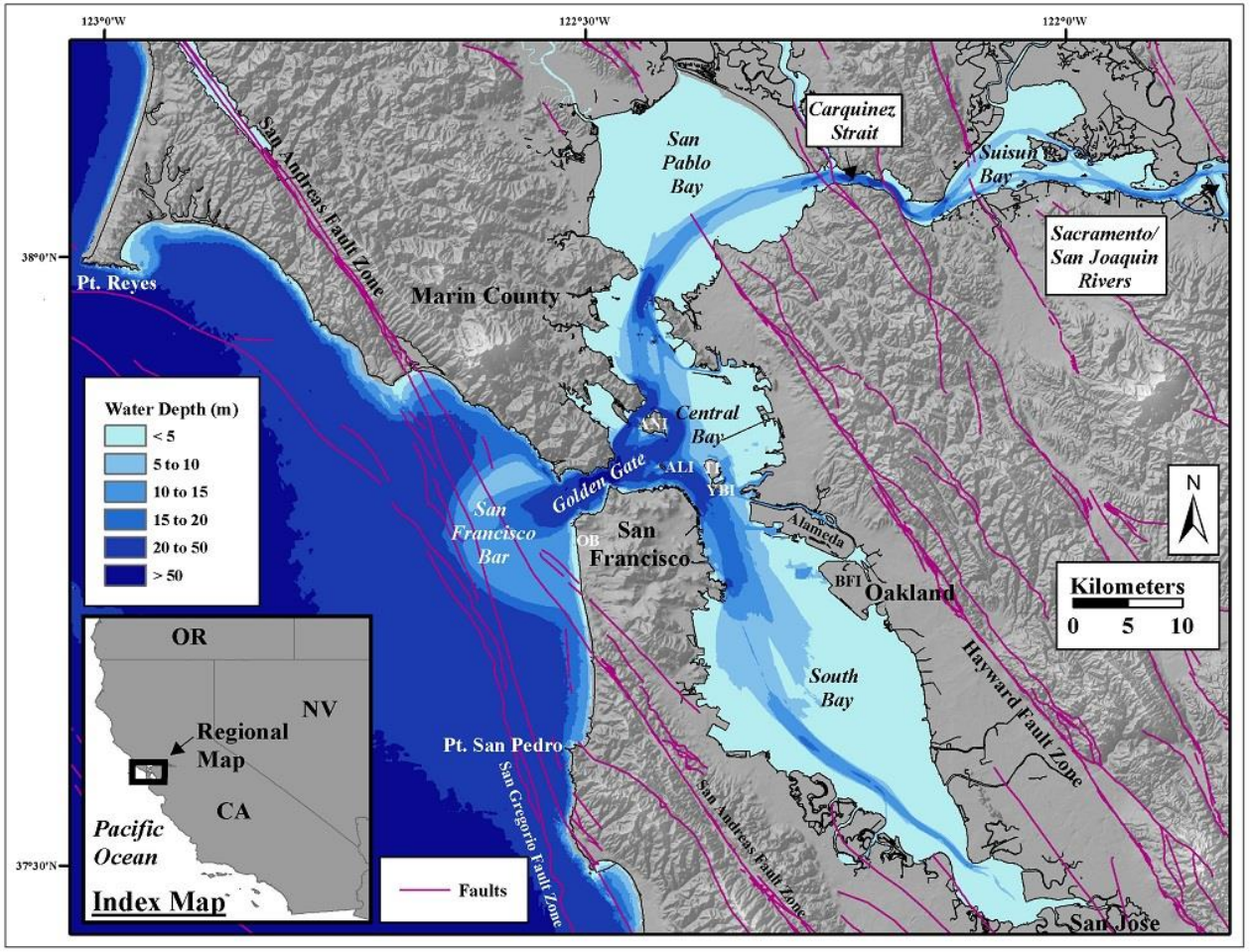
Beyond Size and Sorting:

More proxies for sediment transport in the San Francisco Bay Coastal System

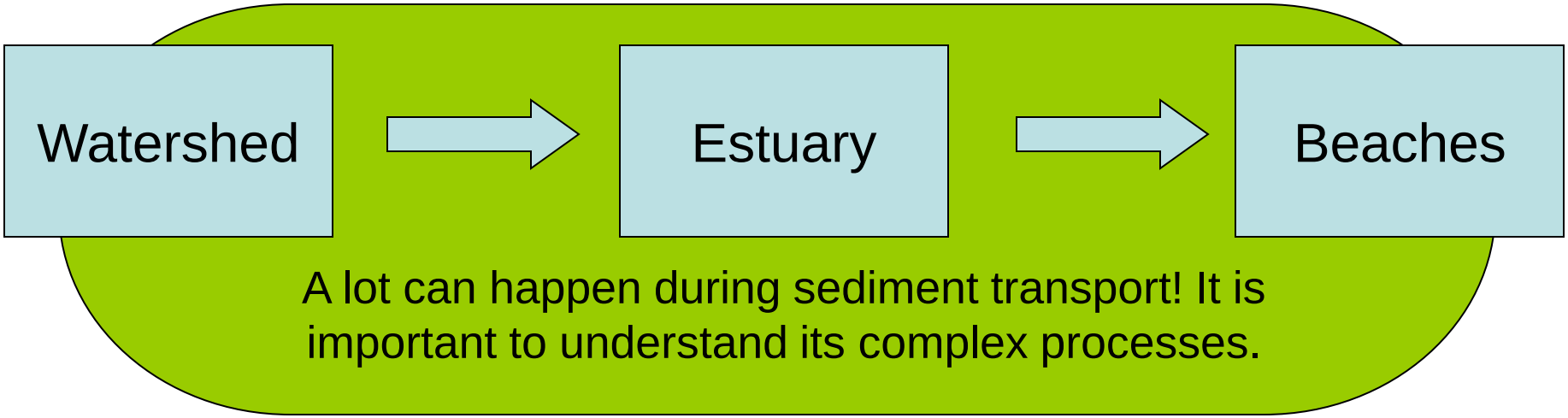


The San Francisco Bay Coastal System.
(Barnard et al [1], Figure 1)

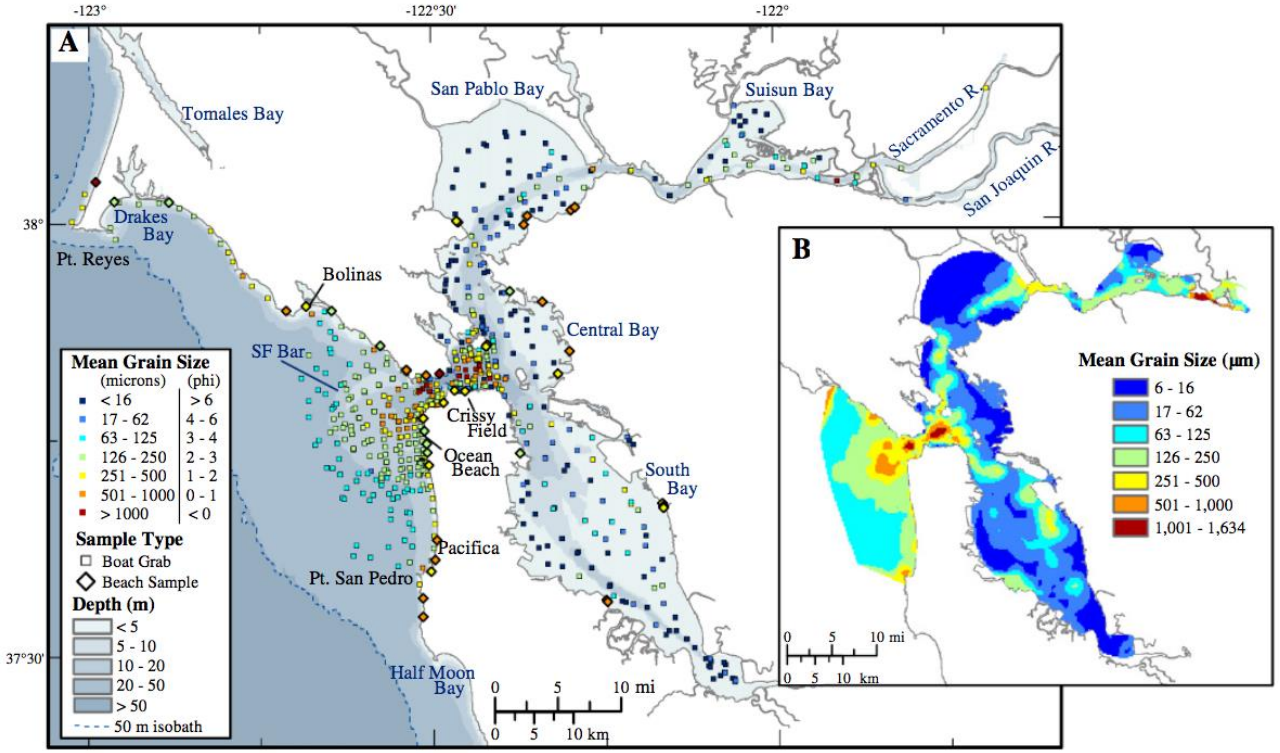
Sediments help us understand the processes which shape our natural world.

- Sediment = particles of sand, silt, or clay
- Flowing water almost always carries sediment; sediment also travels by air/gravity
- As it is transported, sediment scours, accumulates, disperses, and deposits
- Plays a role in formation and alteration of Earth's features and geography

Sediment plays a significant role in the San Francisco Bay Coastal System. Water quality, beaches, wetlands, and regional quality of life are all affected by sediment.



By analyzing a sediment sample, we can discern a lot about the history of an area. Grain size and composition offer insight to how long the material may have traveled, and where it may have come from.



A) Mean grain size of surface sediment samples, and B) interpolated surface of mean grain size. (Barnard et al [2], Figure 10)

Near their source, sediments are largest. As they are transported, they are physically weathered and break down. Smaller grains can be carried for longer distances, though high-energy water can move bigger grains as well.

Analyzing grain size and composition of sediment helps us better understand local geologic history and processes.

Sediment samples from San Francisco Bay Area beaches.
From left: Rodeo Beach, Baker Beach, Ocean Beach, Rockaway Beach, Pacifica State Beach, Gray Whale Cove State Beach

In addition to having grain size reduced by *physical* weathering, the range of composition in a sediment sample is reduced by *chemical* weathering. Less resistant materials break down as sediments travel and are exposed to the elements. All grain compositions can exist if sediment is found near its source. However, if a sediment sample is only composed of more resistant components, it has probably been transported a significant distance.

Most resistant:

-Quartz
-Magnetite

Moderately resistant:

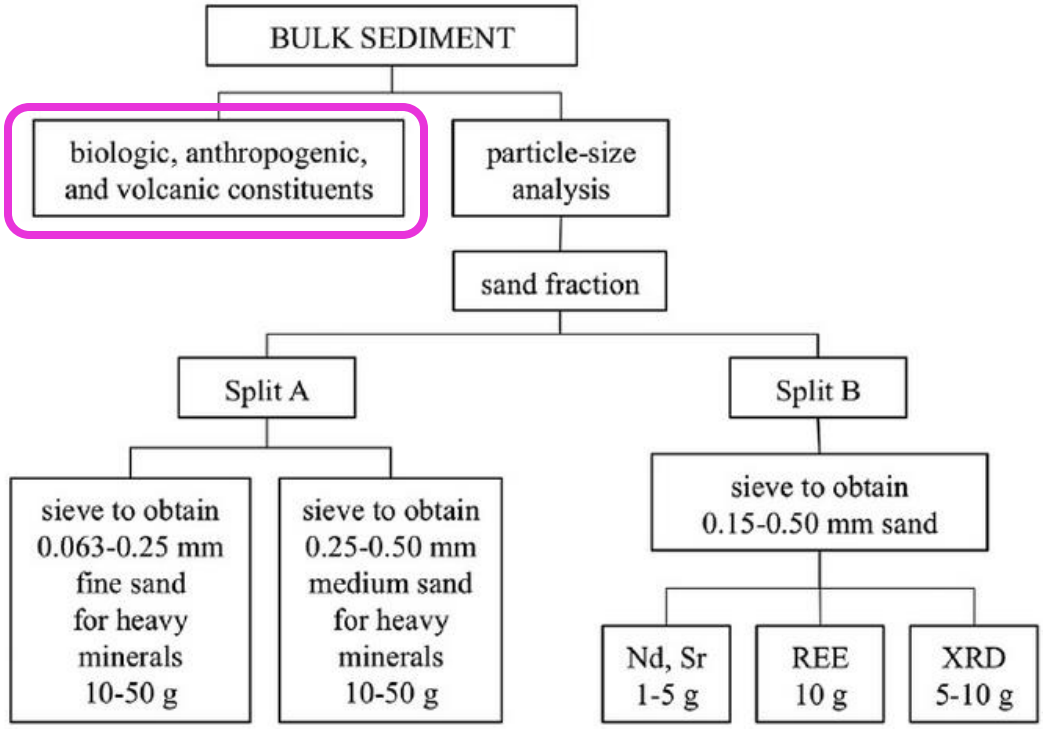
-Feldspar

Least resistant:

-Black nonmagnetic minerals
-Rock fragments
-Shells

However, the grain size and geochemical composition of sediment can only tell so much. There is much more to a sample than meets the eye. Sediments have other constituents which can help us paint a more complete picture of transport processes and history.

Sediment around the Bay Area is full of clues from **biologic, anthropogenic, and volcanic** sources. These constituents can function as additional proxies, offering unique information that contributes to our knowledge of transport and deposition processes.



Flowchart of geochemical analyses. (Barnard et al [2], Figure 4)

1. Biologic Constituents

Most sediments from freshwater, brackish, and marine environments have constituents of biological origin, which come with their own unique species distribution signature. Species distribution is affected by environmental factors such as water temperature, salinity, dissolved O2, organic carbon content, currents and tidal flow.

Although similar in size, biological particles such as forams behave differently than terrigenous sediment during transport. Due to their size, weight, and shape, they are selectively picked up and differentially deposited (McGann et al, p129).

Having distinct environmental signatures as well as differential transport behavior makes biologic constituents a useful proxy that can contribute unique data to help understand sediment transport.

Biologic Constituents:

How does it work?

Benthic foraminiferal faunas are extracted from sediment samples. In the lab, chemical analyses can be run to recognize what portion were alive or recently alive at the time of collection. This data is compiled along with species distribution/abundance and presence/absence values. Similar data is also collected for other biologic constituents such as radiolarians, planktic foraminifera, diatoms, ostracods, and thecamoebians. Data is also collected on the locations and conditions of the sample sites.

A variety of cluster analyses are executed according to species and location data in order to form associations, find patterns, and draw connections.

What can it tell us?

Using clustering, the environments of sample sites can be matched with representative species that would be found in such an environment.

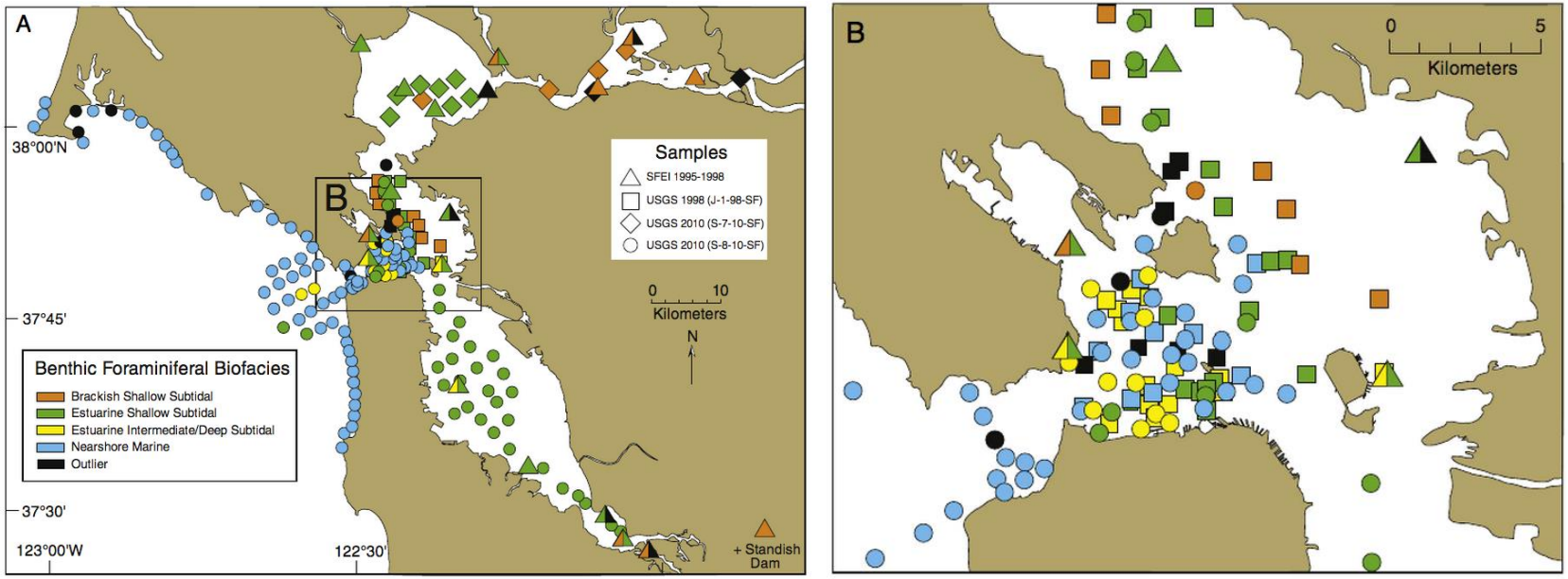
Therefore, finding a certain type of species far from its habitat suggests that it had been transported from its original environment.

For example, radiolarians and planktic foraminifera only live in fully marine, open-ocean environments (McGann et al, p132). Therefore, finding them in deep-water sediment samples from inside the bay must be a result of transport from the ocean.

Biologic Constituents:

What has it told us about the Bay Area?

Integrating the cluster analyses of both the species and sample site data resulted in four distinct benthic foraminiferal biofacies: each sample reflected a species distribution that corresponded with one or two out of four preferred habitats.



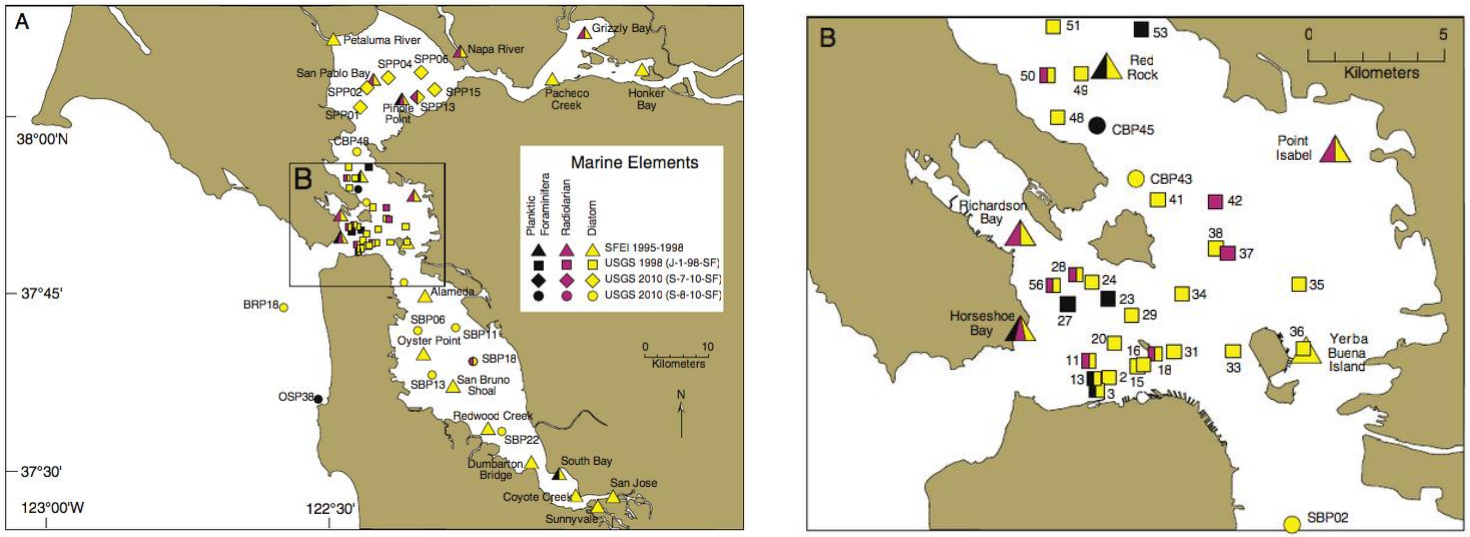
(A) Spatial distribution of the benthic foraminiferal biofacies identified by the R- and Q-mode cluster analyses of the 1995-2010 San Francisco Bay Coastal System stations. (B) Detailed map of the stations in Central Bay, the Golden Gate, and the eastern portion of the San Francisco Bar. Bicolored symbols represent stations where two biofacies are present. (McGann et al, Figure 12)

Freshwater-habitat biologic constituents were found almost everywhere throughout the SF Bay Coastal System. This transport may be due to any of the creeks and sloughs which feed directly into the estuary or marine realm or rivers (McGann et al, p137). There were many other occurrences outside of their preferred environment, and are attributed to sediment transport processes as well.

Biologic Constituents:

What has it told us about the Bay Area?

Radiolarians and planktic foraminifera, which are marine elements, were present in deep-water San Francisco Bay sediments, suggesting transport from the Pacific Ocean through the Golden Gate via strong flood tides. They were also found in western Central Bay, suggesting deposition during the slack tide or when flood tides through the Golden Gate decrease in velocity quickly. Marine habitat biologic constituents including diatoms were ultimately found as far north as Honker Bay, and at the very southern end of the South Bay, suggesting the sediments are carried by currents great distances from the ocean in all directions (McGann et al, p132).



Spatial distribution of marine-indicating biologic elements at the 1995-2010 San Francisco Bay Coastal System stations. Bi- and tri-colored symbols represent stations where two or three constituents are present. (McGann et al, Figure 14)

Overall, the biologic constituents demonstrate the estuary's well-mixed nature. Transport processes bring constituents from fresh, brackish and marine environments into all reaches of the bay.

2. Anthropogenic Constituents

The San Francisco Bay is the second largest estuary in the country, and one of the most human-altered in the world. Together with the Sacramento-San Joaquin Delta, the San Francisco Bay Coastal System is surrounded by seven million people (Barnard et al [1], p3).

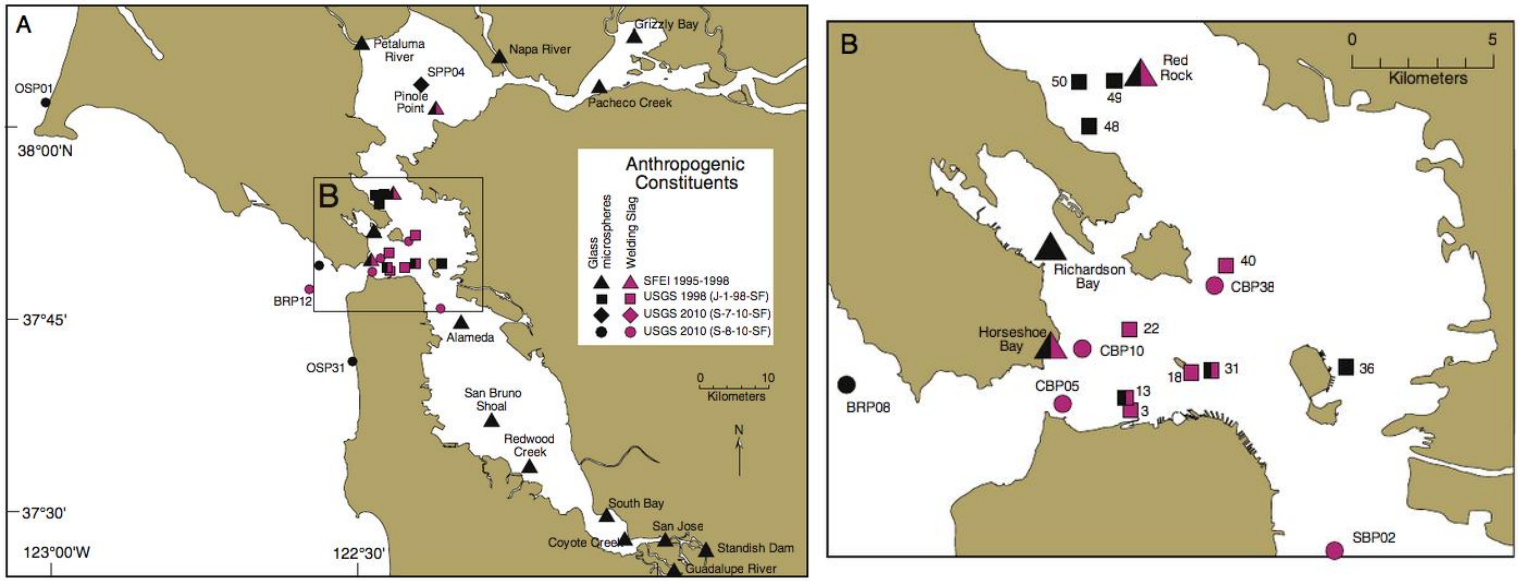
Constituents in sediment that originate from human activities are classified as anthropogenic. These constituents generally fall into two categories: welding slag, which is a byproduct of welding, and glass microspheres, which have widespread used and are most commonly used today in road striping and pavement marking material (McGann et al, p125).

Anthropogenic constituents are considered to be sourced from the terrestrial realm. Much like biological constituents, particles that represent anthropogenic constituents behave differently than terrigenous sediment during transport. Therefore, looking at them can offer unique information in a multi-proxy approach to better understand sediment transport processes.

Anthropogenic Constituents:

What has it told us about the Bay Area?

In the 2013 study, anthropogenic constituents were found at 26 sites. They were picked out of sieved sediment samples and identified as welding slag or glass microspheres (McGann et al, p125).



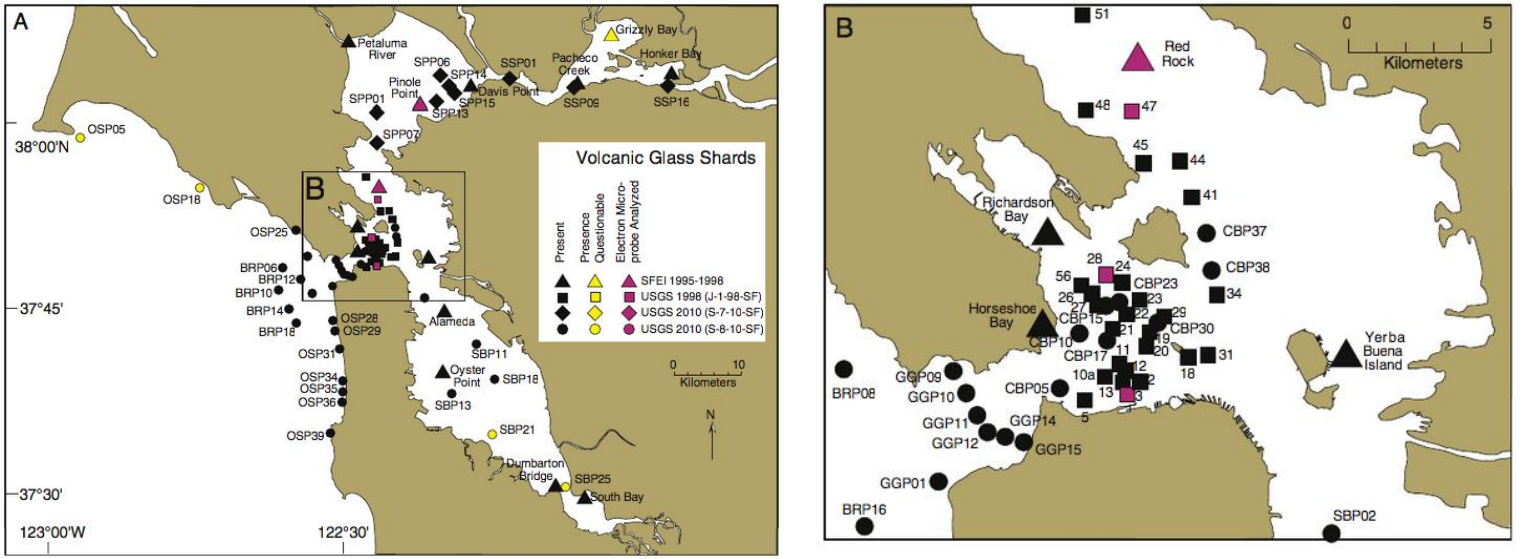
(A) Spatial distribution of the anthropogenic constituents at the San Francisco Bay Coastal System stations. (B) Detailed map of the stations in Central Bay, the Golden Gate, and the eastern portion of the San Francisco Bar. (McGann et al, Figure 10)

The constituents were generally found along estuary margins, where they are presumed to be derived locally. However some anthropogenic constituents occurred in samples taken from the middle of South and Central Bays. In these cases, sediment was definitely transported via local and regional watercourses away from its source (McGann et al, p139).

3. Volcanic Constituents

The San Francisco Bay Area Coastal System is in distant proximity to volcanic eruptive source areas in the Great Valley. Fragments from volcanic eruptions are known as tephra, and have disseminated throughout the Bay Area to be found as constituents in sediment.

Isotropic volcanic glass shards were found in at least 78 sieved sediment samples in the 2013 study. The highest abundance of volcanic constituents were found in the Central Bay, through the Golden Gate, and on the SF Bar. However, the volcanic glass was found far north and south throughout the Bay Area (McGann et al, p125).



(A) Spatial distribution of volcanic glass shards at the 1995-2010 San Francisco Bay Coastal System stations. (B) Detailed map of the stations. (McGann et al, Figure 11)

Volcanic Constituents:

What has it told us in the Bay Area?

Individual shards were submitted for electron microprobe analysis, which was evaluated in conjunction with shard morphology and mineralogy to determine the age and eruptive source location of the different ash samples (McGann et al, p122).

The analyses revealed that all of the samples of volcanic glass were heterogeneous, with shards transported from a wide geographic and temporal variety of eruptive source areas from the Great Valley; thus, none were local (p126).

The weathered morphology and heterogeneous geochemistry of the shards suggest a high degree of fluvial transport before reaching the SF Bay Area Coastal System, primarily through the Sacramento and San Joaquin Rivers. The tephra then becomes distributed throughout the bay through sediment transport processes (p138).

Putting the pieces together…

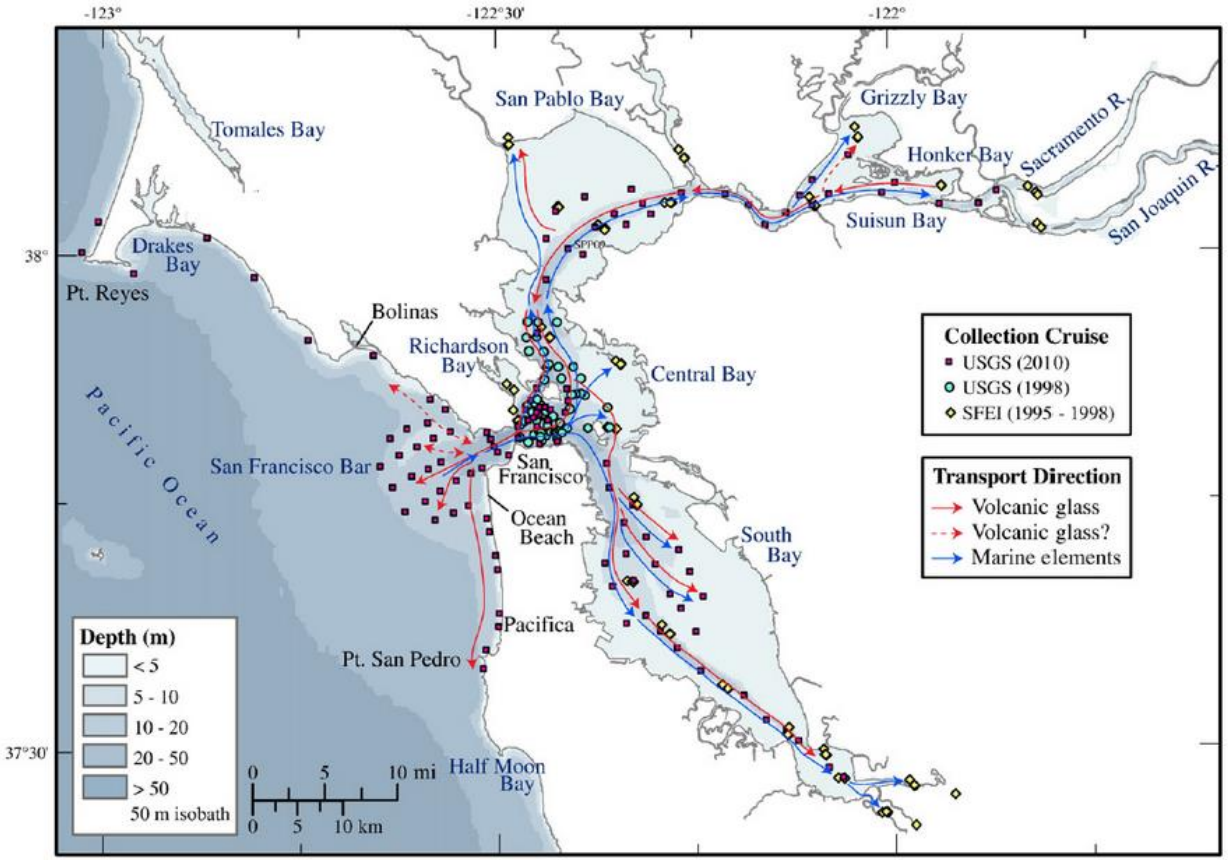
We consider which source area each key sediment constituent represents, and compare it with the actual spatial distribution of the constituents as found in sediment samples:

			San Francisco Bay Coastal System regions						
		Constituent	Suisun, Grizzly, and Honker Bays	San Pablo Bay	South Bay	Central Bay	Golden Gate	San Francisco Bar	Offshore
Source area	Freshwater	Diatom	X						
		Gastropod	X	X	X	X	X		X
		Ostracod			X				
		Thecamoebian	X	X		X			
	Brackish/estuarine	Benthic foraminifera	X	X	X	X	X	X	X
		Bivalve mollusk		X	X				
		Gastropod			X				
		Ostracod	X	X	X	X		X	X
		Thecamoebian	X	X	X	X			
	Marine	Benthic foraminifera		X	X	X	X	X	X
		Diatom	X	X	X	X		X	X
		Gastropod			X		X		
		Ostracod		X	X	X		X	X
		Planktic foraminifera		X	X	X			
		Radiolarian		X	X	X			X
	Introduced	Benthic foraminifera	X	X	X	X	X	X	X
		Bivalve mollusk		X	X				
		Ostracod			X				
	Terrestrial	Glass microsphere	X	X	X	X		X	X
		Recrystallized foraminifera	X	X	X	X			X
		Recrystallized radiolarian	X						X
		Welding slag		X	X	X		X	
	Volcanic indeterminate	Glass shard	X	X	X	X	X	X	X
		Bryozoan	X	X		X	X	X	X
		Crab claw			X	X			X
		Echinoid spine		X	X	X	X	X	X
		Fish element	X	X	X	X	X	X	X
		Gastropod operculum			X	X			
		Scirpus seed		X	X	X			
		Seed (other)	X	X	X	X			
		Spore	X	X		X			
		Worm tube		X		X			
Benthic foraminiferal biofacies	Brackish shallow subtidal		X	X	X	X			
	Estuarine shallow subtidal			X	X	X		X	
	Estuarine intermediate/deep subtidal				X	X		X	
	Nearshore marine					X	X	X	X

Spatial distribution of the key sediment constituents and the source areas they represent in the San Francisco Bay Coastal System. (McGann et al, Table 3)

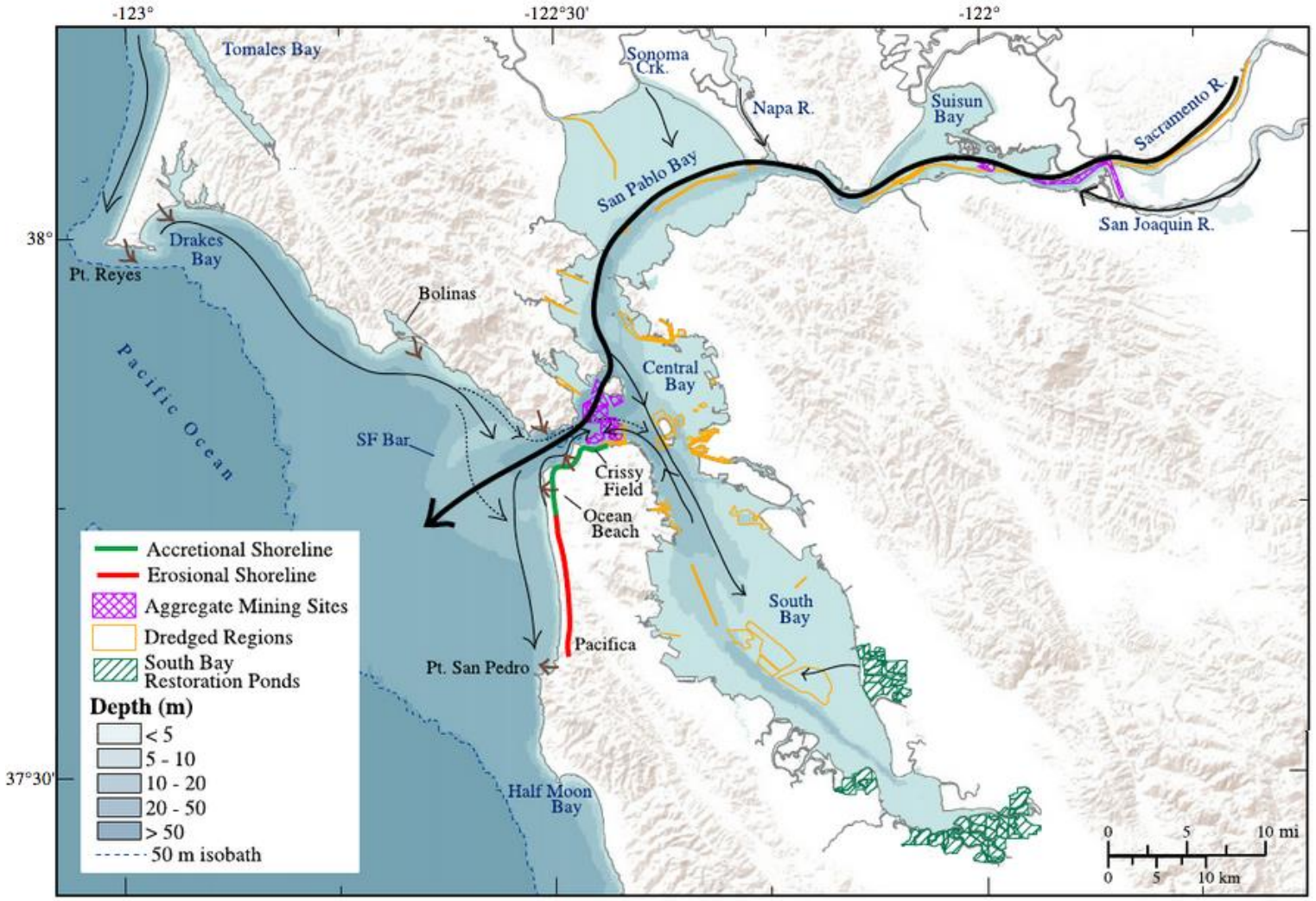
Putting the pieces together…

These findings of distributional patterns observed from different constituents can be synthesized to infer the pathways of sediment transport in the San Francisco Bay Coastal System:

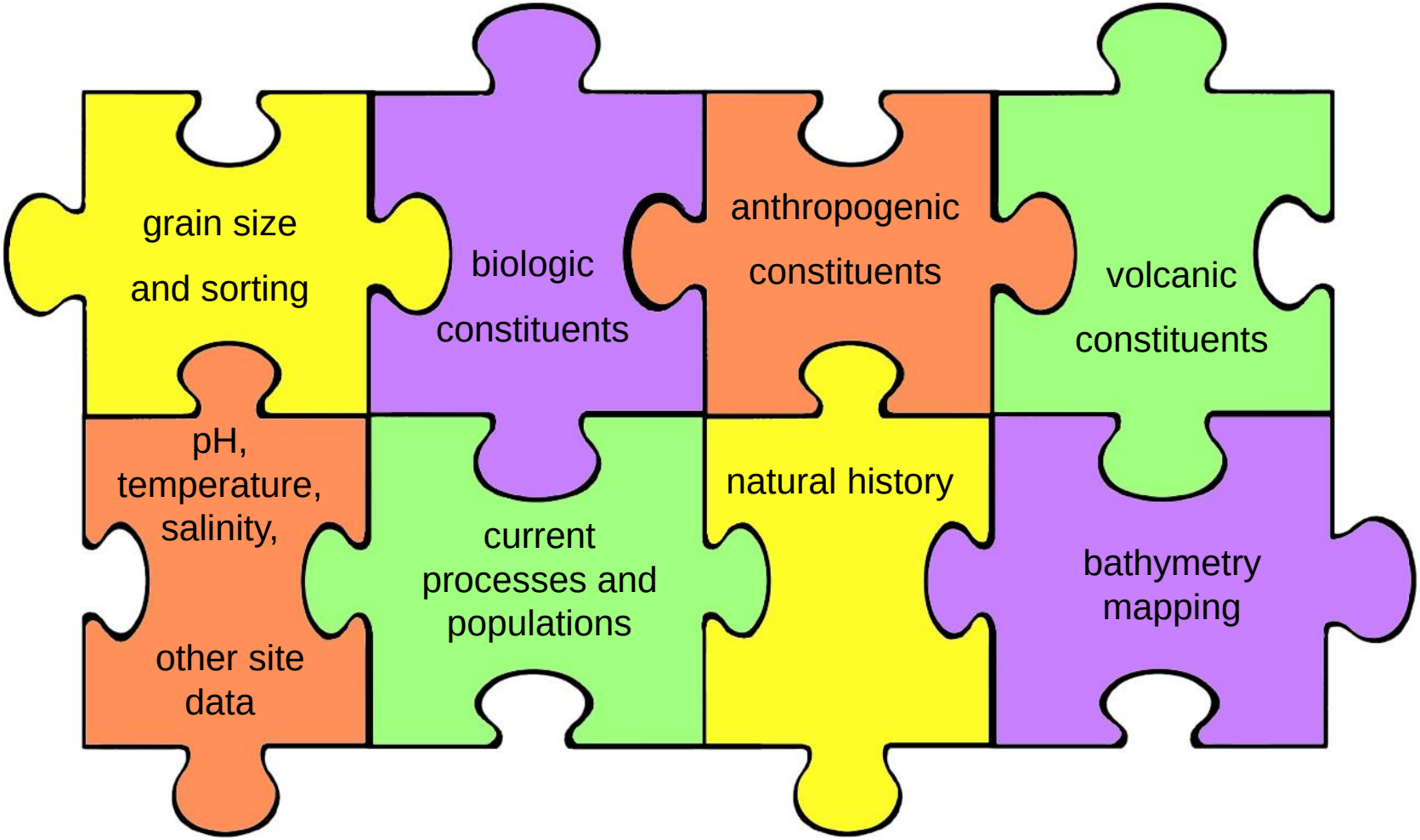


Location of the sediment constituent study sites and pathways of sediment transport in the San Francisco Bay Coastal System inferred b the presence of marine elements from the offshore realm as well as volcanic glass originating in the Central Valley. (Barnard et al [2], Figure 15)

Putting the pieces together…



Final conceptual model of the primary beach-sized sand transport pathways in the San Francisco Bay Coastal system, based on the integration of provenance techniques. (Barnard et al [2], Figure 20)



A multi-proxy approach allows us to put the puzzle pieces together, so that we may better understand sediment transport and other coastal-estuarine processes in the San Francisco Bay Coastal System.

Conclusion

"The only means to implement effective local and regional sediment management plans that promote the sustainability of coastal environments is to understand the entire coastal system, from source to sink."

(Barnard et al [2], p121)

Biologic, anthropogenic, and volcanic constituents are useful proxies for discerning sediment transport pathways. Additionally, they can give us insight into environmental health and lead to management techniques for a better future for the earth and those who live on it.

"Despite the importance of estuaries as a critical physical, biological, and chemical interface between drainage basins and the coastal ocean, there is still a great deal to be learned about how they function, especially in light of the vast direct and indirect anthropogenic influences that have severely altered their functioning throughout human history."

(Barnard et al [1], p13-14)

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