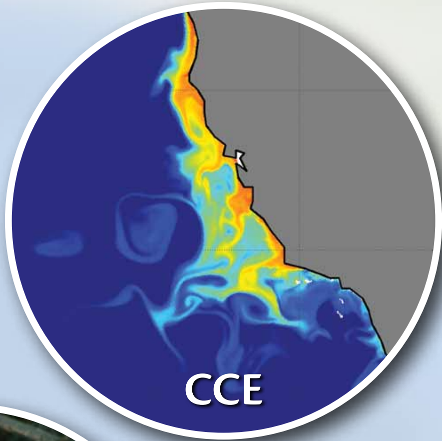

COASTAL LONG TERM ECOLOGICAL RESEARCH

Introduction to the Special Issue

BY MERRYL ALBER, DANIEL REED, AND KAREN McGLATHERY

The US National Science Foundation's Long Term Ecological Research (LTER) network was established in 1980 to provide the scientific expertise, research platforms, and long-term data sets necessary to document and analyze environmental change (http://www.lternet.edu). There are currently 25 sites in the US LTER network representing a range of ecosystems, including deserts, prairies, forests, tundra, lakes, urban areas, estuaries, coastal reefs, the pelagic ocean, and production agriculture. Although the research questions being addressed vary across the network, each site collects data on primary production, population dynamics, the cycling of both organic and inorganic matter, and disturbance patterns. Long-term data in these core areas enable changes in critical ecological processes to be tracked over time and facilitate comparisons among different ecosystem types.

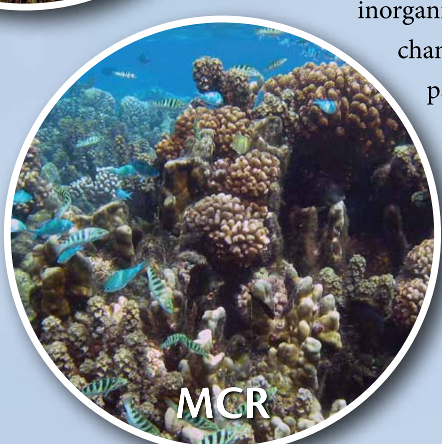

PHOTO CREDITS
CCE: Fanny Chenillat
FCE: Garrett Miller
GCE: Steve Pennings
MCR: Russell Schmitt
PAL: William Fraser
PIE: Robert Buchsbaum
SBC: Ron McPeak
VCR: John Porter

Eight of the LTER sites focus on coastal marine systems that encompass a range of intertidal, subtidal, and pelagic habitats (Table 1). All of these sites have been collecting data since at least 2004, with some dating back more than 20 years. Research at each of the sites takes advantage of a variety of approaches, including long-term measurements of key environmental drivers and ecological response variables, manipulative field experiments, short-term intensive studies, and integrated modeling. The various LTER research efforts also address similar questions pertaining to the structure and function of coastal ecosystems and how long-term changes in climate and human activities affect them. The papers in this special issue highlight insights gained from these efforts, focusing on research conducted over the past decade.

All of the coastal LTER sites measure a variety of oceanographic variables to describe the physical drivers of ecological dynamics. Data collection takes many forms, including shipboard sampling, moored oceanographic sensors, remote sensing, and in situ sampling. A relatively new way to collect oceanographic data is through the use of autonomous instruments, which can sample with enough frequency to capture short-lived processes. In this issue, **Ohman et al.** describe the use of autonomous platforms in combination with remote sensing to capture mesoscale and smaller features in the California Current Ecosystem (CCE; note that each LTER site has a three-letter designation), and **Schofield et al.** provide results from an autonomous glider that sampled deep submarine canyons at Palmer Station (PAL), Antarctica, that would otherwise be inaccessible. Other technologies are being adapted for use in novel ways. For

Table 1. Attributes of coastal marine LTER sites. More information and links to each site can be found at http://lternet.edu.

Site	Lead Institution*	Focal Habitats	Year Started
California Current Ecosystem (CCE)	Scripps Institution of Oceanography	Pelagic ocean	2004
Florida Coastal Everglades (FCE)	Florida International University	Mangroves, fresh marsh, estuaries, coastal watersheds	2000
Georgia Coastal Ecosystems (GCE)	University of Georgia	Fresh and salt marsh, estuaries, coastal watersheds	2000
Moorea Coral Reef (MCR)	UC Santa Barbara	Coral reefs	2004
Palmer Antarctica (PAL)	Columbia University	Pelagic ocean	1990
Plum Island Ecosystems (PIE)	Marine Biological Laboratory	Salt marsh, estuaries, coastal watersheds	1998
Santa Barbara Coastal (SBC)	UC Santa Barbara	Kelp forest, beaches, coastal watersheds, nearshore pelagic	2000
Virginia Coast Reserve (VCR)	University of Virginia	Seagrass beds, salt marsh, lagoons, barrier islands	1986

*Note that each LTER project has numerous co-PIs and affiliated investigators from various institutions, as well as partnerships with a range of agencies and other organizations.

example, **Wdowinski et al.** depict the use of specialized radar (InSAR, or interferometric synthetic aperture radar), which has been used primarily for geological applications, to estimate water level changes in tidal wetlands at the Florida Coastal Everglades (FCE) LTER.

Hydrodynamic models constructed using oceanographic observations provide an important tool for delineating transport patterns and understanding the relative importance of wind, tide, and river forcing, and most of the coastal LTER sites are using three-dimensional models for this purpose. **Di Iorio and Castelao** combine an analysis of 10 years of oceanic and meteorological data collected at the Georgia Coastal Ecosystems (GCE) LTER with an idealized estuary model to assess the relative importance of river discharge and winds for driving salinity patterns. **Franks et al.** summarize several different uses of both biological and physical models at CCE, and identify how the dominant modes of climate change affect the planktonic ecosystems.

Information on water movement can be used to explain patterns in nutrients and organic matter, and all of the coastal LTER sites make regular measurements of these constituents. **Washburn and McPhee** characterize water circulation patterns in the Santa Barbara Coastal (SBC) LTER and their effects on the delivery of nutrients to the kelp forest. Similarly, **Leichter et al.** examine how water flow, in combination with biological mechanisms, can explain the high retention of materials associated with the coral reefs at Moorea Coral Reef (MCR). This theme is followed by **Alldredge et al.**, who estimate that up to 13% of the net organic carbon input to their study reef is allochthonous material brought in by currents. **Schutte et al.** present data from GCE showing that a combination of river discharge, groundwater inputs, exchange with the marsh platform, and biological processes influence spatial patterns in water chemistry.

Coastal ecosystems are often hot spots for nutrient cycling. **Brzezinski et al.** use long-term data collected from kelp forests at SBC to show how different sources of nitrogen to this system vary though the year, and to describe how kelp respond to these variations. **Giblin et al.** present evidence, based on research conducted in the Plum Island Ecosystems (PIE) and other wetland-dominated LTER sites, for dissimilatory nitrate reduction to ammonium (DNRA) as a newly described, potentially dominant fate for nitrate in coastal systems. In the FCE, **Troxler et al.** provide a carbon budget that suggests riverine mangrove forests and associated marshes can store more carbon than tropical forests.

The primary producers at the coastal LTER sites range from phytoplankton to mangrove trees (see Table 1 in **Ducklow et al.**). At GCE, **Schalles et al.** show how hyperspectral imagery used in combination with a digital elevation model can provide information on vegetation structure and biomass of salt marsh plants, and can also be used to estimate densities of invertebrates. At a much smaller scale, **Blum and Davey** describe the use of a CT scanner, which was designed for medical imaging, to evaluate belowground production in salt marshes at the Virginia Coast Reserve (VCR).

The population dynamics of organisms and their roles in ecosystem processes are also active areas of LTER research. **Page et al.** describe the use of nitrogen isotopes to evaluate the trophic positions of organisms at both SBC and MCR. At both sites, they found that larger fish consumers are not feeding exclusively on smaller fish, as is often assumed, but instead rely heavily on invertebrates. **Mather et al.** present data on acoustically tagged striped bass that

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document movement between PIE and at least three other coastal locations, suggesting that fish migration is a process that can move nutrients and energy between systems. Finally, **Rosenblatt et al.** make the point that top predators can play important roles in coastal ecosystems based on ongoing research on bull sharks, alligators, and bottlenose dolphins in FCE, alligators in GCE, and striped bass at PIE.

Understanding how climate variability affects coastal ecosystems is a central theme at all coastal LTER sites. **Ohman et al.** describe research at CCE to separate long-term trends, multidecadal patterns, and interannual variability in their observations of zooplankton and climate indices such as the Pacific Decadal Oscillation. At PAL, **Ducklow et al.** find that long-term decreases in the spatial extent of sea ice cover have had system-wide effects related to reductions in Antarctic krill, which may be affecting Adélie penguin populations. **Fraser et al.** suggest that variability in the terrestrial environment must also be considered as a partial explanation for changes in penguin demography.

One of the long-term changes that is important in intertidal areas is sea level rise, which is only expected to accelerate in the coming years. **Morris et al.** use long-term observations in salt marshes at both PIE and North Inlet in South Carolina to suggest that primary production will increase initially in response to sea level rise, but ultimately will decline once a threshold is exceeded. **Fagherazzi et al.**, from VCR, provide a different perspective, arguing that marshes may be more vulnerable to changes in sediment input than to sea level. Ocean acidification is another aspect of climate change that is actively being investigated. **Edmunds et al.** evaluate rates of calcification in coral reefs at MCR, and suggest that there may be a shift in species composition toward organisms that are more resistant to low pH and warming. **Forsman et al.**, also working at MCR, describe the use of molecular methods to identify coral species, which can be cryptic. **Hofmann et al.** highlight the utility of linking environmental data with long-term observations of biological processes to address questions in global change biology, and provide an example of the use of new autonomous sensors to monitor pH at both SBC and MCR as a way to assess ocean acidification.

The response of an ecosystem to variability in external drivers is complex, and will depend not only on the pattern of change in drivers over time (e.g., a step-change vs. a linear increase) but also on the relationship between the driver and the response variable. In the final paper of the issue, **McGlathery et al.** explore alternative community states observed at VCR, and briefly review evidence for regime shifts and nonlinear dynamics at other marine sites. Understanding these habitat shifts and the accompanying changes in ecosystem properties is a common theme among several of the coastal LTER sites.

Taken together, the papers presented here serve as an introduction to the breadth and depth of the research being conducted at the coastal LTER sites. As made clear by the individual contributions, the long-term data collected by the sites provide context for a broad range of studies and also allow researchers to extend their inferences both spatially and temporally. In addition, the sites function as long-term research platforms that provide multiple opportunities for interdisciplinary collaboration and partnerships. The observational and experimental data being collected at these sites provide a strong foundation for not only detecting, but also understanding, the underlying mechanisms and consequences of secular changes in the environment.