

**Development of an Estuarine Fish Habitat Suitability Indicator Based
on Delta Outflow and Other Factors**

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Background and Rationale

The Department of Fish and Game Water Branch is developing performance measures for the CALFED Ecosystem Restoration Program. We have looked at indicators of estuarine habitat suitability for the Delta Regional Ecosystem Restoration Implementation Program (DRERIP) component of the ERP. This report explains the development of our estuarine habitat suitability index. The datasets used are presented in Table 1 and included in the associated Microsoft Excel spreadsheet.

The estuarine habitat indicator will eventually include four components. To date, we have compiled the data needed for three of these. Our GIS staff is working on the fourth. Ultimately, the indicator will include outflow + sediment concentration + food supply + acreage of open-water and hydraulically connected land-water interface. The latter data set is not compiled, so this document focuses on a partial indicator comprised of the first three components.

Table 1. Data used to develop the estuarine habitat performance indicator for the DRERIP.

Data set	Source	Time period
Daily X ₂ position	Wim Kimmerer (San Francisco State University and DAYFLOW; http://www.water.ca.gov/dayflow/)	Water years 1957-2006
Central Valley unimpaired runoff index	California Data Exchange Center (http://cdec.water.ca.gov/intro.html)	Water years 1957-2006
Sacramento River sediment concentration	Scott Wright (US Geological Survey)	Water years 1957-2006
Average density of mysid shrimp	Randy Baxter (DFG Bay-Delta, Region 3)	March-November 1972-2006 ¹

¹Estimated back to 1957 following Jassby et al. (1995)

The nursery function of habitats in tidal river estuaries has been conceptually described as the outcome of a flow regime over a landscape (Peterson 2003). This conceptual model was based in part on the research that led to the use of X₂ in the San Francisco Estuary. The location of X₂ has been used in the scientific literature as an indicator of how “high” or “low” habitat suitability is in the San Francisco Estuary’s low-salinity zone (Jassby et al. 1995; Feyrer et al. in revision). The estuary’s low-salinity zone (LSZ) has for many years been recognized as a fish nursery habitat of significance (Turner and Chadwick 1972; Herbold et al. 1992).

The location of X_2 is the distance in km from the Golden Gate Bridge to the 2 psu isohaline (Jassby et al. 1995; Kimmerer 2002; Figure 1). X_2 is always presented as a numeral with lower values indicating locations closer to the Golden Gate and higher values indicating locations closer to the Delta. For instance, during the past 40 years, monthly mean X_2 has varied from as far downstream as San Pablo Bay (~ 45 km) to as far upstream as Rio Vista on the Sacramento River (~ 95 km). However, the LSZ habitat that X_2 indexes also expands when river flows into the estuary are high (e.g, Kimmerer et al. 2009). Similarly, the LSZ contracts as it moves upstream when river flows are low, and because channel depth and width vary greatly up the axis of the estuary, changes in X_2 change habitat area or volume in a non-linear manner.

The evolution of the state of science regarding Delta outflow is briefly:

- Higher spring river flows were statistically associated with higher striped bass townet survey abundance indices (Turner and Chadwick 1972)
- Higher spring river flows were statistically associated with higher Fall Midwater Trawl survey (FMWT) abundance indices of several fishes including striped bass and longfin smelt, but not delta smelt (Stevens and Miller 1983)
- Higher river flows were credited with having a large influence on striped bass population dynamics (Stevens et al. 1985)
- The number of 2 psu isohaline days in Suisun Bay during spring was statistically associated with delta smelt abundance in the fall (Herbold et al. 1992)
- The concept and derivation of X_2 as an estuarine habitat suitability indicator correlated with river flow were formalized; variation in winter-spring X_2 was statistically associated with variation in the abundance of several estuarine organisms (Jassby et al. 1995)
- Changes in the estuarine food web following the overbite clam *Corbula amurensis* invasion changed fish production per unit flow. The clam appeared to have stolen some of the potential low-salinity zone productivity for some fishes, but its effect did not change the slopes of the statistical associations between X_2 and abundance (or survival) of several estuarine organisms. Therefore, river flow-driven enhancement of the estuarine food web was not the primary reason for the historically observed “fish-flow relationships” (Kimmerer 2002).
- The “Pelagic Organism Decline” years were characterized by a coincident abundance decline of 4 pelagic fishes and a drop in striped bass and longfin

smelt abundance indices below those predicted by the post-*Corbula* X_2 abundance relationships (Sommer et al. 2007).

- Water quality parameters that covary with Delta outflow during the fall (estuarine salinity and turbidity) were statistically associated with the presence or absence of several fishes including delta smelt in the FMWT. Statistical evidence for an effect of fall salinity on delta smelt population dynamics following the overbite clam invasion was also reported (Feyrer et al. 2007).
- Variation in winter-spring X_2 was shown to be statistically associated with abundance indices of more fishes than reported previously. It was also shown through modeling that variation in X_2 represents changes in the volume of low-salinity zone habitat. Kimmerer et al. (2009) concluded that in most cases, this habitat expansion during winter-spring did not appear to be a likely mechanism for the “fish-flow relationships”.
- The statistical association of winter-spring X_2 and longfin smelt abundance indices continues to be supported – even after controlling for some potential longfin smelt predators and prey in the same analysis. X_2 effects on delta smelt continue to not be supported, though export effects were (Thompson et al. in press; Mac Nally et al. in press).
- During fall, there is a strong nonlinear correlation between X_2 and delta smelt habitat suitability. Fall habitat suitability is correlated with the FMWT abundance indices for delta smelt (Feyrer et al. in revision).

The Flow Component: Herbold et al. (1992) reported that the FMWT index for delta smelt could be predicted from the number of days that X_2 was in Suisun Bay during spring. This definition refers to Suisun Bay in the broadest sense, about 55-74 km as shown in Figure 1. Since their writing, it has repeatedly been shown that the “spring X_2 days” and other summaries of spring X_2 do not predict delta smelt abundance as indexed by the FMWT (Jassby et al. 1995; Bennett 2005). This might be because spring X_2 is less important to delta smelt population dynamics than entrainment or habitat conditions later in the year, which have become increasingly decoupled from winter-spring conditions (Figure 2).

The estuarine habitat indicator should reflect habitat suitability for delta smelt, but not be limited to delta smelt. Thus, we have used the Herbold et al. (1992) notion of X_2 days, but expanded on it based on the increasing scientific understanding of estuarine habitat since 1992. First, we have not limited our use of X_2 only to days that it is in Suisun Bay, but rather to days it is at least as far downstream as Chipps Island in eastern Suisun Bay (≤ 74 km). The 74-km X_2 position is a current compliance point in D-1641. Very high outflows that cause X_2 to move all the way down into San Pablo Bay do not improve habitat conditions for delta smelt

(Herbold et al. 1992; Feyrer et al. in revision), but they do for other estuarine organisms (Jassby et al. 1995; Kimmerer 2002; Kimmerer et al. 2009).

Second, we have included the number of X_2 days ≤ 74 km for entire water years. We did this to correct for the increasing disconnect between winter-spring flow conditions and flow conditions the following fall that have recently been considered detrimental to delta smelt (Feyrer et al. 2007; in revision).

Lastly, estuaries are dynamic and variable aquatic habitats and variability in habitat conditions has been considered an important aspect of the San Francisco Estuary ecosystem (Lund et al. 2008). Most of the variability in winter-spring X_2 is driven by year to year differences in precipitation. Therefore, we divided the X_2 days per water year, by the Central Valley unimpaired runoff estimates for the same water year. This corrected the number of X_2 days for how wet or dry it was. This step “removes” the part of the variation in X_2 days that is due to variation in precipitation. The pattern of variability in the long-term mean then reflects how the interaction of flow over a landscape indexed by X_2 positions over Suisun and San Pablo bays has changed over time due mainly to our society’s demand for fresh water and perhaps to a lesser extent, sea level rise.

The Sediment Component: The amount of sediment that is transported into the estuary from its watershed is affected by river flow (Wright and Schoellhamer 2005). However, due mainly to dams that trap sediment and levees that disconnect river channels from their floodplains, the concentration of sediment entering the Delta has declined over the past 50 years (Wright and Schoellhamer 2004). The transparency of Delta water as indicated by long-term records of Secchi disk depth has likewise increased (Jassby et al. 2002). This long-term increase in water transparency has been associated with seasonal changes in the distribution and abundance of delta smelt and other fishes (Feyrer et al. 2007; Nobriga et al. 2008; Kimmerer et al. 2009; Thompson et al. in press; Mac Nally et al. in press). It might also be a fundamental cause of submerged vegetation proliferation in the Delta, which further increases water clarity, helping to drive changes in fish assemblages toward dominance by non-native warmwater species (Nobriga et al. 2005).

We used long-term data on the concentration of sediment in the Sacramento River at Freeport (Wright and Schoellhamer 2004; Table 1) to index this change in estuarine water quality. Note that by using sediment concentration instead of sediment load, the river flow effect is factored out so that changes in the outflow component are not double-counted.

The Food Component: Fishes using the San Francisco Estuary’s low-salinity zone (LSZ) eat a variety of prey and in general bigger fishes eat bigger prey than smaller fishes. That said, mysid shrimp (particularly *Neomysis mercedis*) historically were an important prey for most small fish species and young

individuals of larger species like striped bass (Turner and Kelley 1966; Feyrer et al. 2003).

Mysid shrimp abundance declined precipitously following the overbite clam invasion of San Francisco Estuary (Kimmerer and Orsi 1996; Kimmerer 2002). This decline was attributed to competition with the clam for phytoplankton (Orsi and Mecum 1996). *Neomysis mercedis* has been largely replaced by a smaller introduced species *Acanthomysis bowmani* in the LSZ, but even with multiple species considered, mysid shrimp abundance is a small fraction of what it sometimes was historically. This depressed mysid productivity occurs regardless of how wet or dry the watershed is (Kimmerer 2002).

All LSZ fishes eat fewer mysids than they did historically; although juvenile striped bass continue to use them more than most other fishes (Feyrer et al. 2003). Delta smelt, like most LSZ fishes eat fewer mysids than they used to (Moyle et al. 1992; Lott 1998). The LSZ fish assemblage has found other prey to eat, but as explained by Nobriga and Feyrer (2008), the ability of a fish to change its diet does not ensure that it acquires enough food. The few bioenergetics modeling simulations done for fishes in and near the Delta have shown they can be food-limited (Sommer et al. 2001; Nobriga in press). There have been no formal bioenergetic comparisons of fish feeding success before and after the mysid shrimp decline. However, Kimmerer (2002) showed that some fishes like longfin smelt and starry flounder showed lower relative abundance per unit X_2 after the invasion of overbite clam. Similarly, the size of delta smelt collected in the FMWT has been chronically lower since 1990 than it was prior, which is circumstantial evidence for food limitation (Bennett 2005).

The DFG has collected data on the density of mysid shrimp since 1972 under the auspices of the Interagency Ecological Program. We were provided the mean March-November mysid shrimp (all species combined) data for 1972-2006. Note this averaging period does not perfectly match the timing of a water year as used for the variables mentioned above. However, year to year variation in mysid abundance is driven by the summer months, which is when densities historically peaked, so we do not think this causes a significant bias. These are the same mysid shrimp data used to develop the X_2 relationship originally reported by Jassby et al. (1995). We recreated their historical relationship to predict mysid shrimp densities for 1957-1971 as a function of mean X_2 location.

We standardized the time series of all component data used in the estuarine habitat indicator by converting them to z-scores that normalize the data to a mean of zero and standard deviation of 1. This standardization serves two purposes. It enables a quickly digestible visual depiction of a long-term trend relative to a zero line and it allows each of the components to be added together with equal weight and equal variance.

Results and Discussion

The time series of the flow component of the habitat indicator shows a general step-decline beginning in 1977 (gray line; Figure 3). This means that X_2 has spent fewer days downstream of the Sacramento-San Joaquin river confluence per water year, regardless of water year type since 1977 than it did prior to 1977. The lowest values of the index occur during the 1977 and 1987-1992 droughts. It appears that this generalization even includes the very wettest years in the time series.

However, the very wettest years should be interpreted with some caution because the numerator of the index has a maximum value of 365 (or 366 in a leap year), but the denominator is unconstrained. It can go as high as nature takes it. Thus, there is a tendency for very wet years, which are generally “good” for the estuary to appear to be about average.

The multifactor habitat index shows a stronger decline with multiple step-changes (Figure 3). This version also shows the steep drop in habitat suitability during 1977. However, unlike the flow-only version, it indicates partial recovery of habitat suitability through 1986. Thereafter, the index drops sharply again due to the interaction of drought and the drop in mysid density caused by the overbite clam. Since 1986, water year 1996 is the only one that has registered a value higher than the long-term average.

Our current science-based conceptual model is that placement of X_2 in Suisun Bay represents the best interaction of water quality and landscape for fisheries production given the current estuary geometry. This is consistent with D-1641, which calls for X_2 to be maintained at one of two compliance points in Suisun Bay (65 km or 74 km) from February-June. However, it is expected that major changes to the estuary landscape will occur over the next several decades (Lund et al. 2007; 2008). Sea level rise and human water demand will likely lessen the ability of resource managers to keep X_2 as far downstream as frequently as we do under current regulations. And as we have shown above, the current placement is already less frequently in Suisun Bay (or downstream) than it was prior to 1977. Some of this change is due to reductions in fall outflows (Feyrer et al. in revision). Further, as we have also noted above, other components of estuarine habitat are changing independent of X_2 variation that are also likely lowering estuarine habitat suitability. For some of the estuary’s animals (longfin smelt, starry flounder, striped bass) this has meant lower productivity per unit of outflow or X_2 (Kimmerer 2002; Sommer et al. 2007; Kimmerer et al. 2009). These findings demonstrate that X_2 (or Delta outflow) is necessary, but not sufficient to sustain and recover the estuary’s low-salinity zone ecosystem.

However, that should not be taken to mean that outflow is unimportant. The estuary’s fauna of management interest may be able to be recovered in the future

with less total outflow. However, we think that will only be possible if the low-salinity zone overlies a suitably large, unchannelized landscape east of Suisun Bay (that does not presently exist). This also assumes that water quality is sufficient to support aquatic life-related beneficial uses.

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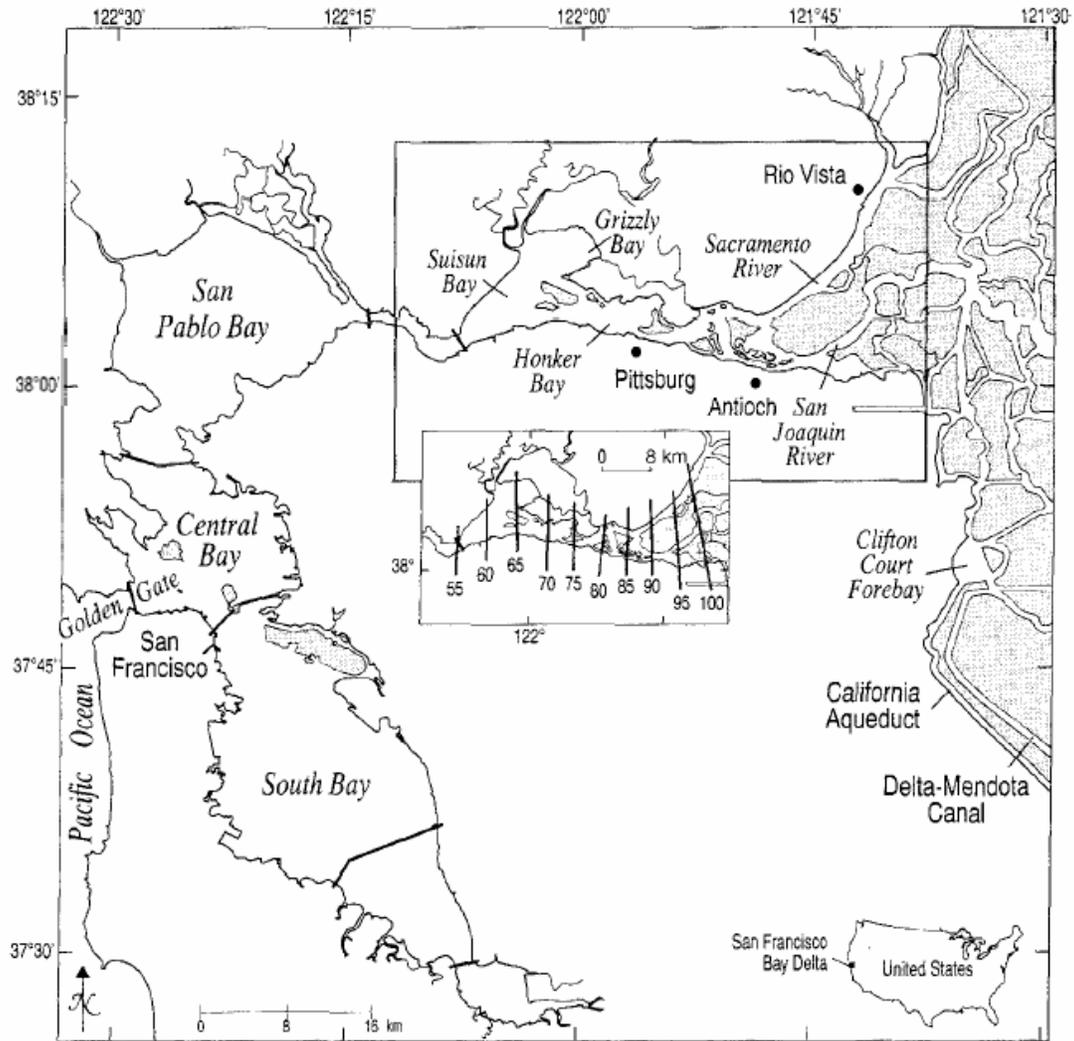


Figure 1. Map of the San Francisco Estuary. Suisun Bay and the western portion of the Delta are shown with lines positioned at nominal distances (in kilometers) from the Golden Gate along the axis of the estuary. Map taken from Jassby et al. 1995.

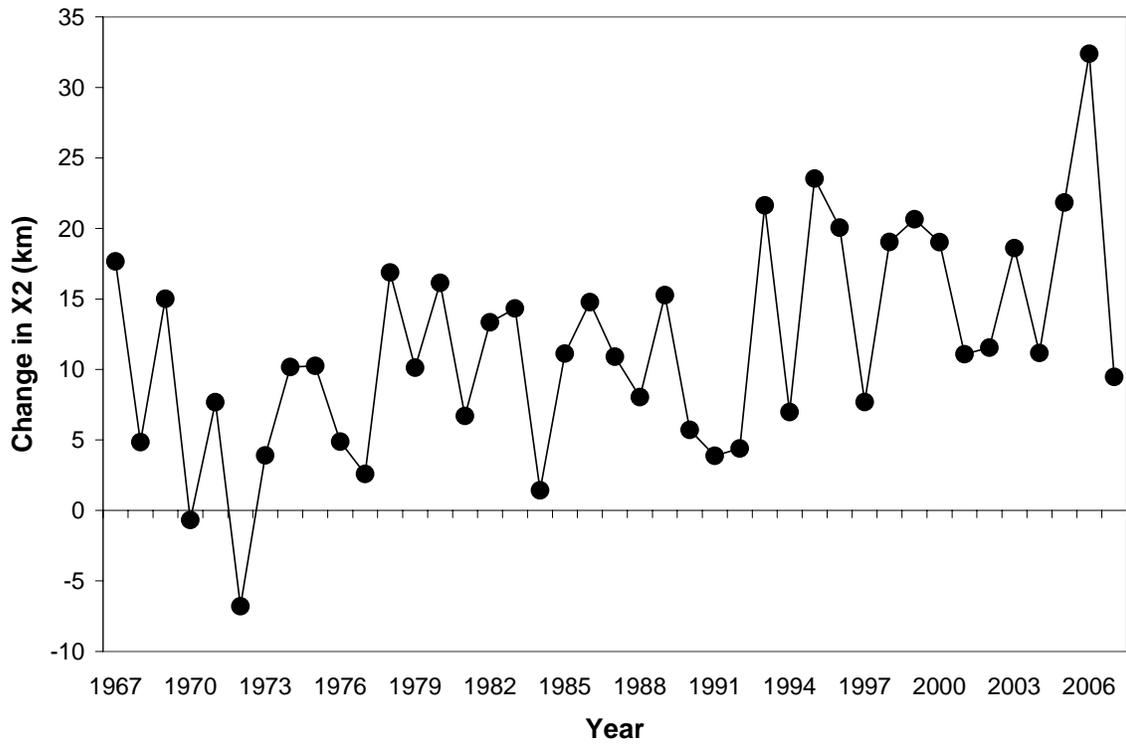


Figure 2. Time series of the difference in average X2 between February-June and its subsequent average in September-November.

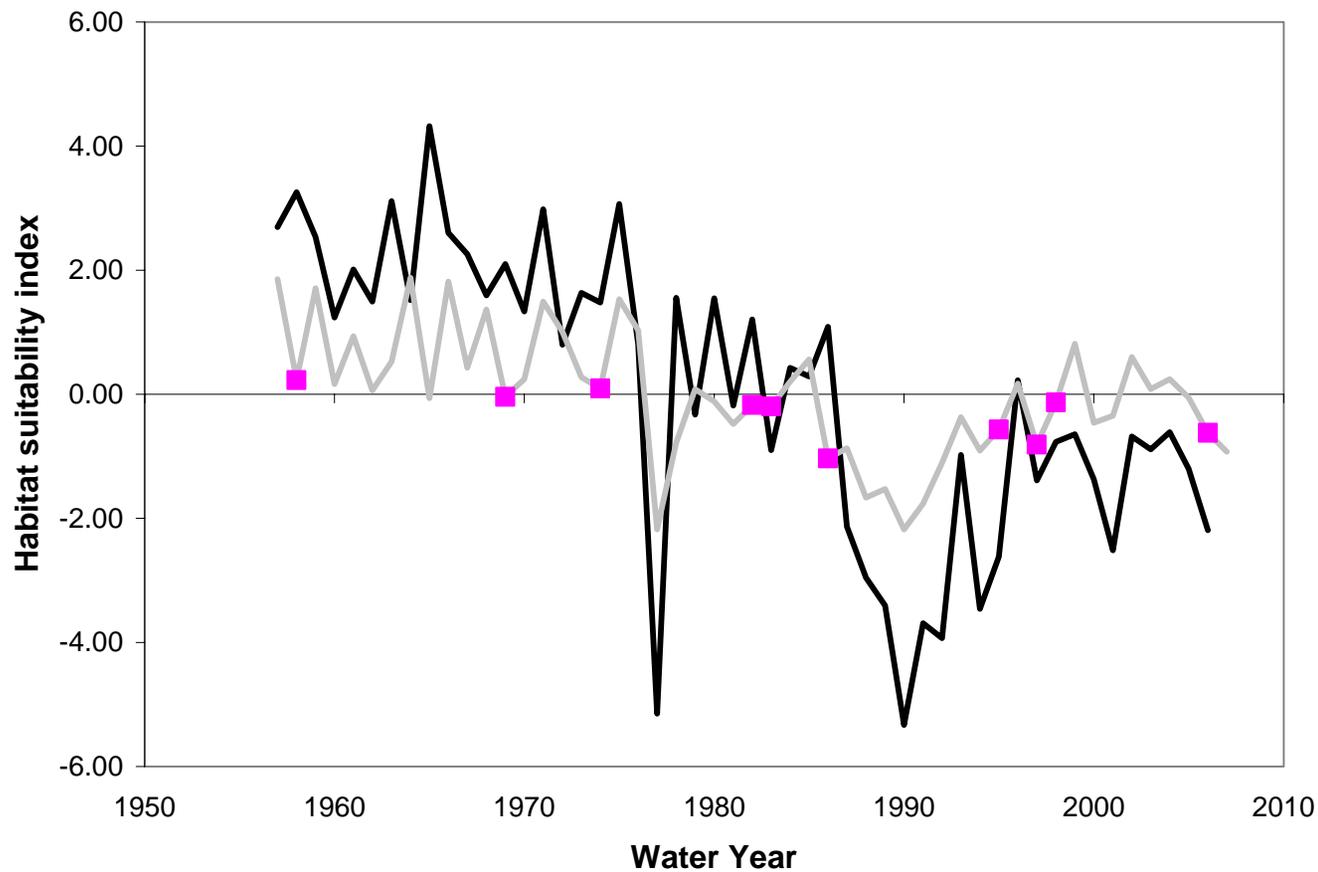


Figure 3. Time series of the flow portion of the ERP estuarine habitat suitability index (gray line; water years 1957-2007) and the flow + sediment + food portion of the index (black line; water years 1957-2006). The ten wettest years are shown on the gray line with pink boxes.

Table 1. Data used to develop the estuarine habitat performance indicator for the DRERIP.
Excel workbook containing graphs and data provided in electronic format.

