State of the Estuary Report 2015

Summary

PROCESSES – Heron and Egret Brood Size

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State of the San Francisco Estuary 2015
Processes – Heron and Egret Brood-size Indicator

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What is the indicator?

As top wetland predators that operate over large areas of the San Francisco Estuary, herons and egrets depend on extensive tidal marshes, seasonal wetlands, and associated freshwater systems. The State of the Estuary Report uses prefledging brood size among successful heron and egret nests to assess ecological conditions across broad wetland landscapes. The section on "Feeding Chicks," in the "Processes" chapter of the 2015 State of the Estuary Report, summarizes the Heron and Egret Brood-size Indicator, described more fully here. This indicator uses the number of young produced in successful nests to index conditions that affect the availability of food, the productivity of estuarine food webs, and the quality of wetland feeding areas.

The "Wildlife" chapter of the 2015 State of the Estuary Report includes two additional heron and egret indicators, for nest density and nest survival. The Heron and Egret Nest Density Indicator provides an index of regional heron and egret population sizes. The Heron and Egret Nest Survival Indicator is based on the survival of nesting attempts through the breeding cycle and is used to assess the dynamics of nest-predator populations, human disturbance, and changes in human land use that can affect the size and distribution heron and egrets nesting colonies

Attribute	Indicator	Benchmark
Food web	Great Egret/Great Blue Heron Brood Size (number of young produced per successful nest)	The benchmark is the number of young produced per nest from 1991-2000, across Central San Francisco Bay, San Pablo Bay, and Suisun Bay, and all three areas combined.

How are the current Brood-size Indicator conditions measured?

The Heron and Egret Brood-size Indicator was evaluated using methods and analysis described in Kelly *et al*. (1993, 2007) and Kelly and Condeso (2014). The Brood Size Indicator is calculated as the mean prefledging brood size, between species. The Brood Size Indicator is also calculated separately for Great Egrets and Great Blue Herons (see Technical Appendix).

The indicator provides insight into change over time in brood size prior to fledging among nests that successfully fledge one or more young. Brood-size measurements were conducted when Great Blue Heron nestlings were known to be 5-8 weeks old and Great Egrets are known to be 5-7 weeks old (Pratt 1970, Pratt and Winkler 1985); during these periods, nestlings are too young to hop away from their nests and old enough to have survived the period when most brood reduction occurs (Pratt 1970; Pratt and Winkler 1985). The Brood Size Indicator is calculated as the mean prefledging brood size (number of young produced in successful nests), between species, based on observations at 40-50

colony sites within foraging range (10 km) of the historic tidal wetland boundary (ca.1770–1820; San Francisco Estuary Institute 1999). Brood size is sampled in approximate proportion to colony size and averaged annually (1991-2014) among nests within and across the three major subregions of northern San Francisco Bay (Central San Francisco Bay, San Pablo Bay, and Suisun Bay).

Trends in the indicator values were measured as proportional annual change, converted to percent change, over the 24 years, 1991-2014, or before/after years with minimum/maximum values, and by comparisons of indicator values between recent years (2009-2014) and a ten-year baseline (1991-2000), weighted equally among years. Patterns of change over time were modeled as quadratic trends with increasing or decreasing slopes, *if and only if* the quadratic term in the model was significant (P<0.05); otherwise changes over time were estimated as linear trends.

What is the benchmark for the Brood-size Indicator and how was it selected?

The benchmark for the Heron and Egret Brood-size Indicator is the mean annual, prefledging brood size (number of young produced in successful nests, as described above) during the first ten years of regional monitoring, 1991-2000. This period was chosen to be consistent with the benchmark selected for the Heron and Egret Nest Density, which was selected because the densities of nesting herons and egrets were relatively stable during this period, compared to subsequent years.

What is the status and trend of Brood-size Indicator in each area?

Heron and Egret Brood Size (Figure 1, Table 1) exhibited a shallow annual decline across northern San Francisco Bay, to 2.02 young per successful nest in 2008, 4.1% below a the baseline average of 2.03 young per nest, then increased slightly in recent years (quadratic trend: $F_{2,3239}$=11.43, P<0.001).

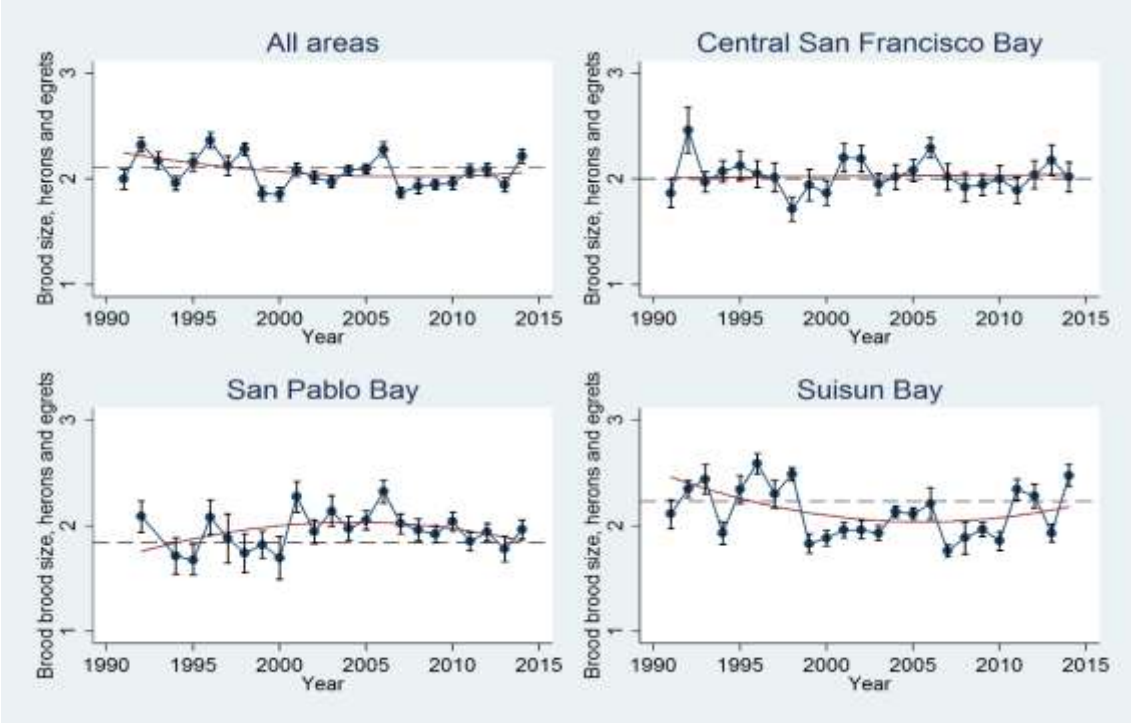

Figure 1. Annual heron/egret brood size and trends in Central San Francisco Bay, San Pablo Bay, and Suisun Bay, and all areas combined, 1991-2014. Error bars represent standard errors; red lines indicate the linear or quadratic trends, 1991-2014; dashed lines indicate the mean values (benchmarks) for the reference period 1991-2000.

Productivity during 2009-2014 was slightly lower than baseline levels in 1991-2000 ($F_{1,14}$=11.8, P<0.001; Table 1).

In San Pablo Bay, Heron and Egret Brood Size increased to a maximum of 2.00 young per successful nest in 2004, then declined by 1.3% per year ($\log_e$ trend over the entire period: -0.013±0.005, P=0.07). Brood sizes were 5.2% higher, on average, in 2009-2014 than during the baseline period, although the difference was not significant ($F_{1,14}$=1.8, P=0.17; Table 1).

In Suisun Bay, Heron and Egret Brood Size declined to a minimum of 2.0 young per successful nest in 2006 ($F_{2,1729}$=20.78, P<0.001), then increased through 2014 ($F_{2,1729}$=20.78, P<0.001). During recent years (2009-2014), brood size averaged 7.5% lower than the baseline period ($F_{1,14}$= 12.3, P<0.001; Table 1).

Table 1. Heron and Egret Brood Size Indicator (species combined) results, including the mean and standard error (SE) of annual brood size, weighted equally among years, during the current period, 2001-2014, and the baseline period, 1991-2000, the mean percent change between current and baseline periods, and the *F*-value and significance (*P*) of the change.

Area	Current (2009-2014)	SE	Baseline (1991-2000)	SE	Percent change	$F_{1, 14}$	*P*
All areas combined	2.0	0.03	2.1	0.02	**-5.4**	**11.8**	**0.001**
Central San Francisco Bay	2.0	0.06	2.0	0.04	2.0	0.3	0.56
San Pablo Bay	1.9	0.04	1.8	0.06	5.2	1.8	0.17
Suisun Bay	2.1	0.04	2.3	0.03	**-7.5**	**12.3**	**<0.001**

In general, what do the results mean and why are they important?

Heron and Egret Brood size is relatively stable across the region but suggests a very gradual, long-term decline in wetland productivity. Within San Pablo Bay, an apparent decline in productivity of successful heron and egret nests since 2005 is consistent with the leveling off of nest densities there in recent years, suggesting a reduction in the quality of wetland feeding areas or, alternatively, the presence of foraging competition.

How does heron and egret brood size relate to the ecological health of the estuary?

The Brood size Indicator is sensitive changes in the extent and quality of foraging habitat, or the supply or availability of prey needed to provision nestlings, 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, Frederick 2002, Kushlan and Hancock 2005). The two target species reflect productivity responses related to the use of different feeding habitats: 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.

What is the historical use of this indicator and current programs for evaluation?

Audubon Canyon Ranch (ACR) has monitored Great Blue Heron (*Ardea herodias*) and Great Egret (*Ardea alba*) nest abundance at all known nesting colonies (40-50 sites) in the northern San Francisco Estuary, annually, since 1991. ACR and continues to sustain this effort on an ongoing basis, and to produce regular reports based on this information (e.g., Kelly et al. 1993, 2005, 2006, 2007, 2008, 2014, Kelly and Rothenbach 2012).

How suitable are the reference conditions and targets for monitoring wetland condition?

The Heron and Egret Brood-size Indicator provides a particularly suitable target for monitoring wetland conditions at landscape scales (Kelly et al. 2008). The productivity of successful nests was relatively stable across the northern San Francisco Bay area during 1991-2000.

Continue to Technical Appendix
with detailed results for Great Blue Heron and Great Egrets.

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Technical Appendix

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Technical Appendix

Great Blue Heron Brood Size

Great Blue Heron brood size declined in the Suisun Bay until 2005, falling to 12.9% below the baseline, then increased gradually to near baseline levels in 2014 ($F_{2,992}$=15.1, P<0.001). During 2009-2014, mean brood sizes in Suisun Bay averaged 2.00±0.12 young per successful nest, which was 4.4% below the baseline level ($F_{1,14}$=5.9, P<0.001; Table 2).

In Central San Francisco Bay, Great Blue Heron brood size declined since 2000, but by less than one percent annually ($F_{1,522}$ =3.47, P=0.06). In 2009-2014, mean Great Blue Heron broods averaged 2.02 young per successful nest, which was 5.6% lower, than the 1991-2000 baseline ($F_{1,14}$=3.8, P=0.053; Table 2).

Great Blue Heron brood size declined in the Suisun Bay until 2005, falling to 12.9% below the baseline, then increased gradually to near baseline levels in 2014 ($F_{2,992}$=15.1, P<0.001). During 2009-2014, mean brood sizes in Suisun Bay averaged 2.00±0.12 young per successful nest, which was 4.4% below the baseline level ($F_{1,14}$=5.9, P<0.001; Table 2).

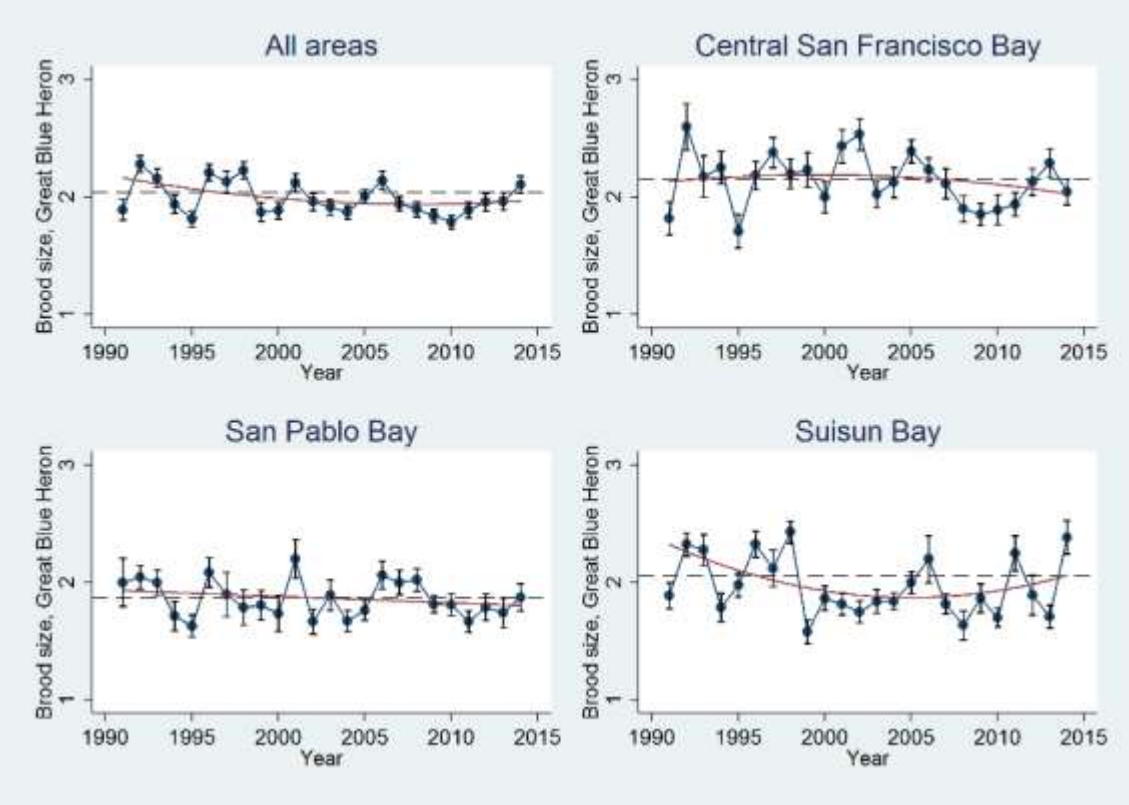

Figure 2. Annual Great Blue Heron brood size and trends in Central San Francisco Bay, San Pablo Bay, and Suisun Bay, and all areas combined, 1991-2014. Error bars represent standard errors; red lines indicate the linear or quadratic trends, 1991-2014; dashed lines indicate the mean values (benchmarks) for the reference period 1991-2000.

***Great Egret Brood Size*.**

Great Egret Brood Size (Figure 3, Table 3) declined in the Central San Francisco Bay until 2006, falling to 5.3% below the baseline, then increased gradually to near baseline levels in 2014 ($F_{2,3907}$=21.0, P<0.001). Mean annual brood sizes in 2009-2014 did not differ significantly from baseline levels ($F_{1,14}$=0.43, P=0.52).

In Central San Francisco Bay, Great Egret broods sizes showed significant quadratic trend (Figure 3; $F_{2,686}$=10.02, P<0.001), suggesting a decline to 1.8 young per nest at the end of the baseline period in 2000, followed by increasing productivity, but with no difference between recent (2001-2014) and baseline (1991-2000) years ($F_{1,14}$=1.9, P=0.17; Table 3).

Table 2. Great Blue Heron Brood Size Indicator results, including the mean and standard error (SE) of annual brood size, weighted equally among years, during the "current" period of recent years, 2009-2014, and the baseline period, 1991-2000, the mean percent change between current and baseline periods, and the F-value and significance (P) of the change.

Area	Current (2009-2014)	SE	Baseline (1991-2000)	SE	Percent change	$F_{1, 14}$	P
All areas combined	1.9	0.03	2.1	0.02	**-6.9**	**15.2**	**<0.001**
Central San Francisco Bay	2.0	0.05	2.1	0.04	**-4.6**	2.3	0.13
San Pablo Bay	1.8	0.04	1.9	0.04	**-5.4**	3.0	0.08
Suisun Bay	2.0	0.05	2.1	0.04	**-7.8**	**6.8**	**0.01**

Baseline brood-sizes among Great Egrets nesting in San Pablo Bay during the 1991-2000 reference period were relatively low (although samples were smaller and less precise than in later years), but increased to 2.4 young per nest in 2004 (19.4% above baseline), then declined to lower levels in recent years ($F_{2,698}$=10.8, P<0.001). Productivity among successful nests was relatively stable in 2009-2014 and did not differ significantly from the baseline period ($F_{1,11}$=0.03, P=0.86; Table 3).

In Suisun Bay during the 1991-2000 baseline period, annual mean productivity in successful Great Egret nests was relatively high, averaging 2.36±0.100 young per nest. However, reduced reproductive output was apparent through 2006, when productivity leveled and began to increase gradually at an annual rate of 1.4% ($F_{2,2517}$=36.7, P<0.001). This increasing trend led to a mean brood size in 2014 that exceeded the estimated baseline mean, but overall productivity remained below baseline levels during 2009-2014 ($F_{1,14}$=10.33, P<0.001; Table 3).

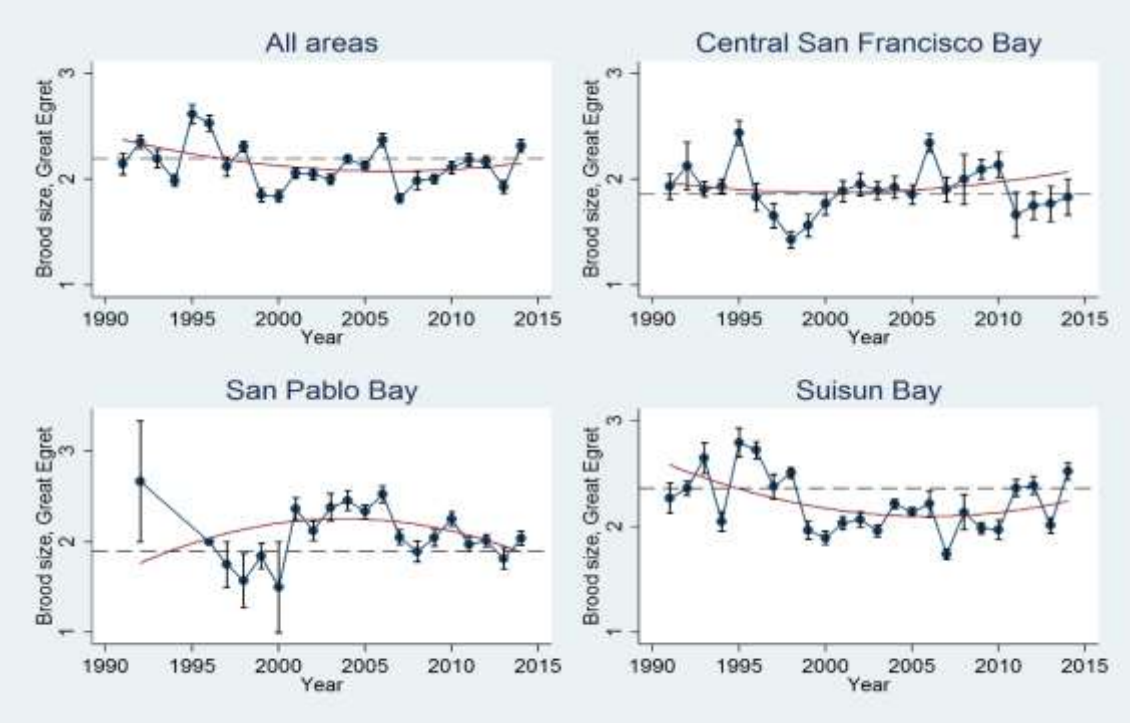

Figure 3. Annual Great Egret brood size and trends in Central San Francisco Bay, San Pablo Bay, and Suisun Bay, and all areas combined, 1991-2014. Error bars represent standard errors; red lines indicate the linear or quadratic trends, 1991-2014; dashed lines indicate the mean values (benchmarks) for the reference period 1991-2000.

Table 3. Great Egret Brood Size Indicator results, including the mean and standard error (SE) of annual brood size, weighted equally among years, during the "current" period of recent years, 2009-2014, and the baseline period, 1991-2000, the mean percent change between current and baseline periods, and the *t*-value and significance (*P*) of the change.

Area	Current (2009-2014)	SE	Baseline (1991-2000)	SE	Percent change	$F_{1, 14}$	*P*
All areas combined	2.1	0.02	2.2	0.02	**-5.2**	**13.0**	**<0.001**
Central San Francisco Bay	2.0	0.06	1.9	0.03	5.2	1.9	0.17
San Pablo Bay	2.0	0.03	1.9	0.10	9.8	2.9	0.09
Suisun Bay	2.2	0.03	2.4	0.03	**-8.6**	**24.5**	**<0.001**

What is the source of these data?

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.

What assumptions and uncertainties are involved?

Heron and Egret Brood Size Indicator 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. It assumes that brood reduction has declined and that nestlings are 5-8 weeks of age closely reflect the number of young fledged from successful nests (Pratt 1970, Pratt and Winkler 1985). Uncertainties are related primarily to unobserved nestlings concealed by vegetation and (2) estimation of nesting ages and (3) timing of the brood-size reduction portion of the nesting cycle. However the conspicuousness of heron and egret nests facilitates the successful use of this indicator.

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