Estuarine, Coastal and Shelf Science 213 (2018) 160–175

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

Hydrodynamics in a shallow seasonally low-inflow estuary following eelgrass collapse

Ryan K. Walter[a,*], Edwin J. Rainville[b], Jennifer K. O'Leary[c]

[a] Physics Department, California Polytechnic State University, San Luis Obispo, CA, USA
[b] Mechanical Engineering, California Polytechnic State University, San Luis Obispo, CA, USA
[c] California Sea Grant, Department of Biology, California Polytechnic State University, San Luis Obispo, CA, USA

ARTICLE INFO

Keywords:
Estuarine hydrodynamics
Environmental gradients
Hypersalinity
Ecological regime shift
Exchange processes
Seagrass

ABSTRACT

Hydrodynamics play a critical role in mediating biological and ecological processes and can have major impacts on the distribution of habitat-forming species. Low-inflow estuaries are widespread in arid regions and during the dry season in Mediterranean climates. There is a growing need to evaluate dynamics and exchange processes in these systems and the resultant ecological linkages. We investigate the role that hydrodynamics play in shaping environmental gradients in a short and seasonally low-inflow estuary located along the central California coast. Since 2007, eelgrass meadows in Morro Bay have declined by more than 90%, representing the collapse of the major biogenic habitat. Despite the large-scale decline, eelgrass beds near the mouth of the bay remain resilient, suggesting that conditions in certain areas of the bay might allow or impede eelgrass retention and recovery. Oceanographic moorings were deployed throughout the bay during the summer dry season to assess spatial differences in environmental conditions and hydrodynamics across gradients in eelgrass survival. Relative to the mouth of the bay, the back bay water mass was significantly warmer (hyperthermal), more saline (hypersaline), less oxygenated, and more turbid, with longer flushing times, all of which have been identified as significant stressors on seagrasses. Moreover, there is weak exchange between the mouth and the back bay that effectively decouples the two water masses during most periods. Though the causes of the decline are not clear, gradients in environmental conditions driven by bay hydrodynamics appear to be preventing eelgrass recovery and restoration attempts in the back bay and keeping this region in an alternative state dominated by unvegetated intertidal mudflats. Ecosystems in low-inflow estuaries may be especially prone to ecological regime shifts or collapse and may require precautionary monitoring and management. This system and the dramatic ecological change that it has experienced, demonstrate the critical role that hydrodynamics play in ecosystem health and habitat suitability.

1. Introduction

Coastal ecosystems and estuaries are among the world's most productive ecosystems, but are under increasing threat from climate change, pollution, and development (Short and Wyllie-Echeverria, 1996; Orth et al., 2006; Halpern et al., 2008; Waycott et al., 2009). In these systems, hydrodynamics mediate various ecological and biological processes. Furthermore, the spatial and temporal variations of these hydrodynamic processes and associated changes to the local environment can have major impacts on the distribution of various species, including habitat forming species and the biodiversity they support (cf., Van der Heide et al., 2007; Hansen and Reidenbach, 2012, 2013; Wilson et al., 2013; Carr et al., 2016; Boch et al., 2018; Phelan et al., 2018). With the rapid rise of anthropogenic and climatic stressors and modification to shorelines in marine systems worldwide, an improved understanding of the coupling between hydrodynamics and other key processes in estuarine and coastal environments is needed.

Low-inflow estuaries (LIEs) are common in arid regions, or during the dry season in Mediterranean climates (i.e., seasonal LIEs), but the dynamics of LIEs have received considerably less attention in the literature relative to “classical” estuaries with more persistent freshwater inflow (cf. Largier et al., 1997, 2013; Largier, 2010; Nidzieko and Monismith, 2013). In LIEs, freshwater inputs are inadequate to stratify the estuaries during large portions of the year, and exchange between the estuary and open ocean is controlled by tidal diffusion, as opposed to the classical two-layer estuarine circulation observed in systems with substantial freshwater inputs (Largier et al., 1997; Largier, 2010). In many cases, weak tidal mixing near the head of LIE estuaries can lead to

---

* Corresponding author.
E-mail address: rkwalter@calpoly.edu (R.K. Walter).

https://doi.org/10.1016/j.ecss.2018.08.026
Received 2 June 2018; Received in revised form 3 August 2018; Accepted 20 August 2018

long residence times and the development of various along-estuary (i.e., longitudinal) zones with distinct water mass properties (Largier, 2010; Buck et al., 2014). When the residence times are long relative to the time scales of evaporative surface fluxes, hypersaline basins develop, and depending on the degree of hypersalinity and the prevailing temperature gradients, inverse estuaries can also form (Largier et al., 1997; Nidzieko and Monismith, 2013). As noted by Largier (2010), there is a growing need to not only document and describe the dynamics and exchange processes in small to moderate-sized LIEs, but also to better understand the ecological linkages such as larval retention, species distribution, and habitat suitability (cf. Buck et al., 2014; Morgan et al., 2014; Schettini et al., 2017).

Shallow coastal and estuarine environments are often dominated by seagrass meadows, a critically important biogenic habitat that supports ecosystem function (Waycott et al., 2009). However, seagrasses are sensitive to changing environmental conditions and have been declining worldwide, with the rate of loss increasing substantially over the last century (Orth et al., 2006; Waycott et al., 2009). Loss rates of seagrass meadows are comparable to those reported for tropical rainforests, mangroves, and coral reefs, placing them among the most threatened ecosystems on the planet, despite receiving considerably less attention in the literature and public (Waycott et al., 2009). The rapid declines have been attributed to a variety of different stressors acting on global, regional, and local scales (Orth et al., 2006). These include a variety of physical and biological factors such as increased temperatures, salinity changes, extreme weather events, sedimentation, hypoxia, altered wave and current patterns, wasting disease, eutrophication, and competition with other macroalgae, among others (see Table 1 in Short and Wyllie-Echeverria (1996) and the references therein; Table 1 in Orth et al. (2006)). On a local scale, seagrasses are often influenced by multiple stressors, highlighting the need for a better understanding of how spatiotemporal variations in environmental conditions help shape seagrass populations and influence restoration efforts (cf. Orth et al., 2006).

Accelerated losses of seagrasses can have a profound impact on estuarine systems because they support a diverse range of fish, invertebrates, and resident and migratory birds (Short and Wyllie-Echeverria, 1996; Fonseca and Uhrin, 2009; Holsman et al., 2006; Waycott et al., 2009; Shaughnessy et al., 2012). Given their importance and sensitivity to loss, seagrasses are often regarded as biological sentinels, or "coastal canaries" (Orth et al., 2006). Further, seagrasses are ecosystem engineers that strongly modify their physical (and biological) environment and maintain the environment in a state that supports their growth (Van der Heide et al., 2007; Maxwell et al., 2017). When physical conditions change, either abruptly or slowly over time, there is a possibility for ecological regime shifts, where an ecosystem changes it structure and function (Scheffer et al., 2001; Andersen et al., 2009). When an ecosystem enters a new regime, attributes of the changed system can prevent the system from returning to its original state, even after initial conditions are restored (Mayer and Reitkerk, 2004). Since seagrasses are ecosystem engineers, once lost, physical conditions (e.g., turbidity, flow, and light) may change in their absence and make recolonization and restoration attempts difficult through reinforcing feedback loops (Van der Heide et al., 2007; Carr et al., 2016; Maxwell et al., 2017; Moksnes et al., 2018). Thus, positive (self-amplifying) feedback mechanisms in seagrass systems can weaken seagrass resilience when conditions change (Nyström et al., 2012; Maxwell et al., 2017). For example, when seagrass beds were lost in the Dutch Wadden Sea due to a wasting disease, altered hydrodynamics prevented recovery (Van der Heide et al., 2007). Specifically, in the absence of seagrass beds, sediments became destabilized and currents and waves were no longer reduced, resulting in suspended sediment and turbidity levels too high to maintain seagrass growth and thus perpetuating the loss of seagrasses.

LIEs represent a class of estuaries that may be especially prone to changes in environmental conditions that can impact seagrass and the

Table 1
Experimental setup and mooring configuration in 2016.

Mooring Name	Sampling Period (2016)	Mean Water Depth	Text Reference	Measured Parameters	Sampling Period	Instrument Height (mab)	Sensor Type
BM (Bay Mouth)	29 Jun to 4 Aug	7.3 m (8.3 m for ADP)	BM	Velocity	10 min avg (1 s)	First bin at 0.5 mab (0.3 m bins)	Nortek 2.0 MHz ADP
			BM Bottom	Dissolved Oxygen	1 min	1.4	PME MiniDOT
				Temperature	5 s	1.4, 2.6, 3.8, 6.1	Sea Bird 56
				Temperature/Conductivity/Pressure	15 s	2	Sea Bird 37 SMP
				Chlorophyll/Turbidity	15 min (2 min burst avg)	2.9	WET Labs ECO NTU
			BM Top	Temperature/Conductivity/Pressure	15 min (2 min burst avg)	5.6	Sea Bird 37 SIP
				Dissolved Oxygen		5.6	Aanderaa Optode
BC (Bay Center)	29 Jun to 4 Aug (22 Jul to 4 Aug for ADP)	4.8 m (5.3 m for ADP)	BC	Velocity	10 min avg (1 s)	First bin at 0.5 mab (0.3 m bins)	Nortek 2.0 MHz ADP
				Temperature	5 s	0.9	Sea Bird 56
				Temperature/Conductivity/Pressure	2.5 min	1.2	Sea Bird 37 SMP
				Dissolved Oxygen	2.5 min	1.2	Sea Bird 63 Optode
BH (Bay Head)	29 Jun to 4 Aug	2 m*	BH	Temperature	5 s	0.5*	Sea Bird 56
				Dissolved Oxygen	1 min	0.5*	PME MiniDOT
				Chlorophyll/Turbidity	30 min (2 min burst avg)	0.5*	WET Labs ECO NTU

*Estimate based on diver depth gauges and referencing to BC.