De-confounding of Relations Between Land-Level and Sea-Level Change, Humboldt Bay, Northern California: Uncertain Predictions of Magnitude and Timing of Tectonic and Eustatic Processes

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Abstract

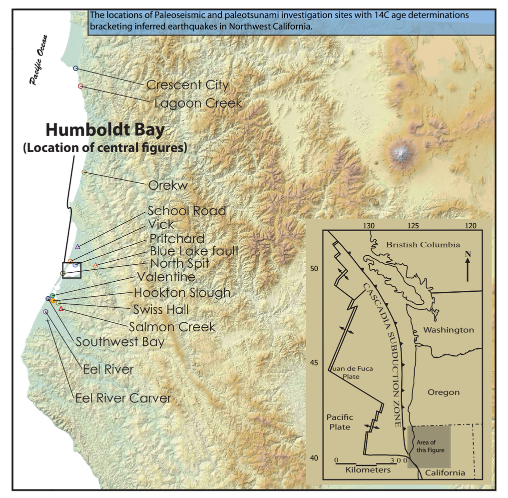
Humboldt Bay in Northern California provides a unique opportunity to investigate the effects of relative sea level change on both native flora and maritime aquiculture as influenced by both tectonic and eustatic sea-level changes. This combination of superposed influences makes quantitatively predicting relative sea-level more uncertain and consumption of the results for public planning purposes exceedingly difficult. Public digestion for practical purposes is confounded by the fact that the uncertainty for eustatic sea-level changes is a magnitude issue while the uncertainty associated with the tectonic land level changes is both a magnitude and timing problem. Secondly, the public is less well informed regarding how crustal deformation contributes to relative sea-level change.

We model the superposed effects of eustatic sea-level rise and tectonically driven land-level changes on the spatial distribution of habitats suitable to native eelgrass (*Zostera marina*) and oyster mariculture operations in Humboldt Bay. While these intertidal organisms were chosen primarily because they have vertically restricted spatial distributions that can be successfully modeled, the public awareness of their ecologic and economic importance is also well developed.

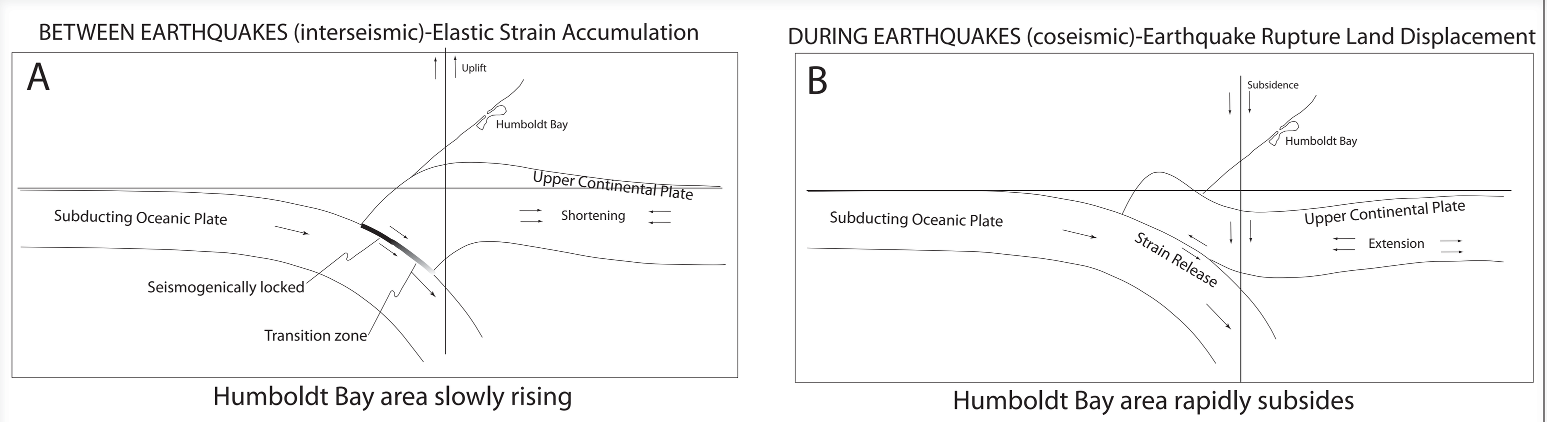
We employ easy to understand graphics depicting conceptual ideas along with maps generated from the modeling results to develop locally relevant estimates of future sea level rise over the next 100 years, a time frame consistent with local planning. We bracket these estimates based on the range of possible vertical deformation changes. These graphic displays can be used as a starting point to propose local outcomes from global and regional relative sea-level changes with respect to changes in the distribution of suitable habitat for ecologically and economically valuable species. Currently the largest sources of uncertainty for changes in relative sea-level in the Humboldt Bay area are 1) the rate and magnitude of tectonic deformation throughout the earthquake cycle and 2) the stability and reliability of the tide gauges and other benchmarks assumed to be stable in the Humboldt Bay region.

1) Introduction

- The Humboldt Bay region is within the portion of the North American / Gorda lithospheric plate interface that it is subject to continued vertical land level changes throughout the seismic cycle.
- In the Humboldt Bay region it is thought that the land subsides (relative to sea level) almost instantaneously during large earthquakes and then slowly, over decades to centuries, rises again as strain accumulates along the plate interface. This process influences relative sea level independently and superimposed on eustatic sea level changes (changes from melting ice and heating of ocean water)
- Recent studies suggest that there is a high probability that a great earthquake may occur within the design life of engineered structures and planning time frames of sea level modeling efforts.
- We model changes in the spatial distribution of preferred elevation ranges for eelgrass habitat and oyster mariculture in Humboldt Bay by combining relative changes in sea level from both eustatic and tectonic driving forces.

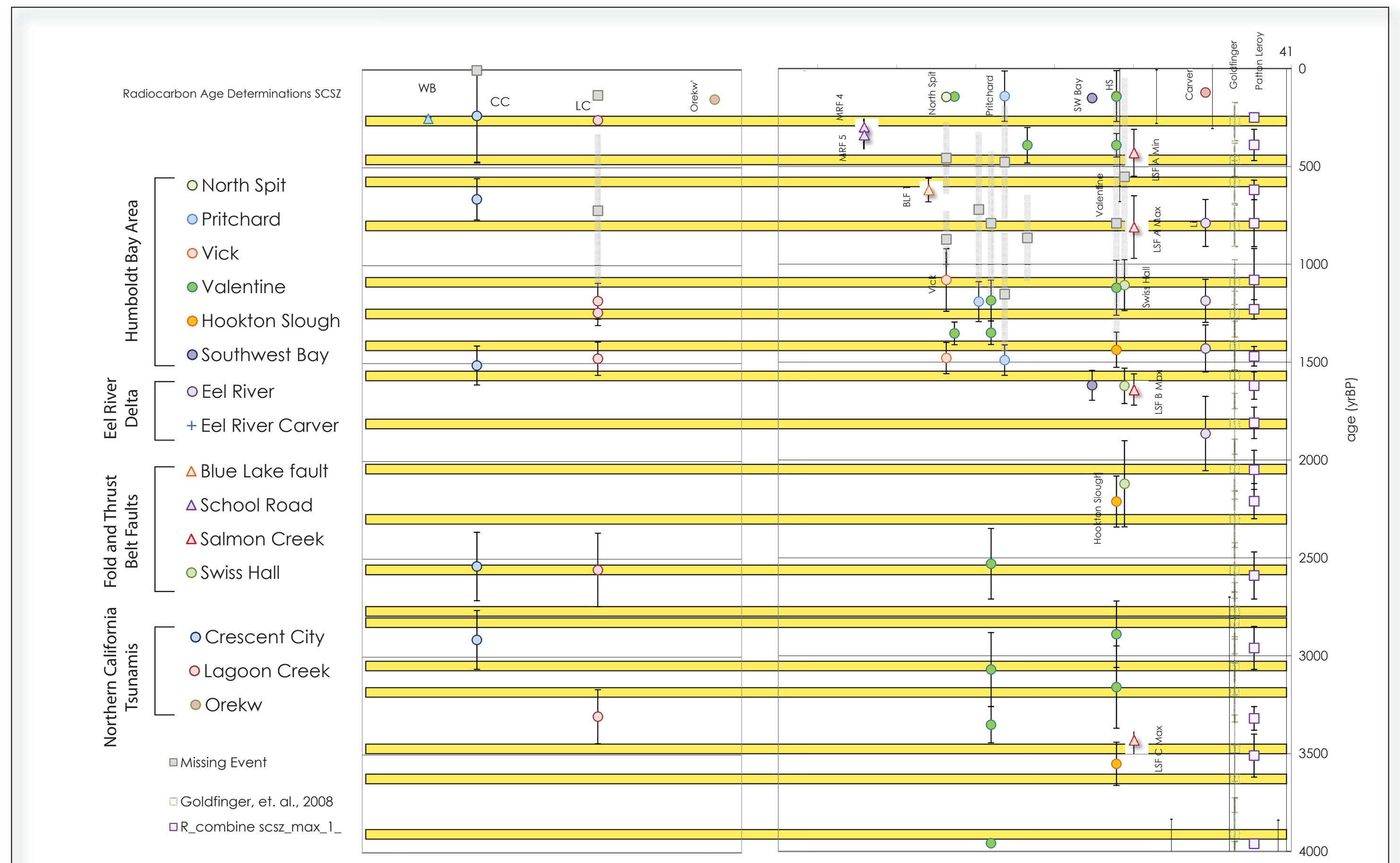


2) How tectonics influence relative sea level at the coast

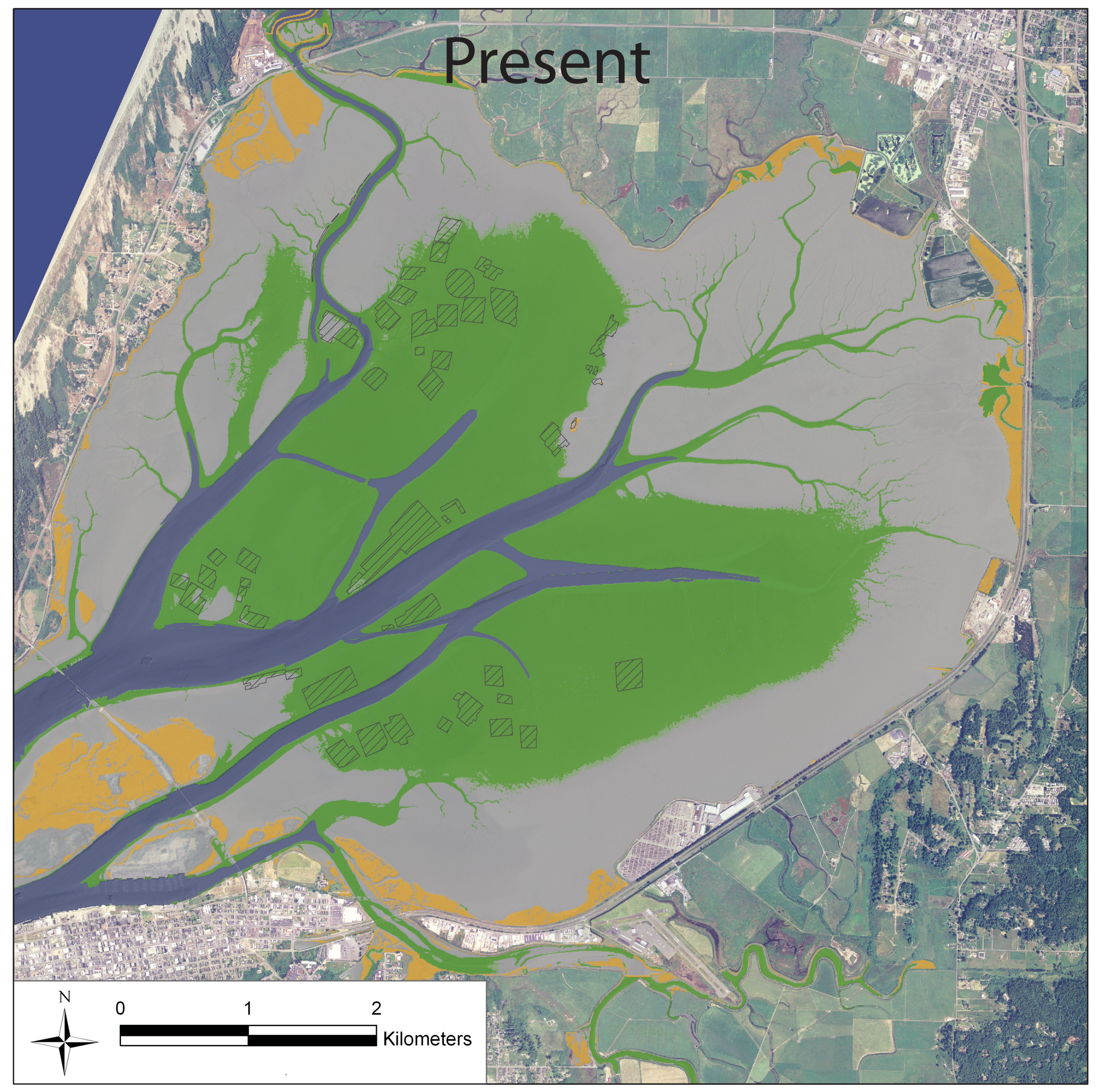


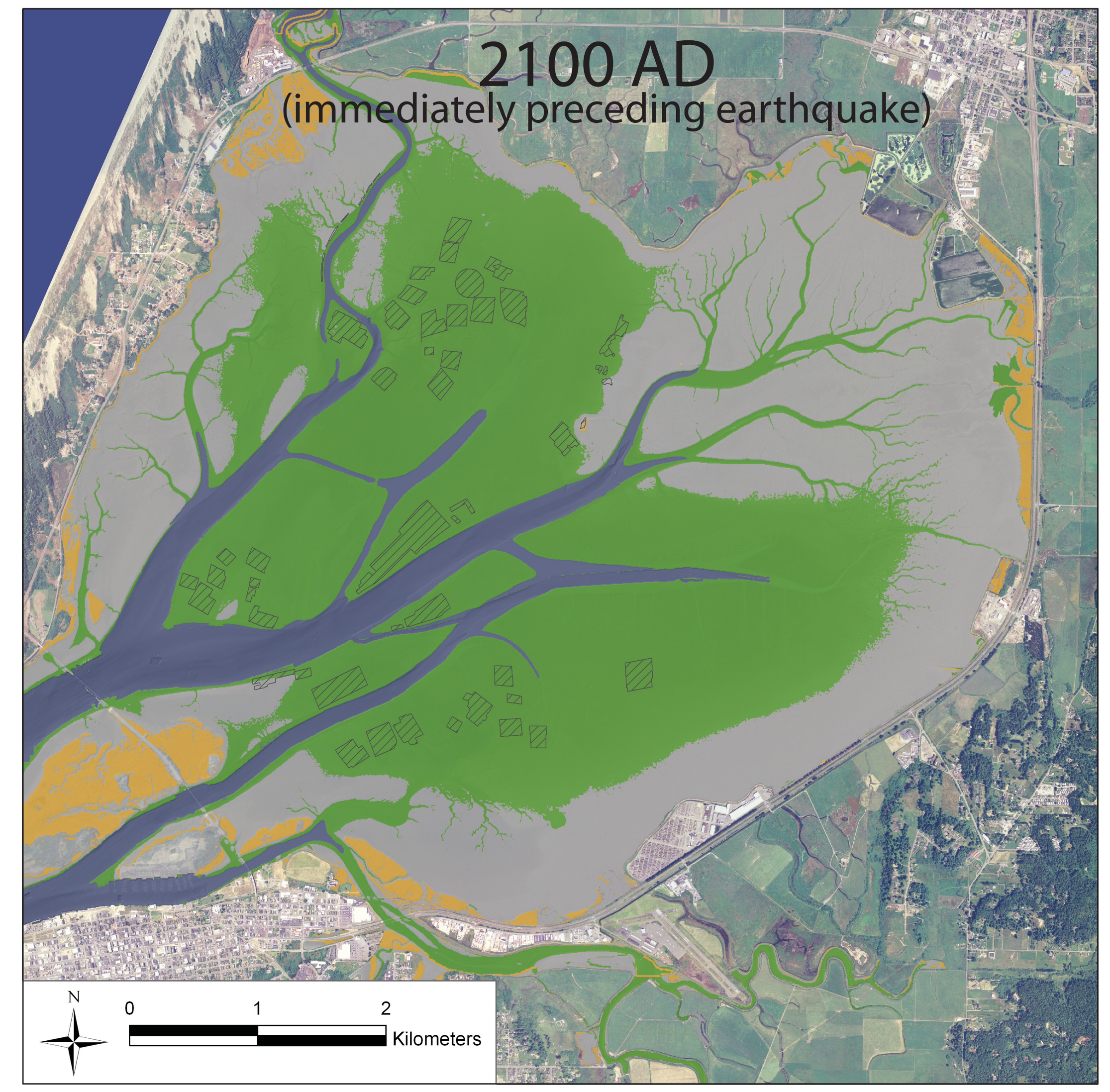
Schematic diagrams showing the pattern of (A) interseismic and (B) coseismic deformation associated with a subduction thrust fault during an earthquake deformation cycle. Modified from Nelson, 1996; modified from Dragert et al, 1994; and Geomatrix consultants, 1994

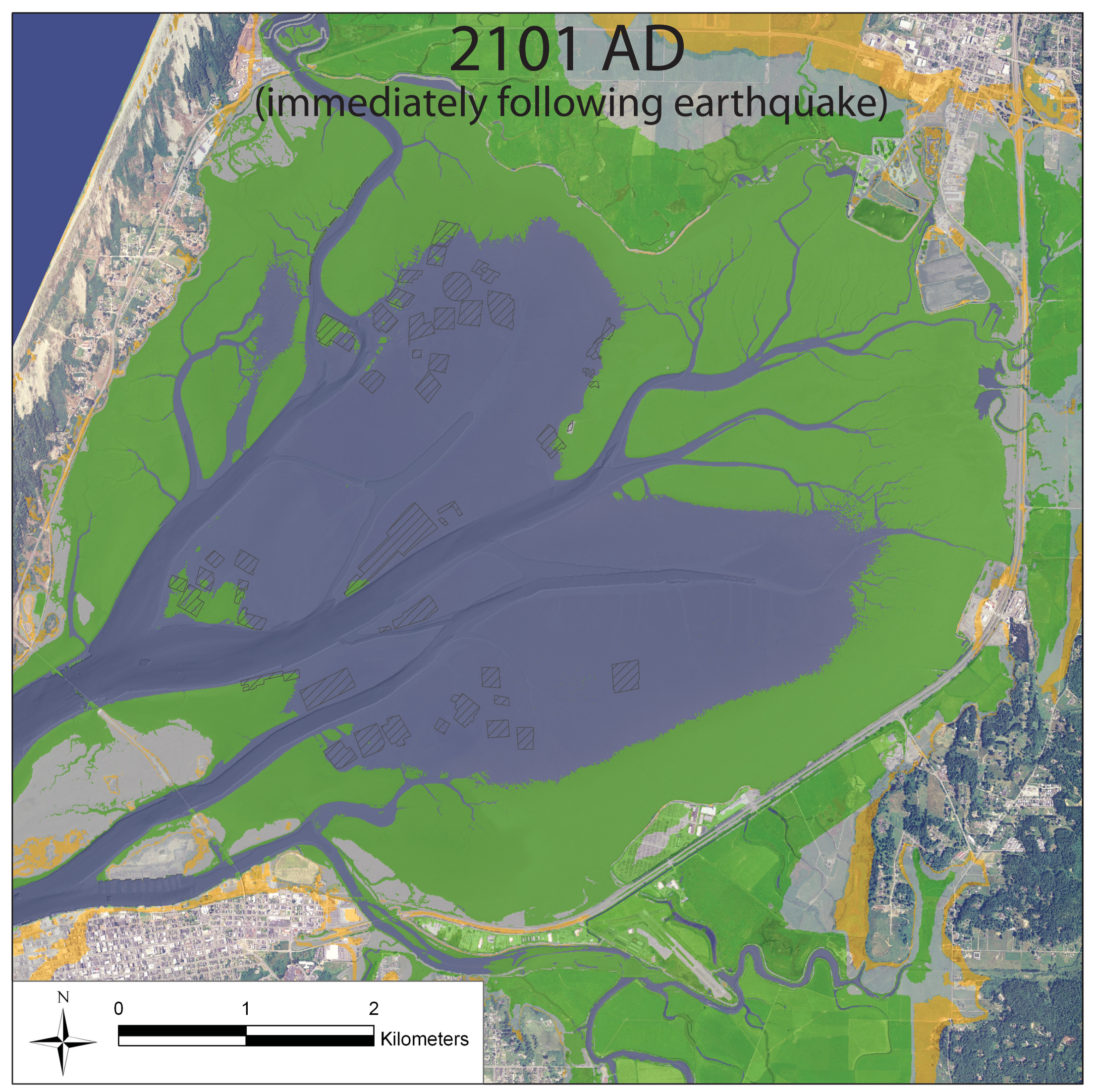
3) Timing of great earthquakes and tsunamis in Northern California

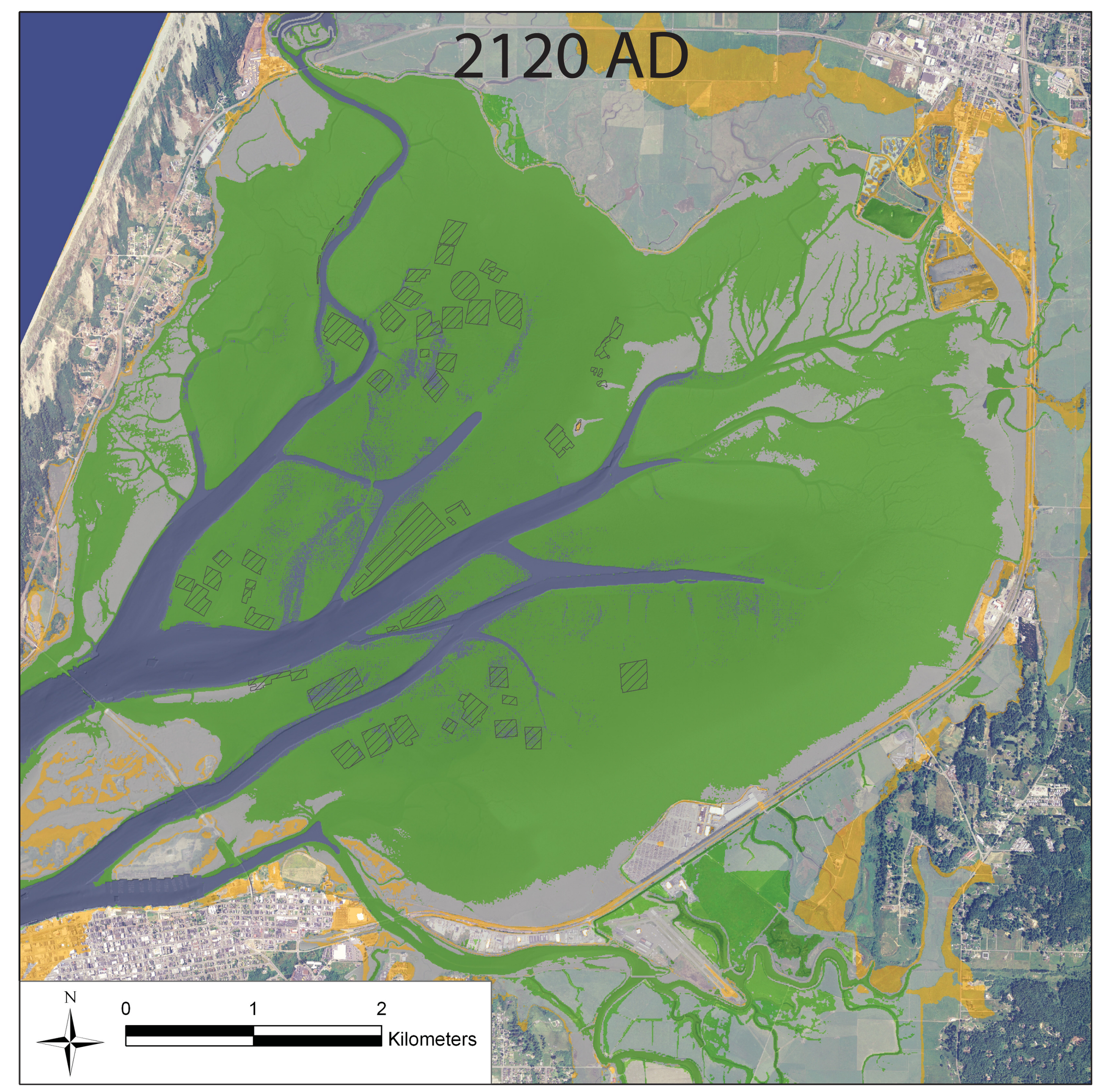


6) Model results









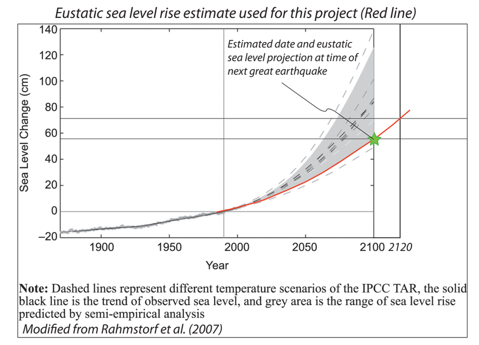
Coast marsh (Preferred elevation range 1.7-2.6m MLLW)

Eel grass and oyster mariculture (Preferred elevation range -1.7-0.5m MLLW)

Subtidal (Elevation range <-1.0m MLLW)

Area of active oyster mariculture

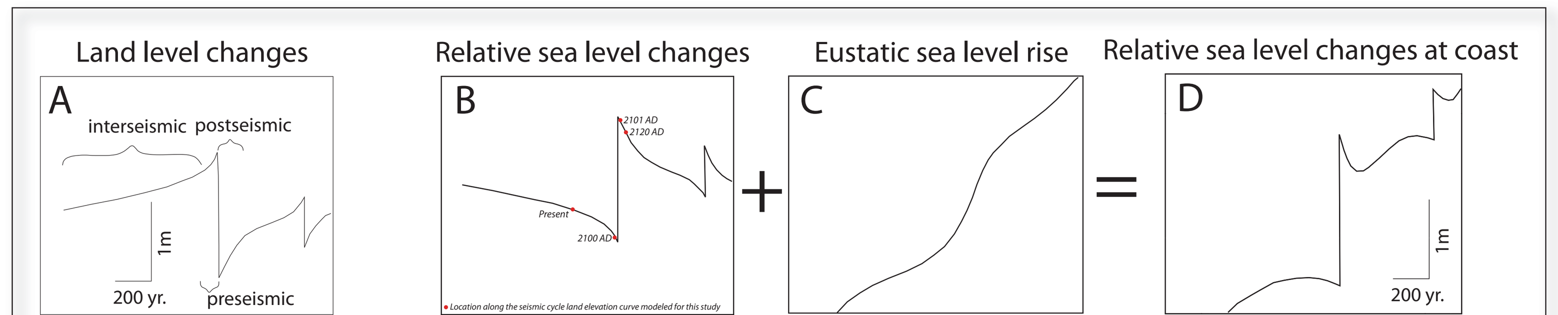
Eustatic sea level rise estimate used for this project (Red line)



Note: Dashed lines represent different temperature scenarios of the IPCC TAR, the solid black line is the trend of observed sea level, and grey area is the range of sea level rise predicted by semi-empirical analysis
Modified from Rahmstorf et al. (2007)

Approach:
1) Create a single 5m DEM referenced to MLLW using tidal benchmark data and the best available bathymetric and topographic DEM's.
2) Define eelgrass, oyster mariculture, and coastal marsh habitats based on preferred tidal elevation ranges (Gilkerson, 2008; Eichert, 1987; see center figure)
3) Define eustatic sea level estimates (Figure to left)
4) Define the spatial distribution and rate of tectonic land level changes through the seismic cycle (for this study we used (A)-land level change gradients from Wang (personal communication) to define time dependent, interseismic, land level change gradients; and (B)-regional paleoseismic investigations to estimate earthquake recurrence and subsidence magnitudes for the modeled coseismic event(Leroy and Patton, 2010; Patton, 2006; Pritchard, Leonard, 2010).
5) The model output (above) displays changes in the spatial distribution of preferred tidal elevation ranges for eelgrass and oyster mariculture, for the years 2010, 2100, 2101, and 2120, as driven by estimates of regional tectonic land level changes and global sea level estimates.

4) How tectonic land level changes and sea level changes combine to determine relative sea level at the coast



A) Land level changes at the coast during two earthquake deformation cycles with different amplitude
B) Relative sea level (RSL) changes produced by the cycles during a period of no change in regional sea level
C) A gradual rise in regional sea level during the cycles that does not include short term or small scale changes in local and regional sea level
D) RSL changes at the coast resulting from the sum of figures B and C

From: Nelson, 1996

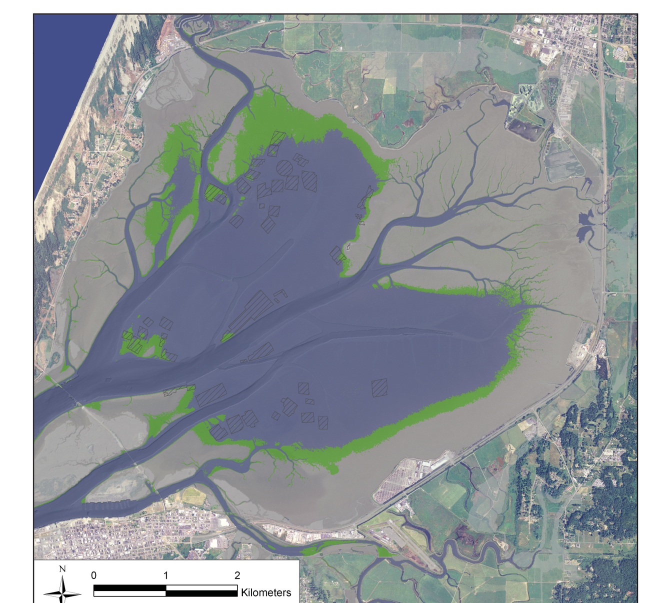
5) The magnitude of coseismic subsidence

The magnitude of subsidence during a subduction event in the Humboldt Bay region is not well constrained and is likely variable. Confounding these estimates is a data gap regarding relations between upper plate thrust faulting in the North American plate and the subduction zone, a particularly importance question is "*do the thrust faults in the fold and thrust belt of the Csz pose an independent seismic hazard or do they rupture coincidentally with the subduction zone?*" Reported coseismic subsidence estimates in Humboldt Bay range from approximately 1 meter to >2.6 meters (Patton, 2006; Pritchard, 2007; Leonard, 2010). Events in coastal Oregon and Washington suggest a maximum value of around 2 meters. For this modeling effort we use a maximum value of 1.5 meters.

7) Observations, uncertainty and conclusions

Present- 2100 AD- the preferable habitat for eelgrass and oyster mariculture slightly increases
2101 AD (post earthquake)- Immediately following the earthquake and associated regional land subsidence (a relative rise in sea level) the preferable elevation range for eelgrass habitat and oyster mariculture is almost entirely shifted out of its present footprint and replaced by subtidal water depths.
2120- The preferable elevation range for eelgrass habitat and oyster mariculture has largely reoccupied most of its former footprint while retaining some if its more recently assimilated elevation range. This is largely a result of re-accumulation of strain along the subduction zone and sedimentation

There are many uncertainties associated with this type of model which limit its ability to forecast future relative sea levels, the primary ones are:
(1) It excludes accretion as an explicit model input.
(2) It assumes that levees/dikes and other hardened shoreline infrastructure fails due to coseismic displacement.
(3) It ignores any plastic deformation associated with thrust faults in the North American plate.
(4) It assumes that the tidal range will remain the same relative to changes in (relative) local mean sea level.



The green area above is where the current preferable elevation ranges for eelgrass habitat and oyster mariculture overlap with the same preferred elevation ranges forecasted for the year 2101, the year after our modeled earthquake. Notice most of the current oyster mariculture sites (hatched areas) are predicted to be submerged to sub tidal elevations.

Coastal communities around the world are planning for future sea level rise, ones along subduction zones, where land levels are not static, will have to undertake significantly more robust efforts. This poster presents the results of our efforts to model the superposed effects of eustatic sea-level rise and tectonically driven land-level changes on the spatial distribution of preferred tidal elevations for native eelgrass (*Zostera marina*) and oyster mariculture operations in Humboldt Bay. These intertidal organisms were chosen primarily because they have vertically restricted spatial distributions that can be successfully modeled. Future efforts will include refinement of the tectonic input component of the model.