Habitats: Inshore Flats

Michael Savarese
Florida Gulf Coast University

In a nutshell

- Subtidal and intertidal sand and mud flats serve as habitat to a diverse assemblage of infaunal and epifaunal organisms and provide shoreline protection against erosion and storms, sustenance through food web connections to foraging birds and finfishes, and carbon sequestration and organic degradation.
- Through these connections, inshore flats help to support commercial and sport fisheries, preserve endangered species, provide shoreline protection, and contribute to the aesthetics of the coast.
- The drivers with greatest significance to the coast are climate change, water management, and coastal development.
- Altered freshwater inflow is the most serious and immediate pressure requiring attention along the SWFS.

Four habitat types are recognized for the Inshore Flats submodel: (1) siliciclastic or carbonate subtidal mud flats (subtidal soft bottom); (2) siliciclastic subtidal sand/mud flats (subtidal firm bottom); (3) intertidal tidal deltas (intertidal firm bottom); and (4) intertidal sand shoreline fringe (intertidal firm bottom). All four habitat types are found among the four geomorphologic provinces: Barrier Islands, Ten Thousand Islands, Everglades, and Cape Sable. Subtidal flats composed of sand and mud or mud are ubiquitous throughout the system. The distribution of intertidal deltas varies, however. Tidal deltas tend to be large and most active within the Barrier Islands Province. Here, inlets between barrier islands experience swift tidal currents, and the coast's position relative to Gulf-crossing tropical storms mobilizes and deposits deltaic sediments with greatest frequency. The Everglades Province has narrow rivers separating the inner bays from the open coast; strong tidal currents through these channels generate large deltas. Tidal deltas exist within the outer and inner bays of the Ten Thousand Islands, but the more open construction of the coast less effectively focuses tidal currents to generate large deltas. Finally, Whitewater and Oyster bays, located within the Cape Sable Province, are almost completely isolated from open water. Tidal deltas here are inconsequential. Intertidal shoreline fringe is found in all four provinces, but fringe is best developed in the Barrier Islands and Ten Thousand Islands provinces where accommodation area on the backside of islands is great.

Inshore flats are defined as flat bottom, sub- or intertidal habitats that lack an epifaunal oyster or seagrass community and are located inside the outer coastal margin. The two most significant environmental characteristics that control a flat's infauna and epifauna are: the height of the substrate relative to mean sea level and the sedimentary consistency of the substrate. The position relative to mean sea level dictates whether the habitat is emergent in air for part of a tidal cycle (i.e., intertidal) or how deep within the subtidal zone the benthos sits. This latter characteristic controls other physical water quality measures, like dissolved oxygen and the frequency and duration of hypoxia events, and ambient light level, which is affected by depth of light penetration. Firmness of the substrate affects the capacity to support an epifauna—preventing the sinking of an organism in the substrate—and the burrowing behavior of the infauna. Substrates that consist of sand and sand mixed with mud (mud is an admixture of clay- and silt-sized particles) tend to be firm, supporting an epifauna, and typically have high sediment porosity and permeability leading to well oxygenated interstitial fluids that can support a diverse and deeply penetrating infauna. Muds may be incompetent and not support a shelly epifauna (De Deckere *et al.,* 2001) and often have low porosity and permeability, prohibiting the existence of an extensive infauna (Sanders, 1958; Rhoads and Morse, 1971; Rhoads and Germano, 1982).

The composition of the sediment can vary. Sand-sized material is most commonly composed of quartz that is either derived from offshore-longshore drift, which is then moved landward due to storm and tidal activity (Tanner *et al.,* 1963; Perlmutter, 1982; Davis *et al.,* 1993) or, less commonly, from downstream transport from the watershed. Less commonly, the coarser sediment is composed of calcium carbonate shell fragments (Scholl, 1963; Sussko, 1989). Mud may be composed of phyllosilicate clays, carbonate, or finely disseminated organics. Phyllosilicates are the rarest of the three and are derived from upstream in the watershed as weathering products of silicate minerals within older sediments or sedimentary rocks. Carbonate mud is biogenically produced either in the estuary itself, in marine sediments that are transported upstream by storms or tides, or in freshwater and brackish water marshes (marls produced by algal and microbial communities; Browder *et al.,* 1991; Merz, 1992) that are moved to the estuary by sheet or channel flow. Finally, organics can be derived in situ or be transported in from upstream. Intertidal flats are invariably dominated by quartz sand-sized grains. Wave influences, regardless of the limited fetch in inshore settings, are energetic enough to prohibit the deposition of mud-sized grains.

The distinguishing characteristics that define inshore flat habitat types are relative water depth with respect to mean sea level and the sedimentary substrate composition: habitats may be subtidal or intertidal; subtidal substrates may be composed of sand and mud or mud; and intertidal substrates are composed of sand. Additionally, intertidal sand flats occur as one of two varieties that are distinguished by the relative stability and residence time of the sands. Storm tidal deltas form on the inside edges of the outer and inner bays landward of tidal inlets. During storm flood, tides sands are transported landward and deposited on these deltas. (Ebb flood deltas may also occur seaward but tend to be ephemeral, as the sands deposited in these features are quickly remobilized and transported away; see Reinson [1979] for general description of tidal deltas.) Consequently, storm tidal deltas remain stable between storm and extreme tidal events. Intertidal sand flats also occur as beach aprons on the bayside of islands. These structures are influenced by waves and by tidal cycle fluctuations.

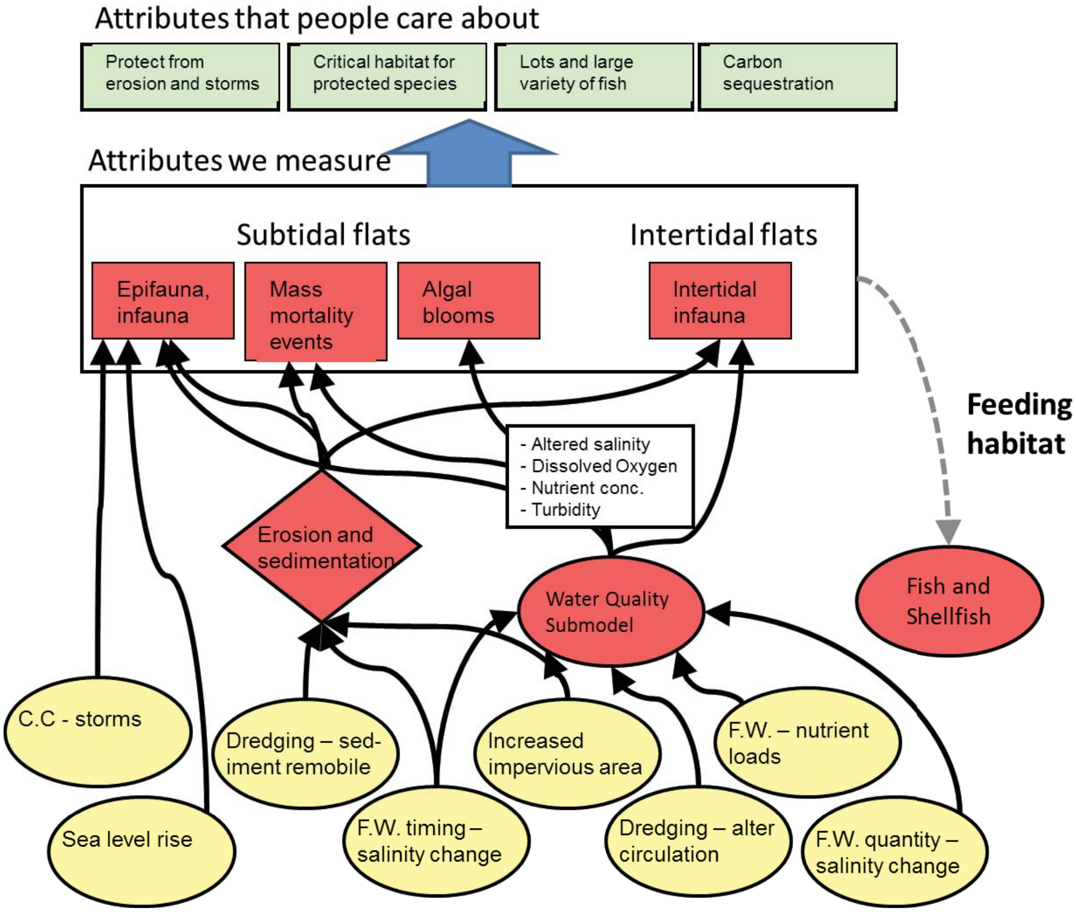
Attributes People Care About

Critical Habitat for Protected Species

Intertidal mudflats are highly productive ecosystems that are often poorly acknowledged (Erftemeijer and Lewis, 1999; Dittman, 2002). Infaunas and epifaunas have been described for a number of regions in Florida and the eastern Gulf of Mexico coast (Lyons and Collard, 1974; Culter, 1988; Posey *et al.,* 1998; Brooks *et al.,* 2004, 2006). Intertidal flats serve as habitat for foraging wading birds, and many of these are protected or listed species (Quammen, 1984; Ogden, 1994; Erwin, 1996). Exposed mud and sand flats provide sustenance from the available infauna and epifaunal invertebrates; invertebrate densities can exceed 10,000 individuals per m2 (Barnes *et al.,* 1997). Intertidal, when submerged, and subtidal flats serve as critical grazing and predation habitat for finfish, many of which are protected.

Abundance and Large Variety of Fish

Similarly, inshore flats serve as feeding habitat for a large variety of fish species, regardless of their protected status. Many of these fish species are benthic feeders and prey upon epifaunal invertebrates. Sand and muddy substrates in southwest Florida support a diverse invertebrate infauna (Hooks *et al.,* 1976; Phillips *et al.,* 1990; Dawes *et al.,* 1995). Certain fish (e.g., skates and rays) are specialized to feed on shallow burrowing invertebrates (Howard *et al.,* 1977; Smith and Merriner, 1985).



Inshore flats submodel diagram for the Southwest Florida Shelf.

Protection from Erosion and Storms

Intertidal flats are commonly found adjacent to the leeward shorelines of barrier and outer coastal islands. Depth gradients are often slight, thereby creating a wide protective shallow fringe to an island's lee shoreline. Though storm erosion is typically more impactful on an island's windward face, tidal surge and wave fetch can be great on the backside. The intertidal flats, therefore, do provide an erosion buffer for back-barrier wetlands. Additionally, mangrove forests commonly prograde onto adjacent intertidal flats, making these paralic environments important buffers for mangrove forest development (Alongi, 2008).

Carbon Sequestration (Burial of Organic Carbon)

Inshore flat sediments, particularly those dominated by muds, are typically rich in organic carbon. Organics settle from suspension either independently or attached to clay-size detrital sediments, accumulate on the estuarine seafloor, and can be quickly buried (Bridgham *et al.,*2006; Howe *et al.,* 2009; Sanders *et al.,* 2010). Because sediments are rarely well oxygenated below a few centimeters of the substrate, these organics have greater likelihood of becoming buried. Over geologic time during intervals of relative sea-level rise, shorelines transgress and organic-rich muds remain buried, increasing the likelihood of long-term carbon storage.

Drivers and Pressures

Of the lengthy list of drivers affecting southwest Florida, those of greatest significance for inshore flats are: (1) climate change; (2) water management practices; and (3) urban development. Climate influences manifest themselves as ecosystem pressures from changes in storm intensity and frequency and from sea-level rise. Water management practices generate pressures associated with the changes in the quantity and timing of delivery of freshwater, and in the delivery of nutrients. Finally, urban development influences hydrology by increasing impervious area on land and through channel dredging in the estuaries. Each of these pressures will be considered separately.

Climate Change – Storms

One of the predictions of global warming is an increase in intensity and perhaps frequency of tropical storms (Webster *et al.*,2005; Oouchi *et al.*, 2006). Hurricanes generate extreme tidal surges and deepen wavebase; this influences the transport, deposition, and erosion of sediment. Storm deltas are activated; overwash can occur on barrier islands to build overwash fans, thereby affecting the back-barrier marshes and aprons (e.g., Donnelly *et al.*, 2004; Wang and Horwitz, 2007); and mangrove fringe forests can be back-stepped through erosion to enlarge inner and outer bays to create new subtidal mud and sand flats (e.g., Risi *et al.*, 1995; Baldwin *et al.*, 2001). Because flood storm tides are typically more energetic than ebb storm tides, traction- and suspended-transported sediments are redistributed with net transport shoreward. Coarser materials (sand and shell gravels) are moved inshore, while muds, which are capable of remaining in suspension during less-energetic flows, are transported and eventually deposited offshore (Davis *et al.*, 1989). Consequently, storm tidal deltas of the inner and outer bays tend to build, and muds are deposited on the broad shelf of the Gulf of Mexico and Gullivan Bay.

Sea-Level Rise

Sea-level rise influences the coast through two mechanisms. The net effect of the combined rates of sea-level rise and sedimentation influence coastal geomorphology (see "Physical Setting: Dynamic Geomorphology" section, page 8), and sea-level rise alters the distribution of salinities within the estuaries and, therefore, the position of the salinity gradient and ecotones.

Over decadal and centennial time scales, the high rate of sea-level rise relative to the rate of sedimentation will eventually cause an environment to become deeper. Intertidal flats may become subtidal; subtidal flats may deepen and experience lower ambient light levels and greater frequencies or intensities of hypoxia. With deepening comes a concomitant change in sedimentary character, with substrates becoming finer grained and more mud-rich. Oyster reefs become less productive with increasing subtidal depth and can effectively "drown" and disappear; such phenomena have been documented in Holocene sediment cores (Bratton *et al.*, 2003; Wohlpart *et al.*, 2007). Mangrove-forested islands can also drown when the rate of sea-level rise exceeds the rate of production (Ellison and Stoddart, 1991).

Shifts in salinity affect an organism's abilities to osmoregulate and can cause physiologic stress and mortality. Changes in the salinity gradient due to sea-level rise not only shift the biogeographic distribution of organisms, but may also place appropriate salinities in what is otherwise a less hospitable habitat due to other environmental conditions. For example, the incursion of higher salinity water within estuaries of the Ten Thousand Islands has placed the most productive waters for oyster growth and reproduction within the river channels, rather than the inner bays. River channels have much less accommodation space for oyster reef development than inner bays, and river channel substrates are generally too mobile to permit oyster settlement and survival (Savarese ane Volety, 2001; Savarese *et al.*, 2003).

Altered Freshwater Inflow – Quantity and Timing

The alteration of freshwater inflow due to water management practices is perhaps the most serious and immediate pressure requiring attention along the SWFS. Freshwater is over-discharged into some estuaries (e.g., Faka Union Bay in the Ten Thousand Islands [US ACOE, 2004]; Caloosahatchee River in the Barrier Islands Province [Chamberlain and Doering, 1998]); the magnitude of freshwater releases can be extreme, causing freshets that can unduly stress faunas and floras (Doering *et al.*, 2002; Barnes, 2005). In other estuaries, freshwater sheetflow is interrupted because of drainage canal networks that redirect freshwater to one bay. This phenomenon has been particularly devastating to the bays west of Faka Union Bay in the Ten Thousand Islands which, as a result, have anomalously high salinities (Savarese and Volety, 2001; Savarese *et al.*, 2003; Tolley *et al.*, 2005). The timing of freshwater delivery is also of importance. Freshets during times of spawning or larval recruitment can obviate an entire year's reproductive effort.

Increases in freshwater delivery to the estuary can also affect sedimentation rate. The suspended sediment load is amplified when freshwater flow increases. If the suspended load becomes extreme, benthic communities can become smothered and mass mortality can occur.

Channel Dredging – Altered Circulation and Sediment Remobilization

The dredging and maintenance of channels effectively reduces tidal friction, thereby allowing easier transport of marine and freshwater during tidal cycles and times of freshwater runoff (Bray, 2008). Consequently, channels further influence the quantity and timing of freshwater delivery, which can alter the distribution of salinities in the estuary. Swifter tidal flows are more competent and carry greater sediment loads. This may alter the deposition and erosion of sediments on inshore flats.

Increased Impervious Area

An increase in the impervious area of a watershed effectively increases runoff and the delivery of freshwater to an estuary which, in turn, can increase the sediment load. Pervious surfaces, alternatively, promote groundwater recharge and reduce the volume of runoff (Arnold and Gibbons, 1996).

Altered Freshwater Inflow – Nutrients

Freshwater can become enriched in nutrients by the excessive use of fertilizers within a watershed. The resulting principal effects can be numerous. Eutrophication can lead to algal blooms which may further result in decreased concentrations of dissolved oxygen, hypoxia, and anoxia events both in the water column and within the benthic pore waters, and a reduction in light transmission to the substrate (Heisler *et al.,* 2008; Anderson *et al.,* 2008).

Attributes We Can Measure

The taxonomic diversity and abundance of species are appropriate measures for the monitoring of ecosystem services of subtidal sand and mud flats. Unfortunately, these are monitoring efforts that are rarely pursued.

Subtidal Flats

Changes in epifauna and infauna. Seasonal sampling of the infauna and epifauna, to reflect wet and dry season variability, of a collection of flats spanning an estuary's salinity gradient should be used to monitor the productivity of this habitat type over time as other studies have demonstrated that significant intra-annual variability can exist (Trueblood *et al.,* 1994; Shen *et al.,* 2006). A variety of benthic indices has been established whose effectiveness has been established (Borja *et al.,* 2008). A biologist with expertise in invertebrate zoology and ecology and with a familiarity with the local fauna and field sampling methodology would be required.

Monitoring mass mortality events. The frequency and intensity of mass mortality events is symptomatic of more influential regional drivers of ecosystem change. Mass mortality is most often caused by hypoxia events, and these are most often related to harmful algal blooms. Mass mortality of epifauna is more readily observed; regular monitoring visits to a subtidal flat will reveal extensive die-offs. Infaunal mass mortality is more fleeting, however. Nonetheless, by undertaking a life versus death assemblage comparison of infauna (Kidwell, 2007; Agobian, 2010), in association with the regular monitoring described above, events that devastate an infauna can be observed (no life assemblage present in an infaunal sample).

Monitoring algal blooms. The monitoring of harmful algal blooms and their geographic and temporal patterns should be a component of the management of all southwest Florida's estuaries. Practices for measuring this attribute are found among the other ICEM submodels.

Intertidal Flats

Changes in infauna. Procedures and expertise required to monitor the infauna on intertidal flats (i.e., epifauna on intertidally exposed flats is ephemeral) are identical to what is needed for subtidal flats.

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