is in much better condition than it was in 1970s. However, thousands of chemicals are carried into the Bay by society's waste streams, and significant and challenging water quality problems still remain.

The Bay Area is fortunate to have one of the best water quality monitoring programs in the world (the Regional Monitoring Program for Water Quality in the San Francisco Estuary) in place to track conditions in the Bay and to provide the information that water quality managers need to address the remaining problems. This report on Bay water quality is based largely on information generated by the Regional Monitoring Program. Other valuable sources of information are also available and were also considered.

The availability of appropriate water quality guidelines is fundamentally important to assessing the condition of the Bay, and is a limiting factor for many pollutants. Pollutants can be placed into three categories with regard to the availability of water quality guidelines. The first group includes pollutants that pose the greatest threats to water quality and have been the subject of intense scrutiny by managers. Section 303(d) of the federal Clean Water Act requires that states develop a list of water bodies that do not meet water quality standards, establish priority rankings for waters on the list, and develop action plans, called Total Maximum Daily Loads (TMDLs), to improve water quality (http://www.swrcb.ca.gov/rwqcb2/water_issues/programs/TMDLs/303dlist.shtml). The provisions of Section 303(d) result in highly vetted and site-specific guidelines for pollutants on the 303(d) List. Due to the importance of these pollutants in Bay water quality and the general availability of highly appropriate thresholds, this report card focuses primarily on these 303(d) List pollutants.

A second group consists of pollutants where guidelines exist but the degree of concern is low. Many pollutants with water quality objectives set forth in either the Basin Plan (xxlink) or the California Toxics Rule (xxlink) have concentrations that are far below the objectives and do not threaten to approach those thresholds in the foreseeable future. Some of these pollutants used to be problems in the past, but now do not pose a threat because of effective management. While it is important to recognize this category of pollutants and to continue monitoring them to make sure they stay below thresholds, this report card focuses on the pollutants that are the current focus of managers and where progress is most needed.

A third, and very large, group consists of pollutants where water quality objectives are not available. Some of these pollutants are suspected to potentially be causing impairment in the Bay, but regulators have not yet established objectives either due to a lack of scientific information or resources to address the long list of pollutants of potential concern. The focus of the Bay report card on quantitative measures of progress toward established goals precludes the inclusion of these pollutants. Some of the pollutants in this category that represent rising concerns will be discussed in a narrative form.

Evaluation Scheme

The water quality indicators presented in this section will be evaluated in a subsequent phase of report card development using a scheme that takes into account both the position of the data distribution relative to the relevant guideline and the estimated length of time expected for the distribution to reach the desired condition. For each pollutant, the distribution of the data for each sampling year is compared to the target. One measure of impact is the proportion of the distribution that does not meet the clean water goal. The distributions are described in percentiles, as this does not require any assumptions about the shape of the distribution or about censored data. A second measure for pollutants that do not meet the goal is the estimated length of time that is thought to be required for the goal to be met – estimated recovery time. Quantitative recovery time estimates are available for some pollutants. For others, the estimates are based on conceptual models.

The statistics and graphs presented in this report are preliminary. The final Bay water quality report card will be based on all available data (including data for 2009 that were not yet available for inclusion in this report) and possibly including additional indicators. The guidelines included in this report will also undergo further review and may be different from those that are used in the final report card.

1. Mercury in Sport Fish

Background and Rationale: Mercury is one of four pollutants (the others are PCBs, dioxins, and exotic species) that are classified as having the most severe impacts on Bay water quality because the entire Bay is considered impaired by these pollutants, and the degree of impairment is well above established thresholds of concern.

Mercury is perhaps the Bay's most serious water quality concern. Mercury is a primary driver of the fish consumption advisory for the Bay (OEHHA 1994, Hunt et al. 2008), and also is suspected to be adversely affecting wildlife populations, including the endangered California Clapper Rail (Schwarzbach et al. 2006, Eagles-Smith et al. 2009). Due to these concerns, the first TMDL for the Bay has been developed for mercury (SFBRWQCB 2006).

Methylmercury typically represents only about 1% of total mercury, but is the specific form that accumulates in aquatic life and poses health risks to humans and wildlife. Methylmercury is a neurotoxicant, and is particularly hazardous for fetuses and children and early life-stages of wildlife species as their nervous systems develop. The sources of methylmercury in the Bay, particularly the methylmercury that actually gets taken up into the food web, are not well understood. Methylmercury concentrations in the Estuary (as indicated by accumulation in striped bass) have been relatively constant since the early 1970s (Hunt et al. 2008), but could quite plausibly increase, remain constant, or decrease in the next 20 years. Wetlands are often sites of methylmercury production, and restoration of wetlands in the Bay on a grand scale is now beginning, raising concern that methylmercury concentrations could increase across major portions of the Bay. However, methylmercury cycling is not yet well understood, and recent findings suggest that some wetlands actually trap methylmercury and remove it from circulation. Consequently, with improved understanding of methylmercury dynamics in the Bay, approaches might be found that would prevent increases in methylmercury concentrations, or possibly even reduce concentrations and associated health risks in the next 20 years.

Concentrations of mercury in sport fish tissue represent a key regulatory target for this pollutant. The mercury TMDL for the Bay, approved by USEPA in 2008, established a water quality objective for mercury in the Bay for protection of human health and the fishing beneficial use. The objective is an average of 0.2 ppm in the edible portion of the five most commonly consumed fish species in the Bay (striped bass, California halibut, jacksmelt, white sturgeon, and white croaker). This fish tissue objective replaced the previous objective based on concentrations of total mercury in water. Pooled data for these five species therefore provide the basis for a mercury indicator for the Bay.

Data Source: The mercury in sport fish indicator was calculated using data from the Regional Monitoring Program for Water Quality in the San Francisco Estuary (RMP) (www.sfei.org/rmp). The data are available from the RMP website (www.sfei.org/rmp/data). The RMP measures contaminant concentrations in Bay sport fish every three years. Monitoring began with a pilot study in 1994 (Fairey et al. 1997), and has continued to the present (Davis et al. 2002, Greenfield et al. 2005, Davis et al. 2006, Hunt et al. 2008). Data from the latest survey in 2009 were not entirely available for inclusion in this draft report.

The RMP collects sport fish from five popular fishing locations in the Bay (Figure 1). The monitoring is specifically directed at assessing trends in potential human exposure to contaminants in fish tissue. Sampling in Suisun Bay was attempted in the early years of the program, but was discontinued due to the low catch per unit sampling effort in that region, and the correspondingly low fishing pressure. The species targeted and the pollutant analyte list have varied slightly over the years. The five most commonly consumed species that are designated by the mercury water quality objective for the Bay (striped bass, California halibut, jacksmelt, white sturgeon, and white croaker) have been inconsistently sampled (Table 1). The sport fish mercury index (Figure 2) was calculated using whatever data were available for each sampling year. The RMP sampling targets specific size ranges of each species (Table 2) to control for variation of concentrations of mercury and other pollutants with fish size.

Methods and Calculations: The mercury in sport fish indicator was calculated for each year of RMP monitoring. Data for the five species listed in the water quality objective were pooled. The time series plot shows the distribution of the pooled raw data for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}). This approach was used for consistency even though the objective is based on the average of the pooled data. Data are presented for the Bay as a whole and for the three segments of the Bay which have consistently been sampled over the years: San Pablo Bay, Central Bay, and South Bay.

Goals, Targets and Reference Conditions: As a result of the Mercury TMDL, the Basin Plan now includes a mercury water quality objective of 0.2 ppm wet weight in fish tissue for the average of the five most commonly consumed sport fish species. This objective represents the maximum level that is considered to be safe for people consuming Bay fish at a rate less than the 95th percentile rate (32 g/day, or 8 ounces per week) for all Bay fish consumers (SFBRWQCB 2006). In other words, this objective provides for safe consumption by 95% of the Bay's fishing population, including the subpopulations that are most sensitive to the toxic effects of methylmercury (children and women of child-bearing age). Information on Bay Area consumption rates and popular fish species were obtained from an extensive consumption survey conducted in 1998 and 1999 (SFEI 2000).

Results: In the most recent sampling year, all samples of the five designated sport fish mercury indicator species had mercury concentrations higher than the target of 200 ppb. No clear pattern of long-term decline has been evident in the time series. Comparison of recent striped bass data to data from 1970 also indicates no decline (Greenfield et al. 2005). Preliminary modeling included in the Mercury TMDL suggested that recovery would take more than 100 years. Our current conceptual understanding of mercury sources and cycling in the Bay also indicates that reducing concentrations of mercury in the Bay food web poses a considerable challenge that is likely to take many decades.

2. PCBs in Sport Fish

Background and Rationale: Polychlorinated biphenyls (PCBs) are also in the class of pollutants considered to have the most severe impacts on Bay water quality because the entire Bay is considered impaired, and the degree of impairment is well above established thresholds of concern.

The term "polychlorinated biphenyl" refers to a group of hundreds of individual chemicals ("congeners"). Due to their resistance to electrical, thermal, and chemical processes, PCBs were used in a wide variety of applications (e.g., in electrical transformers and capacitors, vacuum pumps, hydraulic fluids, lubricants, inks, and as a plasticizer) from the time of their initial commercial production in 1929 (Brinkmann and de Kok, 1980). In the U.S. PCBs were sold as mixtures of congeners known as "Aroclors" with varying degrees of chlorine content. By the 1970s a growing appreciation of the toxicity of PCBs led to restrictions on their production and use. In 1979, a final PCB ban was implemented by USEPA, prohibiting the manufacture, processing, commercial distribution, and use of PCBs except in totally enclosed applications (Rice and O'Keefe, 1995). A significant amount of the world inventory of PCBs is still in place in industrial equipment (Rice and O'Keefe, 1995). Leakage from or improper handling of such equipment has led to PCB contamination of runoff from industrial areas. Other sources of PCBs to the Estuary are atmospheric deposition, effluents, and remobilization from sediment (Davis et al. 2007).

Like mercury, PCBs are highly persistent, bound to sediment particles, and widely distributed throughout the Bay and its watershed. PCBs reach high concentrations in humans and wildlife at the top of the food chain where they can cause developmental abnormalities and growth suppression, endocrine disruption, impairment of immune system function, and cancer. PCBs are another significant driver of the fish consumption advisory for the Bay (OEHHA 1994, Hunt et al. 2008). PCB concentrations in sport fish are substantially higher than thresholds of concern for human health. There is also concern for the effects of PCBs on wildlife, including species like harbor seals (Thompson et al. 2007) and piscivorous birds (Adelsbach and Maurer 2007) at the top of the Bay food web and sensitive organisms such as young fish. General recovery of the Bay from PCB contamination is likely to take many decades because the rate of decline is slow and concentrations are so far above the threshold for concern. One bright spot is Suisun Bay, where present concentrations are not as high and may be below the threshold in 20 years. Due to concerns about PCB impacts, a PCBs TMDL for the Bay has been developed and incorporated into the Basin Plan (SFBRWQCB 2008a,b). Mercury concentrations in Bay sport fish, while clearly a significant water quality concern, are not that elevated relative to concentrations observed across the country.

Concentrations of PCBs in sport fish tissue are the key regulatory target for this pollutant. The PCBs TMDL for the Bay (SFBRWQCB 2008a,b), approved by USEPA in 2010, established a fish tissue target for PCBs in the Bay for protection of both human health (and the fishing beneficial use) and wildlife (the preservation of rare and endangered species, estuarine habitat and wildlife habitat beneficial uses). The target is an average of 10 ppb in the edible portion of two commonly consumed fish species in the Bay that accumulate relatively high concentrations of PCBs: white croaker and shiner surfperch. Pooled data for these two species therefore provide the basis for the PCB index for the Bay.

Data Source: The PCBs index was calculated using data from the same RMP sport fish monitoring program described for the mercury in sport fish index. The data are available from the RMP website (www.sfei.org/rmp/data). Additional details on this sampling were provided in the mercury section. The two key indicator species for PCBs have been sampled consistently over the years (xxTable 1). The sport fish PCBs index (Figure 2) was calculated using whatever data were available for each sampling year.

Methods and Calculations: The PCBs in sport fish index was calculated for each year of RMP monitoring. Data for the two species listed in the water quality objective were pooled. The time series plot shows the distribution of the pooled raw data for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}). This approach was used for consistency even though the objective is based on the average of the pooled data for the two species. PCB concentrations expressed as the sum of all reported congeners were used in the evaluation. Values for congeners reported as below the limit of detection were set to zero.

Goals, Targets and Reference Conditions: The numeric target to protect both human health and wildlife is an average concentration of 10 ppb total PCBs wet weight in the tissue of typically consumed fish. Attainment of the total PCBs fish tissue numeric target is expected to protect both human health and wildlife for dioxin-like PCBs. The Basin Plan Amendment states that attainment of the fish tissue target for PCBs in San Francisco Bay will be initially evaluated by comparing the average total PCBs concentrations in white croaker (size class, 20 to 30 cm in length) and shiner surfperch (size class, 10 to 15 cm in length) to the target. Comparison of the fish target against these two species of fish is considered to be protective and provides a margin of safety for the TMDL, because PCBs concentrations in these species are the highest of the fish species measured and sport recreational fishers likely consume a variety of fish species, including those species with lower PCBs concentrations.

Like the mercury objective, the PCB target represents the maximum level that is considered to be safe for people consuming Bay fish at a rate less than the 95th percentile rate (32 g/day, or 8 ounces per week) for all Bay fish consumers (SFBRWQCB 2008b). In other words, this objective provides for safe consumption by 95% of the Bay's fishing population. Information on Bay Area consumption rates and popular fish species were obtained from an extensive consumption survey conducted in 1998 and 1999 (SFEI 2000).

Results: All samples of the two designated sport fish PCB indicator species measured since 1994 have been higher than the PCB target of 10 ppb. No clear pattern of long-term decline has been evident in the time series. Concentrations in white croaker in 2009 were the lowest observed since monitoring began in 1994. This does not, however, signal a decline in PCB contamination in the Bay. The primary reason for this low concentration is the low average fat content of the croaker collected in 2009, which was the lowest for the period of record (2.8% compared to a long-term average of 4.6%). PCBs and other organic contaminants accumulate in fat, so concentrations rise and fall with changing fat content. Concentrations in shiner surfperch in 2009 were also lower than in most other years. The model used in the PCB TMDL to forecast recovery (Davis et al. 2007) indicates that declines sufficient to bring fish concentrations down to the target are likely to take many decades.

3. Dioxins in Sport Fish

Background and Rationale: Dioxins (including chlorinated dibenzodioxins and dibenzofurans) are a third member of the class of pollutants considered to have the most severe impacts on Bay water quality because the entire Bay is above thresholds for concern, and the degree of impairment is well above those thresholds (Connor et al. 2004a).

Dioxins have many similarities to PCBs. They are highly persistent, strongly associated with sediment particles, and widely distributed throughout the Bay and its watershed. Dioxins also reach high concentrations in humans and wildlife at the top of the food chain. The human and wildlife health risks of dioxins are similar to those for PCBs. Dioxins have not received as much attention from water quality managers because there are no large individual sources in the Bay Area and concentrations in the Bay are among the lowest measured across the U.S. Nevertheless, concentrations in sport fish are well above the threshold for concern and the entire Bay is included on the 303(d) List. Dioxins are similar to PCBs in their persistence and distribution throughout the Bay and its watershed, and are unlikely to decline significantly in the next 20 years.

Concentrations of dioxins in sport fish tissue are the key regulatory indicator for this pollutant. Connor et al. (2004a) discussed screening values and impairment relative to those values. The San Francisco Bay Regional Water Quality Control Board (Water Board) has not established a target for dioxins. A TMDL for dioxins is currently in the early development stage. In the absence of a Water Board target, a screening value for use in this report was calculated using the same parameters for consumption rate and risk that were employed in the PCBs TMDL. White croaker is the species that has been monitored for dioxins in Bay fish – the dioxins index is therefore based on data for this species.

Data Source: The dioxins index was calculated using data from the same RMP sport fish monitoring program described for the mercury in sport fish index. The data are available from the RMP website (www.sfei.org/rmp/data). Additional details on this sampling were provided in the mercury section. White croaker, the key indicator species for dioxins, has been sampled consistently over the years (Table 1).

Methods and Calculations: The dioxins in sport fish index was calculated for each year of RMP monitoring. The time series plot shows the distribution of the data for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}). Dioxins concentrations expressed as the sum of the dioxin toxic equivalents (TEQs) were calculated for comparison to the screening value, following USEPA guidance (USEPA 2000). TEQs express the potency of a mixture of dioxin-like compounds relative to the potency of 2,3,7,8-TCDD, the most toxic dioxin congener. The sum of TEQs for all of the congeners is the overall measure of the dioxin-like potency of a sample. Values for congeners reported as below the limit of detection were set to zero.

Goals, Targets and Reference Conditions: The calculated screening value to protect human health is a concentration of 0.14 pg/g wet weight in the tissue of white croaker. The same size class specified in the PCBs TMDL for white croaker (20 to 30 cm in length) was used. Comparison of white croaker data to the screening value is a conservative approach because this species is likely to have the highest concentration among the species that are popular for consumption, and anglers likely consume a variety of fish species, including species with lower concentrations.

As for the mercury and PCB targets, this screening value represents the maximum level that is considered to be safe for people consuming Bay fish at a rate less than the 95^{th} percentile rate (32 g/day, or 8 ounces per week) for all Bay fish consumers (Connor et al. 2004a).

Results: Nearly all of the white croaker samples analyzed since 2000 have been higher than the dioxin TEQ target of 0.14 parts per trillion. Median dioxin TEQ concentrations in white croaker have been over ten times higher than the target. No pattern of long-term decline has been evident in the time series.

4. Dieldrin in Sport Fish

Background and Rationale: Dieldrin is an organochlorine insecticide that was widely used in the U.S. from 1950 to 1974, primarily on termites and other soil-dwelling insects, as a wood preservative, in moth-proofing clothing and carpets, and on cotton, corn, and citrus crops (U.S. EPA, 1995a). Restrictions on dieldrin use began in 1974. Most uses in the U.S. were banned in 1985. Dieldrin use for underground termite control continued until voluntarily canceled by industry in 1987 (U.S. EPA, 1995a).

Dieldrin and two other organochlorine pesticides (DDTs and chlordanes) are often referred to as "legacy pesticides" (Connor et al. 2004b). Dieldrin falls into a category of moderate concern for its impact on Bay water quality. For pollutants in this category either the entire Bay or several Bay locations are included on the 303(d) List and concentrations are above thresholds of concern.

Dieldrin and the other legacy pesticides have similar properties, and are also similar in many ways to PCBs and dioxins. They are highly persistent, strongly associated with sediment particles, widely distributed throughout the Bay and its watershed, and reach high concentrations in humans and wildlife at the top of the food chain. The human and wildlife health risks of the legacy pesticides are similar to those for PCBs. However, concentrations of the legacy pesticides in sport fish are not as elevated relative to their thresholds for concern.

Concentrations of dieldrin and the other legacy pesticides in sport fish tissue are the key impairment indicator for this pollutant. Connor et al. (2004a) discussed screening values and impairment relative to those values. The San Francisco Bay Regional Water Quality Control Board (Water Board) has not established targets for the legacy pesticides. A TMDL for legacy pesticides is currently in the early development stage. In the absence of a Water Board target, screening values for use in this report was calculated using the same parameters for consumption rate and risk that were employed in the PCBs TMDL. Also, the same indicator species used for the PCBs TMDL (white croaker and shiner surfperch) were used.

Data Source: The dieldrin index was calculated using data from the same RMP sport fish monitoring program described for the mercury in sport fish index. The data are available from the RMP website (www.sfei.org/rmp/data). Additional details on this sampling were provided in the mercury section. White croaker and shiner surfperch, the key indicator species for the legacy pesticides, have been sampled consistently over the years (Table 1).

Methods and Calculations: The dieldrin in sport fish index was calculated for each year of RMP monitoring. The time series plot shows the distribution of the data for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}).

Goals, Targets and Reference Conditions: The calculated screening value to protect human health is a dieldrin concentration of 1.4 ppb wet weight in sport fish tissue. The same size classes specified in the PCBs TMDL for white croaker (20 to 30 cm in length) and shiner surfperch (10 to 15 cm in length) were used. Comparison of data for these species to the screening value is a conservative approach because these species are likely to have the highest concentration among the species that are popular for consumption, and anglers likely consume a variety of fish species, including species with lower concentrations.

As for the other fish targets, this screening value represents the maximum level that is considered to be safe for people consuming Bay fish at a rate less than the 95^{th} percentile rate (32 g/day, or 8 ounces per week) for all Bay fish consumers (Connor et al. 2004b).

Results: For dieldrin, the 25th percentile of the distribution in the most recent sampling year (1.5 ppb) was higher than the 1.4 ppb screening value (Figure 5). Dieldrin concentrations in mussels in the Bay declined sharply in the 1980s (Gunther et al. 1999), but have not declined appreciably in either sport fish or bivalves over the past 20 years (Davis et al. 2007). It seems likely, however, that the distribution of dieldrin concentrations may decline over the next 20 years such that the median would be below the screening value.

5. DDTs in Sport Fish

Background and Rationale: DDT is an organochlorine insecticide that was used very extensively in home and agricultural applications in the U.S. beginning in the late 1940s and continuing in the U.S. until the end of 1972, when all uses, except emergency public health uses, were canceled (U.S. EPA 1995). The primary sources of DDT to the Bay are probably continuing transport of contaminated soils and sediments from urban and agricultural sites of historic use, and remobilization of residues from Bay sediments. The terms DDT or DDTs are often used to refer to a family of isomers (i.e., p,p'-DDT and o,p'-DDT) and their breakdown products (p,p'-DDE, o,p'-DDE, p,p'-DDD, and p,p'-DDD). DDT data are often expressed as the sum of these six components, and this approach is recommended by U.S. EPA (2000). DDT and its metabolites DDE and DDD are neurotoxic and are also classified by U.S. EPA as probable human carcinogens (U.S. EPA 1995).

DDTs fall into a category of low concern for their impact on Bay water quality. DDTs are included on the 303(d) List. However, concentrations in sport fish in recent years have not exceeded a DDT screening value calculated using the same consumption and risk parameters employed in the PCBs TMDL.

Concentrations of DDTs in sport fish tissue are the key impairment indicator for this pollutant. Other considerations regarding thresholds were described above in the Dieldrin section.

Data Source: The DDTs index was calculated using data from the same RMP sport fish monitoring program described for the mercury in sport fish index. The data are available from the RMP website (www.sfei.org/rmp/data). Additional details on this sampling were provided in the mercury section. White croaker and shiner surfperch, the key indicator species for the legacy pesticides, have been sampled consistently over the years (Table 1).

Methods and Calculations: The DDTs in sport fish index was calculated for each year of RMP monitoring (Figure 6). The time series plot shows the distribution of the data for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5th, 25th, 50th, 75th, 95th).

Goals, Targets and Reference Conditions: The calculated screening value to protect human health is a DDTs concentration of 64 ppb wet weight in sport fish tissue. The same size classes specified in the PCBs TMDL for white croaker (20 to 30 cm in length) and shiner surfperch (10 to 15 cm in length) were used. Comparison of data for these species to the screening value is a conservative approach because these species are likely to have the highest concentration among the species that are popular for consumption, and anglers likely consume a variety of fish species, including species with lower concentrations. The sum of the six DDT isomers was used in calculating the index values, with values for isomers reported as below the limit of detection set to zero.

As for the other fish targets, this screening value represents the maximum level that is considered to be safe for people consuming Bay fish at a rate less than the 95th percentile rate (32 g/day, or 8 ounces per week) for all Bay fish consumers (Connor et al. 2004b).

Results: For DDTs, the 95th percentile of the distribution in the most recent sampling year was below the screening value (Figure 5). DDT concentrations in the Bay have declined since the ban in 1972 (Davis et al. 2007), and are expected to continue on a downward trajectory.

6. Chlordanes in Sport Fish

Background and Rationale: Chlordane is another organochlorine insecticide that was used extensively in home and agricultural applications (including corn, grapes, and other crops) in the U.S. for the control of termites and many other insects (U.S. EPA 1995). Like PCB, chlordane is a term that represents a group of a large number (140) of individual compounds (Dearth and Hites 1991). Restrictions on chlordane use began in 1978, and domestic sales and production ceased in 1988 (U.S. EPA 1995). As for DDT, the primary sources of chlordane to the Bay are probably continuing transport of soils and sediments from urban and agricultural sites of historic use and remobilization of residues from Bay sediments.

Chlordane data are usually expressed as the sum of several of the five most abundant and persistent components and metabolites of the technical chlordane mixture. Chlordane is neurotoxic and is classified by U.S. EPA as a probable human carcinogen (USEPA 2000). Like PCBs and DDT, chlordane compounds are very persistent in the environment, resistant to metabolism, have a strong affinity for lipid, and biomagnify in aquatic food webs (Suedel et al. 1994).

Chlordanes fall into a category of moderate concern for their impact on Bay water quality. For pollutants in this category either the entire Bay or several Bay locations are included on the 303(d) List and concentrations are above thresholds of concern.

Concentrations of chlordanes in sport fish tissue are the key impairment indicator for this pollutant. Other considerations regarding thresholds were described above in the Dieldrin section.

Data Source: The chlordanes index was calculated using data from the same RMP sport fish monitoring program described for the mercury in sport fish index. The data are available from the RMP website (www.sfei.org/rmp/data). Additional details on this sampling were provided in the mercury section. White croaker and shiner surfperch, the key indicator species for the legacy pesticides, have been sampled consistently over the years (Table 1).

Methods and Calculations: The chlordanes in sport fish index was calculated for each year of RMP monitoring (Figure 7). The time series plot shows the distribution of the data for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5th, 25th, 50th, 75th, 95th).

Goals, Targets and Reference Conditions: The calculated screening value to protect human health is a chlordanes concentration of 17 ppb wet weight in sport fish tissue. The same size classes specified in the PCBs TMDL for white croaker (20 to 30 cm in length) and shiner surfperch (10 to 15 cm in length) were used. Comparison of data for these species to the screening value is a conservative approach because these species are likely to have the highest concentration among the species that are popular for consumption, and anglers likely consume a variety of fish species, including species with lower concentrations. The sum of five key chlordane isomers was used in calculating the index values, with values for isomers reported as below the limit of detection set to zero.

As for the other fish targets, this screening value represents the maximum level that is considered to be safe for people consuming Bay fish at a rate less than the 95th percentile rate (32 g/day, or 8 ounces per week) for all Bay fish consumers (Connor et al. 2004a).

Results: For chlordanes, the 75th percentile of the distribution in the most recent sampling year was above the screening value (Figure 5). Chlordane concentrations in the Bay have declined since the ban in 1988 (Davis et al. 2007), and are expected to continue on a downward trajectory.

7. Copper in Water

Background and Rationale: Copper pollution was a major concern in the Estuary in the 1990s, as concentrations were frequently above the water quality objective. An evaluation of the issue by the Water Board and stakeholders led to new site-specific water quality objectives for copper in the Bay (less stringent but still considered fully protective of the aquatic environment), pollution prevention and monitoring activities, and the removal of copper from the 303(d) List in 2002. Along with the new objectives, a program has been established to guard against future increases in concentrations in the Bay. The program includes actions to control known sources in wastewater, urban runoff, and use of copper in shoreline lagoons and on boats. More aggressive actions to control sources can be triggered by increases in copper or nickel concentrations.

Concentrations of copper in water are the key impairment indicator for this pollutant.

Data Source: The copper index was calculated using data from water sampling conducted by the RMP. The data are available from the RMP website (www.sfei.org/rmp/data).

Methods and Calculations: The copper index was calculated for each year of RMP monitoring from 1993 to 2009 (Figure 7). The time series plot shows the distribution of the data (dissolved concentrations in water) for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5th, 25th, 50th, 75th, 95th).

Goals, Targets and Reference Conditions: Two different site-specific copper objectives have been established for the Bay. For Lower San Francisco Bay south of the line representing the Hayward Shoals shown and South San Francisco Bay the objective is 6.9 ug/L. For the portion of the delta located in the San Francisco Bay Region, Suisun Bay, Carquinez Strait, San Pablo Bay, Central San Francisco Bay, and the portion of Lower San Francisco Bay north of the line representing the Hayward Shoals the objective is 6.0 ug/L. The objectives are for dissolved concentrations.

Results: Copper concentrations in the Bay have been below the site-specific objectives for all samples measured from 1993 to 2009.

8. Silver in Water

Background and Rationale: Enforcement of the Clean Water Act and other environmental laws over the past 35 years has resulted in tremendous improvements in overall Bay water quality, solving serious problems related to organic waste, nutrients, and silver contamination. In the 1970s the Bay had the highest silver concentrations recorded for any estuary in the world, but the closure of a major photo processing plant and improved wastewater treatment led to a reduction in concentrations in South Bay clams from 100 ppm in the late 1970s to 3 ppm in 2003, eliminating adverse impacts on clam reproduction. With the continued vigilance of regulators and treatment plant operators, broad-scale adverse impacts of dissolved oxygen, nutrients, and silver on Bay water quality are not likely.

Concentrations of silver in water are the key impairment indicator for this pollutant.

Data Source: The silver index was calculated using data from water sampling conducted by the RMP. The data are available from the RMP website (www.sfei.org/rmp/data).

Methods and Calculations: The silver index was calculated for each year of RMP monitoring from 1993 to 2009 (Figure 7). The time series plot shows the distribution of the data (dissolved concentrations in water) for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}).

Goals, Targets and Reference Conditions: The water quality objective for silver in the Bay is 1.9 ug/L (SFBRWQCB 2007). The objective applies to dissolved concentrations.

Results: Silver concentrations in the Bay have been far below the objective for all samples measured from 1993 to 2009, and are not expected to increase.

9. Dissolved Oxygen in Water

Background and Rationale: Enforcement of the Clean Water Act and other environmental laws over the past 35 years has resulted in tremendous improvements in overall Bay water quality, solving serious problems related to organic waste, nutrients, and silver contamination. In the early 1970s the Bay suffered from severely degraded water quality. The discharge of poorly treated wastewater, primarily from publicly-owned treatment works (POTWs) serving the Bay Area's growing population, was the cause of large and frequent fish kills, unsafe levels of bacteria in water and shellfish, and a notoriously foul stench (Krieger et al 2007). The Clean Water Act provided a major impetus toward cleaning up the Bay by setting clear goals and supplying over a billion dollars that supported construction of POTWs. In response, POTWs and industrial wastewater dischargers achieved significant reductions in their emissions of pollutants into the Bay, and the most noticeable problems of the 1970s have been solved. Inputs of organic waste and nutrients have been greatly reduced and no longer cause fish kills or odor problems.

Some concerns remain with regard to dissolved oxygen concentrations in the Bay. Low dissolved oxygen resulting indirectly from the large amount of freshwater input to the Bay in 2006 was considered a possible cause of a fish kill in June of that year. Dissolved oxygen and nutrient concerns still exist for salt ponds, lagoons, and other areas around the edges of the Bay. Recent observations of increasing transparency in the Bay due to declining suspended sediment concentrations (Schoellhamer 2009) and increasing chlorophyll concentrations (SFEI 2009) are raising concerns that dissolved oxygen concentrations could decline to problematic levels.

Concentrations of dissolved oxygen in water are a key impairment indicator for organic waste and nutrients.

Data Source: The dissolved oxygen index was calculated using data from water sampling conducted by the RMP. The data are available from the RMP website (www.sfei.org/rmp/data).

Methods and Calculations: The dissolved oxygen index was calculated for each year of RMP monitoring from 1993 to 2009 (Figure 9). The time series plot shows the distribution of the data (dissolved concentrations in water) for each year sampled. Consistent with the evaluation scheme described under "Background and Rationale," the distribution is described with percentiles (5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}).

Goals, Targets and Reference Conditions: There are two objectives for dissolved oxygen in the Bay. An objective of 5 mg/L applies to waters downstream of the Carquinez Strait. The objective for Suisun Bay is 7 mg/L.

Results: Dissolved oxygen concentrations in the Bay have been exceeded the objective for almost all samples measured from 1993 to 2009. Increasing phytoplankton abundance in the South Bay has raised concern that concentrations could decline again to problematic levels.

Figure 1. Locations of the five sampling stations for the RMP sport fish monitoring.

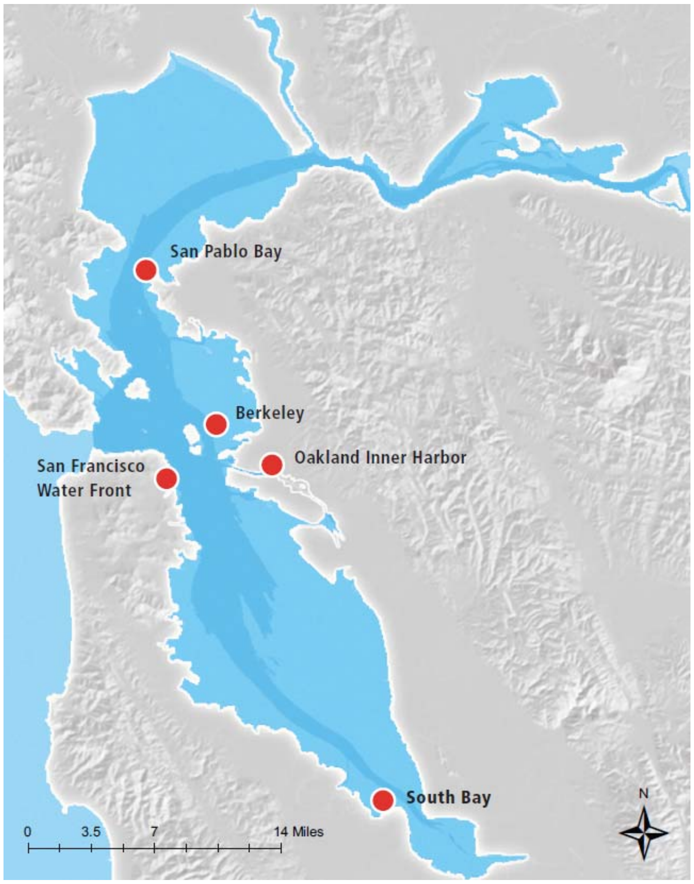


Figure 2. Distributions of the data for the mercury in sport fish indicator (see text for details) for each year sampled.

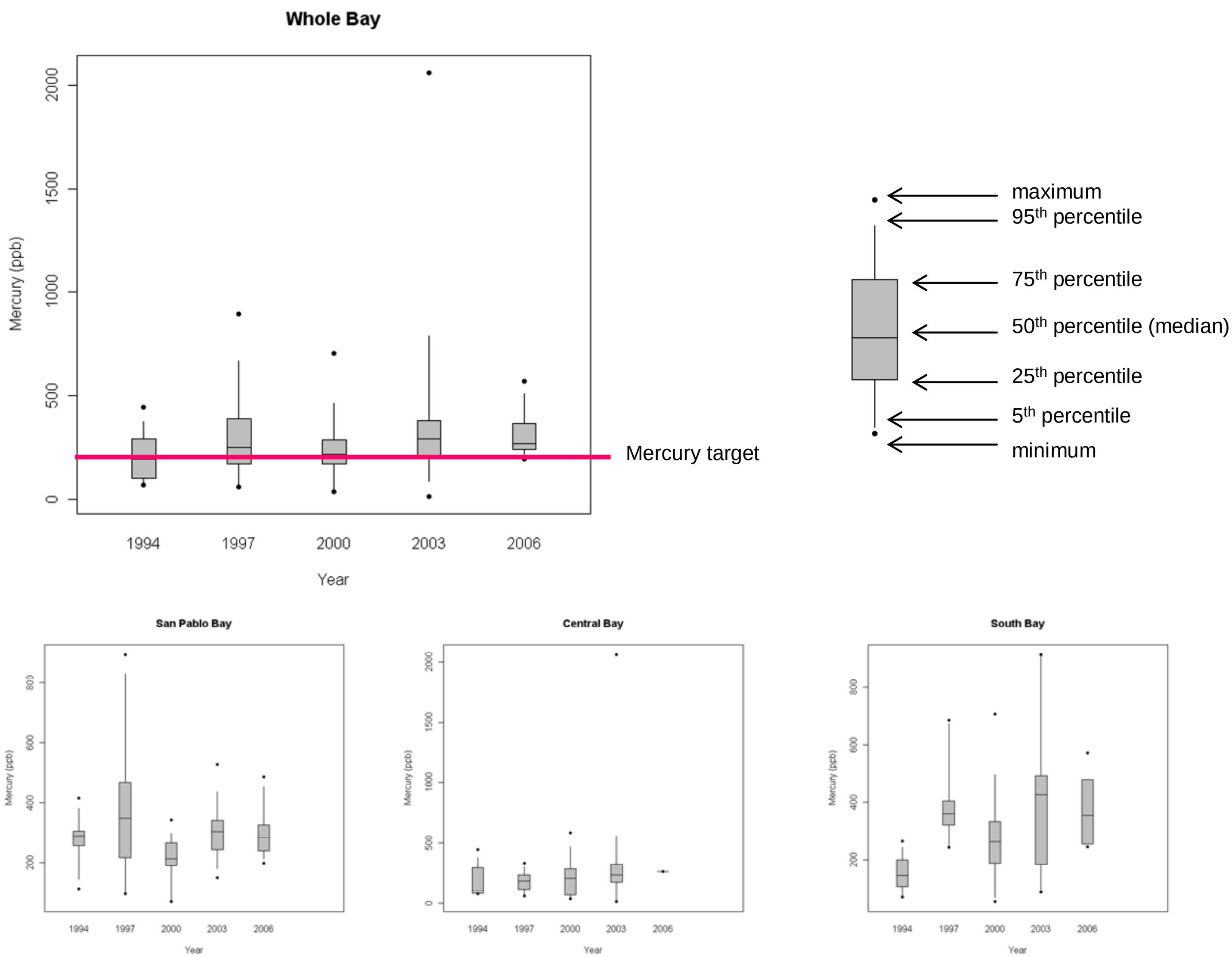


Figure 3. Distributions of the data for the PCBs in sport fish indicator (see text for details) for each year sampled.

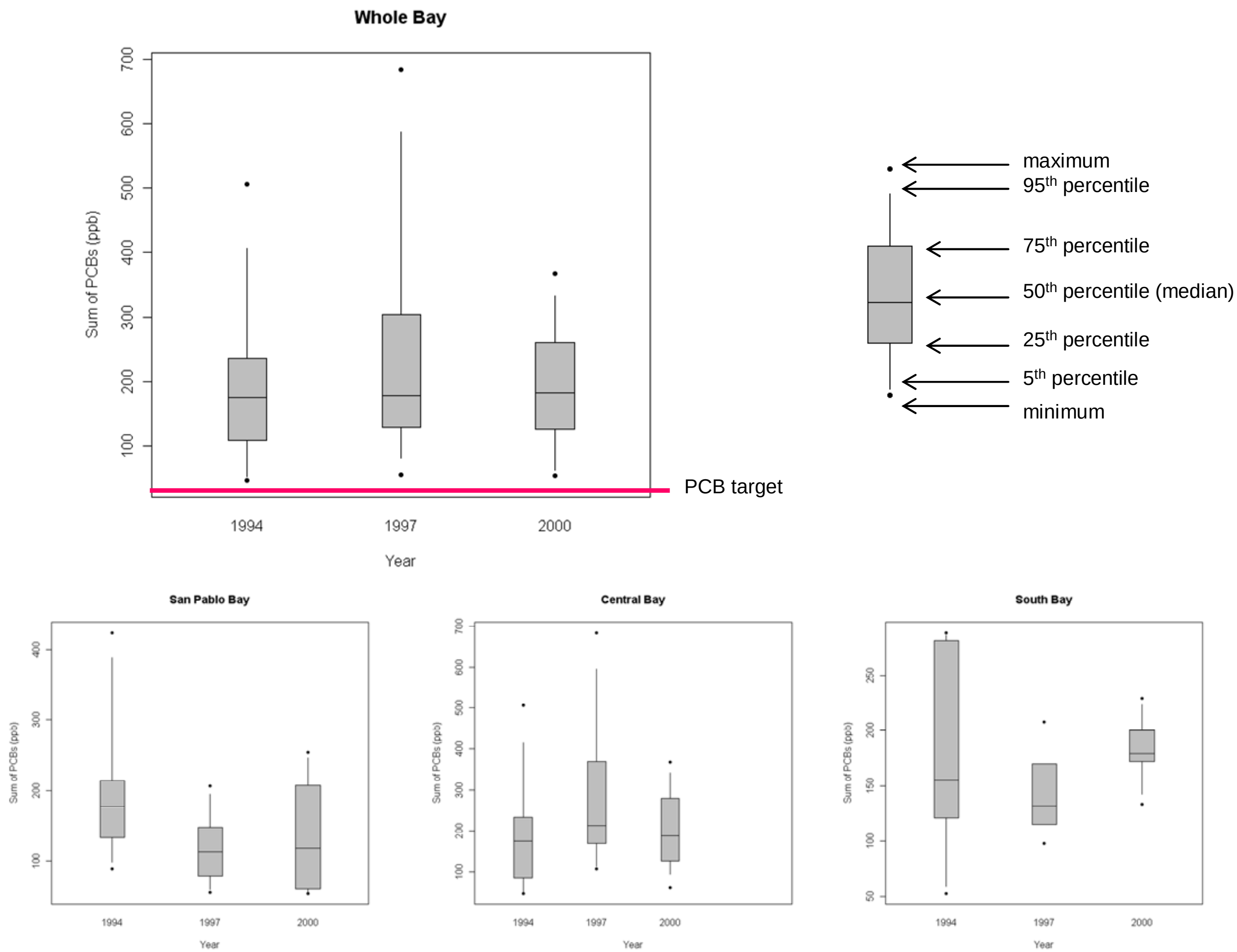


Figure 4. Distributions of the data for the dioxins in sport fish indicator (see text for details) for each year sampled.

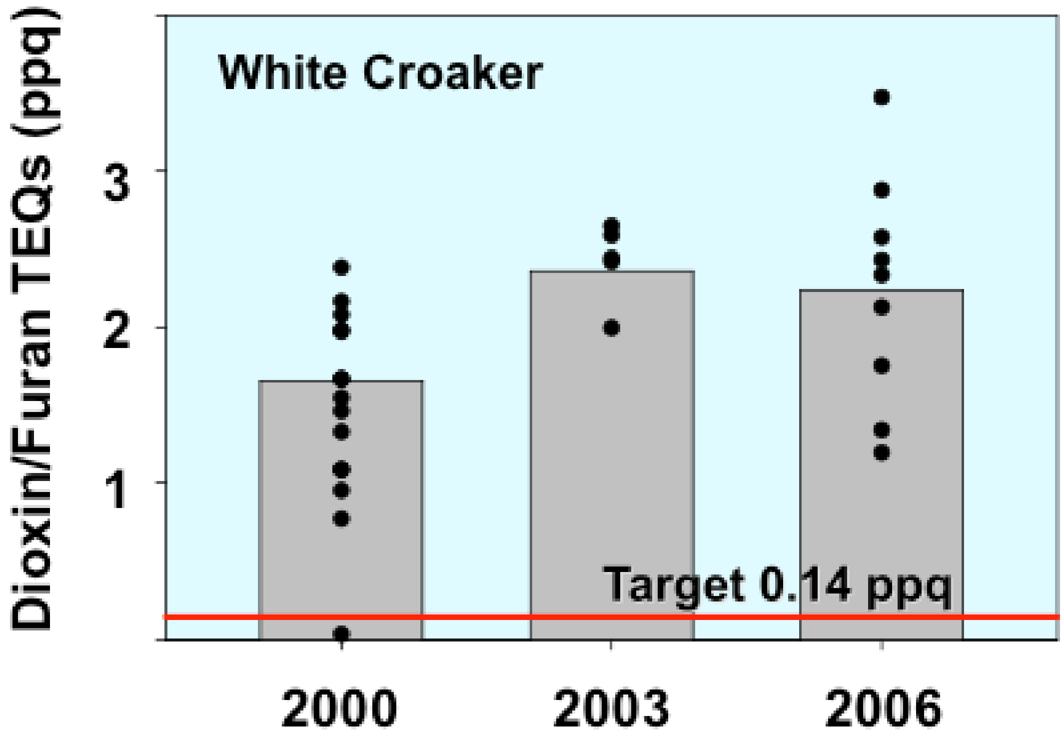


Figure 5. Distributions of the data for the dieldrin in sport fish indicator (see text for details) for each year sampled.

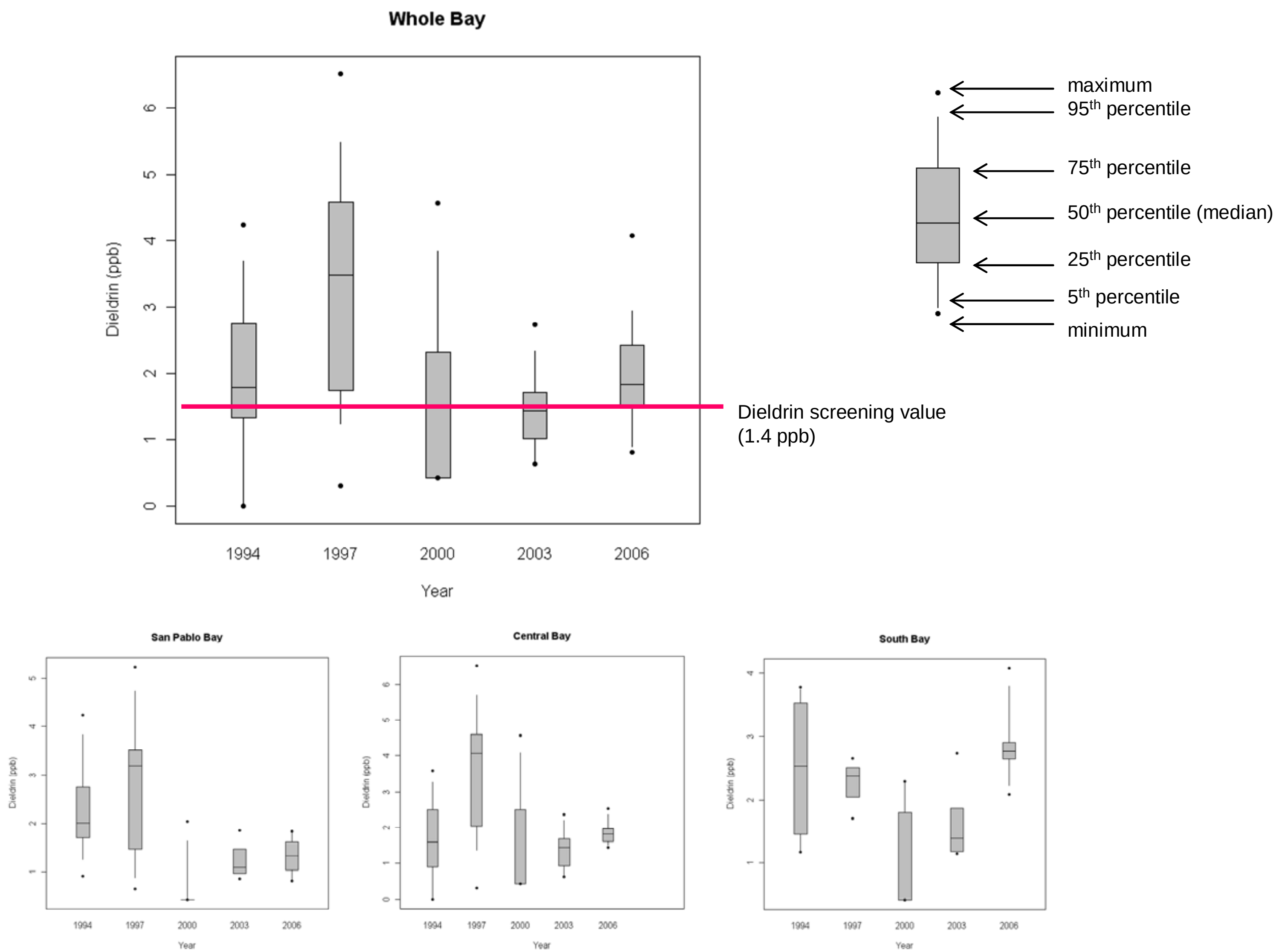


Figure 6. Distributions of the data for the DDTs in sport fish indicator (see text for details) for each year sampled.

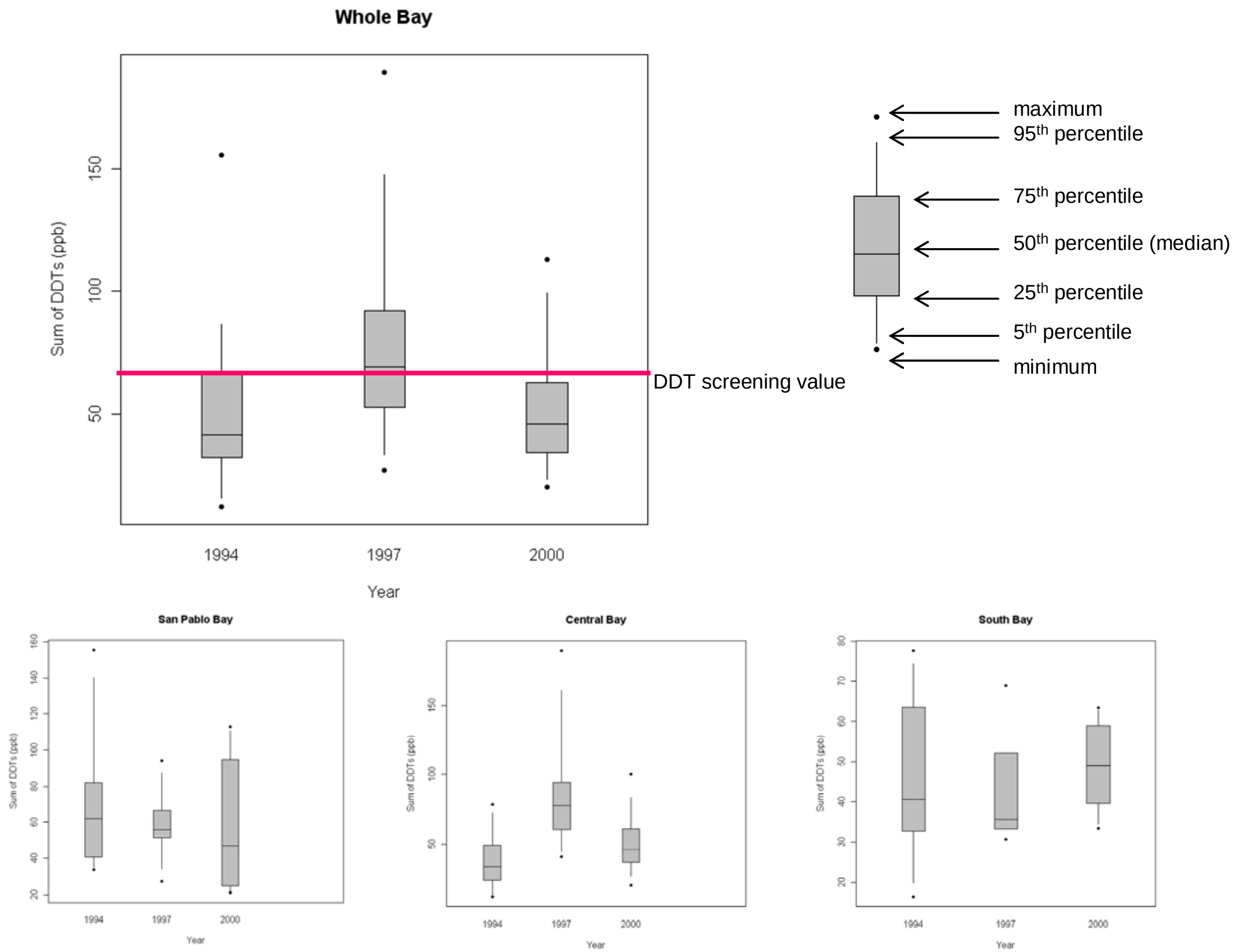


Figure 7. Distributions of the data for the chlordanes in sport fish indicator (see text for details) for each year sampled.

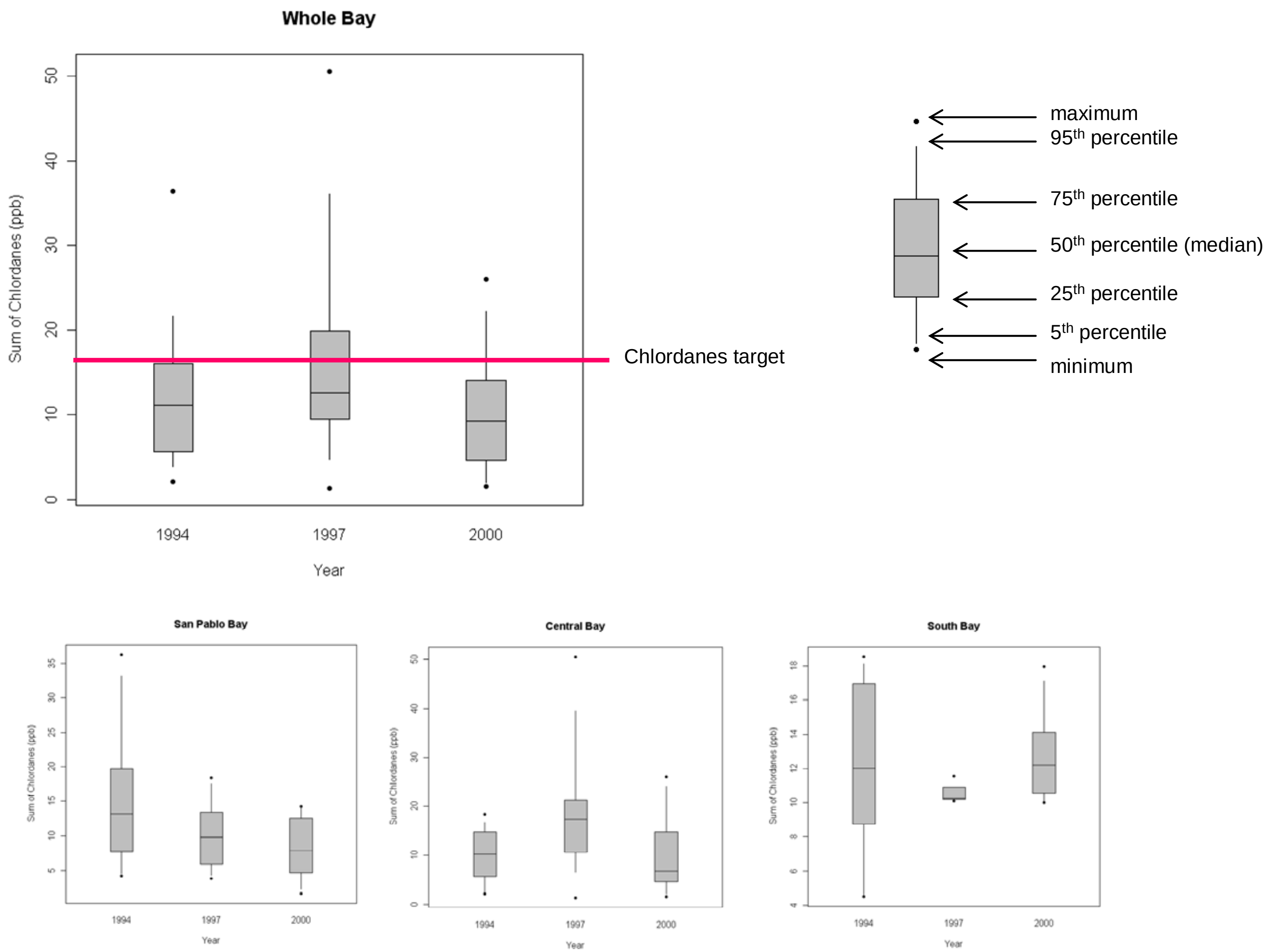
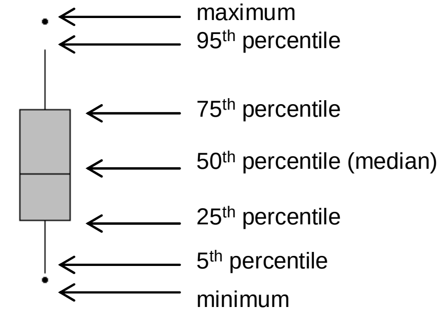


Figure 8. Distributions of the data for the copper in water indicator (see text for details) for each year sampled.



Copper objective (6.0 ug/L) | Copper objective (6.0 ug/L) | Copper objective (6.0 ug/L) | Copper objective (6.9 ug/L)

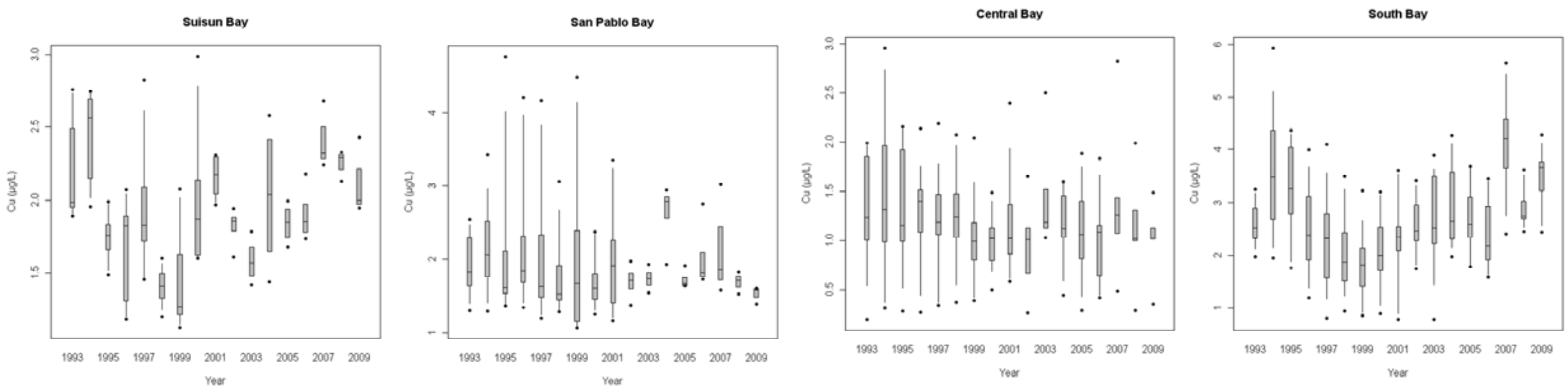


Figure 9. Distributions of the data for the silver in water indicator (see text for details) for each year sampled.

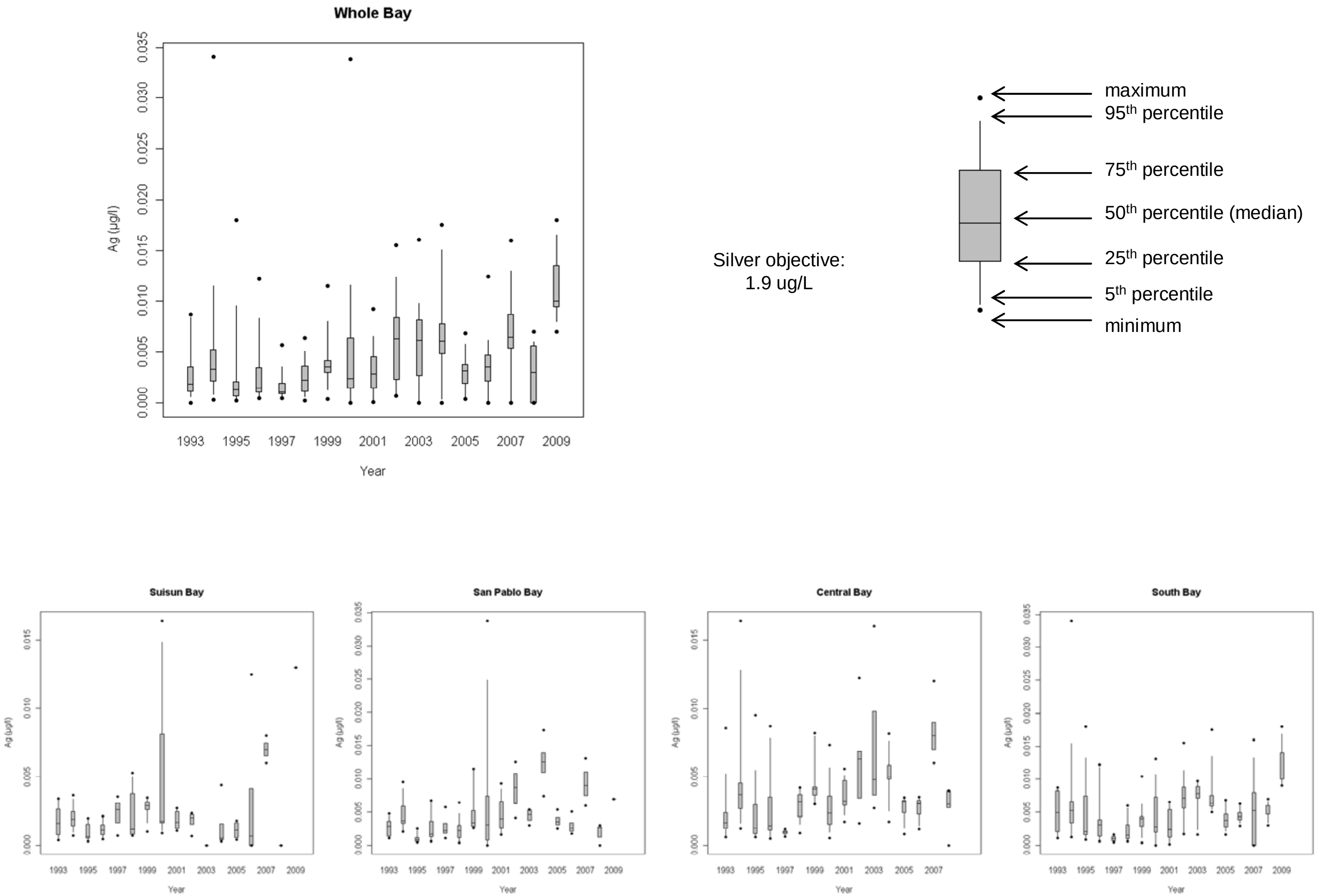
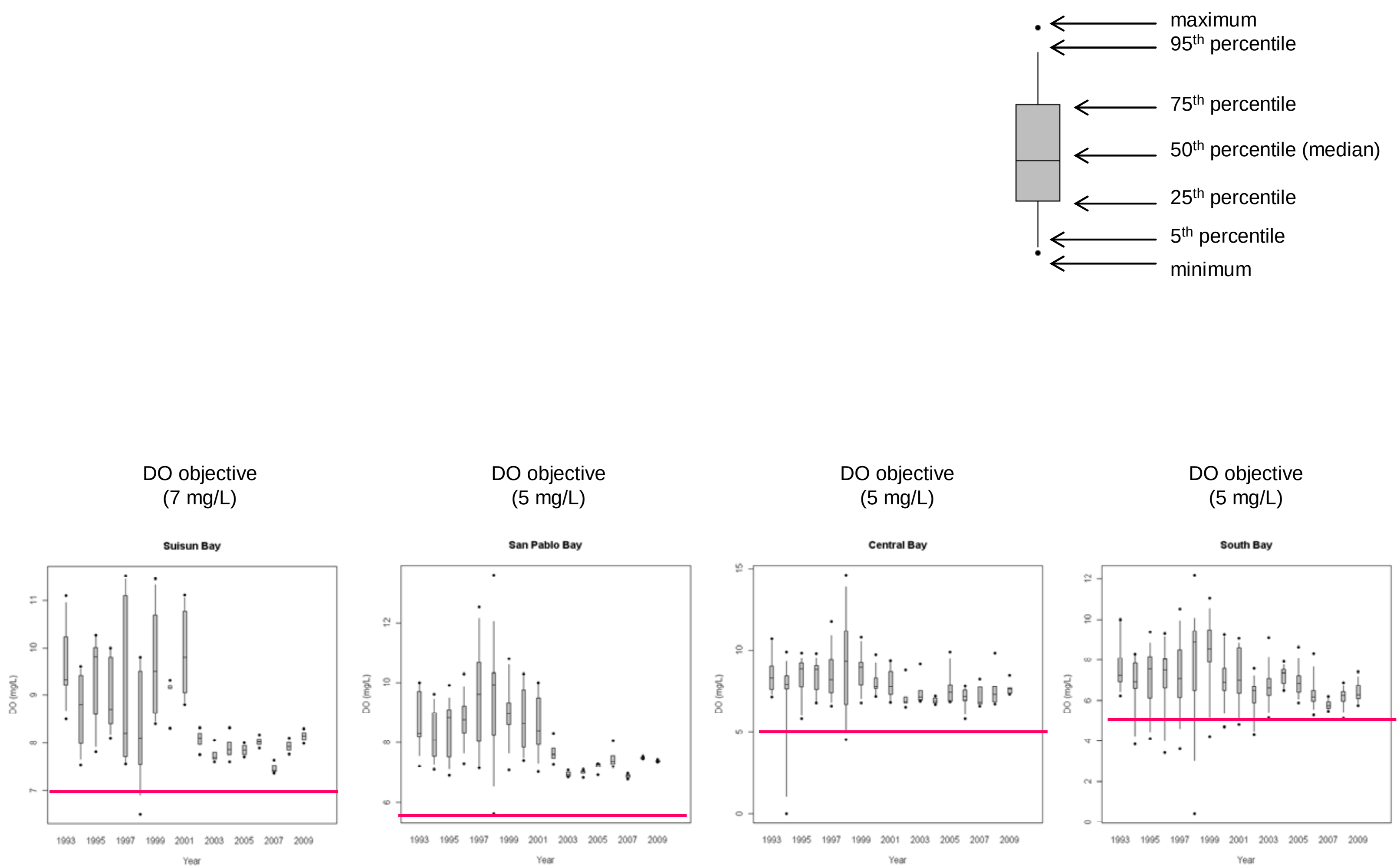


Figure 10. Distributions of the data for the dissolved oxygen in water indicator (see text for details) for each year sampled.



WAF Category: Ecological Processes

Ecological Processes Indicator 1. Heron and Egret Brood Size

By Nadav Nur and John Kelly

Background and Rationale:

Audubon Canyon Ranch has monitored brood size, prior to fledging, in Great Blue Heron and Great Egret nests across all known nesting colonies (40-50 sites) in the northern San Francisco Estuary, annually, since 1991. The number of young produced in successful heron and egret nests depends on the number of young hatched in the nest and the extent of subsequent brood reduction (i.e., mortality of nestlings during the brood-rearing period). Both parameters (young hatched per nest and survival of those young), reflect the amount of suitable foraging habitat, or supply or availability of prey, in surrounding wetlands, especially that which is needed to provision nestlings with food (Frederick 2002, Kushlan and Hancock 2005). The Heron and Egret Brood Size Indicator is sensitive to changes in the extent and quality of foraging habitat, and is likely to be influenced by changes in land-use, hydrology (especially water circulation and depth), geomorphology, environmental contamination, vegetation characteristics, and the availability of suitable prey (Kushlan 2000). The two target species reflect differences in feeding habitat preference: Great Egrets preferentially forage in small ponds in emergent wetlands and areas with shallow, fluctuating water depths for foraging. In contrast, Great Blue Herons forage along the edges of larger bodies of water and creeks and are less sensitive to water depth (Custer and Galli 2002, Gawlik 2002). Previous work in the northern San Francisco Estuary demonstrated that prefledging brood size in herons and egrets is influenced by the extent of wetland habitat types as far as 10 km from nest sites (Kelly et al. 2008). Thus, this indicator reflects wetland condition over large spatial scales. The conspicuousness of heron and egret nesting colonies and the visibility of nests and broods—especially when nestlings are too young to leave the nests but old enough to have survived the period when most brood size reduction occurs—facilitates the use of brood size as an effective index of breeding productivity.

Data Source:

The Heron and Egret Brood Size Indicator was calculated using data from ongoing regional heron and egret studies by Audubon Canyon Ranch (Kelly et al. 1993, 2007). The data, which reflect brood size in successful nests at all known colony sites, provide an effective index of regional and subregional heron and egret productivity.

Methods and Calculations:

The Heron and Egret Brood Size Indicator includes metrics calculated for Great Egrets and Great Blue Herons. It is based on the number of young in completely visible nests when Great Blue Heron nestlings are known to be 5-8 weeks old and Great Egrets are known to be 5-7 weeks old (Pratt 1970, Pratt and Winkler 1985). The indicator measures changes or differences in brood size prior to fledging among nests that successfully fledge one or more young. Brood size counts are sampled in approximate proportion to colony size and averaged annually (1991-2008) among nests within and across the three major subregions of northern San Francisco Bay (Central San Francisco Bay, San Pablo Bay, and Suisun Bay). Brood size estimates are based on observations at most of the 40-50 colony sites within foraging range (i.e., 10 km) of the historic tidal wetland boundary (ca.1770–1820; San Francisco Estuary Institute 1999; Figure H1). The Brood Size Indicator is calculated as the geometric mean, calculated between species, of percent deviation of prefledging brood size (number of young produced in successful nests), when compared with the 1991-1995 average (Great Blue Heron: 2.01±0.088 young; Great Egret: 2.26±0.107 young, weighted equally across years).

Goals, Targets and Reference Conditions:

CCMP goals to "restore" and "enhance" the ecological productivity and habitat values of wetlands are non-quantitative. However, the use of time series back to 1991 allows the specification of appropriate quantitative reference conditions. Differences or trends in nest density can be quantified and used for assessment.

<u>Maintenance of current resource levels</u>

- Target: current 3-year mean (2006-2008) ≥ 5-year reference mean (1991-1995).

<u>Enhancement of resources with wetland restoration</u>

- Target: current 3-year mean (2006-2008) ≥ highest 5-year *subregional* reference mean (1991-1995)

Results:

Results of the Heron and Egret Brood Size Indicator are shown in Figure H4.

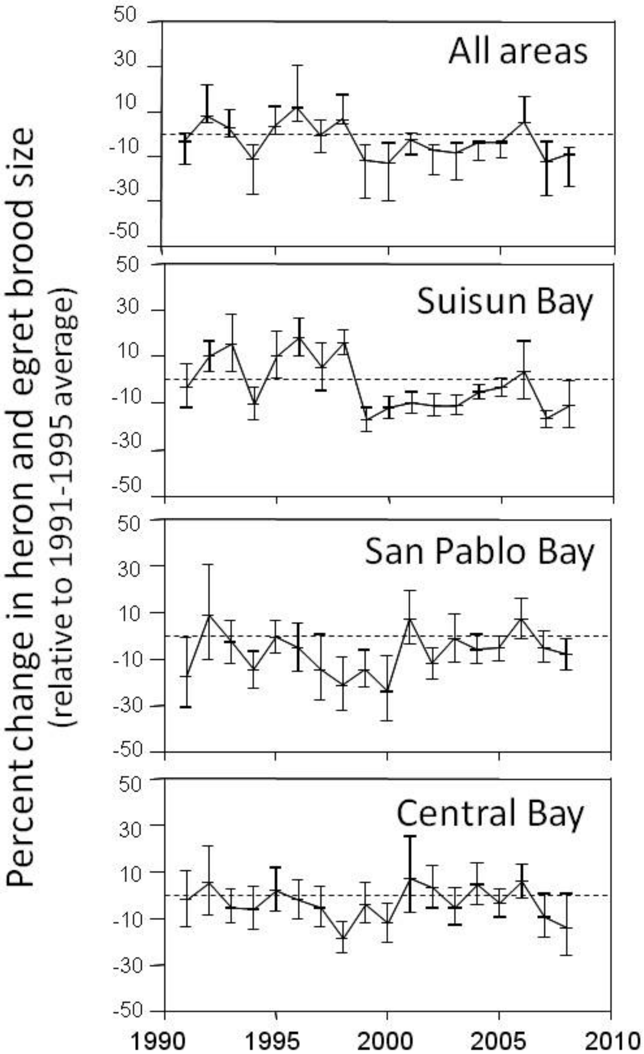


Figure H4. Annual percent change in heron and egret brood size, 1991-2008, relative to the average brood size (dashed line), 1991-1995, in the northern San Francisco Estuary.

Current brood sizes (2006-2008) declined from reference levels (1991-1995).

Brood sizes in the northern San Francisco Estuary declined significantly in 2006-2008, relative to 1991-1995 reference levels (t_{745} = -9.9, $P < 0.001$; Figure H4), with 8.4% and 17.1% fewer young produced in successful Great Blue Heron and Great Egret nests, respectively. Therefore, the proposed target associated with overall resource enhancement was also not achieved: regional productivity per nest was significantly less (t_{570} = 5.1, $P < 0.001$) than the highest subregional 1991-1995 level (Suisun Bay, 4.6% above regional reference value).

Changes in brood size differ among subregions.

During the 1991-1995 reference period, brood sizes were significantly smaller in San Pablo Bay than in other subregions (multiple comparisons, $P < 0.001$). In recent years (2006-2008), the Brood Size Indicator revealed significantly smaller broods in Suisun Bay than in other subregions ($P < 0.02$), suggesting a shift in relative per capita productivity among subregions (Figure H4). In addition, brood sizes in Suisun Bay in 2006-2008 were significantly smaller than the regional 1991-1995 average ($t_{353} = -8.3$, $P < 0.001$), with nests producing 14% fewer Great Blue Heron young and 19% fewer Great Egret young. The productivity of nests in San Pablo Bay in the recent years was also significantly lower than in the reference period ($t_{273} = -3.7$, $P < 0.001$), with average declines of 5.2% in Great Blue Herons and 10.5% in Great Egrets. In the Central Bay, the productivity of Great Egret nests declined by 13.8% ($t_{56} = 3.8$, $P < 0.001$) relative to reference levels, but the productivity in Great Blue Heron nests was apparently stable ($P > 0.05$).

Based on brood size estimates for Great Blue Heron and Great Egret, CCMP goals of restoring or enhancing wetland productivity and associated wetland habitat values have not been met in the region or within any subregion.
Recent productivity in successful nests of both species declined by 8-17% relative to the 1991-1995 reference period, with declines generally observed across the subregions. Subregional differences in productivity suggest opportunities for habitat restoration or enhancement, especially in Suisun Bay.

WAF Category: Hydro-Geomorphology

Hydro-Geo Indicator 1. Annual Freshwater Inflow

By Christina Swanson

Background and Rationale: Estuaries, at the interface between rivers and the ocean, are important spawning, nursery and rearing habitat for a host of fishes and invertebrates; migration corridors for anadromous fishes like salmon, steelhead and sturgeon; and breeding and nesting habitat for waterfowl and shorebirds. The amount of freshwater inflow to an estuary is a physical and ecological driver that defines the quality and quantity of estuarine habitat (Jassby et al. 1995; Kimmerer 2002; Feyrer et al. 2007, 2010; Moyle and Bennett, 2008; Moyle et al., 2010).[7] Most of the fresh water that flows into the San Francisco Estuary comes from the Sacramento and San Joaquin River basins, which provide >90% of total inflow in most years.[8] Smaller streams around the estuary, principally the Napa and Guadalupe Rivers, Alameda, San Francisquito, Coyote, Sonoma Creeks, and many smaller tributaries, contribute the balance. During the past 80 years, freshwater inflows into the estuary have been greatly altered by upstream dams and water diversions (Figure X1). These changes have affected the estuarine ecosystem and the plants and animals that depend on it.

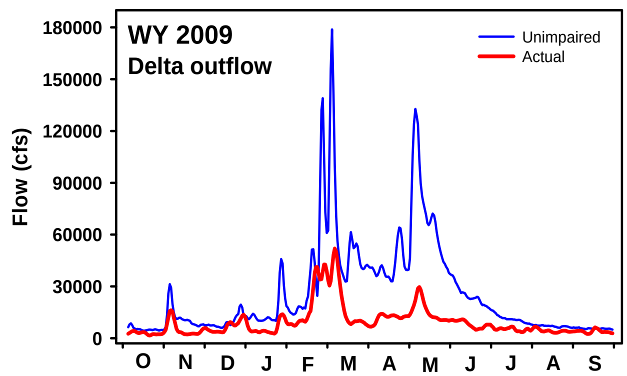


Figure X1. Actual and estimated unimpaired freshwater inflow to the San Francisco Estuary in Water Year 2009.

Data Sources: The Annual Freshwater Inflow indicator was calculated for each year[9] using data from the California Department of Water Resources (CDWR) DAYFLOW model (for "actual flows") and CDWR's Central Valley Streams Unimpaired Flows and Full Natural Flows datasets (for "unimpaired flows").[10] DAYFLOW is a computer model developed in 1978 as an accounting tool for calculating historical Delta outflow and other internal Delta flows.[11] DAYFLOW output is used extensively in studies by State and federal agencies, universities, and consultants. DAYFLOW output is available for the period 1930-2009. Annual unimpaired flow

[7] The timing and inter- and intra-annual variability in freshwater inflows are also important environmental factors; see Inter-annual Variation in Freshwater Inflow, Peak Flow and Critical Dry Year Frequency indicators for Hydrology and Geomorphology, Flood Frequency indicator for Natural Disturbance category, and Estuarine Open Water Habitat indicator for Landscape Condition category.
[8] The Sacramento River provides 69-95% (median=85%) and the San Joaquin River provides 4-25% (median=11%) of total freshwater inflow to the San Francisco Bay (Kimmerer, 2002).
[9] Flow indicators were calculated for each water year. The water year is from October 1-September 30.
[10] For both the DAYFLOW and Central Valley Streams Unimpaired Flows datasets, total freshwater inflow to the San Francisco Estuary from the Sacramento-San Joaquin watershed is referred to as "net Delta outflow".
[11] More information about DAYFLOW is available at www.iep.ca.gov/dayflow.

data for total Delta outflow were from the CDWR California Central Valley Unimpaired Flow dataset (1921-2003). For 2004-2009, annual unimpaired flows were calculated by a regression developed from the Central Valley unimpaired flow data (using the 1930-1994 period) and the corresponding unimpaired runoff estimates from the "Full Natural Flows" (FNF) dataset[12] for the ten largest rivers in the watershed.[13]

Methods and Calculations: The Annual Inflow Indicator measures the amount of fresh water from the Sacramento-San Joaquin watershed that flows into San Francisco Estuary each year compared to the amount that would have flowed into the estuary under unimpaired conditions. The indicator was calculated for each year (1930-2009) using data for total annual freshwater inflow ("actual" inflow, referred to as "Delta outflow" in DAYFLOW) and estimated total annual unimpaired inflow (referred to as "Delta Unimpaired Total Outflow" in CDWR's California Central Valley Unimpaired Flow dataset).

The indicator is calculated as:

Annual Freshwater Inflow (% of unimpaired) = [(actual inflow/unimpaired inflow)*100].

By incorporating unimpaired inflow as a component of the indicator calculation, the Annual Freshwater Inflow indicator has been normalized to account for natural year-to-year variations in hydrology.

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT 2008) for "increase[ing] freshwater availability to the estuary", "restor[ing] healthy estuarine habitat" and "promot[ing] restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary" are non-quantitative. However, California's State Water Resources Control Board (SWRCB) recently determined that, in order to protect public trust resources in the Sacramento-San Joaquin Delta and San Francisco Estuary, 75% of unimpaired runoff from the Sacramento-San Joaquin watershed should flow out of the Delta and into the estuary (SWRCB 2010).[14] Therefore, the reference condition for the Annual Freshwater Inflow indicator was established as 75%, a level roughly comparable to the SWRCB's recommendation.

Results: Results of the Annual Freshwater Inflow indicator are show in Figure X2.

The amount of fresh water from the San Francisco Estuary's largest watershed has been reduced.

On an annual basis, the percentage of the freshwater runoff from estuary's largest watershed that flows into the estuary has been significantly reduced. For the most recent 10-year period (2000-2009), on average only 52% of estimated unimpaired inflow actually flowed into the estuary. In 2009, only 32% of estimated unimpaired inflow reached the estuary, the third lowest percentage

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[12] Full Natural Flows datasets are available at: http://cdec.water.ca.gov/cgi-progs/previous/FNF

[13] The ten rivers are the Sacramento, Feather, Yuba, American, Cosumnes, Mokelumne, Stanislaus, Merced and San Joaquin Rivers. The regression is: Unimpaired Delta outflow = -3692.54 + 1.31(10-river unimpaired runoff); n=65, $r^2=0.998$, $p<0.001$.

[14] The SWRCB recommendation was for the winter-spring period (January-June) and it was expressed as the 14-day running average of estimated unimpaired runoff, rather than as an annual or seasonal total.

of freshwater inflow in the 80-year data record. In ten of the past 20 years (50% of years), the percentage of estimated unimpaired flow that flowed into the estuary was less than 50%.

The proportional alteration in annual freshwater inflow to the estuary differs by water year type.
The greatest alterations to freshwater inflows (expressed as a percentage of estimated unimpaired inflow) occur in dry years. Since the 1950s, the percentages of unimpaired flow that reached the estuary averaged 43% in critically dry years, 53% in dry years, 62% in below normal years, 68% in above normal years and 73% in wet years.

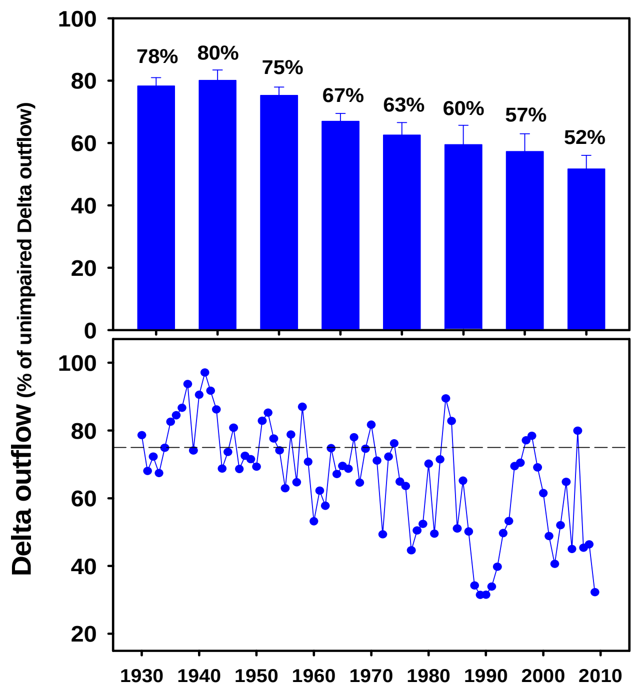

Figure X2. Changes in the annual freshwater inflow to the San Francisco Estuary, expressed as the percentage of estimated unimpaired flow that reaches the estuary, from 1930-2009. The top panel shows the results as the decadal average and the bottom panel shows results for each year. Horizontal dashed line shows the reference condition (75%).

Freshwater flow into the San Francisco Estuary, as a percentage of unimpaired flow, has declined over time.
The percentage of unimpaired flow that actually flowed into the estuary has declined significantly over the past several decades (regression, $p<0.001$). Significant declines in the percentage of unimpaired inflow reaching the estuary have occurred in all water years types (regression, all test, $p<0.05$). Before construction of most of the major dams on the estuary's tributary rivers (1930-1943, the "pre-dam" period), an average of 82% of estimated unimpaired flow actually reached the estuary. By the 1980s, the percentage had decreased significantly to just 60% (1980-1989 average; Mann-Whitney, $p<0.01$). The average for the most recent 10-year period, 52%, is somewhat lower but, due to the large inter-annual variability associated with hydrology, not significantly different than flows during the 1980s.

Based on the annual freshwater inflow to the estuary, CCMP goals to increase freshwater availability to the estuary have not been met.
Current freshwater inflows to the estuary are below the 75% level identified by the SWRCB as necessary to protect public trust resources and estuarine health. Current inflows are also somewhat lower than those measured in the 1980s, the period during which the CCMP was developed and established.

Hydro-Geo Indicator 2. Inter-annual Variation in Freshwater Inflow

By: Christina Swanson

Background and Rationale: Runoff from the Sacramento-San Joaquin watershed, which provides >90% of the total freshwater inflow to the San Francisco Estuary, can vary dramatically from year to year, a function of California's temperate climate and unpredictable cycle of droughts and floods. Just as the amount of freshwater inflow into an estuary is a physical and ecological driver that defines the quality and quantity of estuarine habitat (Jassby et al. 1995; Kimmerer 2002; Feyrer et al. 2007, 2010; Moyle and Bennett, 2008; Moyle et al., 2010), the inter-annual variability of freshwater inflows, a key feature of estuaries, drives spatial and temporal variability in the ecosystem and creates the dynamic habitat conditions upon which native fish and invertebrate species depend.

Data Sources: The Inter-annual Variation in Freshwater Inflow indicator was calculated for each year using data from the California Department of Water Resources (CDWR) DAYFLOW model (for "actual flows") and CDWR's Central Valley Streams Unimpaired Flows and Full Natural Flows datasets (for "unimpaired flows"). For more information on these two datasets, see the Data Sources section for the Annual Freshwater inflow indicator, above.

Methods and Calculations: The Inter-annual Variation in Freshwater Inflow Indicator measures the difference between the inter-annual variation in actual annual freshwater inflow from the Sacramento-San Joaquin watershed that flows into San Francisco Estuary and that of estimated unimpaired annual inflow for the same period. For the two annual inflow measures, variation was measured as the standard deviation (expressed in units of thousands of acre-feet, TAF) for prior ten-year period that ended in the measured year. The indicator was calculated for each year (1939-2009) as the difference between the standard deviations.

The indicator is calculated as:

Inter-annual Variation in Freshwater Inflow (TAF)
= (SD in actual inflow for $\text{year}_{(0 \text{ to } -9)}$) – (SD in unimpaired inflow for $\text{year}_{(0 \text{ to } -9)}$).

By incorporating unimpaired inflow as a component of the indicator calculation, the Inter-annual Variation in Freshwater Inflow indicator has been normalized to account for natural year-to-year variations in hydrology.

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT 2008) for "increase[ing] freshwater availability to the estuary", "restor[ing] healthy estuarine habitat" and "promot[ing] restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary" are non-quantitative. However, California's State Water Resources Control Board (SWRCB) recently determined that, in order to protect public trust resources in the Sacramento-San Joaquin Delta and San Francisco Estuary, 75% of unimpaired runoff from the Sacramento-San Joaquin watershed should flow out of the Delta and into the estuary (SWRCB 2010).[15] Therefore, the reference condition for the Inter-

[15] The SWRCB recommendation was for the winter-spring period (January-June) and it was expressed as the 14-day running average of estimated unimpaired runoff, rather than as an annual or seasonal total.

annual Variation in Freshwater Inflow indicator was established by calculating the average inter-annual variation in unimpaired inflows that had been reduced by 15-25% (depending on water year type).[16] Based on this calculation, the reference condition was set at -1700 TAF.

Results: Results of the Inter-annual Variation in Freshwater Inflow indicator are show in Figure V2.

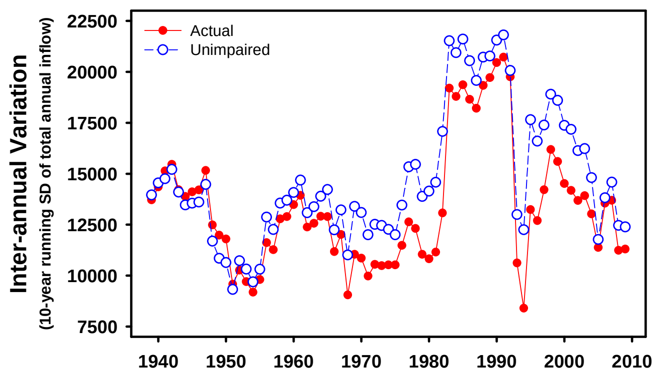

Figure V1. Inter-annual variation in actual and unimpaired annual freshwater inflows to the San Francisco Estuary from 1939-2009 (each point is the SD for running 10-year periods ending in that year).

Inter-annual variability in freshwater inflows to the San Francisco Estuary has varied substantially over time. The magnitude of inter-annual variability of estimated unimpaired and actual freshwater flows to the San Francisco Estuary is itself highly variable, reflecting unpredictable periodic differences in total annual flows that can vary by an order of magnitude (i.e., high inter-annual variation and large standard deviation) as well as periodic sequences of years with relatively comparable annual flows (i.e., low inter-annual variation and low small standard deviation) (Figure V1). Over the 71-year data record, unimpaired annual flows since the early 1980s have been substantially more variable (1939-1979 average variability: 17,199 TAF) than annual unimpaired flows during the earlier 40 years (1980-2009 average variability: 12,908 TAF). Inter-annual variation in actual annual flows showed a similar pattern (1939-1980 average: 12,583 TAF compared to the 1981-2009 average: 13,835 TAF).

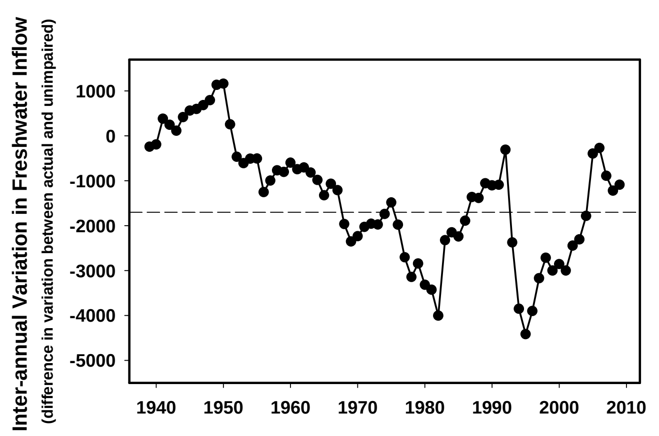

Figure V2. Changes in the difference between actual and unimpaired inter-annual variations in freshwater inflow to the San Francisco Estuary, from 1939-2009. Horizontal dashed line shows the reference condition (-1500 TAF).

Inter-annual variability in annual freshwater flows into the San Francisco Estuary has been reduced. Since the late 1960s, when large storage dams on most the estuary's large tributary rivers were completed (i.e., the "post-dam" period), there has been a significant decrease in the inter-annual variability of actual inflows to the estuary compared to the inter-annual variability of unimpaired flows measured for the same 10-year periods (t-test, $p<0.001$) (Figure V2). For the 1939-1967 period, the average difference in variability between actual and unimpaired flows was -256 TAF compared to the average difference in

[16] For calculation of the reference condition, unimpaired inflows<29,500 TAF (60% of years) were reduced by 25%, unimpaired inflows between 29,500 and 42,000 TAF were reduced 20%, and unimpaired inflows >42,000 TAF were reduced by 15%.

variability for the 1968-2009 period of -2184 TAF. Since the 1980s, inter-annual variation in annual freshwater inflows has varied but not changed significantly: the difference between actual and unimpaired variation in the 1980s (1980-1989), -2315 TAF, is not significantly different than that measured in the 2000s (2000-2009), -1625 TAF (t-test, p>0.5).

Based on recent inter-annual variation of annual freshwater inflows to the estuary, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have been met in some years.
Since 2005, inter-annual variation in annual freshwater inflow to the estuary conditions have been above the reference condition developed based on the SWRCB flow criteria. However, Inter-annual variation conditions were well below this reference condition for the decade prior to this and for 19 of the past 30 years. This most recent five-year period also coincides with a period of relatively low inter-annual variation in annual flows (see Figure V1).

Hydro-Geo Indicator 3. Peak Flow –By Christina Swanson

Background and Rationale: High, or "peak", freshwater flows into the San Francisco Estuary occur following winter rainstorms and during the spring snowmelt. High inflows transport sediment and nutrients to the estuary, increase mixing of estuarine waters, and create low salinity habitat in Suisun and San Pablo Bays (the upstream reaches of the estuary), conditions favorable for many estuary-dependent fish and invertebrate species. In rivers and estuaries, peak flows and the flood events they typically produce are also a form of "natural disturbance" (Moyle et al., 2010).[17]

Data Sources: The Peak Flow indicator was calculated for each year using daily freshwater inflow data (or net Delta outflow) from the California Department of Water Resources (CDWR) DAYFLOW model and estimated annual unimpaired inflow from CDWR's Central Valley Streams Unimpaired Flows and Full Natural Flows datasets. For more information on these two datasets, see the Data Sources section for the Annual Freshwater inflow indicator, above.

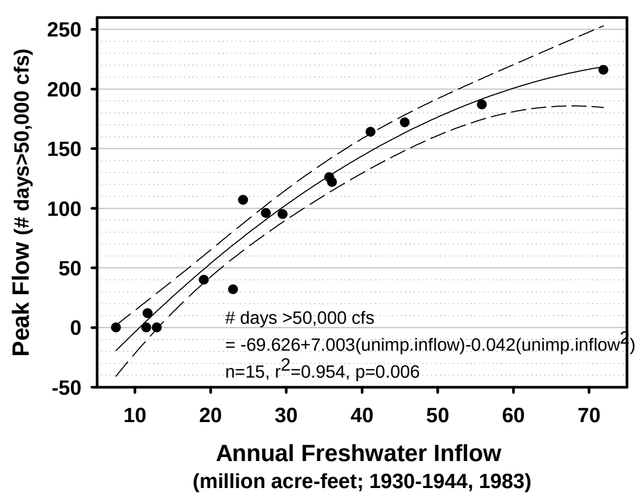

Figure P1. Actual (symbols) and predicted (regression with confidence limits) number of days of peak flow per year in relation to total annual inflow for 1930-1943 and 1983. This relationship was used to establish the reference condition for evaluation of the Peak Flow indicator.

Methods and Calculations: The Peak Flow indicator measures the frequency, as number of days per year, of peak flows into the San Francisco Estuary, compared to the number of days that would be expected based on unimpaired runoff from the estuary's watershed. Peak flow was defined as the 5-day running average of freshwater inflow>50,000 cfs. Selection of

[17] The Peak Flow indicator is also included in the Natural Disturbance Regimes Water Assessment Framework category.

this threshold value was based on two rationales: 1) flows of this magnitude shift the location of low salinity habitat[18] downstream to 50-60 km (depending on antecedent conditions), providing favorable conditions for many estuarine invertebrate and fish species; and 2) examination of DAYFLOW data suggested that flows above this threshold corresponded to winter rainfall events as well as some periods during the more prolonged spring snowmelt, therefore this indicator evaluated the estuary's responses to a key aspect of seasonal flow variation in its watershed.

The indicator is calculated as the difference between the actual number of days of peak flow per year and the expected number of days of peak flow per year:

Peak flow (days) = # days peak flow (actual) – # days peak flow (predicted).

Daily unimpaired flow data are available for only a few recent years therefore, to predict the number of days of peak flow per year under these conditions, a polynomial regression was developed based on actual flows from the 1930-1943 "pre-dam" period, before major storage dams were constructed on the watershed's large rivers (Figure P1). Water Year 1983, the year with the highest annual unimpaired inflow on record and during which flows were minimally affected by water management operations, was also included in this regression analysis to provide a high inflow value and anchor the regression. The regression equation is shown in Figure P1. For years in which the polynomial regression predicted a number of days of peak that was less than zero and in which the actual number of days of peak flows was zero, the indicator value (the difference between actual and predicted) was set to zero.[19] By incorporating unimpaired inflow as a component of the indicator calculation, the Peak Flow indicator has been normalized to account for natural year-to-year variations in hydrology.

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT 2008) for "increase[ing] freshwater availability to the estuary", "restor[ing] healthy estuarine habitat" and "promot[ing] restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary" are non-quantitative. Therefore, the reference condition was established based on the 95% confidence interval for the polynomial regression developed from pre-dam and 1983 data (see Figure P1 above). Over most of the range of unimpaired inflows, the maximum value for the 95% confidence interval was 15 days. Therefore the reference condition was set at twice this value, or -30 days (i.e., 30 fewer days of peak flow compared to the number predicted based on unimpaired inflow).

Results:

Results: Results of the Peak Flow indicator are show in Figure P2.

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[18] The location of low salinity habitat in the San Francisco Estuary is often expressed in terms of X2, the distance in km from the Golden Gate to the 2 ppt isohaline.

[19] This occurred in only three years: 1931, 1976 and 1977.

The frequency of peak flows into the San Francisco Estuary varies with water year type.
Peak flow frequency (as number of days per year) is highest in wet years, when there are of 144 days of peak flow per year on average for the 80 year data record, lowest in critically dry years (<2 days/year). Dry years have an average of 13 days/years, below normal years an average of 50 days/year and above normal years an average of 85 days. Since 1944, after dams on most the estuary's large tributary rivers were completed, actual peak flow frequency is significantly lower that would be predicted based on estimated unimpaired flow conditions (Mann-Whitney, $p<0.001$). There are an average of 12 fewer days of peak flows in critically dry years, 31 fewer days in dry years, 37 fewer days in below normal years, 54 fewer days in above normal years and 41 fewer days in wet year.

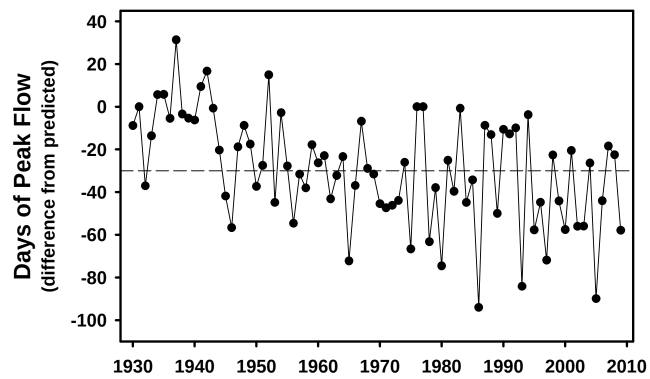

Figure P2. Changes in the peak flow frequency of freshwater inflow to the San Francisco Estuary, from 1930-2009. Horizontal dashed line shows the reference condition (-30 days).

Peak flow frequency has declined over time.
Peak flow frequency, expressed as the difference between actual peak flow frequency and predicted peak flow frequency under estimated unimpaired flow conditions, is highly variable but has declined significantly over the 80-year period of record (regression, $p<0.001$). Most of the decline occurred after 1943, immediately following completion of most of the large dams on the estuary's large tributaries. However, since 1944, peak flow frequency has continued to decline over time in dry, above normal and wet years (regression, $p<0.05$; regression for critically dry years, $p=0.052$; regression for below normal years, $p=0.87$). On average, there are 34 fewer days of peak flows per year since the mid-1940s than during the 1930-1943 period. In the 1980s, peak flows were reduced by an average of 39 days. In the 2000s, there was an average of 45 fewer days of peak flows.

Based on recent peak flow frequency, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have been met in less than 50% of years.
In the most recent decade (as well as for the most recent 5-year period), the reduction in peak flow frequency has been greater the reference conditions (30 days) in 60% of years. Since 1980, the reference condition for peak flow frequency has not been met in 57% of years.

Hydro-Geo Indicator 4. Dry Year Frequency

By Christina Swanson

Background and Rationale: California's Mediterranean climate is typified by unpredictable cycles of droughts and floods. Runoff from the Sacramento-San Joaquin watershed, which provides >90% of the total freshwater inflow to the San Francisco Estuary, can vary dramatically from year to year, and freshwater inflow to the San Francisco Estuary is a key physical and ecological driver that defines the quality and quantity of estuarine habitat (Jassby et al. 1995; Kimmerer 2002; Feyrer et al. 2007, 2010; Moyle and Bennett, 2008; Moyle et al., 2010). Water storage and diversions in the estuary's watershed reduce the amounts of freshwater that reaches the estuary and can result in inflow conditions comparable to dry hydrological conditions in years when actual hydrological conditions in the watershed are not dry. In dry years, total annual freshwater inflow, seasonal variations in inflow and the quantity and quality of low-salinity estuarine habitat are all reduced, resulting in stressful conditions for native resident and migratory species that rely on the estuary. Multi-year sequences of dry years, or droughts, exacerbate these stressful conditions and often correspond to populations declines and shifts and/or decreases in species' distributions.

Data Sources: The Dry Year Frequency indicator was calculated for each year using data from the California Department of Water Resources (CDWR) DAYFLOW model (for "actual flows") and CDWR's Central Valley Streams Unimpaired Flows and Full Natural Flows datasets (for "unimpaired flows"). For more information on these two datasets, see the Data Sources section for the Annual Freshwater inflow indicator, above.

Methods and Calculations: The Dry Year Frequency indicator measures the difference between the frequency of critically dry years based on estimated unimpaired freshwater inflows to the estuary and the frequency of critically dry years experienced by the estuary based on actual freshwater inflows. Critically dry (CD) years were defined as the driest 20% of years in the 80-year estimated unimpaired Delta outflows dataset, with total annual inflows to the estuary of less than 15,000 thousand acre-feet (see Table DY1).

Table DY1. Frequency-based classification of water years types based on estimated unimpaired annual inflow to the San Francisco Estuary.

Water year type	Estimated unimpaired inflow to the San Francisco Estuary (total annual, TAF)	Years (1930-2009)
Critically dry (driest 20% of years) NOTE: a "super-critical" category, corresponding to the driest 2.5% of years was also identified (see Figure DY2)	<15,000 TAF (Super-critical: <8,000 TAF)	**1931**, 1933, 1934, 1939, 1947, 1976, **1977**, 1987, 1988, 1990, 1991, 1992, 1994, 2001, 2007, 2008 (n=16) Super-critical years are shown in **bold**.
Dry	15,000-21,500 TAF	1930, 1944, 1949, 1955, 1957, 1959, 1960, 1961, 1964, 1966, 1968, 1972, 1981, 1985, 1989, 2009 (n=16)
Below normal	21,500-29,500 TAF	1932, 1935, 1936, 1937, 1945, 1946, 1948, 1950, 1953, 1954, 1962, 1979, 2000, 2002, 2003, 2004 (n=16)
Above normal	29,500-42,000 TAF	1940, 1942, 1943, 1951, 1963, 1965, 1970, 1971, 1973, 1975, 1980, 1984, 1993, 1996, 1999, 2005 (n=16)
Wet (wettest 20% of years)	>42,000 TAF	1938, 1941, 1952, 1956, 1958, 1967, 1969, 1974, 1978, 1982, 1983, 1986, 1995, 1997, 1998, 2006 (n=16)

For the indicator, actual total annual freshwater inflows to the estuary for each year were categorized using this water year type classification scale. For each year (1939-2009), the number of CD years that occurred for the prior ten-year period that ended in the measured year was calculated for both unimpaired flows and actual flows. The indicator measured the difference between the number of CD years that occurred under unimpaired conditions and the number that occurred in actual conditions.

The indicator is calculated as:

Dry Year Frequency

= (# CD years, unimpaired inflow conditions for year$_{(0\ \text{to}\ -9)}$) – (# CD years, actual inflow conditions for year$_{(0\ \text{to}\ -9)}$).

By incorporating unimpaired inflow as a component of the indicator calculation, the Inter-annual Variation in Freshwater Inflow indicator has been normalized to account for natural year-to-year variations in hydrology.

Goals, Targets and Reference Conditions: The CCMP goals (see Technical Report #1; SFEIT 2008) for "increase[ing] freshwater availability to the estuary", "restor[ing] healthy estuarine habitat" and "promot[ing] restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary" are non-quantitative. However, California's State Water Resources Control Board (SWRCB) recently determined that, in order to protect public trust resources in the Sacramento-San Joaquin Delta and San Francisco Estuary, 75% of unimpaired runoff from the Sacramento-San Joaquin watershed should flow out of the Delta and into the estuary (SWRCB 2010).[20] Therefore, the reference condition for the Dry Year Frequency indicator was established by calculating the average difference between CD frequency in unimpaired inflows that had been reduced by 15-25% (depending on water year type).[21] Based on this calculation, the reference condition was set at 1.5 years.

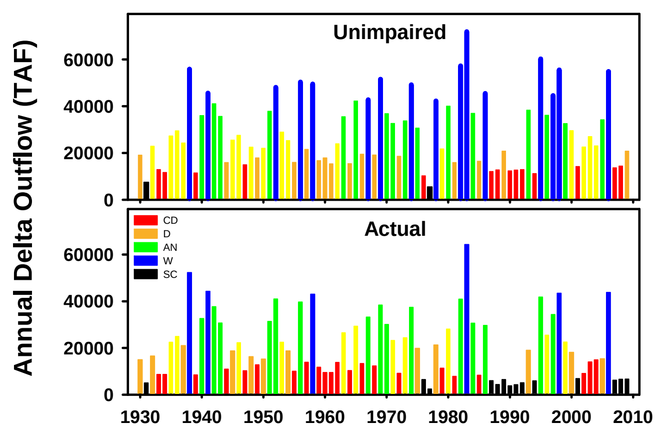

Figure DY2. Freshwater inflows to the San Francisco Estuary under unimpaired conditions (top panel) and actual conditions (bottom panel). Each histogram bar has been colored to show the frequency-based water year type classification for unimpaired flows. The critically dry category was further partitioned to show "super-critical" years, comparable to the driest 2.5% of years of unimpaired flows.

Results: Results of the Dry Year Frequency indicator are show in Figure DY3.

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[20] The SWRCB recommendation was for the winter-spring period (January-June) and it was expressed as the 14-day running average of estimated unimpaired runoff, rather than as an annual or seasonal total.

[21] For calculation of the reference condition, unimpaired inflows<29,500 TAF (60% of years) were reduced by 25%, unimpaired inflows between 29,500 and 42,000 TAF were reduced 20%, and unimpaired inflows >42,000 TAF were reduced by 15%.

The frequency of critically dry inflows to the San Francisco Estuary has varied over time. While the classification of critically dry year inflows is based on the bottom quintile from the 80-year unimpaired dataset, the frequency of critically dry hydrological conditions (i.e., that result in CD freshwater inflow to the estuary) has been more variable over that period (Figure DY2). The number of CD years per 10 year period for unimpaired conditions ranged from zero, during the 1950s and 1960s, to as high as six years, during the 1990s. For actual conditions, which were affected by the amounts of water stored and diverted from the estuary's watershed, the frequency of freshwater inflows in amounts comparable to what the estuary would experience in critically dry years under unimpaired conditions, was higher (Figures DY2 and DY3). The largest increases in CD year frequency occurred in the 1960s, a period during which, based on hydrological conditions, there were no critically dry years. However, on the basis of the amount of freshwater that actually flowed into the estuary, an average of six out of 10 years were critically dry during this period. In the 1980s, an average of 1.8 years were critically dry in the watershed but, in the estuary, and average of 4.4 years out of 10 years were critically dry (i.e., there were an average of 2.6 more CD years out of 10 years than there were based on hydrological conditions in the estuary). Conditions during the most recent decade (2000-2009) were similar, with an average of 4.3 CD out of 10 years for the estuary compared to just 2.1 CD years based on unimpaired conditions in the estuary's watershed.

The frequency of freshwater inflow conditions in the San Francisco Estuary that are comparable to critically dry years has increased.
Since 1944, when major dams on the estuary's tributary rivers were completed, the frequency of freshwater inflow conditions that correspond to critically dry years has increased significantly (Wilcoxon Signed Rank test, $p<0.001$) (Figure DY3). On average, the estuary experiences 2.8 more CD years per 10-year period than it would based on estimated unimpaired inflows and hydrological conditions in its largest watershed.

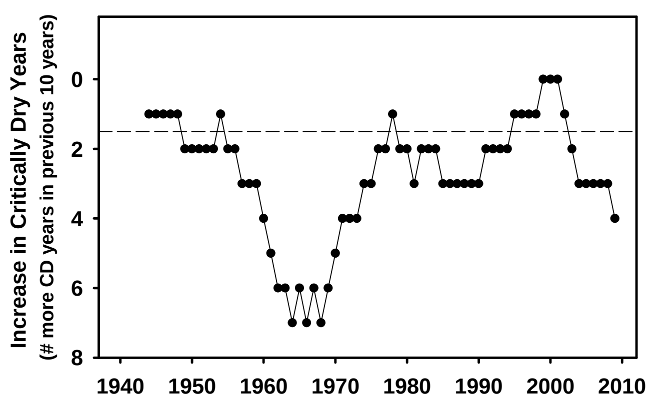


Figure DY3. Changes in the frequency (expressed as number of years more in a 10-year period) of critically dry freshwater inflow conditions to the San Francisco Estuary, from 1939-2009. Horizontal dashed line shows the reference condition (1.5 years).

Based on recent critically dry year frequencies in the estuary, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have not been met in most years.
Since 2003, the estuary has experienced two to four more years per 10-year period of critically dry freshwater inflow conditions that it would have under unimpaired conditions. As of 2009, seven of past 10 years have, for the estuary, been critically dry. Over the past 60 year, the frequency of critically dry conditions in the estuary has been greater than the reference condition in 41 years (68% of years).

Summary of result for flow indicators for Hydrology and Geomorphology

Collectively the four indicators of freshwater inflows developed for the hydrology and geomorphology Water Assessment Framework category provide a comprehensive assessment of the status and trends for freshwater inflow conditions to the San Francisco Estuary from its largest watershed. Each of the indicators shows significant alterations to inflows to the estuary, including reductions in annual inflows, reductions in inter-annual variability of annual inflows, reductions in the frequency of peak flows and increased frequency of annual inflows to the estuary that are comparable to the relatively rare critically dry hydrological conditions in the watershed. Table DY4 summarizes the indicator results relative to the CCMP goals (as they are expressed by the reference conditions).

Table DY4. Summary of results, relative to the CCMP goals to "increase freshwater availability to the estuary", "restore healthy estuarine habitat" and "promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary," of the four freshwater inflow indicators for the San Francisco Estuary.

Indicator	**CCMP Goal Met (yes, no or % met)**	
	Past 10 years	**Past 5 years**
Annual Inflow	No (not met in 90% of years)	No (not met in 80% of years)
Inter-annual Variation in Inflow	Partially met (50% of years)	Yes
Peak Flow	Partially met (40% of years)	Partially met (40% of years)
Dry Year Frequency	Partially met (30% of years)	No

Hydro-Geo Indicator 5: Stream Alteration and Drainage Modification

(Estuary Tributaries excluding the Central Valley Rivers)

Background and Rationale: Urban and agricultural development have dramatically altered the natural streams in many of the watersheds tributary to the Estuary, especially in the highly urbanized areas on the alluvial plain surrounding the Bay. Creeks that once spread out and dropped their sediment on the flatlands, and rivers that overflowed onto floodplains now connect to the Estuary in engineered channels or underground storm drains. The network of underground storm drains and engineered channels over the flatlands has gradually expanded as increased impervious area has resulted in greater runoff. In the upland portions of the watershed creeks may be impounded to create reservoirs, resulting in the loss of stream channels through inundation.

Urban and suburban streams are no longer viewed merely as conduits for storm runoff; this earlier view has been replaced by recognition of the value of natural or restored streams in urbanized areas for wildlife habitat, pollution control, public education and enjoyment, and economic revitalization. The value of protecting and restoring the estuary's tributary streams is firmly established, and despite severe physical and cost constraints, the multi-decadal efforts are entering a second "generation" that requires better assessment of their condition and the opportunity to make measurable changes in the health and recovery of the estuary and its watersheds.

A stream alteration and drainage modification indicator is proposed for streams tributary to the San Francisco Bay Estuary, excluding the Central Valley Rivers. The indicator is based on the lengths of the natural, piped, engineered, and impounded reaches relative to the total length of the historical stream channel. Two metrics are proposed: (1) percent length of natural channel remaining, and (2) drainage length change relative to historical length. These metric are direct measures of drainage and channel modification relative to the historical condition, and can be used to characterize present watershed alteration as well as track future changes in channel and drainage characteristics. They can be integrated with other indicators of watershed alteration such as imperviousness and hydromodification. They could also be integrated with indicators of stream habitat quality if more detailed measures of stream condition are included such as length of shaded riparian reach, length of incised channels, or length of various stream habitats.

Because consistent data for all the watersheds tributary to San Francisco Bay is not available (see data sources below) and no targets have been established, a Bay-wide indicator is not calculated. The metrics for watersheds in San Mateo County, however, are calculated and shown in the results.

Data Sources: The Oakland Museum Creek and Watershed map series (Oakland Museum maps) has digitally mapped the current and historical position and condition of the streams in watersheds tributary to the Bay in San Francisco, San Mateo, Santa Clara, most of Alameda, and West Contra Costa counties (see attached reference map). The Oakland Museum maps are a consistent dataset developed over the past 17 years. Early maps have been updated, so that the available digital data now range in publication date from 2002 to 2010. The dataset consistently maps only those natural and engineered channels having a minimum of 0.2 square kilometers of watershed, and storm drains 24 inches or greater in diameter. Engineered channels include natural creeks significantly reinforced by concrete, rip-rap on at least 2 out 3 sides (3 sides = bottom and 2 sides) as well as artificial channels not coincident with a natural or historic creek. Wide engineered channels, mapped as flood control channels, would be included in the total length of engineered channels for the indicator. Engineered channels may provide aquatic habitat and have riparian corridors and thus cannot always be interpreted as being devoid of habitat although many of them are. Some newer engineered channels are designed to mimic natural channels.

On the Oakland Museum maps, historical streams are presently shown only where they do not coincide, at 1:24,000 scale, with modern streams, storm drains, and engineered channels. Thus the total length of historical channel will equal the sum of historical channels mapped, modern natural channels, and engineered channels and storm drains that have been constructed in the corridor of the historical channel.

Information for the watersheds not mapped in the Oakland Museum series would either have to wait until the additional maps are completed or could be compiled from county and city flood control and public works agencies but it will not have the same QA/QC or level of detail that the Oakland Museum series has made standard. In addition, the historical position of the streams will likely not be readily available from the public agencies.

Methods and Calculations: For each watershed tributary to the Estuary, the length of stream channels in each of the following categories is measured from the Oakland Museum maps. Letters in parentheses refer to column headings in Table 1 in the results. All measurements are exclusive of any historical tidal marsh areas of the watershed.

1. Stream length of natural channel occupying its historical position (C)
2. Stream length of engineered channel, defined as either a channel with man-made features on 2 out of the 3 sides or a constructed channel that occupies a position different from the historical stream (i.e. stream straightened or moved to a new location) (D)
3. Stream length of underground drains (pipes, culverts, storm drains) (E)
4. Stream length of original historical channel. This includes the present natural channel plus portions now buried, drained, replaced by underground drains or engineered channels, or inundated by impoundments. (B)

The indicator is expressed as two metrics as dimensionless ratios, one showing the **percent of natural creek remaining** and the other showing the **change in drainage length** from the historical condition.

$$\text{Percent natural creeks remaining (G)} = 100 \times \frac{\text{Modern natural creeks (C)}}{\text{Historical natural creeks (B)}}$$

$$\text{Drainage Length Change (H)} = \frac{\text{Modern flow network length (C+D+E)}}{\text{Historical natural creeks (B)}}$$

These metrics represent two ways of expressing the alteration of the stream condition. The first metric illustrates the net loss of natural creeks. It varies widely with watershed topography, history, and degree of urbanization. The second metric shows the change in drainage density, and is typically greater than unity for urban watersheds where drainage has been added as a response to increased runoff from impervious surfaces.

Goals, Targets and Reference Conditions: The historical stream length is the baseline to which the modern condition is compared. There is no agreed-upon goal for restoring natural stream channel length but restoring historical stream length is not a realistic goal or reference condition in highly urbanized watersheds. It would be more realistic to use current stream lengths as a reference condition and to measure change from the current lengths. Thresholds of alteration are not defined for stream or drainage length change as has been attempted to assess how changes in percent impervious cover impact watershed and stream function.

Results: Example calculations for selected streams in San Mateo County are shown in Table SA1, which is derived a poster prepared by from Sowers et al 2010 for CalFed Bay-Delta Science Conference. The Oakland Museum maps can also be seen at http://www.museumca.org/creeks/ (Link to all published creek & watershed maps and digital data). Sowers et al 2010 also recently compiled the watersheds in western Alameda County in Google Earth so that they can be seen in 3-D.

Table SA1. Examples of the stream alteration and drainage modification indicator for San Mateo County watersheds. Percent natural channel remaining varies widely with watershed. The observed increase in drainage length in most watersheds reflects the addition of underground drains. The loss of length of San Mateo Creek is primarily a result of the impoundment of the stream, inundating about 30 miles of channel.

	A	B	C	D	E	F	G	H
		Historical	**Modern flow network**				**Indicator Metrics**	
Watershed name	**Watershed Area (km²)**	**Natural creeks (km)**	**Natural creeks (km)**	**Engineered channels (km)**	**Underground drains (km)**	**TOTAL drainage (km)**	**Natural creeks remaining**	**Drainage length change**
Colma Creek	38	48	4	8	73	85	**8%**	**1.8**
San Bruno/Zanjon Creek	11	14.1	1.3	4.1	13.6	19	**9%**	**1.4**
San Pedro Creek	20	28.9	14.5	4.5	10.3	29	**50%**	**1.0**
Laurel Creek	10	11	6	1	14	21	**55%**	**1.9**
San Mateo Creek	56	75	43	1	10	54	**57%**	**0.7**

These indicators can be reported for individual watersheds or for groups of watersheds as appropriate. Because the level of human modification of the Estuary watersheds varies significantly – ranging from the mostly developed smaller ones in the urban core to the much smaller percentage modification in some of the North Bay streams – the indicator could be sub-divided based either on geography, watershed area or a threshold of developed area. For example, the "scores" for each of the smaller urban watersheds would be aggregated into one "urban" indicator.

WAF Category: Landscape Condition

Landcape Condition Indicator 1. Wetlands abundance

By Josh Collins and Thomas Jabusch

Background and rationale: Wetlands (including tidal flats) and riparian areas provide numerous and important services including pollution filtration, groundwater recharge, erosion control, and flood control. They support most of the rare and endangered plants and animals in the region and account for a large proportion of its native biological diversity. They are transitions between aquatic and terrestrial environments and are therefore sensitive to changes in climate or land use that affect water supplies and sediment supplies. Numerous local, state, and federal policies, programs, and projects are designed to protect and restore wetlands and riparian areas.

Data sources: The methods of mapping historical and current wetlands and riparian areas have been developed by SFEI and SCCWRP and are being implemented in the San Francisco Bay Area by SFEI on behalf of state and federal agencies. The methods are being incorporated into the state's comprehensive wetland and riparian monitoring plan and are being transferred from SFEI to other work centers.

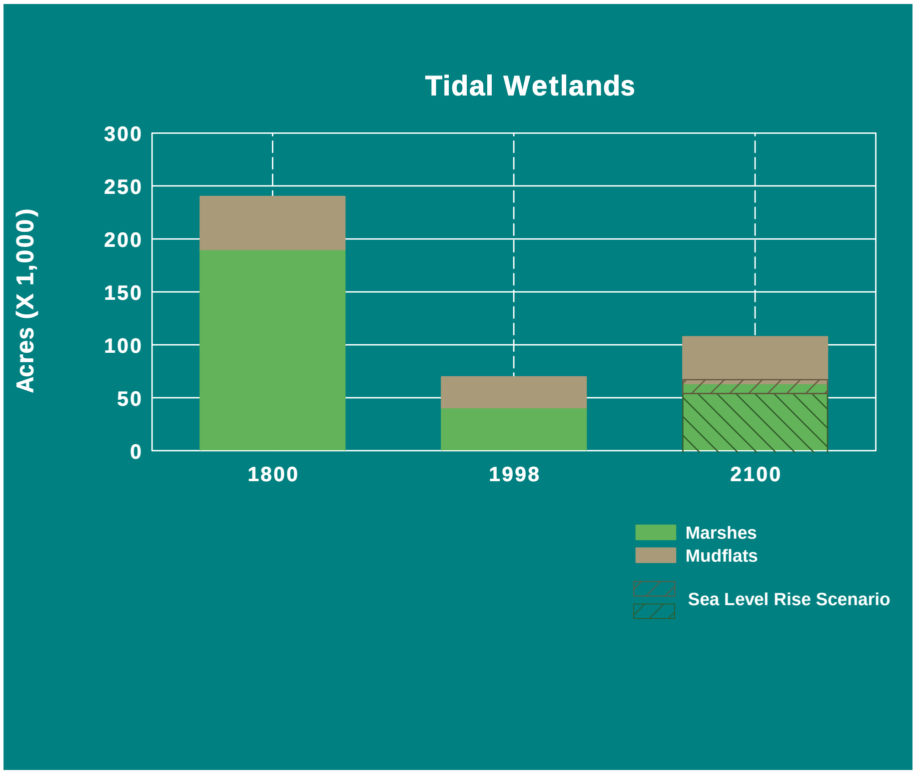
Methods and calculations: this indicator determines the abundance of tidal wetlands in acres relative to historical conditions. The indicator uses the Bay Area Aquatic Habitat Basemap available on Wetland Tracker (www.wetlandtracker.org). The Basemap constitutes a baseline data set for tracking changes in the extent and condition of aquatic resources and features inventories of aquatic habitat. Base map layers have been developed with mapping protocols and QAQC procedures that comply with state and federal data standards (http://www.wrmp.org/protocols.html) while meeting local planning needs for detail and accuracy. Mapping of tidal wetlands has been completed and will be continuously updated by designated local data stewards. Mapping of riparian areas is expected to be completed by the end of 2009 and can be included in the indicator once available.

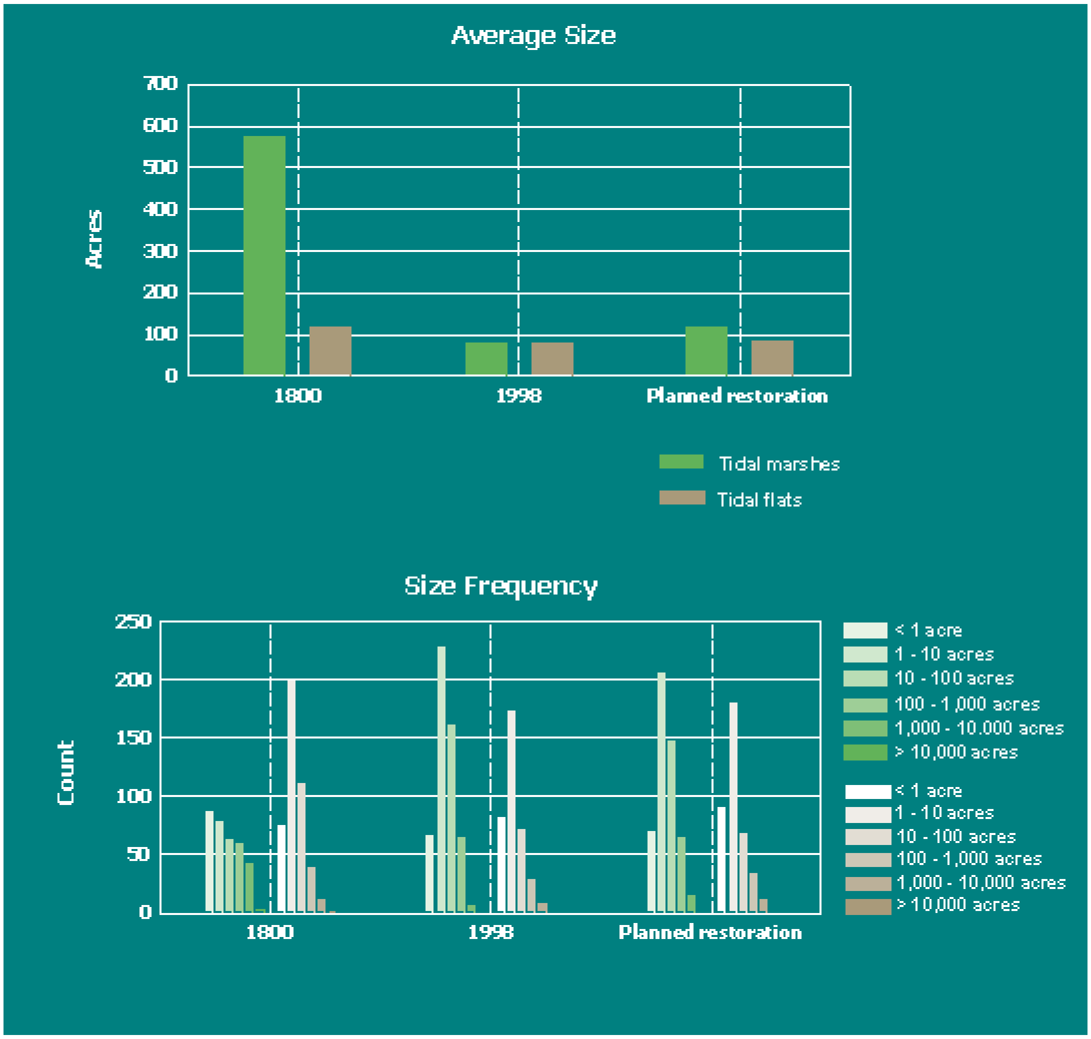
Goals, targets, and reference conditions: This indicator assesses progress towards recommended future Bayland habitat acreage, as proposed by the Baylands Ecosystem Habitat Goals Project (Goals Project). The Goals call for increasing the total area of tidal marsh to about 100,000 acres and maintaining the present extent of tidal flats.

The indicator also identifies trends in the acreage of tidal wetlands in the Bay. Historical reference conditions are represented in the Historical Baylands ca. 1800 map, and the CCMP benchmark is represented in the Modern Baylands map generated in 1998. Both maps are from San Francisco Bay Area EcoAtlas (http://legacy.sfei.org/ecoatlas/index.html).

A goal for riparian areas has not been identified.

Results:


Tidal Wetlands
Acres (X 1,000)
300
250
200
150
100
50
0
1800
1998
2100
Marshes
Mudflats
Sea Level Rise Scenario



<u>Value against reference condition and target</u>

The tidal habitat acreage ca. 1998 can be used as a reference condition to towards the goal of establishing 100,000 acres of tidal marshes and maintaining 30,000 acres of tidal flats, as proposed by the Baylands Ecosystem Habitat Goals Project (Goals Project). The recommended future acreage is intended to support shorebirds, waterfowl, mammals, and other wildlife.

The reference condition is roughly 40,000 acres of tidal marshes, or 40% of the total desired acreage. This could be interpreted as the goal being 40% met as of today. Alternatively, the reference condition could be interpreted as ground zero for tracking. For example, restoring 70,000 acres would then mean the goal is 50% achieved

An updated value to compare against these targets and goals will be available by the end of 2010, with completion of the Bay Area Aquatic Habitat Base Map.

Additional metrics presented here are the average size and size frequency of tidal marshes. These metrics are not used to measure progress towards a goal, but to identify trends in morphological wetlands features on a regional scale.

Trend

Comparison of past and present data shows that about 80% of historic tidal marshes around the Bay have been lost. A total of 40,000 acres remain, compared to 190,000 acres that existed around 1800. The total acreage of tidal flats has been from 50,000 to 30,000 acres (more than 30% lost). If all current and planned restoration projects are implemented and assuming no changes in other drivers, the future acreage of tidal wetlands could increase to 63,000 acres of tidal marshes and that of tidal flats to 44,000 acres. Some of these restored wetlands could be lost again due to climate-driven sea level rise.

The average size of tidal marshes around the Bay has decreased dramatically since the early 1800s, from 580 acres to 80 acres. In other words, today's marshes are less than a sixth the size of historic marshes. Restoration efforts may increase the average size of marshes by more than a third to 115 acres. The average size of tidal flats has been reduced by 30% from 115 to 80 acres. Planned restoration efforts may increase the average size slightly: the projected average size of tidal flats upon completion of planned restoration efforts is 88 acres.

The size frequency graph shows that in the early 1800s there were extensive marshlands >10,000 acres that no longer exist and that the number of very small marshes was also reduced since then. There are also less extensive tidal flats than there were in the past.

Interpretation

The available and projected numbers on the extent of tidal wetlands indicate that the trend of wetland loss is being reversed and that restoration projects will increase the overall acreage of tidal wetlands compared to the present. Based on these numbers, current restoration plans will not achieve the recommended Baylands Goal of increasing the total area of tidal marsh from the existing 40,000 acres to 100,000 acres. Planned restoration projects but will increase the total acreage of tidal flats above the present extent, unless these restoration efforts are counteracted by sea level rise.

Sea level rise poses a challenge to achieving any set goals for protecting or increasing the total acreage of tidal wetlands. However, the overall effect of sea level rise is difficult to predict, not only because the magnitude of future sea level rise is unknown. Factors such sedimentation, tidal erosion, or invasive species may counteract or accelerate the effects of seal level rise.

Met or not met CCMP goal?

The total acreage of tidal marsh in 1998 was 40,000 acres or 40% of the Baylands Goal of 100,000 acres. Once the Bay Area Aquatic Habitat Base Map becomes available in December 2010, it will be possible to assess whether progress towards this goal has been made in the last 12 years. If the Baylands Goals would be adopted, there should be no expectation that the CCMP goal will be met in the foreseeable future by existing and planned restoration efforts. More restoration projects than those under way or planned are needed to achieve the goal of restoring 100,000 acres. The total acreage of tidal flats may be increasing as restoration projects are implemented, unless they are counteracted by sea level rise.

Landscape Condition Indicator 2: Quality of tidal habitat

By Josh Collins and Thomas Jabusch

Background and rationale: The California Rapid Assessment Method (CRAM) is designed to assess the health of wetlands and riparian areas based on visual indicators of field condition. CRAM provides standardized scores for a set of metrics and attributes of wetland form, structure, and landscape setting. It has passed review by the U.S. Army Corps of Engineers for use in its regulatory and restoration programs and is currently being reviewed by the state for use in its programs. CRAM was recently used to assess the health of estuarine wetlands and riparian health in the Bay Area and elsewhere in California.

Rationale: The overall condition or health of tidal habitats can be assessed in terms of the complexity of their physical and biological structure, and their connectivity to other habitats. When these terms are assessed together across an integral area of habitat, they represent the area's overall capacity or potential to support the functions and services to which it is naturally suited. When these assessments are standardized relative to reference conditions, they can be compared to each other and over time.

Data sources: Regional and statewide ambient surveys and project assessments.

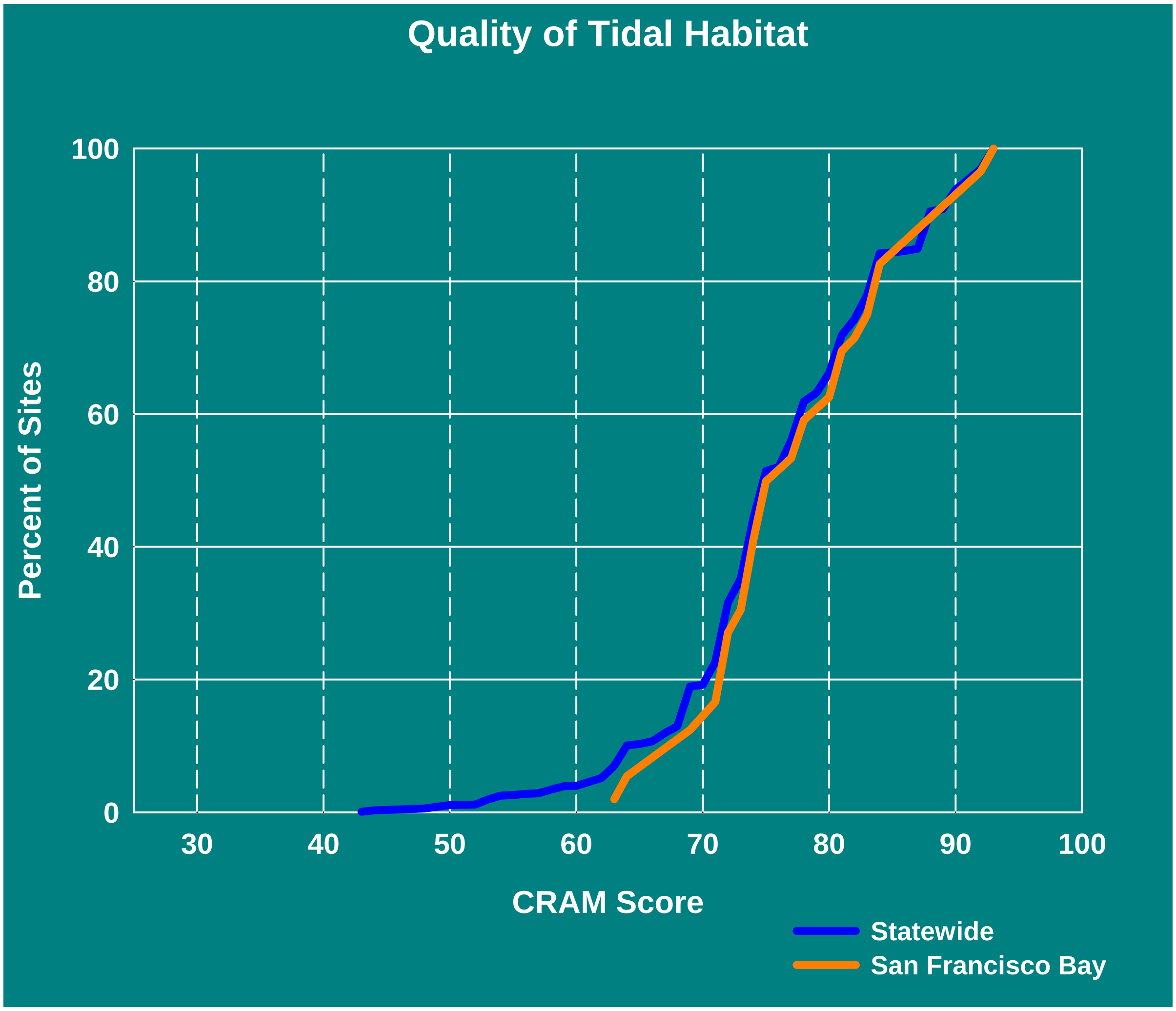
Methods and calculations: results of the CRAM index the indicator results are dimensionless scores for overall health or functional capacity as percentages of maximum possible scores as determined from reference conditions and ambient surveys. The CRAM index is based on four universal wetland attributes: buffer and landscape context, hydrology, abiotic structure, and biotic structure. Each of these attributes consists of a number of metrics:

Attributes		Metrics
Buffer and Landscape Context		Landscape Connectivity
		Percent of AA with Buffer
		Average Width of Buffer
		Buffer Condition
Hydrology		Water Source
		Hydroperiod or Channel Stability
		Hydrologic Connectivity
Structure	Physical	Structural Patch Richness
		Topographic Complexity
	Biotic	Organic Matter Accumulation
		Interspersion and Zonation
		Number of Plant Layers Present
		Percent of Layers Dominated by Native Species
		Number of Co-dominant Species
		Percent of Co-dominant Species that are Native
		Vertical Biotic Structure

The CRAM index score is calculated as follows:

Steps to Calculate Attribute and Site Scores	
Step 1: Calculate Metric Score	For each metric, covert the letter score into the corresponding numeric score (A=4; B=3; C=2; D=1)
Step 2: Calculate raw Attribute Score	For each attribute, calculate the raw attribute score as the sum of the numeric scores of the component metrics
Step 3: Calculate final Attribute Score	For each attribute, covert the raw score into a percentage of the maximum possible score (max. possible score = 52 for vernal pools and playas; 64 for all other wetland classes). Round the percentage to the nearest whole value.
Step 4: Calculate the Overall Site Score	For each site, calculate the average value for the final attribute scores. Round the average to the nearest whole value less than or equal to 100.

For comparisons, CRAM index results are commonly reported as cumulative distribution frequencies (CDFs). The following graph compares the CDFs of CRAM results from ambient surveys conducted in 2007 for the Bay Area and the entire state:



To arrive at an index value, the CDFs are summarized by calculating the Ecosystem Index of Services (EIS):

EIS = SUM (CRAM score x Proportion of total area represented by score)

The EIS statistic varies from 25-100 corresponding to the possible range in CRAM Index scores. An EIS of 100 indicates that the surveyed area is at the highest possible function, whereas an EIS of 25 would indicate the lowest possible function. EIS can be employed as a simple statistic to inform managers on current condition of natural resources, such as represented on a CDF.

Goals, targets, and reference conditions: this indicator measures achievement of the goal of "anti-degradation", i.e. no decrease from baseline condition.

CRAM reference sites have 90th percentile scores for the overall CRAM index, the four different attributes, or the metric scores (within the attributes).

Results:
In the analysis performed, the SF Bay EIS was 78 and the State EIS was 76.

Value against reference condition and target
Tidal habitats around the Bay perform well compared with other regions in the state. The 2007 survey can be used as a baseline to compare against future results.

Trend
Long-term data are not yet available to assess trends, but this will be possible within the next 15 years.

Interpretation
Both results suggest that tidal habitats around the Bay perform relatively well, with SF Bay only slightly better than the State as a whole. The similar numbers makes sense since the majority of estuarine area in the state is in SF Bay.

Met or not met CCMP goal?
"Anti-degradation" could be interpreted as performing better or at least as good as a region than the statewide average. More research is needed to determine whether current conditions of existing habitat do in fact support CCMP Goals for wildlife and habitat.

V. Statistical Methodology for Aggregation: Analyzing Indicator Data Across Space and Time

By Nadav Nur, PRBO Conservation Science

Introduction

As previous chapters of this report have demonstrated, there is a wealth of information on indicators, indicators whose values vary over space and time. Given that variation, how can we maximize the information value of an indicator or set of indicators, thus separating signal from noise? The "signal" we are trying to extract can be with respect to **temporal variation** (in particular, variation among years) as well as **spatial variation.** Thus, in this chapter, we will try to address the more specific question:

- How best to characterize variation in time, especially in the context of spatial patterns of variability?

In addition to considerations of space and time, an additional challenge is posed when we have multiple metrics for an indicator, such as multiple species. Thus, a second specific question we address here is,

- How best to combine indicator metrics from multiple species?

Preceding chapters of this Report provide a multitude of indicator results addressing each of the attributes of the Watershed Assessment Framework. Here we selectively pick a few examples (some culled from preceding results and others from other sources) in order to illustrate the statistical challenges posed above. The objective of this chapter is to identify pitfalls in the analysis and presentation of indicator results and provide some guidance and recommendations to address the statistical challenges.

The San Francisco Estuary Indicators Team (SFEIT) has focused on analyzing and presenting quantitative metrics, rather than qualitative values (e.g., ordinal scores), and thus this chapter focuses on the former. Two good references for additional information on analysis of indicator data are provided by Shilling (2010), especially Appendix A, and Nur et al. (1999).

Variation Across Time

The indicators presented in previous chapters all have a temporal component. In many cases, they reflect change from one year to the next. A large body of work has developed in the social sciences and ecological sciences under the category of "Time Series." Many excellent references deal with time series analysis (e.g., Hamilton 1994).

Here is a simple example of data collected over time, in this case the peak number of pairs of a tern species, the roseate tern, counted at their breeding sites in a year (USFWS; http:/www.esasuccess.org/reports). If we were interested in using the tern species to assess the biotic condition of a region we might use the number of breeding terns in a year as an indicator. A simple regression line has been fit to the data, as is often performed.

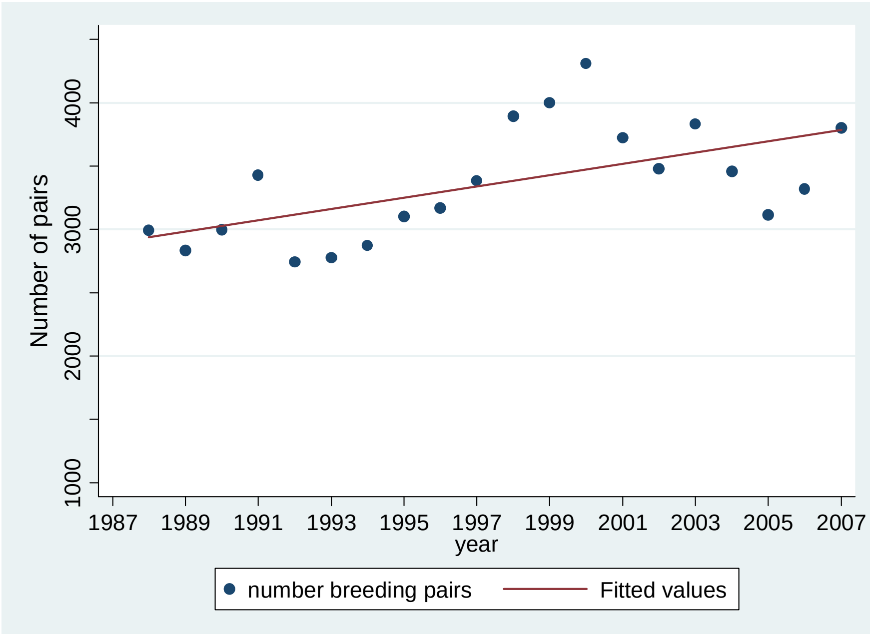


Figure 5-1. Number of breeding pairs of roseate terns in each year and a linear regression fit.

In this case, and in many other cases, simply fitting a linear trend to the indicator is inadequate. Here, we draw attention to three shortcomings of such an analysis: (1) One must consider non-linearity of the change over time, (2) specific attention should be paid to "change-points," and (3) analysis of log-transformed values is often desirable. Each shortcoming represents a potentially important aspect of indicator analysis, and thus each is discussed in some detail in its own section in this chapter.

Beyond Linearity: Allowing for Non-linear change over time

In the above example a simple linear trend has been fit to the data, but such a fit appears to be a misleading representation of change over time: In the early years, the trend appears to be positive (e.g., increase from 1992 to 2000), followed by a decrease. If one wanted to characterize the trend over time, then a better approach is to fit a **non-linear trend or trajectory** (some have argued that 'trajectory' is the preferred term as it does not imply linearity, which 'trend' may imply). We argue that the fitting of non-linear trends should be a common place practice and should always be considered when analyzing and presenting indicator results. This can be done in several ways:

i. fit a polynomial, such as a quadratic or cubic equation. An example of a cubic equation fit to the data is shown in Figure 5-2. See Kutner et al. (2005) and Harrell (2001) for further information. One advantage of this approach is that one can estimate the quadratic and cubic coefficients, obtain a C.I. around the estimate, obtain P-values of AIC (Akaike's Information Criterion) scores for a cubic vs. a quadratic equation, and so on. In this case, a cubic equation appears to give a good fit ($R^2 = 0.517$, adjusted $R^2 = 0.426$, $P = 0.008$) and captures some of the trajectory.

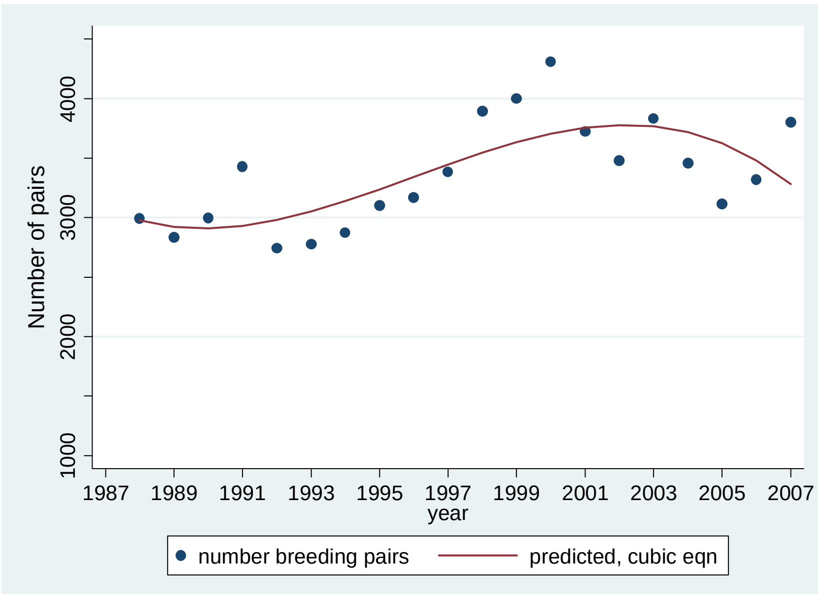


Figure 5-2. Number of breeding pairs of the tern species in each year and a cubic equation fit to the data.

ii. transform the independent variable to better **linearize** the relationship between dependent variable and independent variable. For example one can fit Y to the log of X, the inverse of X (= 1/X), the square-root of X, the square of X, etc. In this case, with respect to the original metric (in this case number of breeding pairs) there is a non-linear relationship, but by transforming the independent variable, we may obtain a linear relationship. The same may apply to transforming the dependent variable (Nur et al. 1999, Kutner et al. 2005). The assumption in applying this method is that there is a monotonic (increasing or decreasing) relationship between the indicator and the independent variable, but that the relationship is non-linear unless transformed. Below is an example in which the independent variable is an inverse transformation of year. Not surprisingly, with only two parameters (an intercept and a coefficient of the year-transformed variable), the R^2 is not as great (= 0.371; R^2 adj = 0.336), but it is highly significant (P = 0.004).

One advantage to an inverse transformation is that it allows the variable to reach an asymptotic (i.e., stable or "plateau") value, and furthermore this plateau is estimated by modeling procedure (whether linear or other approaches). The implication here is that with enough time, the terns will plateau at about 4000 pairs.

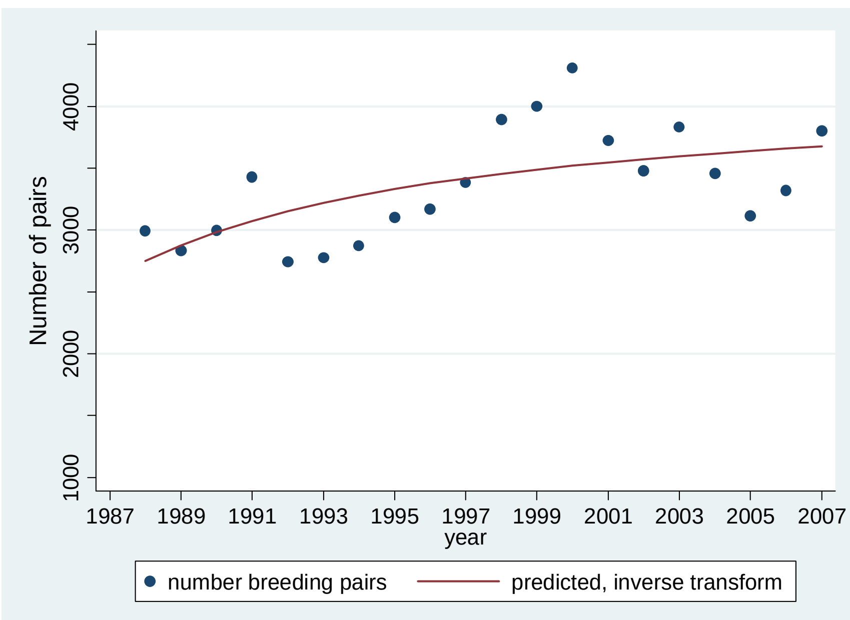


Figure 5-3. Number of breeding pairs of the tern species in each year and the equation of best fit to (1/X) where X = number of years since 1987.

iii. fit a non-linear "smooth" to the data, using one of several techniques such as **lowess** (also called **loess**) or a cubic spline (Cleveland 1979, Davison 2003, Hastie et al. 2009). From a descriptive point of view, non-linear smooths are very desirable, especially because of their high degree of flexibility (Davison 2003). However, such an approach does not provide a parametric estimate of the trend (e.g., trend coefficient) with an associated standard error. Figure 5-4 demonstrates an example of use of a lowess smoother.

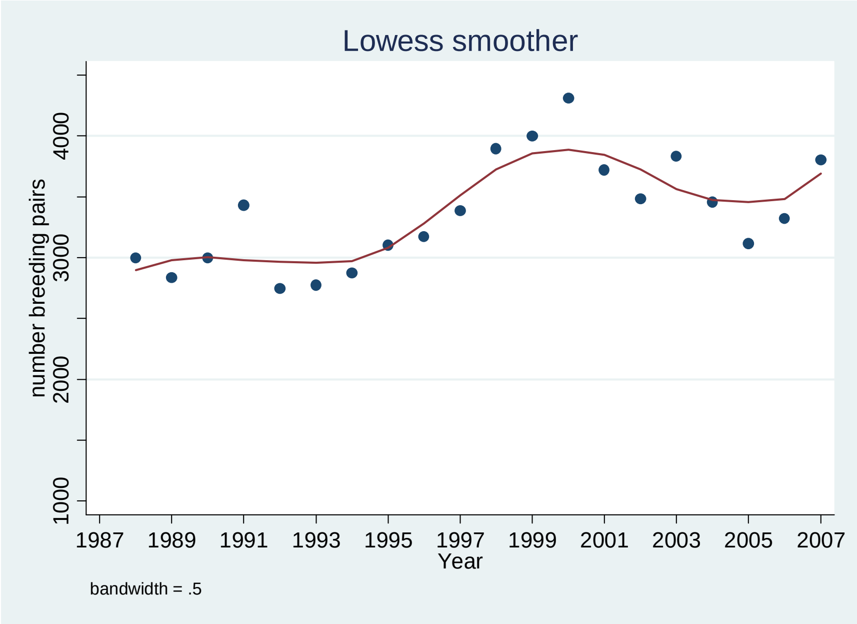


Figure 5-4. Number of breeding pairs of the tern species in each year and a lowess smoother (locally weighted regression), with degree of smoothing (bandwidth) = 0.5.

iv. fit a "fractional polynomial" to the data. Fractional polynomials represent a recently developed technique that combines some of the best elements of the above (i) – (iii), while improving on them. They demonstrate more flexibility than standard polynomial regression, while providing for parametric estimates of trend coefficients and statistical tests. The reader may consult Royston and Sauerbrei (2005) for detailed explanation and examples.

Change-point Analysis

An additional alternative to a simple linear regression is to fit linear trends piece-wise. A simple intuitive approach would be to divide the years into time periods and then fit **separate regressions** to each time period. Often this is done post-hoc: one "eye-balls" the results and decides where to demarcate the periods, and then fits the separate regression lines. Previous investigators applied this approach, yielding three separate regressions.

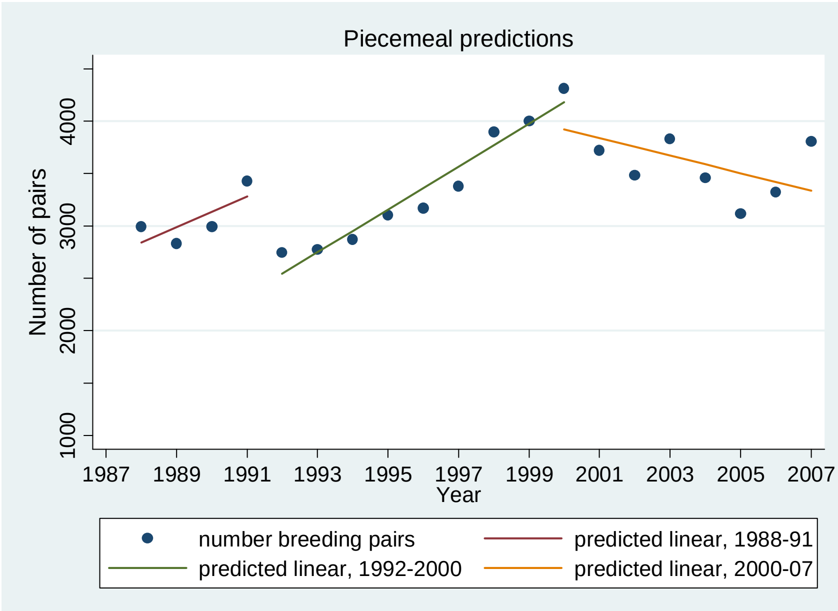


Figure 5-5. Piecemeal fit of number of breeding pairs in each year, with three separate linear pieces.

As a first step, such an approach has some value, highlighting two periods of growth (1988 to 1991 and 1992 to 2000) followed by a period of decline (2000 to 2007). However, there are important drawbacks to this approach. The decline from 1991 to 1992 is not addressed; it is ignored. And the expected number in 2000 is either high (about 4200) or not so high (3920). As a result of fitting three separate regression lines, there are two disjunct gaps in the trends being fitted: one between 1991 and 1992 and one in 2000.

Instead of using this intuitive, ad-hoc approach, we advocate the use of **splines**, especially in the context of “change-point” analysis (Harrell 2001, Hastie et al. 2009). Such an approach can have large pay-offs for the analysis of estuarine indicators.

Here, we apply change-point analysis to the tern example.

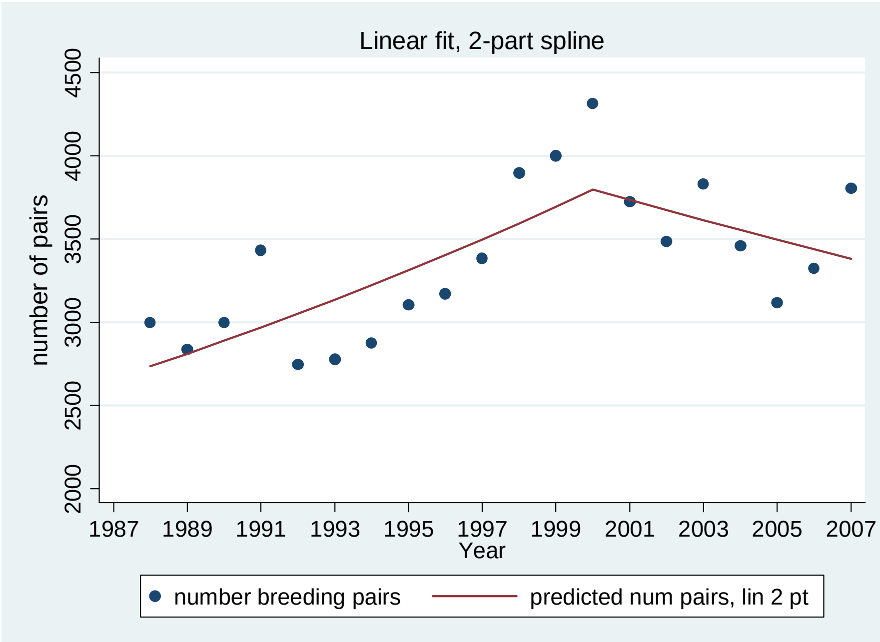


Figure 5-6. Changepoint analysis on number of breeding tern pairs: two linear segments joined with "knot" at 2000.

Here I have simplified the analysis into only a 2-part spline, one period from 1988 to 2000 and the second from 2000 to 2007, joined with a "knot" at 2000. There are two important advantages of this approach:

(1) The predicted trend now eliminates the disjunct predictions for 2000: there is a single predicted value for 2000, together with the standard error of the prediction. In other words, we have a line of best fit such that the population increases (or decreases) at a constant rate from 1988 to 2000 and decreases (or increases) at a constant rate from 2000 to 2007. This leaves open the question of why the population changed its trajectory in the year 2000; but the objective here is simply to identify an important change-point.

(2) This approach makes it easy to evaluate the change in trajectory before and after 2000 and, in particular, to determine the statistical significance of the change in trend at this "hinge point". That is, we fit one slope (b_1) from 1988 to 2000 and then add a difference in slope (b_2), such that slope from 2000 to 2007 is now ($b_1 + b_2$). We can test whether b_2 is different from zero, which would mean that the slope indeed changed from 2000 on. When we conduct such an analysis we find that, yes, the change in slope is significant, $P = 0.012$. Given the divergent behavior up to and including 2000, and from 2000 onward, we feel this approach is an improvement, but we are not done yet. There is one more step needed for the analysis, which we return to below (see section, "Value of Fitting Models to Log-transformed Values").

A strength of the **parametric approach** presented here, exemplified by the change point analysis, is that one obtains estimates of the slope (i.e., change in the indicator per year) for the two separate periods, in this case up to 2000, and from 2000, with associated confidence intervals around the estimated slopes, and, in addition, one can effectively test for the **change in slope** from one period to the other. In contrast, one may take a non-parametric approach as presented by Shilling (2010; Appendix A). A **non-parametric approach**, as they describe allows one to determine whether there has been a decline or not over a given period but does not allow for estimation of the slope in the first place, nor to quantify the change in slope (Shilling 2010, Appendix A, p. 20). The non-parametric approach has its advantages (fewer assumptions, more flexibility in analyzing the relationship of the dependent variable to the independent variable) but also disadvantages: (1) lack of quantification of the estimate and the confidence around that estimate, (2) hard to compare change in time periods or between two spatial units, and (3) reduced statistical power. If quantification is not important, then the Mann-Kendall statistic advocated by Shilling (2010) may provide a good alternative. Shilling's example analysis is graphed below, as he has presented it.

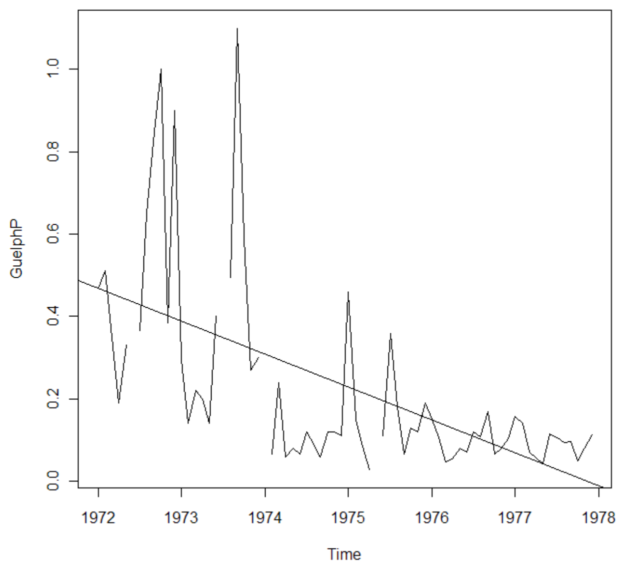


Figure 5-7. Phosphorus concentration example, with linear regression for 60 months, January 1972 to December 1978 (from Shilling 2010, Appendix A, pp. 18-19).

What is graphed is the indicator, "phosphorus (P) concentration in a waterway", labeled "GuelphP" in the figure. The linear regression of y on time (x-axis) is also shown, used as more of a straw man by Shilling (2010). That is, he is not recommending linear regression in this case, but instead contrasts simple linear regression of phosphorus concentration with the nonparametric Mann-Kendall approach, which Shilling (2010) advocates. We agree that a linear regression of GeulphP on time is not desirable; in the section "Modeling Multiplicative or Proportional Change", below, we present an alternative parametric analysis, one that utilizes **change-point analysis on log-transformed values**, an approach that we feel provides a superior quantitative analysis.

We advocate the use of change-point analysis, where appropriate, because it gets directly at an important question in evaluating estuarine indicators: "Was there a change in behavior of the system (or the indicator) at a specified point in time?" The "point in time" may be meaningful from an ecological perspective or a management perspective. For example, one can evaluate the change in trajectory following an important ecological milestone (e.g., major storm event, significant oil spill) or management action (e.g., banning of a particular pesticide, restriction of human disturbance, or introduction of nestboxes for a breeding species).

Value of Fitting Models to Log-transformed Values

We argue that in many cases, rather than analyzing the original dependent variable, Y, for example, the number of individuals (birds, fish, shrimp) of a certain species that were counted, or the concentration of phosphorus, **the analysis should be conducted on the log(Y) or natural log of Y** (i.e., ln[Y]). For the tidal marsh bird populations and the mid-winter waterfowl data (see Biotic Condition 1 and 3, in Chapter IV), analyses were indeed done on the ln-transformed values. There are several important reasons for this. We present two important reasons immediately below, and then return to this point in section, “Combining data across multiple species and multiple regions.”

Modeling Multiplicative or Proportional Change

Where the change in an indicator (e.g., number of breeding pairs, phosphorus concentration) is of a multiplicative nature, that is, a certain proportional or percent change is observed with a change of one unit (e.g., one time period), the statistical analysis needs to take that into account. In the case of population growth, we recognize that a population that is growing or shrinking at a given rate, is increasing (or decreasing) at a constant **multiple**. No change in population size implies that the multiplicative factor is 1. We will call this multiplier, R. $R > 1$ implies population growth, $R < 1$ implies population decline.

The appropriate statistical analysis needs to be applied whenever the change in an indicator is of a multiplicative nature, and applies to many situations, not just population growth. A simple example is that an indicator (Y) is the product of two factors (X and Z). In such a case, we would not want to try and anlyze an additive model, $Y = X + Z$. This would be inappropriate, since :

$$[1]\ Y = X * Z.$$

However, we can take the logs of both sides and get: $\text{Log } Y = \log X + \log Z$. We can just as well take natural logarithms as use logarithms base 10. Taking the natural log of both sides of Eqn [1], we can get the equation

$$[2]\ \ln Y = \ln X + \ln Z.$$

This can be written as $\ln Y = X` + Z`$ where X` and Z` are simply the ln-tansformed values of X and Z. The analysis of ln Y rather than of Y is of great value in a number of different cases, not just for analyzing population change. That said, we begin with discussion of an analysis of population change, and then discuss other examples not related to population change.

Population-growth example:

A population that is growing at a constant rate of, say, 10% every year is one in which numbers at time t+1 are 10% greater than they were at time t. The annual multiplier in this case, R, is 1.1. In contrast, a population that is decreasing at 10% per year is one in which the annual multiplier is $R = 0.9$. By conducting a linear regression on the ln-transformed we convert a multiplicative process (e.g., the population is 1.1 times as large as it was the year before; i.e., $R = 1.1$) into an additive model that can be analyzed using a variety of statistical techniques, not just simple linear regression, but other statistical methods, such as Poisson regression and negative-binomial regression (Faraway 2006).

In the example given above, eqn [2], we can substitute $Y = N_{t+1}$, $X = N_t$, and $Z = R$, where R is the annual multiplier and N_t means the number of individuals enumerated at time t. Instead of eqn [2]: ln Y = ln X + ln Z, we now have

$$[3]\ \ln N_{t+1} = \ln N_t + \ln R.$$

A population that is growing at, say 10 % per year, means that R = 1.1, which can be written as $R = 1.1 = e^{.09531}$ where e is the base of natural logarithms. Since the second term of the right-hand side of equation [3] is ln R, then we get ln (1.1) = 0.09531.

The point here is that conducting regression on the log (or natural-log) of numbers (e.g., counts of breeding population of species X) over time will provide us with an estimate of the population growth per time period, in this case per year. Furthermore, if we conduct a change-point analysis we can estimate **the change in population growth rate from one time period to another**. Here is an example of change point analysis conducted on the tern example, but now we are analyzing ln(Y) where Y is number of breeding pairs. First, we conducted the change-point analysis on the ln-transformed numbers. Using the fitting of linear splines, we obtain the result that between 1988 and 2000, the population grew at an average rate of 2.77% per year. But from 2000 to 2007 the result of the spline analysis is that the population declined at a rate of 1.64% per year. The most important point is that there was a change of 4.41% and such a change is significant (P = 0.012). The predictive equations were used to back-transform the ln(breeding pairs) into numbers of breeding pairs; these are plotted below. Here there is little difference in the predicted behavior based on number of pairs or on ln(number of pairs), but the justification for using the latter still holds: it provides a better quantitative assessment.

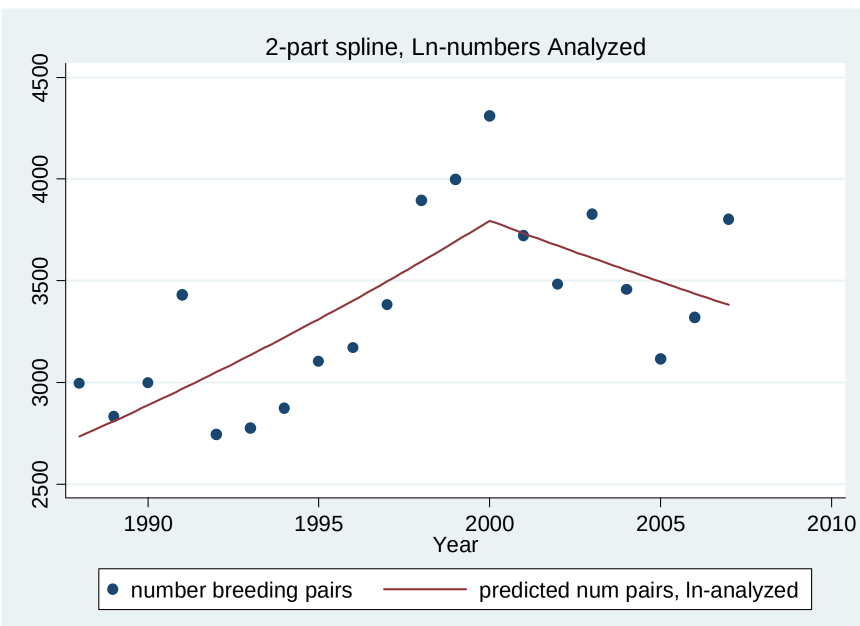


Figure 5-8. Change point analysis on ln(number of pairs), backtranformed to predicted number of pairs, see text.

This is what is shown in Table T1 of the tidal marsh bird population indicator results: the back-transformed proportional trends, based on analyses of the ln-transformed population densities. We reiterate that analyses of ln Y, rather than of Y, whether conducted in the context of linear regression, Poisson regression, negative binomial regression, etc., applies anytime that Y is a function of the **product of two or more variables**, **rather than the sum of two or more variables** (Nur et al. 1999).

A second example of using change-point analysis conducted on ln-transformed variables uses the phosphorus example, first presented above. Examination of Figure 5-7 (above), reveals that during the 60 month time series, the variation in the first 24 months was much greater than in the last 48 months. (One could argue that the middle 24 months showed a level of variation intermediate between the high variability demonstrated in the first 24 months and the low variability demonstrated in the last 24 months of the time series, but for now we will follow Shilling [2010] in dividing the time period in two: prior to January 1974 and from January 1974 on). For example, the standard deviation of phosphorus in the first time period is 0.278 vs. 0.077 for the second time period. This translates into much larger variability around the trend line in the first time period (prior to January 1974) than the second period. The difference is problematic—if one analyzes the actual phosphorus values using linear regression (as shown in Figure 5-7, above). An assumption of linear regression is that residuals are homoskedastic (Nur et al. 1999, Kutner et al. 2005). One solution is to analyze ln(GuelphP), just as we analyzed ln(number of pairs) in the example of the terns (see Figure 5-8, above).

Analyses on ln-transformed values essentially eliminates the problem of differences in variability between the two time periods. The standard deviation of ln(phosphorus) in the first time period is 0.599 vs.0.530 in the second time period.

More importantly, analyses of ln(phosphorus) over the 60 month time series provides greater insight of the behavior of phosphorus over time. We can now conduct a **change-point analysis** on ln(phosphorus) with a knot (change-point) between months 24 and 25 (December 1973, January 1974). The result is shown below.

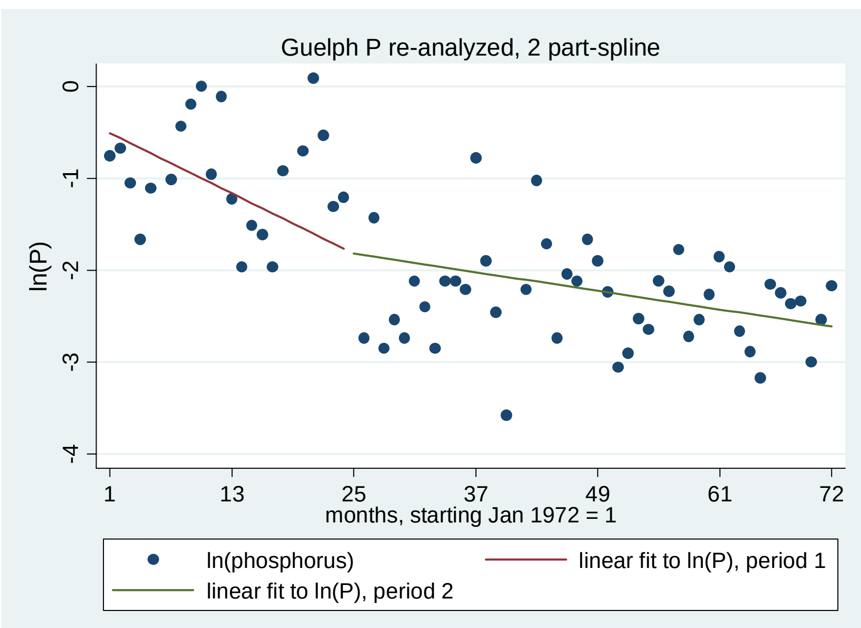


Figure 5-9. Change point analysis on ln(phosphorus), with knot between months 24 and 25. (Because of the lack of data in “month 24.5”, there is a small gap in the fitted lines.)

Results of the re-analysis, with a 2-part spline, on ln-transformed values indicates that during the first 24 months, phosphorus (P) declined at 5.32% per month (S.E. = 1.31%), but from January 1974 on, the decline was 1.67% per month (S.E. = 0.58%). Linear regression on the 2-part spline indicates that the slope for each period was significantly different from zero ($P < 0.001$ and $P = 0.005$, respectively) and that the two slopes were significantly different from each other ($P = 0.031$). To summarize, the phosphorus (P) indicator is best analyzed as ln(P), rather than in the original units. The superiority of analysis on the log value of an indicator is widespread and applies whenever the change in an indicator is of a proportional (i.e., multiplicative nature). That is one important reason for conducting analyses on ln-transformed values.

In this case, the month to month variation in this indicator is best modeled as reflecting a multiplicative process, i.e., demonstrating proportional change. The advantage of the **parametric approach** is that we have a simple trend, with an estimate of proportional change per month, and an associated standard error, for each of the two time periods.

There is, however, one more complication we need to consider, which applies to all time series: autocorrelation.

Autocorrelation in time series

Standard linear regression analysis (and more sophisticated analyses as well) assume that residuals are uncorrelated. Residuals in this example are the difference between the observed value and the expected value, where the latter is the value predicted by the regression line. Standard analyses assume that residuals are independent of one another. Independence implies that, if an observation lies above the regression line in one month, then the next month it is as likely to be below the regression line as it is to be above the regression line. However, the assumption is often not met in ecological time series, whether of physical variables, biotic, or even economic indicators. In Figure 5-9 above, a month below the regression line is often followed by another month below the regression line, and the same goes for months above the regression line. This **autocorrelation of residuals** needs to be adjusted for, otherwise estimates can be biased, and P-values and AIC values obtained will also be misleading.

Below, are results for re-analyzing the analyses on ln(P) with a 2-part spline, but this time allowing for a first-order autocorrelation (residuals from one month to the next are correlated with each other). We find that the estimated autocorrelation of residuals is 0.380, and is significant. Incorporating this autocorrelation changed the parameter estimates for the trends only a little, but the standard errors are greater, and the P-values have increased: the trends are still significant, but not as strongly as before. These are results obtained with the program STATA, but they can equally be carried out using the program R (R Development Core Team 2008). In this example, the dependent variable is ln(P), and the months are classified up to, but not including, January 1974, and from January 1974 on, just as in Fig 5-9.

Table 5-1. Results from time series analysis of GuelphP (ln-transformed) allowing for first order autocorrelation (using STATA 10). Shown are slope estimates for "month" prior to January 1974 and "month" from January 1974 on.

```
Method used: Feasible Generalized Least Squares regression
```

```
Coefficients:  generalized least squares
Correlation:   AR(1) coefficient = 0.3803

Estimated covariances      =         1          Number of obs      =        68
Estimated autocorrelations =         1          Number of groups   =         1
Estimated coefficients     =         3          Time periods       =        68
                                                Wald chi2(2)       =     29.58
                                                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
       lphos |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  montoJan74 |  -.0543083   .0183802    -2.95   0.003    -.0903329   -.0182837
   sincJan74 |  -.0162914   .0082858    -1.97   0.049    -.0325312   -.0000515
   intercept |  -.4659155   .3398678    -1.37   0.170    -1.132044    .2002133
------------------------------------------------------------------------------
```

Combining results and analyses across spatial units and across species

The examples considered above were relatively simple: In each case, results were presented as a single time series. We now turn to a greater challenge: how to analyze indicators when combining results across spatial units and across species. The methods outlined above can be extended to incorporate this next level of complexity.

Combining metrics using common slope models: spatial variation

The examples we consider here draw on the waterfowl data analyzed and presented as part of Task 4 (see Biotic Condition Indicator 3, Chapter IV). In the first example, we consider the winter-time counts of a single species, the northern pintail, an abundant dabbling duck, in three regions of the San Francisco Estuary, from 1992 to 2006:

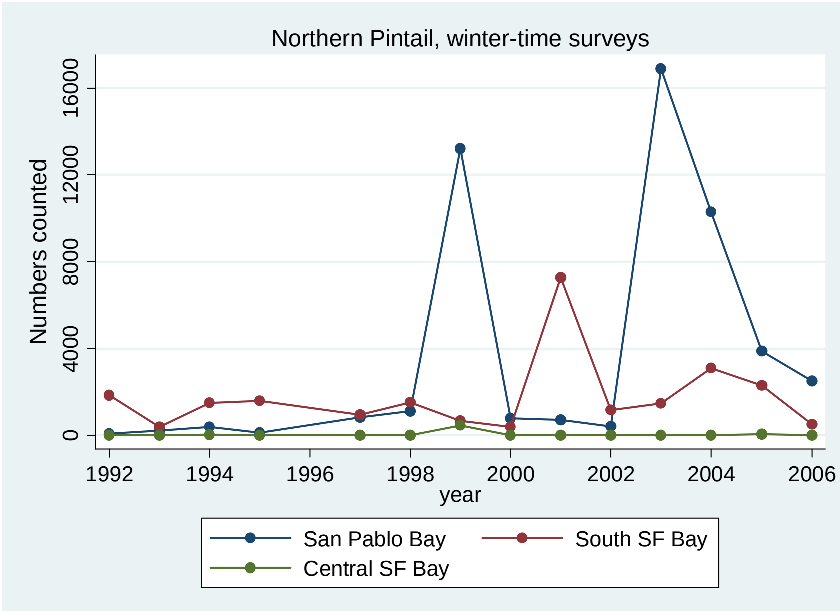


Figure 5-10. Number of Northern Pintails counted in mid-winter waterfowl surveys by region, 1992 to 2006 (see text).

The graph demonstrates several difficulties: (1) Numbers fluctuate greatly from year to year, and (2) numbers in San Pablo Bay are much greater than in Central San Francisco Bay, making it hard to discern any pattern in counts in the latter, and (3) numbers in San Pablo Bay fluctuate more than in South Francisco Bay. Thus a difficulty faces us if we want to combine results across the three regions. If we simply summed the number of pintails across the three regions, then San Pablo Bay numbers would swamp any fluctuations in Central Francisco Bay, and the high variability in San Pablo Bay numbers would dominate the summed pintail numbers. The first step we take is to graph ln(numbers) by bay region.

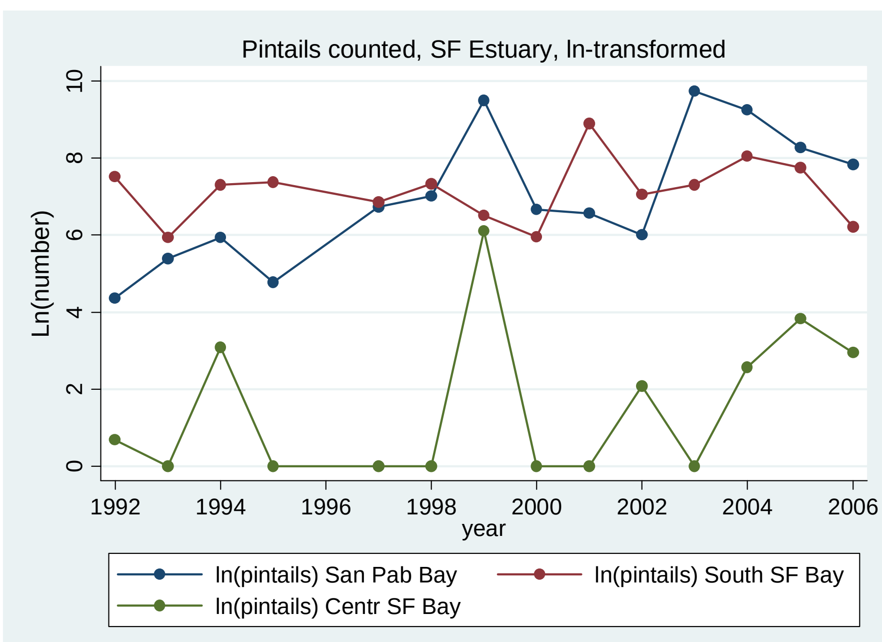


Figure 5-11. Ln(number of Northern Pintails + 1) counted in mid-winter waterfowl surveys. (1 added to all counts, to avoid taking ln(0).)

This certainly helps us see the patterns in the three bay regions. Results suggest that San Pablo Bay numbers may have increased, while South Bay numbers have been fairly stable, with less fluctuation. We also see that Central Bay numbers have been as variable as San Pablo Bay numbers, at least proportionally-speaking.

But, overall, we may ask, Are pintail numbers increasing, decreasing, or neither? To address this question, we recommend a "common slope" analysis, one that is especially suited to combining data across spatial units, across species, etc. What we do is to fit a model on ln(Y), where Y = number of pintails counted in this case, that includes a "main effect" for region (here, 3 regions) and a single slope for all three regions. The single slope is the estimated trend, common to all three regions. By including a "region main effect" with respect to ln(numbers), we are statistically adjusting for differences in number (i.e., abundance), in a proportionate matter. That is, the analysis adjusts for pintail counts being more than 200-fold greater in the north bay than central bay (as indicated by the geometric mean of counts). The results of a common slope analysis are shown below.

Table 5-2. Linear model on ln(pintail) = region (as factor) + year-trend

Source	SS	df	MS
Model	305.009182	3	101.669727
Residual	78.2743116	38	2.0598503
Total	383.283493	41	9.34837788

Number of obs = 42
F(3, 38) = 49.36
Prob > F = 0.0000
R-squared = 0.7958
Adj R-squared = 0.7797
Root MSE = 1.4352

lpintail	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
No bay vs. centr	5.474394	.5424614	10.09	0.000	4.376239	6.57255
So bay vs. centr	5.621102	.5424614	10.36	0.000	4.522946	6.719257
year	.1473157	.0503951	2.92	0.006	.0452961	.2493352
Intercept	-292.9935	100.7513	-2.91	0.006	-496.9539	-89.03311

The estimate of trend, common to all three regions is 0.147 (S.E. = 0.050), which translates into an increase of 15.9% per year.

Results are graphed below (Figure 5-12), which depicts three trend lines (one for each region), but each with the same (i.e., common) slope. The only difference in the trend lines is the elevation of the line, which reflects the overall abundance (number counted) in each region.

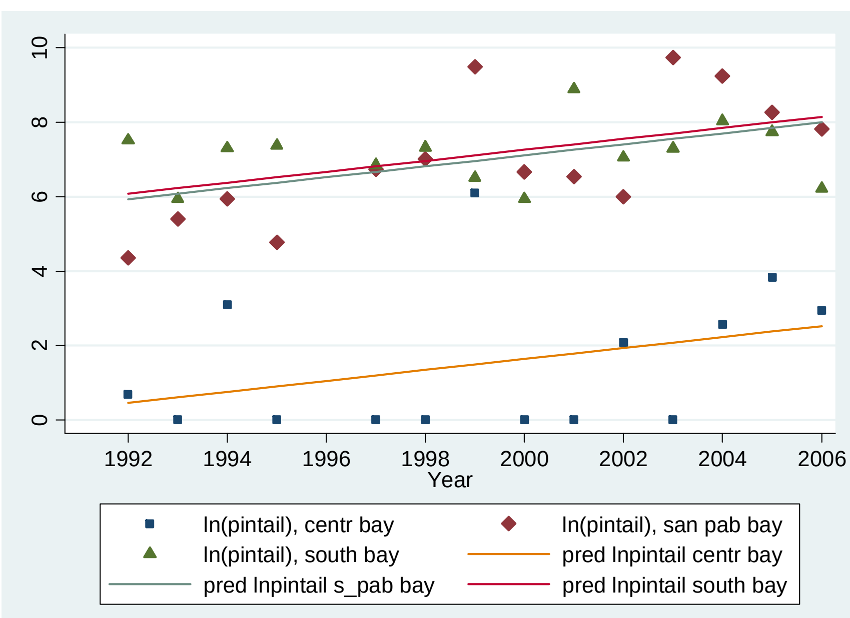


Figure 5-12. Common slope analysis for pintails. Each trend line (per bay region) shows the same slope (see Table 5-2).

One advantage of this approach is that it is easy to compare a model with a single, common slope, to one in which each region is fit with its own slope. We can then test whether the slopes (the linear trends in year for ln(number)) differ significantly among the three regions.

Below are results of a model that fits separate slopes for each region.

Table 5-3. Linear model on ln(pintail) = region (as factor) + year-trend by region

```
      Source |       SS       df       MS              Number of obs =      42
-------------+------------------------------           F(  5,    36) =   32.20
       Model |  313.236313     5  62.6472625           Prob > F      =  0.0000
    Residual |  70.0471804    36  1.94575501           R-squared     =  0.8172
-------------+------------------------------           Adj R-squared =  0.7919
       Total |  383.283493    41  9.34837788           Root MSE      =  1.3949
```

lpintail	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intercept	-48.71914	169.6038	-0.29	0.776	-392.6916	295.2533
Region coeff:						
Centr vs SoBay	-229.0764	239.856	-0.96	0.346	-715.5269	257.3741
NoBay vs SoBay	-492.651	239.856	-2.05	0.047	-979.1017	-6.200713
Year(by region)						
Centr Bay	.1397137	.084835	1.65	0.108	-.0323397	.3117671
No Bay	.2742911	.084835	3.23	0.003	.1022377	.4463445
So Bay	.0279421	.084835	0.33	0.744	-.1441113	.1999955

This analysis shows that only the North Bay pintails demonstrate a significant trend, a conclusion that appears consistent with Figure 5-11. Finally, we can ask, Do the three slopes (i.e., indicating proportional increases or decreases in pintail counts) differ from each other?

The answer appears to be, No. The difference among the three slopes (one for each region) is not significant, P = 0.136 (output not shown). Thus, though Table 5-3 suggests differences in slope, we are not able to statistically distinguish the region-specific slopes: the standard errors around the slope estimates are fairly large and thus the confidence intervals around the region-specific slopes are broad.

Year-specific values, aggregated across regions

An additional component of the analysis might be to combine results across the three regions, in order to arrive at a single number per year for pintails across the three regions. Aggregating year-specific values across the three regions would complement the trend analysis shown above that aggregated across regions (see Table 5-2 and Figure 5-12).

We can average the ln-number of pintail across the three regions, for each year. This average can be the ordinary arithmetic mean or it can be a weighted mean, if some regions are more important than others. If we calculate the arithmetic mean of ln-transformed values, and back-transform (to obtain numbers of pintails), we will obtain the geometric mean of values for that year.

The average ln-transformed values are shown in Figure 5-13, together with a linear fit to the average values. By averaging after the log-transformation, we adjust for differences in abundance among regions, that could lead to one region swamping the other regions. In Figure 5-13, we now have a three-region composite value for each year, together with a single trend line fit to the annual means.

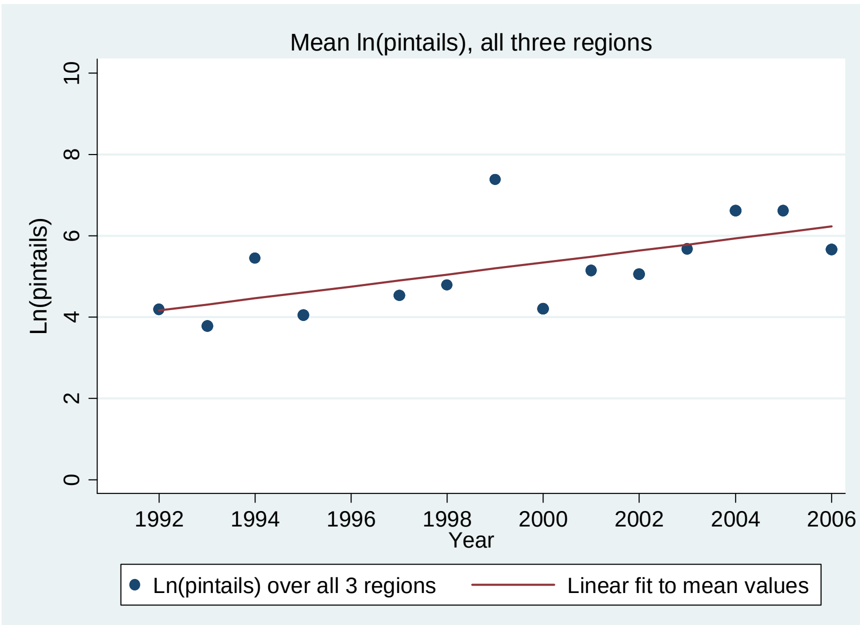


Figure 5-13. Averaged ln(pintails) across regions, with a linear fit.

To summarize, this type of analysis allows us to estimate region-specific trends, estimate a common trend across regions, and to evaluate whether trends differ among regions. Even if there is support for differences in trend among regions, we may want to report the overall trend, common to all three regions, using the common-slope model, or convert the data to a single line of best fit.

Using common slope models to combine data from multiple species

The same difficulty with combining data across spatial units, applies also to combining data across species. Some species are much more abundant and/or much more variable than other species. Simply adding up counts of each species to get a summed abundance results in some species swamping the variation in other species. The same point applies to combining any set of metrics, in which mean and variance of the individual metrics differ to a great extent.

The recommended solution is the same as for combining trend-data across spatial units: analyze ln-transformed values, fitting a common slope model across species, while including a "species main effect." One can then compare the common-slope model to a model in which each species has its own slope (proportionate year trend) to determine whether trends are statistically similar or different among species. Furthermore, one can calculate a composite value across species, taking the averages of ln-transformed values.

This analytical approach was used for the analyses of tidal marsh bird populations and wintertime waterfowl surveys (see Biotic Condition Indicators 1 and 3, Chapter IV).

Below is an example, using counts of three dabbling duck species, Mallards, Northern Pintail, and Northern Shoveler, for the San Pablo Bay region,

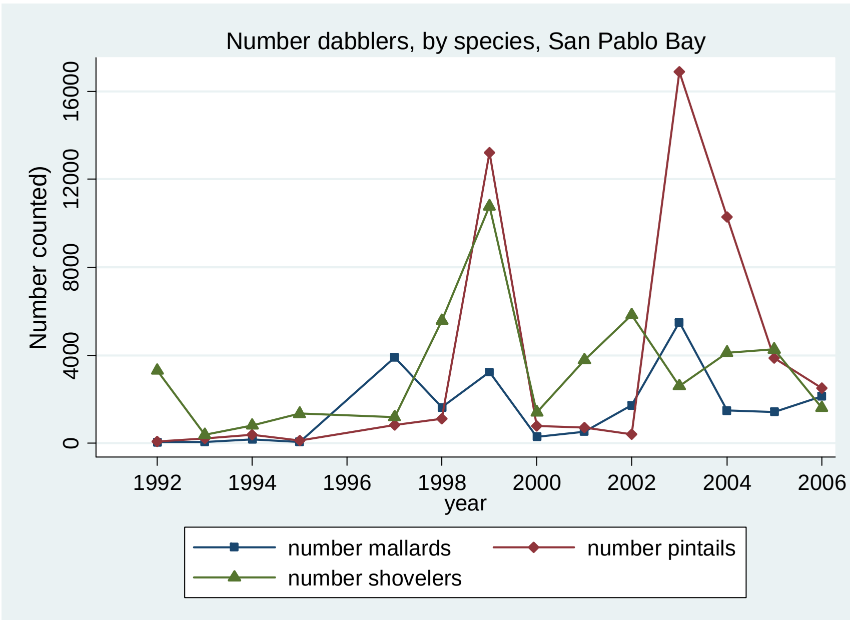


Figure 5-14. Number waterfowl counted in mid-winter surveys in San Pablo Bay for mallards, northern pintails, and northern shovelers.

The data show large fluctuations from year to year, with some concordance (e.g., in 1999) and some discordance (e.g., 2004). The first step is to ln-transform the counts.

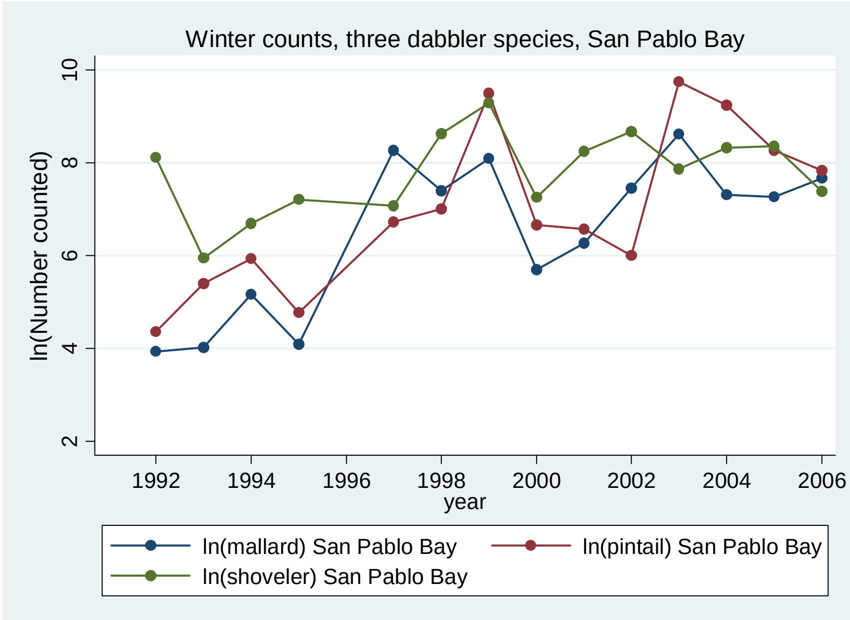


Figure 5-15. Ln(number counted) in mid-winter waterfowl surveys in San Pablo Bay for three dabbling duck species.

Inspecting Figure 5-15, it appears that mallards and northern pintails have increased, but perhaps northern shovelers have not. Applying a common-slope model, we can quantify the overall change, common to the three species, and then ask if the slopes differ among the three species. The result of the common-slope model is shown below.

Table 5-4. Linear model on ln(SP Bay dabbler counts) = species (as factor) + year-trend

Source	SS	df	MS
Model	46.9566768	3	15.6522256
Residual	48.5073671	38	1.27650966
Total	95.4640439	41	2.32839131

Number of obs =	42
F(3, 38) =	12.26
Prob > F =	0.0000
R-squared =	0.4919
Adj R-squared =	0.4518
Root MSE =	1.1298

lnSPBay	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
pintail vs mallard	.482673	.427034	1.13	0.265	-.3818131	1.347159
shoveler v mallard	1.27032	.4270346	2.97	0.005	.4058345	2.134807
year	.209045	.0396719	5.27	0.000	.1287335	.2893564
Intercept	-411.410	79.31311	-5.19	0.000	-571.9709	-250.8489

The three dabbler species are increasing, averaged over all three species, at about 23% per year. The model also confirms that shovelers are more abundant than mallards (by a factor of 3.56), but once the common trend is included in the model, pintails are not more abundant than mallards (pintails more abundant than mallards by a factor 1.61, but the confidence interval includes 1.0).

Fitting separate slopes for each species, we obtain the following:

Table 5-5. Linear model on ln(SP Bay dabbler number) = species (as factor) + year-trend by species.

```
      Source |       SS       df       MS              Number of obs =      42
-------------+------------------------------           F(  5,    36) =    8.94
       Model |  52.8840259     5  10.5768052           Prob > F      =  0.0000
    Residual |   42.580018    36  1.18277828           R-squared     =  0.5540
-------------+------------------------------           Adj R-squared =  0.4920
       Total |  95.4640439    41  2.32839131           Root MSE      =  1.0876
```

lnobay	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
Intercept	-168.7213	132.234	-1.28	0.210	-436.9043	99.46167
Species coeff						
mallard vs shovelr	-353.3108	187.0071	-1.89	0.067	-732.578	25.9572
pintail vs shovelr	-373.0021	187.0071	-1.99	0.054	-752.270	6.2659
year trends by species						
Mallard	.2643778	.0661428	4.00	0.000	.1302339	.3985216
pintail	.2744687	.0661428	4.15	0.000	.1403248	.4086126
shoveler	.0882884	.0661428	1.33	0.190	-.0458555	.2224322

Note that the intercept shown (=-168.7) is predicted ln(number) for shovelers in year 0 = 1 B.C.E.(!) We also fit a model in which 1992, the first year in this analysis, is coded = 0 (i.e., year values go from 0 to 14), which is certainly easier to interpret. Identical slope coefficients were obtained no matter how year was coded.

What is most important, though, are the species-specific estimates of year-trends. For mallard and pintail, trends are very significant and show proportional increases of 30 to 32% per year. For shoveler, the trend is estimated to be 9.2% per year, but the confidence interval around the estimate is large and includes zero.

Next, the analysis evaluated whether the three slopes were different from each other. The result was ambiguous: the P-value for the difference in slopes among the three species was P = 0.096. Examination of Table 5-5 indicates that the mallard and pintail year-trend coefficients are similar to each other, but that both differ from that of shovelers.

Finally, if we desired to aggregate results for San Pablo Bay across all three species, we can calculate mean values of the ln-transformed species-specific numbers, plot these, and determine the trend, whether linear or not. Results are shown below (Figure 5-16). There is a suggestion of quadratic curvature (in this case, some downturning in recent years), but a quadratic coefficient is not significant ($P > 0.1$).

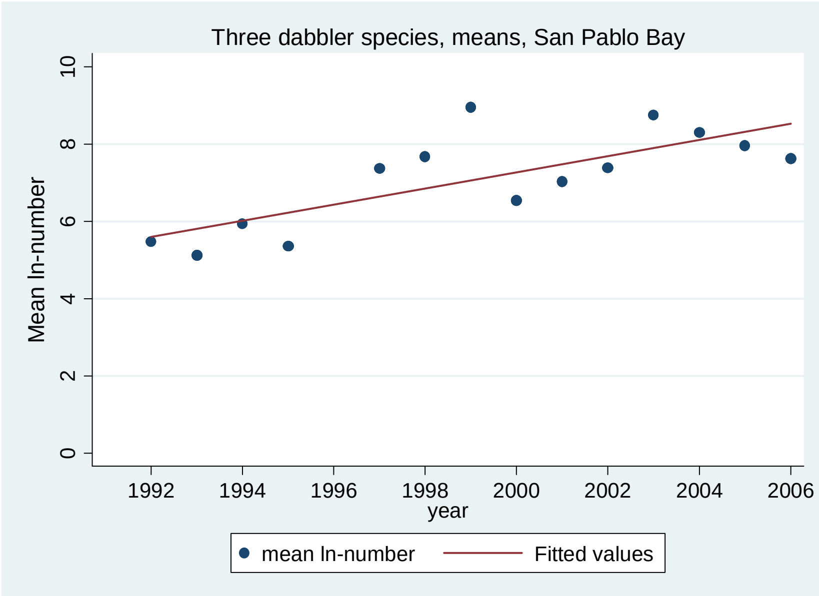


Figure 5-16. Ln(dabblers) averaged over three species (mallards, northern pintails, northern shovelers), for San Pablo Bay, with best linear fit .

In the analysis presented of the winter waterfowl (Biotic Condition Indicator 3), results are shown averaged over six dabbler species (after ln-transforming counts). In that section, graphs depict the back-transformed values, so that the y-axis shows numbers of ducks per species (i.e., the geometric mean value across species, per year) rather than mean ln-number as shown here.

Additional Considerations for Combining Metric

The preceding section focused on analysis of trends over time (whether linear or non-linear), when data are combined across spatial units or across species. There will be times when one wishes to aggregate metrics across spatial units or species in the absence of any trend or trajectory analysis. In that case, we make two recommendations:

(1) For presentation of results with regard to the central tendency, consider providing the **geometric mean** of values. The geometric mean is a natural statistic to use if, as we recommend above, one is analyzing log-transformed values of a metric. More specifically, if one log-transforms the original data, takes the arithmetic mean of those values, and then back-transforms the resultant statistic, one obtains the geometric mean of the original data. In other words, the geometric mean is the back-transformed value of the arithmetic mean that has been calculated on log- (or ln-) transformed values. One limitation of the geometric mean is that any zeroes in the data, cause the geometric mean to be zero. This property can limit the utility of the geometric mean. One fix is to add a small constant first (to cause all values to be positive), then calculate the geometric mean, and then subtract the constant after the calculation.

(2) When combining data across different metrics, such as across different species, consider standardizing the data first and then combining. This approach is recommended any time where the various metrics differ strongly with respect to their means and/or variances. Two useful approaches are to (i) standardize each metric to mean = 0 and SD = 1, or (ii) log-transform the values first, and then standardize the log-transformed metric to mean = 0 and SD = 1.

An additional recommendation is that when combining metrics, consider weighting the various components in an appropriate or informative manner. Just because one is combining, say, four metrics does not mean that all should be contributing equally. For example, if one is combining results from different species, one might weight some species (e.g., those of high conservation concern) more heavily than others.

Summary

Indicator data demonstrate a large degree of variation over time and over space. Only a fraction of the variation is meaningful, but identifying meaningful patterns is not easy. Analyses need to consider non-linearity in trends over time. This non-linearity can be modeled in several different ways. In some cases, it may be possibly to turn a non-linear pattern into a linear one; in other cases, the temporal pattern may be more complex. In particular, we advocate the use of "change-point" analysis to identify or characterize time periods that display contrasting trends. Change-point analysis can be used to determine the magnitude and statistical significance of a change in trend.

Change over time and space is often of a proportional, or multiplicative, nature. There are many examples of indicators that display such a pattern, including the change in the abundance of a population or change in phosphorus concentration over time. In such cases, analyses should be conducted on the log- (or ln-) transformed values. Log-transformation can help reduce the variability present in the original indicator values, and elucidate meaningful patterns. Analyses of log-transformed can be especially useful when extracting a trend from data that are aggregated over space (e.g., different regions) or over multiple metrics (e.g., different species). "Common-slope" analysis allows one to estimate, and test the statistical significance of, a trend common to multiple regions or multiple species. We demonstrate how to evaluate whether trends are indeed similar across spatial regions or across species. Finally, we provide a method to aggregate time-specific estimates of an indicator, calculated for multiple spatial units or multiple species. This approach of calculating indicator values for a given time period (e.g., year by year) can complement the characterization of trends over time.

VI. Project Assessment and Evaluation

By Rainer Hoenicke

Application of the Watershed Assessment Framework as a Tool for Integrating and Communicating Watershed Health Indicators for the San Francisco Estuary

The project, as originally scoped prior to the suspension of bond-funded projects, had five goals that, despite the challenges associated with re-scoping and re-starting the project in 2009/10, were to a large extent met. They were:

1) Identify available data and group by Watershed Assessment Attribute
2) Identify and develop candidate indicators relevant to the Bay-Delta region and evaluate them according to broadly accepted scientific criteria
3) Identify common aggregation and scaling challenges and method for selecting appropriate metrics suitable for aggregation
4) Document types of decisions that can be informed at various aggregation levels of candidate indicators for the Bay-Delta
5) Evaluate comparability of indices common to multiple regions and watersheds based on indicators and indices developed in the Bay-Delta and other regions and specific watersheds

1) Available Data

The project team applied the now fairly commonly used practice of starting the indicator development process by linking management goals and associated assessment questions with data that could inform these questions and answer to what extent goals were being met. We decided on a fairly broad definition of "goals" that would enable us to hierarchically arrange goal statements along a continuum of qualitative (e.g., "stem and reverse the decline in the health and abundance of biota") to quantitative (e.g., increase hatchling survival of tidal marsh song sparrows to a minimum of 2.3 per breeding pair per year). Our project had the advantage of having available an extensive list of qualitative goals that are the foundation of the Comprehensive Conservation and Management Plan for the Estuary (CCMP). These goals are associated with nine major management categories, somewhat comparable to the "Essential Watershed Attributes" in the Watershed Assessment Framework: Aquatic Resources, Wildlife, Wetlands, Water Use, Pollution Prevention and Reduction, Dredging and Waterway Modification, Land Use and Watershed Management, Public Involvement and Education, and Research and Monitoring. We cross-walked the goals associated with each of these nine categories to evaluate a "fit" with the Essential Watershed Attributes: Biotic Condition, Landscape Condition, Socio-economic Conditions, Chemical/Physical Characteristics, Ecological Processes, Hydrology/Geomorphology, and Natural Disturbance Regimes. We were successful in compiling a list of data sources that could be sorted into the seven categories corresponding to the Essential Watershed Attributes, while at the same time having strong relationship to CCMP goals.

2) Candidate Indicators

Because the standing committee overseeing the implementation of the CCMP also serves as the steering committee of the San Francisco Estuary Partnership's WAF project, we had quarterly opportunities to obtain review and advice on project milestones. We utilized several opportunities to vet milestones, one of them being the list of candidate indicators, grouped by WAF attribute. We slightly modified the selection criteria recommended by the National Research Council and successfully used the criteria (see page 4) as a screening tool.

3) Identify Aggregation and Scaling Challenges

Throughout the project, the team used one key question for evaluating scaling challenges and selecting appropriate metrics for indicator development: "For which kinds of decisions is the sensitivity of the selected indicator or multi-metric index insufficient to provide a meaningful tool for communicating to the interested public or management practitioners for policy adjustments?" This question was our guiding principle for determining at what spatial and temporal scales an indicator could or could not answer questions lined up along a gradient of specificity. Our approach to aggregation and scaling challenges relied throughout our project on a standardized scale for comparisons to a quantifiable goal or reference. Societal preferences and values play a key role in emphasizing certain indicators over others and may influence the relative weight by which an attribute comprised of multiple indicators is scored.

4) Decision Support

Following our candidate indicator evaluation, we recognized that management decisions generally require indicators with predictive sensitivities that are in direct relation to the cost associated with various intervention options designed to reach a quantifiable goal or reference condition enshrined in statute or broadly agreed upon by society. In other words, the greater the investment in restoring a watershed attribute is, the greater the confidence in an indicator needs to be to insure that the investment will be reflected in increasing indicator scores. We recognized during the indicator development process that high-level indicators that inform regional (vs. site-specific) condition assessments often require very different sampling designs for the same type of metrics that project-specific questions require.

5) Index and Indicator Comparability among Regions and Watersheds

All of the indicators and indices that we developed for this project are applicable at multiple scales, regions, subregions, and watersheds. While the individual metrics may vary, depending on geographic area, the methodology we developed here allows for common scaling and comparisons of indices from the statewide scale to the sub-drainage scale.

References

Biotic Condition: Birds

Albertson, J. D. and J. Evens. 2000. California Clapper Rail. Pp. 332-341 **in**: Baylands Ecosystem Species and Community Profiles, Olofson, P. R., Ed. Goals Project, San Francisco Bay Regional Water Quality Control Board, Oakland, California.

Chase, M. K., N. Nur, and G. R. Geupel. 2005. Effects of weather and population density on reproductive success and population dynamics in a Song Sparrow (*Melospiza melodia*) population: A long-term study. Auk 122:571-592.

Custer, C. M., and J. Galli. 2002. Feeding habitat selection by Great Blue Herons and Great Egrets nesting in east central Minnesota. Waterbirds 25:115–124.

Custer, C. M., S. A. Suarez, and D. A. Olsen. 2004. Feeding habitat characteristics of the Great Blue Heron and Great Egret nesting along the upper Mississippi River, 1995-1998. Waterbirds 27:254-268.

Eggeman, D. R. and F. A. Johnson. 1989. Variation in effort and methodology for the midwinter waterfowl inventory in the Atlantic Flyway. Wildlife Society Bulletin 17:227-233.

Elphick, C. 2008. Landscape effects on waterbird densities in California rice fields: Taxonomic differences, scale-dependence, and conservation implications. Waterbirds 31:62-69.

Erwin, R. M., and T. W. Custer. 2000. Herons as indicators. Pp. 311-330, in J. A. Kushlan and H. Hafner (eds.), Heron Conservation. Academic Press, San Diego, CA, USA.

Fasola, M., D. Rubolini, E. Merli, E. Boncompagni, and U. Bressan. 2010. Long-term trends of heron and egret populations in Italy, and the effects of climate, human-induced mortality, and habitat on population dynamics. Population Ecology 52: 59-72.

Frederick, P. C. 2002. Wading birds in the marine environment. Pp. 617–55. In E. A. Schreiber and J. Burger (eds.) Biology of Marine Birds. CRC Press, Boca Raton, FL, USA.

Frederick, P. C., and M. G. Spalding. 1994. Factors affecting reproductive success of wading birds (Ciconiiformes) in the Everglades ecosystem. Pp. 659-691, in S. Davis and J. C, Ogden (eds.), Everglades: The Ecosystem and Its Restoration. St. Lucie Press, Delray Beach, FL.

Gawlik, D. E. 2002. The effects of prey availability on the numerical response of wading birds. Ecological Monographs 72:329–346.

Gibbs, J. P. 1991. Spatial relationships between nesting colonies and foraging areas of Great Blue Herons. Auk 108:764–770.

Goals Project. 1999. Baylands ecosystem habitat goals. A report of habitat recommendations prepared by the San Francisco Bay Area Wetlands Ecosystems Goals Project. Joint publication of the U. S. Environmental Protection Agency, San Francisco, CA, and San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

Goals Project. 2000. *Baylands ecosystem species and community profiles: Life histories and environmental requirements of key plants, fish, and wildlife.* Prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. P.R. Olofson,ed. San Francisco Bay Regional Water Quality Control Board, Oakland, Calif.

Greenberg, R., C. Elphick, J. C. Nordby, C. Gjerdrum, H. Spautz, G. Shriver, B. Schmeling, B. Olsen, P. Marra, N. Nur, and M. Winter. 2006. Flooding and predation: trade-offs in the nesting ecology of tidal-marsh sparrows. Studies in Avian Biology 32:96-109.

Jones, S. L. and G. R. Geupel, Eds. 2007. Beyond Mayfield: Measurements of nest-survival data. Studies in Avian Biology 34, Cooper Ornithological Society.

Kelly, J. P., K. Etienne, C. Strong, M. McCaustland, and M. L. Parkes. 2007. Status, trends, and implications for the conservation of heron and egret nesting colonies in the San Francisco Bay area. Waterbirds 30: 455-478.

Kelly, J. P., K. Etienne, and J. E. Roth. 2005a. Factors influencing the nest predatory behaviors of common ravens in heronries. Condor 107: 402-415.

Kelly, J. P., H. M. Pratt, and P. L. Greene. 1993. The distribution, reproductive success, and habitat characteristics of heron and egret breeding colonies in the San Francisco Bay area. Colonial Waterbirds 16:18–27.

Kelly, J. P., D. Stralberg, K. Etienne, and M. McCaustland. 2008. Landscape influences on the quality of heron and egret colony sites. Wetlands 28: 257-275.

Kushlan, J. A. 2000. Heron feeding habitat conservation. Pp. 219-235, in J. A. Kushlan and H. Hafner (eds.), Heron Conservation. Academic Press, San Diego, CA.

Kushlan, J. A. and J. A. Hancock. 2005. The Herons. Oxford University Press, New York, NY, USA.

Liu, L., P. Abbaspour, M. Herzog, N. Nur, and N. Warnock. 2007. San Francisco Bay Tidal Marsh Project Annual Report 2006: Distribution, abundance, and reproductive success of tidal marsh birds. PRBO Conservation Science, Petaluma, CA.

Liu, L., J. Wood, N. Nur, D. Stralberg, and M. Herzog. 2009. California Clapper Rail (*Rallus longirostris obsoletus*) population monitoring: 2005-2008. Report to California Department of Fish and Game from PRBO Conservation Science. PRBO Conservation Science, Petaluma, CA.

Marshall, J. T., and K. G. Dedrick. 1994. Endemic Song Sparrows and yellowthroats of San Francisco Bay. Studies in Avian Biology No. 15:316-327.

Martin, T.E. and G.R. Geupel. 1993. Nest-monitoring plots: Methods for locating nests and monitoring success. Journal of Field Ornithology 64:507-519.

Mayfield, H.F. 1975. Suggestions for calculating nest success. Wilson Bulletin. 87:456-466.

Nordby, J. C., A. N. Cohen, and S. R. Beissinger. 2009. Effects of a habitat-altering invader on nesting sparrows: An ecological trap? Biological Invasions 11:565-575.

Nur, N. and W. J. Sydeman. 1999. Demographic processes and population dynamic models of seabirds: Implications for conservation and restoration. Current Ornithology 15:149-188.

Nur, N., S. Zack, J. Evans, and T. Gardali. 1997. Tidal marsh birds of the San Francisco Bay region: status, distribution, and conservation of five Category 2 taxa. Report of the Point Reyes Bird Observatory, 4990 Shoreline Hwy., Stinson Beach, CA 94970 to USGS-Biological Resources Division. Now: PRBO Conservation Science, Petaluma, CA.

Nur, N., M. Herzog, and A. Pawley. 2007. Avian demographic parameters provide metrics of tidal marsh restoration success at site-specific and program-wide scales. Paper presented at the 2007 State of the Estuary Conference, Oakland, CA.

Nur, N., S. L. Jones and G. R. Geupel. 1999. Statistical Guide to Data Analysis of Avian Monitoring Programs. Biological Technical Publication, US Fish & Wildlife Service, BTP-R6001-1999.

Parnell, J. F., D. G. Ainley, H. Blokpoel, B. Cain, T. W. Custer, J. L. Dusi, S. Kress, J. A. Kushlan, W. E. Southern, L. E. Stenzel, and B. C. Thompson. 1988. Colonial waterbird management in North America. Colonial Waterbirds 11:129–69.

Pratt, H. M. 1970. Breeding biology of Great Blue Herons and Common Egrets in central California. Condor 72: 407-416.

Pyle, P., N. Nur, and D. F. DeSante. 1994. Trends in nocturnal migrant landbird populations at southeast Farallon Island, California, 1968-1992. pp. 58-74 **in** *A Century of Avifaunal Change in Western North America*. N. Johnson & J. Jehl, Ed. Studies in Avian Biology **15**.
Steere, J. T. and N. Schaefer. 2001. Restoring the Estuary: Implementation Strategy of the San Francisco Bay Joint Venture. SFBJV, Oakland, CA.
Shuford, W. D, and T. Gardali, Eds. 2008. California Bird Species of Special Concern. Studies of Western Birds No. 1. Western Field Ornithologists, Camarillo, CA, and California Dept. Fish & Game, Sacramento.
Spautz, H., N. Nur, D. Stralberg, and Y. Chan. 2006. Multiple-scale habitat relationships of tidal-marsh breeding birds in the San Francisco Bay estuary. Studies in Avian Biology 32:247-269.
Spautz, H., and N. Nur. 2008a. San Pablo Song Sparrow, *Melospiza melodia samuelis*. pp. 412-418 in *California Bird Species of Special Concern.* W. D. Shuford and T. Gardali, Eds. Studies of Western Birds 1. Camarillo and Sacramento, California.
Spautz, H., and N. Nur. 2008b. Suisun Song Sparrow, *Melospiza melodia maxillaris*. pp. 405-411 in *California Bird Species of Special Concern.* W. D. Shuford and T. Gardali, Eds. Studies of Western Birds 1. Camarillo and Sacramento, California.
Stralberg, D., D. L. Applegate, S. J. Phillips, M. P. Herzog, N. Nur, and N. Warnock. 2009. Optimizing wetland restoration and management for avian communities using a mixed integer programming approach. Biological Conservation 142:94-109.
Stralberg, D., M. P. Herzog, N. Nur, K. A. Tuxen, and M. Kelly. 2010. Predicting avian abundance within and across tidal marshes using fine-scale vegetation and geomorphic metrics. Wetlands 30:475-487.
Takekawa, J.Y., I. Woo, H. Spautz, N. Nur, J. L. Grenier, K. Malamud-Roam, J. C. Nordby, A. N. Cohen, F. Malamud-Roam, and S. E. Wainwright-De La Cruz. 2006. Environmental threats to tidal-marsh vertebrates of the San Francisco Bay estuary. Studies in Avian Biology 32:176-197.
Takekawa, J. Y. 2002. Data collection protocol: Waterfowl. Pp. 42-48 **in** *San Francisco Estuary Wetlands Regional Monitoring Program Plan: Data Collection Protocol: Wetland Bird Monitoring*. http://www.wrmp.org/protocols.html. Accessed January, 2011.
Thomas, L., S. T. Buckland,E. A. Rexstad,J.L. Laake,S. Strindberg,S. L. Hedley, J. R.B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47:5-14.
U.S. Fish and Wildlife Service. 1998. The North American Waterfowl Management Plan. Expanding the Vision. 1998 Update. Accessed January, 2011. http://www.fws.gov/birdhabitat/NAWMP/files/NAWMP1998.pdf
Wittenberger, J. F. and G. L. Hunt, Jr. 1985. The adaptive significance of coloniality in birds. Avian Biology 8:1–78.

Biotic Condition: Fish

CDFG (2002) Pacific herring commercial fishing regulations. Final Supplemental Environmental Document. California Department of Fish and Game, SCH No. 98052052.

Harrison, T. D. and A. K. Whitfield (2004) A multi-metric fish index to assess the environmental condition of estuaries. J. Fish Biology. 65:283-710.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski (1995) Isohaline position as a habitat indicator for estuarine populations. Ecol. Appl. 5:272-280.

Karr, J. R., J. D. Allan, and A. C. Benke (2000) River conservation in the United States and Canada: science, policy and practice. In: P. J. Boon, B. R. Davies, and G. E. Petts (eds.), *River Conservation: Science Policy and Practice*. J. Wiley & Sons, New York, pp. 502-528.

Kimmerer, W. J. (2002) Physical, biological, and management responses to variable freshwater flow into the San Francisco estuary. Estuaries 25:1275-1290.

May, J. T. and L. R. Brown (2002) Fish communities of the Sacramento River Basin: implications for conservation of native fishes in the Central Valley, California. Env. Biol. Fish. 63:373-388.

Meador, M. R., L. R. Brown, and T. Short (2003) Relations between introduced fish and environmental conditions at large geographic scales. Ecological Indicators 3:81-92.

Moyle, P. B. (2002) Inland Fishes of California. University of California Press, Berkeley. 502 pp.

SFEIT (2008) Assessment Framework as a tool for integrating and communication watershed health conditions for the San Francisco Estuary. Technical Report #1, submitted by the San Francisco Estuary Indicators Team to the California Department of Water Resources, September 30, 2008.

Wang, L. and J. Lyons (2003) Fish and benthic macroinvertebrate assemblages as indicators of stream degradation in urbanizing watersheds. In *Biological Response Signatures. Indicator Patterns Using Aquatic Communities,* (ed. T. P. Simon), pp. 227-249. CRC Press: New York.

Chemical-Physical

Adelsbach, T.L. and T. Maurer. 2007. Dioxin Toxic Equivalents, PCBs, and PBDEs in Eggs of Avian Wildlife of San Francisco Bay. U.S. Fish and Wildlife Service, Sacramento, CA.

Connor, M., D. Yee, J.A. Davis, and C. Werme. 2004a. Dioxins in San Francisco Bay Conceptual Model/Impairment Assessment. SFEI Contribution 309. Prepared for the Clean Estuary Partnership.

Connor, M., J.A. Davis, J. Leatherbarrow, and C. Werme. 2004b. Legacy Pesticides in San Francisco Bay Conceptual Model/Impairment Assessment. SFEI Contribution 313. Prepared for the Clean Estuary Partnership.

Davis, J.A., M.D. May, B.K. Greenield, R. Fairey, C. Roberts, G. Ichikawa, M.S. Stoelting, J.S. Becker, and R.S. Tjeerdema. 2002. Contaminant concentrations in sport fish from San Francisco Bay, 1997. Mar. Pollut. Bulletin. 44: 1117-1129.

Davis, J.A., J.A. Hunt, B.K. Greenfield, R. Fairey, M. Sigala, D.B. Crane, K. Regalado, and A. Bonnema. 2006. Contaminant Concentrations in Fish from San Francisco Bay, 2003. SFEI Contribution #432. San Francisco Estuary Institute, Oakland, CA.

Davis, J.A., F. Hetzel, and J.J. Oram. 2007a. Polychlorinated biphenyls (PCBs) in San Francisco Bay. Environmental Research 105: 67-86.

Davis, J.A., J.L. Grenier, A.R. Melwani, S.N. Bezalel, E.M. Letteney, E.J. Zhang, M. Odaya. 2007. Bioaccumulation of Pollutants in California Waters: A Review of Historic Data and Assessment of Impacts on Fishing and Aquatic Life. A Report of the Surface Water Ambient Monitoring Program (SWAMP). California State Water Resources Control Board, Sacramento, CA.

Dearth, M.A. and R.M. Hites. 1991. Complete analysis of technical chlordane using negative ionization mass spectrometry. Environ. Sci. Technol. 25(2): 245–254.

Eagles-Smith, C.A., J.T. Ackerman, S.E.W. de la Cruz, and J.Y. Takekawa. 2009. Mercury bioaccumulation and risk to three waterbird foraging guilds is influenced by foraging ecology and breeding stage. Environmental Pollution 157: 1993–2002.

Fairey, R., K. Taberski, S. Lamerdin, E. Johnson, R. P. Clark, J. W. Downing, J. Newman, and M. Petreas. 1997. Organochlorines and other environmental contaminants in muscle tissues of sportfish collected from San Francisco Bay. Marine Pollution Bulletin 34:1058-1071.

Greenfield, B. K., J. A. Davis, R. Fairey, C. Roberts, D. Crane and G. Ichikawa. 2005. Seasonal, interannual, and long-term variation in sport fish contamination, San Francisco Bay. Science of the Total Environment 336: 25– 43.

Gunther, A.J., J.A. Davis, D. Hardin, J. Gold, D. Bell, J. Crick, G. Scelfo, J. Sericano, M. Stephenson. 1999. Long term bioaccumulation monitoring with transplanted bivalves in San Francisco Bay. Marine Pollution Bulletin 38(3): 170-181.

Hunt, J.A., J.A. Davis, B.K. Greenfield, A. Melwani, R. Fairey, M. Sigala, D.B. Crane, K. Regalado, and A. Bonnema. 2008. Contaminant Concentrations in Fish from San Francisco Bay, 2006. SFEI Contribution #554. San Francisco Estuary Institute, Oakland, CA.

Krieger, F., M. Pla, and C. Weir. 2007. The History of Municipal Wastewater Treatment: 35 Years of POTWs Protecting the Bay. In SFEI. 2007. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI Contribution 532. San Francisco Estuary Institute, Oakland, CA.

OEHHA. 1994. Health advisory on catching and eating fish: Interim sport fish advisory for San Francisco Bay. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA.

Schoellhamer, D. 2007. Suspended Sediment in the Bay: Past a Tipping Point. In SFEI. 2009. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI Contribution 583. San Francisco Estuary Institute, Oakland, CA.

Schwarzbach, S.E., J.D. Albertson, and C.M. Thomas. 2006. Effects of predation, flooding, and contamination on reproductive success of California Clapper Rails (*Rallus longirorostrus obsoletus*) in San Francisco Bay. The Auk 123(1):45–60.

SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2006.Mercury in San Francisco Bay Proposed Basin Plan Amendment and Staff Report for Revised Total Maximum Daily Load (TMDL) and Proposed Mercury Water Quality Objectives. San Francisco Bay Regional Water Quality Control Board, Oakland, CA.

SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2007. San Francisco Bay Basin (Region 2) Water Quality Control Plan (Basin Plan). San Francisco Bay Regional Water Quality Control Board, Oakland, CA. http://www.swrcb.ca.gov/sanfranciscobay/basin_planning.shtml

SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2008a. Exhibit A: Proposed Basin Plan Amendment. San Francisco Bay Regional Water Quality Control Board, Oakland, CA. http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/sfbaypcbstmdl.shtml

SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2008b. Total Maximum Daily Load for PCBs in San Francisco Bay: Final Staff Report for Proposed Basin Plan Amendment. San Francisco Bay Regional Water Quality Control Board, Oakland, CA. http://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/TMDLs/sfbaypcbstmdl.shtml

SFBRWQCB (San Francisco Bay Regional Water Quality Control Board). 2008c. Adopted Basin Plan Amendment. http://www.swrcb.ca.gov/sanfranciscobay/basin_planning.shtml

SFEI. 2000. San Francisco Bay Seafood Consumption Study. San Francisco Estuary Institute, Oakland, CA.

SFEI. 2009. The Pulse of the Estuary: Monitoring and Managing Water Quality in the San Francisco Estuary. SFEI Contribution 583. San Francisco Estuary Institute, Oakland, CA.

Suedel, B.C., J.A. Boraczek, R.K. Peddicord, P.A. Clifford, and T.M. Dillon. 1994. Trophic transfer and biomagnification potential of contaminants in aquatic ecosystems. Rev. Environ. Contam. Toxicol. 136: 21–89.

Thompson, B., T. Adelsbach, C. Brown, J. Hunt, J. Kuwabara, J. Neale, H. Ohlendorf, S. Schwarzbach, R. Spies, K. Taberski. 2007. Biological effects of anthropogenic contaminants in the San Francisco Estuary. Environmental Research 105: 156–174.

USEPA. 1995. Guidance for assessing chemical contaminant data for use in fish advisories: Volume 1, Fish sampling and analysis. EPA 823-R-93-002, U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA. 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 1, Fish Sampling and Analysis, Third Edition. EPA 823-R-93-002B-00-007. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Hydro-Geomorphology

Feyrer, F., M. L. Nobriga and T. R. Sommer (2008) Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Can J. Fish. Aquat. Sci. 64:723-734.

Feyrer, F., K. Newman, M. Nobriga and T. Sommer (2010) Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. Estuaries and Coasts DOI 10.1007/s12237-010-9343-9.

Jassby, A.D., W. J. Kimmerer, S. G. Monismith, C. Armour J. E. Cloern, T. M. Powell, J. R. Schubel and T. J. Vendlinski (1995) Isohaline Position as a Habitat Indicator for Estuarine Populations. Ecological Applications 5:272-289.

Kimmerer, W. J. (2002) Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25:1275-1290.

Moyle, P. B. and W.A. Bennett. 2008. The future of the Delta ecosystem and its fish. Technical Appendix D. Comparing Futures for the Sacramento-San Joaquin Delta. Public Policy Institute of California. San Francisco, CA. 1-38.

Moyle, P.B., W.A. Bennett, W.E. Fleenor, and J.R. Lund. 2010. Habitat variability and complexity in the Upper San Francisco Estuary. Working Paper, Delta Solutions, Center for Watershed Sciences, University of California, Davis.

San Francisco Bay Area Creek and Watershed maps (2010) Available at: http://www.museumca.org/creeks/ (Link is for all published creek & watershed maps and digital data)

SFEIT (2008) Assessment Framework as a tool for integrating and communication watershed health conditions for the San Francisco Estuary. Technical Report #1, submitted by the San Francisco Estuary Indicators Team to the California Department of Water Resources, September 30, 2008.

Sowers, J. M., Dulberg, R., Richard, C. M., Givler, R., Tillery, A. C., and Pearce, S., 2010, Quantitative parameters of change: Contrasting historical fluvial systems and urban drainage systems in the San Francisco Bay Area: Bay-Delta Science Conference, September 2010, Sacramento, California.

Sowers, J. M., Richard, C. M., Dulberg, R. and Holmberg, J., 2010, Creek & Watershed Map of Western Alameda County: A Digital Database, version 1.0, Fugro William Lettis & Associates, Walnut Creek, CA, 1:24,000 scale.

SWRCB (2010) Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem. State Water Resources Control Board report prepared pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009, August 3, 2010. Available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/final_rpt.shtml.

Statistical Methodology for Aggregation

Cleveland, W. S. 1979. Robust locally weighted regression and smoothing scatterplots. J. American Statistical Association 74:829-836.

Davison, A. C. 2003. Statistical Models. Cambridge U. Press, Cambridge, U.K.

Faraway, J. J. 2006. Extending the Linear Model with R: Generalized Linear, Mixed Effects and Nonparametric Regression Models. Chapman and Hall/CRC, Boca Raton, FL, USA.

Hamilton, J. D. 1994. Time Series Analysis. Princeton U. Press, Princeton, N.J. USA.

Harrell, F. E., Jr. 2001. Regression modeling strategies with applications to linear models, logistic regression and survival analysis. Springer Verlag, New York, USA.

Hastie, T., R. Tibshirani, and J. Friedman. 2009. The elements of statistical learning: data mining, inference, and prediction, 2nd ed. Springer Verlag, New York, USA.

Kutner, M. H., C. J. Nachtsheim, J. Neter, and W. Li. 2005. Applied Linear Statistical Models, 5th ed. McGraw Hill, New York, USA.

Nur, N., S. L. Jones and G. R. Geupel. 1999. Statistical Guide to Data Analysis of Avian Monitoring Programs. Biological Technical Publication, US Fish & Wildlife Service, BTP-R6001-1999.

R Development Core Team. 2008. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Royston, P. and W. Sauerbrei. 2005. Building multivariable regression models with continuous covariates in clinical predictors by using fractional polynomials. Methods of Information in Medicine 44:561-571.

Shilling, F. 2010. Data Analysis Framework for the North Bay-Delta Transect Watershed Assessment Framework. Section 8.6 in Shilling, F., F. Knapczyk, B. Zlomke, C. Cornwall, D. DiPietro, Jeff Sharp, and R. Adams. 2010. Technical and Final Report: Application and Findings of the North Bay-Delta Transect Watershed Assessment Framework (WAF). Report to California Department of Water Resources.