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About the cover image: ASLO is returning to Spain in 2021! Read more inside about the sites near Palma, including Posidonia oceanica meadows which provide shelter for numerous animals, including endangered species like Pinna nobilis as shown here. Photo by Iris Hendriks.
Gulf of Mexico Hypoxia: Past, Present, and Future

Nancy N. Rabalais and R. Eugene Turner

Abstract
One of the largest human-caused areas of bottom-water oxygen deficiency in the coastal ocean is on the northern Gulf of Mexico continental shelf adjacent to the Mississippi River, which discharges nitrogen and phosphorus loads into its surface waters. The beginnings of seasonal hypoxia (≤2 mg L\(^{-1}\) dissolved oxygen) in this area was in the 1950s with an acceleration in the worsening of severity during the 1970s. Currently, the bottom area of hypoxic areas can approach 23,000 km\(^2\), and the volume, 140 km\(^3\). Ecosystems, people, and economies are now at risk within the Mississippi River watershed and in the northern Gulf of Mexico. Strengthened nitrogen and phosphorus mitigation, altered agriculture practices, and reduction in carbon and nutrient footprints are key to the recovery of these systems. In this article, we review the past, present, and possible future conditions of the northern Gulf of Mexico and provide insight into possible management actions.

Introduction
There is no doubt that many areas of the coastal ocean are now receiving enriched loads of nitrogen (N) and phosphorus (P) that are implicated in noxious, and often toxic, harmful algal blooms, and in decreasing dissolved oxygen (DO) concentrations in the bottom waters to ecologically depressed levels (Breitburg et al. 2018). These changes began primarily in the mid-1950s when North American watersheds underwent landscape use change or even earlier in European watersheds during the Industrial Revolution and as human population expanded and fossil fuel use increased. One well-documented area for these ecosystem changes is in the northern Gulf of Mexico adjacent to the discharge of the Mississippi River where it discharges its constituents to affect nearshore and mid-depth areas of the adjacent Louisiana continental shelf and lead to bottom-water low oxygen conditions (hypoxia) (Rabalais et al. 2007a; Rabalais et al. 2010; Rabalais et al. 2014). Oxygen deficiency for the purpose of this article is defined as hypoxic when the DO concentration is ≤2 mg L\(^{-1}\). Our research findings originate from 30+ years of summertime research cruises across the Louisiana shelf, cruises on two transects 100 and 250 km west of the Mississippi River, continuous bottom-water oxygen measurements on moorings, and analyses of Mississippi River landscape and nutrient load changes revealed on the continental shelf by palaeoindicators in dated sediments.

The present
River/Ocean linkages. The main freshwater sources from the Mississippi River watershed to the northern Gulf of Mexico are through two main distributaries: the birdfoot delta southeast of the city of New Orleans, Louisiana, and the Arachafalaya River 250 km to the west, which is formed by the Red River and the regulated diversion of 30% of the Mississippi River through the Old River Control structure. These two rivers are the primary sources of freshwater, N, and P to the northern Gulf of Mexico, delivering 80% of the freshwater inflow, 91% of the estimated annual N load, and 88% of the P load for the water years 1972–1993 (Dunn 1996). The fresh water and dissolved and particulate constituents flow mostly westward during the spring high river discharge in response to winds primarily from the southeast. The discharge is usually much lower in the summer but shifts in winds and currents from the west retain the fresh water and its constituents on the Louisiana shelf.

Extent. Hypoxia occurs each year in bottom waters of the northern Louisiana continental shelf, at least since consistent late July mapping of the low oxygen zone began in 1985 (Rabalais et al. 2002). The area of low oxygen in bottom-waters is found from very nearshore or adjacent to barrier island beaches to about 50 to 150 km offshore (Fig. 1). The hypoxic water mass sometimes extends into upper Texas coastal waters [links to maps of bottom oxygen are at https://www.nodc.noaa.gov/hypoxia/products/ and http://www.gulfhypoxia.net]. Hypoxia also occurs east of the Mississippi River and is becoming more frequent there (Dzwonkowski et al. 2018).

The area of hypoxic bottom-waters in the Gulf of Mexico west of the Mississippi River can reach up to 23,000 km\(^2\) in mid-summer (http://www.gulfhypoxia.net), making it the second largest human-caused area of hypoxia in the coastal ocean (see Carstensen and Conley, this issue). The bottom-water area dimensions are minimal or lower than average following droughts in the watershed that sometimes occur in spring or summer (Fig. 2). The larger areas are coincidental with higher freshwater discharge, which is a factor in determining the N load (= discharge × concentration). The bottom area of hypoxic waters is best correlated with the nitrate-N load of the Mississippi River in the previous May (Turner et al. 2012). There are summers when the bottom area measured is smaller than predicted in early June. These mismatches occur when (1) a
tropical storm or hurricane disturbance mixes the water column before or during the mapping, or (2) sustained winds from the west push the low oxygen water mass toward the Mississippi River delta so that the bottom area is less than predicted (Rabalais et al. 2018) (Fig. 2). The estimated volume of the hypoxic water mass correlates with the bottom-water area and ranges from negligible (severe summer drought) up to near 140 km$^3$ (Obenour et al. 2013).

The low oxygen conditions exist in waters of 5 m or less to as deep as 60-m water depth, but are most common in water depths between 10 and 30 m. The distance above the seabed in which hypoxic conditions may persist is in the lower 10 m of a 20-m water column on the eastern Louisiana shelf, but 2 to 5 m above the seabed on the western Louisiana shelf.

**Seasonality.** The only months in which hypoxia has not been documented are December and January, although there are fewer measurements in those months. Data from transect C (100 km west of the Mississippi delta) and transect F (off Atchafalaya Bay) (locations in Fig. 1) illustrate long-term conditions conducive to the formation of hypoxia and reflect the influence of the two major distributaries (Rabalais et al. 2007a) (Fig. 3). The surface water salinity is lower along both transects during the spring flood season and higher during summer and fall during low flow. Higher concentrations of chlorophyll $a$ (as an indicator of phytoplankton biomass) in surface waters on transect C occur after the winter-early spring peak in nitrate-N. The development of hypoxia along transect C occurs earlier in spring compared to summer along transect F, extends further offshore, and continues into September whereas it has decreased by August off the Atchafalaya.

**Duration.** Continuously recorded bottom-oxygen concentrations in 20-m water depth, along with other biological and physical parameters, provide insight into the duration and severity of hypoxia, respiration rates, reoxygenation events, advection, and short-term intrusions of well-oxygenated waters from deeper waters onto the shelf (Fig. 4). The data from oxygen meters (collected every 15 min) deployed near the bottom at a 20-m station 100 km west of the Mississippi River delta document many other physical and biological processes. Strong mixing events of the stratified water column are associated with cold fronts in spring and fall and with tropical storms and hurricanes in summer. These mixing events result in an almost immediate increase in bottom-water oxygen levels from near anoxic to above 6 mg l$^{-1}$ (Rabalais et al. 2007a). Following a mixing event and reoxygenation of bottom waters, there is a gradual decline of bottom oxygen concentrations that are driven by aerobic respiration of organic matter and continue as long as the stratification is maintained. The reduction of the oxygen concentration from about 6 mg l$^{-1}$ to less than 2 mg l$^{-1}$ is 18, 11, or 9 d, in April, May, and July, respectively, as bottom temperatures warm (calculated from data in Fig. 4).

Stratification persists as long as mixing does not occur. Periods of oxygen concentrations
Effects on living resources. These low-oxygen areas in the bottom waters of the northern Gulf of Mexico are often referred to as “dead zones” by fishers and the public, because of the lack of detectable bottom-dwelling shrimp and fishes (Craig 2015). This popular title, however, does not truly describe the ecosystem (Rabalais et al. 2010). Many fish and shrimp are displaced by the low DO waters and move into shallower inshore waters, deeper offshore waters, or higher in the water column (Rabalais et al. 2001a; Craig 2015) (Fig. 5), and a host of microbes thrives in the low-oxygen conditions at the seabed. The organisms living in the sediments, such as polychaetes, burrowing shrimp, and echinoderms, cannot survive if the DO levels remain low enough for long enough (Rabalais et al. 2001b) (Fig. 6). The larger, deeper burrowing infauna are replaced by a community of opportunistic species and low oxygen-tolerant organisms that can survive extremely low oxygen concentrations and often hydrogen sulfide. The abundance and biomass of the remaining infauna remains low after the hypoxic conditions abate, and food resources for returning demersal species are diminished resulting in lowered secondary production.

Past and present nutrient loads

Nitrogen and phosphorus. The dissolved nitrate-N is about 70% of the total N load, and the relative percent is increasing. The total N load of the Mississippi River has increased by threefold since the mid-1950s (Turner and Rabalais 1991), but has not increased substantially in the last decade, and may have stabilized in some tributaries (Stets et al. 2015). The residence time of the surface waters along the northern Gulf of Mexico coast west of the Mississippi River delta is about 2 to 3 months in the summer (Dinnel and Wiseman Jr. 1986), hence the 2- to 3-month lag between the nitrate-N loading rate calculated for May and the predicted size of the hypoxic zone mapped in late July (partially illustrated in Fig. 3). The cause-and-effect relationships are supported by the enhanced primary production (Lohrenz et al. 1997) and the flux of organic carbon from surface to bottom where it is respirated (Turner et al. 1998). The nitrate-N load in spring versus summer hypoxia area model is evolving, because the coastal ecosystem is changing. For example, the size of the hypoxic zone for the same amount of nitrate loading is increasing. Further, the models will eventually be adjusted to account for the limited space on the shelf for hypoxia to occur (a physiographic constraint) and climate change (Rabalais et al. 2010).

The data on the changes in P are not as well documented as the changes in N, but the general agreement is that the P load increased by twofold since the mid-1950s (Justić et al. 1995). The dissolved silicate concentration in the Mississippi River has decreased by 50% since the early 1900s (Turner and Rabalais 1991). The result of these changes is that either N or P may limit phytoplankton biomass growth (Turner and Rabalais 2013). Diatom growth may be limited or there may be shifts in diatom composition where the relative proportion of silicate to N is less than the Redfield ratio of 1:1 with potential shifts in the diatom-to-zooplankton-to-higher trophic level food web (Turner et al. 1998). There has been a shift from highly silicified-diatoms to less silicified-diatoms (Rabalais et al. 1996), but with increasing abundance of the latter forms despite the potential for silicate limitation (Parsons et al. 2002).

Carbon. The organic carbon (C) isotopic signature in offshore waters where hypoxia occurs dominates as an atmospheric source rather than a terrestrial C signature (Rabalais et al. 2014). In addition, the δ13C composition of surface sediments indicates that the terrestrial C flux is located near the river mouth and adjacent to the wetlands (Turner and Rabalais 1994). Wang et al. (2018) verified in situ produced C of marine origin C played the dominant role in near-bottom water and benthic oxygen consumption in the northern Gulf of Mexico shelf west of the Mississippi River. These findings (and those of N sources) point to N pollution as a product of increased N loads to the Louisiana continental shelf, and not terrestrial sources of C that might support bottom-water respiration rates.

The nutrient-enhanced primary production in coastal waters adjacent to the Mississippi River discharge results in a C budget for the upper mixed layer that is a sink for CO2. It is a sink because of the biological generation of CO2 (and lowered pH) within the water column and not from air–sea exchanges. Simultaneously below the pycnocline, bacterial respiration of organic matter derived from the surface layer depletes DO, generates CO2, and contributes to a decline in pH. The duration of low DO and lower pH can persist for a few days, 2 weeks, or several months in the hypoxic zone if stratification persists (Rabalais et al. 2007a). The coastal ecosystem influence by the Mississippi River is overall autotrophic in the surface waters and heterotrophic in the bottom waters for most of the year (Justić et al. 1997). Thus, an imbalance of surface and bottom water pCO2 and pH conditions can persist for much of the year unlike other
areas exposed to only higher pCO₂ concentrations in the atmosphere.

The past

The nearshore coastal waters of the northern Gulf of Mexico adjacent to the Mississippi River outflow are prone to the development of low DO concentrations because of the amount of fresh water and solar heating that support water-column stratification. However, it was not until the N load to the continental shelf caused an ecosystem shift (Turner and Rabalais 1994; Rabalais et al. 2007a) that the typical sequence of processes leading to hypoxia began to occur. Although historic water quality data collection did not begin until oxygen levels began declining (Rabalais et al. 2002), the contents of dated accumulating sediments document the geological, chemical, and biological indicators of increased primary production and declining oxygen conditions at the same time when N loads from the Mississippi River increased beginning approximately 1950s (Turner and Rabalais 1994; Rabalais et al. 1996; Rabalais et al. 2007b). The evidence for increased C production and accumulation is revealed in the accumulation of diatoms and their remnants (Turner and Rabalais 1994), the increase in total organic C in more recent sediments, and the shift to an isotopic signature of the marine-derived C in the sediments (Rabalais et al. 2014). Surrogates for oxygen conditions, including mineral, isotopic, and microfossils, indicate worsening oxygen stress as the N loads from the Mississippi River system increased beginning in the 1950s (Rabalais et al. 2007b), that is, hypoxia has not always been a feature of this coastal ecosystem despite the stratified water column for much of the year. Temporal shifts in this shelf ecosystem parallel the time sequence of similarly eutrophied coastal waters globally and coincide well with the results of sedimentary analyses there.

The future

Climate change. Human activities are changing climates across the globe to affect landscapes, hydrology, the ocean, and related biogeochemical cycles. The predicted higher stream flows for the upper Mississippi River watershed or increasing coastal water temperatures will result in increased nutrient runoff...
and stronger stratification gradients, respectively, and increase biological rates offshore and perhaps have other confounding consequences (Rabalais et al. 2010) (Fig. 7). These scenarios, et al., could aggravate hypoxia in the northern Gulf of Mexico and other eutrophied coastal waters worldwide. Coupled biogeochemical and three-dimensional ocean models (e.g., Laurent et al. 2018) are used increasingly to study the effects of climate change on the northern Gulf of Mexico and are improving the predictability of effects and the related processes.

While surface water temperatures at a well-monitored station in the hypoxic zone have not increased (from 1963 to 2015) because of land–sea interactions, the bottom-water temperatures have risen over the same period and over a more data-rich period from 1985 to 2015 (Turner et al. 2017). These recent changes in the heat storage on the Louisiana continental shelf will affect oxygen and C cycling. Warmer waters alone hold less DO than do cooler waters, all other parameters held the same.

Although increased temperatures have the potential to strengthen density differences (pycnoclines) in estuarine and coastal waters, lower surface salinity (e.g., from increased freshwater runoff) would be a stronger factor in stratifying the water column. A stronger pycnocline should result in less diffusion of oxygen from the upper water column to the lower water column, leading to less DO in bottom waters.

If the frequency of tropical storms and hurricanes increases as a result of higher water temperatures in the lower to mid-latitudes, there may be, at least, temporarily water column mixing, destratification of the water column, and re-aeration of the bottom water (Rabalais et al. 2010). However, such a disruption of a hypoxic zone would be short-lived.

The rates of biological processes, including both photosynthesis and respiration, are expected to increase with higher water temperatures up to a point. Thus, increased precipitation in the watershed will result in more water, sediments, and nutrients reaching the coastal zone where they are likely to augment eutrophication through nutrient-enhanced production, increased stratification, or both.

The combined effects of higher water temperatures in surface and bottom waters, worsening the DO deficiency, lower pH, and the presence of hydrogen sulfide will add to existing formidable and poisonous habitats for sediment inhabitants, attached macrofauna, and demersal organisms. Additional freshwater discharge and potentially increased nutrient loads also contribute to this challenging PRESENT and FUTURE habitat. Human beings are the ultimate drivers for these changes through
activities that increase the reactive N in the environment.

Recovery. Increased precipitation under current agricultural practices would result in increased erosion and loss of P, and an increased flux of dissolved inorganic N, primarily as nitrate. Reversing this progression of watershed and coastal water quality damage requires reducing the use of artificial fertilizers, mono- or dual-agriculture systems, intensified animal husbandry, insufficiently treated wastewater, and unnecessary consumption of fossil fuels. There are no easy societal shifts to a less consumptive lifestyle, nor is it an easily achieved political outcome. Reducing both a C and N footprint requires a strong societal and political will.

Some governmental units have successfully implemented multifaceted plans to reduce nutrient loading, for example, countries surrounding the Baltic Sea, Denmark and its neighbors surrounding the Kattegat and Skagerrak, European countries affecting the North Sea, U.S. states comprising the watershed of the Chesapeake Bay (U.S. east coast) and municipalities surrounding Tampa Bay, Florida, U.S. Recovery pathways may take years or even decades to reverse the severity and size of hypoxic conditions adjacent to the Mississippi River outflow (Ballard et al. 2019; Van Meter et al. 2019). This calls for a serious commitment to improve coastal water quality (including improvement of hypoxic conditions) on an individual, community, and political basis.

Restoring coastal water quality by decreasing nutrient loads of the Mississippi River watershed means, in large part, changing farming practices (Rabotyagov et al. 2014) and facilitating natural mechanisms for N removal (Mitsch et al. 2001). The nitrate yield from Iowa streams is directly related to farming practices. Much of the total N yield is a result of tile drainage, that is, pipes placed under croplands to speed water removal, which accounts for much of the rise in nitrate (Randall and Gross 2001). McIsaac and Hu (2004) demonstrated that the 1945–1961 riverine nitrate flux in an extensively tile drained region in Illinois averaged 6.6 kg N ha$^{-1}$ year$^{-1}$, compared to 1.3 to 3.1 kg N ha$^{-1}$ year$^{-1}$ for the nontile drained region, even though the N fertilizer application was greater in the nontile drained region.

The use of cover crops figures prominently as a way to reduce N fertilizer applications. N yields are influenced by the N fertilizer application rate and timing, crop rotation, and tile drainage (Randall and Mulla 2001; Dinnes et al. 2002). Tile drainage can go into buffer strips before they reach streams, drain into wetlands, or even not be used if row cropped fields are converted to perennials. Key findings by Liebman et al. (2013) and Davis et al. (2012) were that, by using cover crops for 4 yr, there was a reduction in fertilizer use by 91%, a 97% reduction in herbicide use, a 50% or more reduction in fossil fuel use, and a doubling of employment—all while profits remained unchanged.

Increased nutrients within the Mississippi River watershed that come into the Gulf also affect ecosystems upstream. Nutrient reductions can benefit caretakers of the land in the watershed and farmers of the sea. Many
freshwater lakes and reservoirs suffer from harmful algal blooms comprised of toxic cyanobacteria. They threaten ecosystem functioning and degrade water quality for recreation, drinking water, fisheries, and human health. Similarly, toxic cyanobacterial blooms also plague brackish estuaries in coastal Louisiana (Garcia et al. 2010). The consequences of water quality degradation include higher sewage treatment costs when secondary treatment is called for to remove nitrate; high nitrate levels in water wells do not receive such treatment. Nitrate in drinking water is implicated in birth defects (Brender et al. 2013) and cancer (Ward et al. 2018).

Do not forget people when considering ways to reduce nutrients in the watershed. Dietary choices can reduce the use of N overall (Howarth et al. 2002). Eating less meat is healthy and requires less N (see Scavia, this issue). Proper wastewater treatment is implicit for human health, but also for reducing N loss into streams and rivers. Fossil fuel emissions generate NOx emissions and volatile ammonium that travel far or are more localized, respectively, before returning to the landscape as reactive N in the form of nitrate and ammonia. There are some obvious solutions in that regard. Less consumption of fossil fuels and use of nonethanol gasoline avoids many processes that contribute to increased reactive N in the landscape and airshed.

Optimism or pessimism?. Reducing N and P loading into and out of the watershed will have beneficial effects there and in the northern Gulf of Mexico. Water quality has improved in some subwatersheds streams of the Mississippi River watershed because of conservation practices (Garcia et al. 2016), but nutrient concentrations and yields have increased in others. A net reduction in the bottom area covered by hypoxia has yet to appear 18 yr after the Mississippi River Nutrient/Gulf of Mexico Hypoxia Task Force (2001) called for reducing the size of the hypoxic zone to 5000 km2 or less over a 5-year running average by the year 2015 (Fig. 2). The environmental goal was recently extended from 2015 to 2035, with an intermediate goal of a 20% overall reduction in N and P loads into the Mississippi River from the states bordering the Mississippi River and sections of the Ohio River (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2015). Many efforts are underway or considered that demonstrate the breadth of attention to local and regional efforts that reduce landscape-scale nutrient loads, but there has not been a demonstrable improvement as of 2019. A deliberate and stronger social and political resolve is mandatory to decrease nutrient inputs to aquatic ecosystems and alleviate the associated ecosystem, human health, and economic difficulties.

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Baltic Sea Hypoxia Takes Many Shapes and Sizes

Jacob Carstensen © and Daniel J. Conley ©

ABSTRACT
The Baltic Sea is naturally prone to hypoxia, but the frequency and extent have increased multifold over the last century. Hypoxia manifests itself as perennial in the open central part, seasonal at the entrance area, and episodic at many coastal sites, and the expression of hypoxia is largely driven by differences in bottom water residence times and stratification patterns. Enhanced nutrient inputs from land and atmosphere are the main drivers of expanding hypoxia in the Baltic Sea although deoxygenation has also been exacerbated by increasing temperature over the past 3–4 decades. Hypoxia severely influences ecosystem functions such as fish production through reduced trophic efficiency and harmful cyanobacteria blooms sustained by phosphorus release from sediments. Nutrient inputs from land have created the largest man-made hypoxic area in the world and the only viable long-term solution to mitigation is to continue efforts to reduce nutrient loading.

INTRODUCTION
The Baltic Sea is known for its beauty and attracts millions of tourists every year. However, what is less known to visitors is that below the surface of the water, large areas in the Baltic Sea suffer from low oxygen concentrations (hypoxia: $O_2 < 2$ mg L$^{-1}$) affecting aquatic life and nutrient cycling (Carstensen et al. 2014b). Hypoxia occurs when the consumption of oxygen outpaces the supply. The Baltic Sea is naturally prone to developing hypoxia because of the limited water exchange with the North Sea, numerous isolated deep basins, and a long water residence time of ~30 yr (Fig. 1). More importantly, the extent of hypoxia has increased 10-fold over the 20th century due to increasing nutrient inputs from land and atmosphere (Carstensen et al. 2014a).

Today, the Baltic Sea constitutes the largest man-made "dead zone" in the world, totaling almost 70,000 km$^2$ (Fig. 2a). Whereas this huge "dead zone," equivalent to the 1.5 times the area of Denmark or three times the area of Maryland, has received attention among scientists and in the public, it is less known that the entrance area of the Baltic Sea, the Danish Straits, and several hundred Baltic coastal ecosystems also suffer from hypoxia (Conley et al. 2011). The development of hypoxia in these systems is considerably more dynamic, ranging from months down to a few days. This is in stark contrast to the open central Baltic Sea, where hypoxia is perennial. Furthermore, the underlying mechanisms causing the imbalance between oxygen consumption and supply are also quite diverse. Here, we examine the different forms of hypoxia that are observed in the Baltic Sea.

PERENNIAL HYPOXIA IN THE OPEN CENTRAL BALTIC SEA
The Baltic Sea is comprised several deep basins (the deepest is 450 m) with the exchange of water between the Baltic Sea and the North Sea restricted by two shallow sills (8 and 15 m deep) in the Danish Straits (Fig. 1). Medium intensity summer inflows of saltwater occur regularly, and the inflows interweave themselves along isopycnal surfaces with water of similar density (Meier et al. 2006). However, the renewal of the deep bottom waters is rather infrequent and occurs as large gravity-driven dense intrusions of saline water during specific wind conditions when water is forced through the Danish Straits (Fig. 3a). During such events, the denser saltwater intrusions cascade through the basins, pushing the "old bottom water" into the next basin and higher up into the water column. Consequently, the halocline moves upward during periods with more frequent inflows, whereas it is gradually eroded during periods of low inflows. However, there have been decade long periods of stagnation generally caused by large freshwater inflows and high mean zonal wind speeds. One such stagnation period occurred from around 1973 to 1993 (Fig. 2a). During this period, the halocline was eroded downward by more than 10 m (Carstensen et al. 2014a). Thus, the existing hypoxic water is not removed by saltwater inflows but merely displaced to other areas where it may affect benthic fauna and nutrient cycling. Saltwater inflow also enhances stratification, which reduces vertical mixing of oxygen to the bottom waters.

The saltwater inflows can be saturated with oxygen when they form a bottom current after passing the sills in the Danish Straits, but temperature increases of 1.5°C over the last 3–4 decades imply a reduced oxygen content in this water by 0.3–0.4 mg L$^{-1}$. Due to the large oxygen demand from sediments, oxygen is rapidly depleted in the newly formed bottom water, typically less than 6 months. Thus, saltwater inflows can create a short-term relief from hypoxia but in the end, they worsen oxygen conditions over longer time scales.

Large increases in nutrient inputs from land since the 1950s have stimulated the excess growth of algae that sink to the bottom and is the main reason for causing a high sediment oxygen demand. However, respiration rates have also been enhanced with increasing temperatures with global warming. Furthermore, the expansion of hypoxia in the Baltic Sea has promoted phosphorus release from sediments into the water column, which stimulates the growth of nitrogen-fixing cyanobacteria during summer. These nuisance algae blooms, which have also been enhanced by increasing
temperature, have become increasingly prominent in the Baltic Sea and now can cover up to 200,000 km² every summer (Kahru and Elmgren 2014). They also contribute to eutrophication of the Baltic Sea by adding nitrogen to the system, which further stimulates sediment oxygen demand and consequently, hypoxia may expand and enhance phosphorus release from sediments. This positive feedback between expanding hypoxia and cyanobacteria blooms has been termed the "vicious circle of the Baltic Sea" (Vahtera et al. 2007).

Hypoxia in the open Baltic Sea displays a long-term increase modulated by decadal variations in saltwater inflows (Fig. 2a). Increasing nutrient input from land is the primary reason for this increasing trend in hypoxia but it is exacerbated by warming conditions and the recent proliferation of cyanobacteria.

FIG. 1. The Baltic Sea with its different basins is connected to the North Sea through the Skagerrak. Perennial hypoxia in the open central Baltic Sea is restricted to the Bornholm Basin, the Gotland Basin, and the Gulf of Finland (Carstensen et al. 2014a). The extent of the Baltic Sea is indicated with a white line, and the location of the two sills restricting the inflow of saline water to the Bornholm Basin as well as the sill regulating the further progression of bottom water to the Gotland basin are all indicated with red lines. The stations used for exemplifying seasonal hypoxia in the Danish Straits and episodic hypoxia in the Limfjorden are shown with green dots.

SEASONAL HYPOXIA IN THE DANISH STRAITS
The Danish Straits is essentially the entrance to the Baltic connecting the Baltic Sea to the North Sea through the Skagerrak (Fig. 1). Here, a bottom layer is formed from well-oxygenated surface water from the higher salinity North Sea, which penetrates under the outflowing brackish water from the Baltic Sea in the surface layer (Fig. 3b). The area is permanently stratified and dominated by strong advective transports in both surface and bottom layers. The advective transports are driven by the freshwater surplus of the Baltic Sea and wind conditions, exhibiting a typical seasonal pattern with reduced bottom water transports during summer. In particular, these bottom water transports are slowing down when lower wind speeds from southeasterly directions dominate during summer. Consequently, due to variable meteorological conditions, the supply of oxygen to the bottom waters can also be quite variable. The water residence time in the bottom layer is typically a few months, and the bottom waters get increasingly stagnant closer to the sills of the Baltic Sea located to the southeast of Denmark.

The Danish Straits is also a productive area partly due to its estuarine character, where nutrient-rich bottom water is entrained into the surface layer. Oxygen consumption in the bottom waters is driven by the amount of organic matter sedimentation from the surface waters and from higher temperatures usually peaking in late summer and early autumn. The Danish Straits experience seasonal hypoxia every year at this time, when oxygen consumption exceeds oxygen supply (Fig. 2b), and the extent of hypoxia can vary from 500 km² up to 5500 km². The largest and most severe hypoxic area in bottom waters of the Straits was
EPISODIC HYPOXIA IN SHALLOW SYSTEMS

Just like the open Baltic Sea and the Danish Straits that are naturally prone to hypoxia, so are many coastal systems, just on a smaller scale. There are many coastal systems with restricted exchange of bottom waters due to the complex bottom topography around the Baltic Sea, particularly in the Stockholm and Finnish archipelagos, where hypoxia is observed to occur in a large number of coastal ecosystems (Conley et al. 2011). Occasionally, waters from the open Baltic Sea spill into these topographical depressions due to internal waves and intensifying stratification. Depending on stratification and the residence time of the bottom water in these coastal systems, hypoxia can be episodic, seasonal, or even perennial.

Stratification is a precursor for hypoxia and many coastal systems are intermittently stratified. Some coastal areas experience hypoxia because oxygen-deficient bottom waters of higher density from offshore waters are transported nearshore along the coastline or into estuarine systems, often forming a thin bottom layer (Fig. 3c). Sediment respiration adds to rapid oxygen depletion of this relatively small water volume, resulting in a “hypoxic carpet” laid over the sea bottom. This can be seen in estuaries facing the Danish Straits, where strong winds drive bottom waters, with low oxygen content, onto the shallower coast, and into estuaries and embayments. In other cases, surface water with higher salinity intrudes into the coastal systems and forms a bottom layer. While this oxygen-rich water offers resistance to hypoxia, high respiration rates in the sediments will eventually consume all oxygen unless stratification is broken. Thus, hypoxia will develop depending on the balance between sediment oxygen consumption, the thickness of the bottom layer, and the duration of stratified conditions.

One typical example of this is the Limfjorden estuarine complex in northern Denmark (Fig. 1), where the extent of hypoxia can range from 0 to 200 km². Hypoxia typically builds up over 1 week when water temperatures are high in summer, and it may disappear within hours if wind from the right direction increases. Westerly winds bring saline bottom waters toward the coastline. A good example of this phenomenon occurred in Eckernförde Bay, Germany in August 2018.

ECOSYSTEM CONSEQUENCES

Marine organisms exhibit highly different tolerances to low oxygen concentrations with fish and crustaceans being most sensitive (Vaque-Sunyer and Duarte 2008). Motile species such as fish can escape pockets of hypoxic water, but even fish can be trapped close to the shore by upwelling hypoxic water. This can be seen almost every year at the coasts around the Danish Straits, when strong westerly winds push oxygen-depleted bottom waters toward the coastline. A good example of this phenomenon occurred in Eckernförde Bay, Germany in August 2018.
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The food web, benthic organisms are also hypoxia. This stimulates nitrogen removal via denitrification and sediment accumulation of iron-bound phosphate. Thus, the presence of a healthy benthic community can reduce eutrophication though sustained nutrient removal. However, loss of benthic fauna can lead to nutrient releases from sediments, creating a positive feedback on eutrophication. Hypoxia bottom waters are characterized by high concentrations of ammonium and phosphate, which enhance primary production when mixed into the surface layer. Algae blooms are observed in the Limfjorden, when the water column is remixed to the bottom after periods of hypoxia (Conley et al. 2007). This coupling between hypoxia and algae blooms is particularly pronounced in the open Baltic Sea, where phosphorus liberated from sediments stimulates extensive cyanobacteria blooms (Fig. 4b). These blooms of nitrogen-fixers are typically produced in the open Baltic Sea, where inorganic nitrogen is depleted from the surface layer. However, they also accumulate in nearshore waters and wash onto beaches, with consequences for human recreational activities. Thus, hypoxia in the Baltic Sea has strong negative consequences for the ecosystem services provided, reducing fisheries yields, and nutrient removal and sustaining algae blooms.

**MITIGATING HYPOXIA**

Hypoxia is a natural phenomenon in some of the deepest isolated basins of the Baltic Sea, but it has increased drastically in size and frequency over the last century due to eutrophication driven by enhanced nutrient inputs from land and atmosphere. Nutrient inputs to the Baltic Sea peaked in the 1980s and have since then decreased by approximately 20% for N and 40% for P, primarily through improved sewage treatment (Reusch et al. 2018), although measures targeting diffuse sources have also been successful (Riemann et al. 2016). Yet, nitrogen and phosphorus inputs are still about two times higher than in the early 1900s and above the maximum allowable inputs agreed in the Baltic Sea Action Plan (BSAP).

Due to climate change, the hypoxic area of the Baltic Sea is expected to expand up to 80,000 km² with the present level of nutrient inputs, whereas the hypoxic area is expected to decrease to 50,000 km² with BSAP maximum allowable nutrient inputs (Meier et al. 2011). Thus, the spread of hypoxia will be curbed, but not significantly reduced, if the BSAP nutrient reductions are met. Although this message could be discouraging to environmental managers, it is important to stress that the consequences of not reducing are even worse. This bleak outlook for hypoxia in the Baltic Sea has encouraged people to suggest other measures than controlling nutrient inputs, but proposed geoengineering approaches are unlikely to work at the scale of the Baltic Sea and may cause unanticipated negative consequences for the Baltic Sea (Conley et al. 2009).

Mitigating hypoxia may sound like mission impossible, due to the projected climate change and the positive feedbacks maintaining poor oxygen conditions, but there are examples documenting that hypoxia can be reversed. Oxygen conditions were poor in the inner Stockholm Archipelago after centuries with large sewage inputs, but gradually improved as

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**FIG. 4.** (a) Fish kill in Eckernförde Bay, Germany, August 2018. (b) Cyanobacteria bloom near the Polish coast in the Gulf of Gdansk, July 2018. Photos by Heinz Krimmer and Marek Salatowski.
sewage inputs were reduced. This allowed burrow-forming polychaetes to colonize and bioirrigate the sediments, thereby enhancing the capacity to bind phosphate to iron (Norkko et al. 2012). Phosphate concentrations in the bottom waters decreased substantially with the increasing binding capacity of the sediments, strengthening P-limitation in this highly brackish system. This example shows that positive feedbacks can also come into play when the ecosystem is recovering from hypoxia, but a prerequisite for this is that nutrient inputs are reduced to a level that ensures sufficiently good oxygen conditions for benthic fauna to recolonize sediments.

Nutrient inputs over the last century have shifted the natural balance between oxygen supply and consumption in the coastal and open Baltic Sea. As a consequence, hypoxia has expanded in systems naturally prone to hypoxia and hypoxia has developed in systems that otherwise would not experience hypoxia. Specific meteorological and climate conditions promote or reduce the expression of hypoxia, whereas eutrophication regulates the potential for hypoxia. Undisturbed marine ecosystems are naturally resilient and can absorb meteorological and climate fluctuations through buffer mechanisms, but this resilience can be gradually eroded after periods of nutrient enrichment, rendering these systems more vulnerable to small perturbations. Geoengineering approaches may, at best, temporarily mitigate one of the most prominent symptoms of eutrophication, hypoxia, but oligotrophication will be needed to reestablish the resilience of impaired ecosystems.

Enacting measures to reduce nutrients have been proven to be successful in mitigating eutrophication (Riemann et al., 2016). Reducing nutrient inputs by improving manure use and ensuring that the legacy of nutrients in the watershed remaining in farm soils are essential features needed in the Baltic Sea (Reusch et al., 2018). Fixing the largest man-made hypoxic area in the world as well as reducing coastal hypoxia requires that we must continue to reduce nutrient loading—it is the only viable long-term solution.

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The Making of Infinity Cube, a Bioluminescence Art Exhibit

Michael I. Latz ©

Abstract

Inspired by a midnight stroll on a beach in Mexico, it culminated in an innovative installation at the Birch Aquarium at Scripps Institution of Oceanography. This is the story of a bioluminescence art exhibit called Infinity Cube, which was on display from April 2017 through September 2018.

Introduction

“1 was on the Pacific coast in Mexico in a turtle sanctuary and it was very dark night. I could see the Milky Way and the infinite amount of stars above. There was a bloom happening so the bioluminescent waves were crashing onto the beach and you could see this luminescent glow of infinite amounts of little dots of light. That was the moment that I realized the microcosm and the macrocosm, with me right in the middle. That was the moment when I got my inspiration.”

—Artist Iyvone Khoo

Iyvone had observed the bioluminescence of the dinoflagellate Noctiluca scintillans, long observed by mariners across the globe. Dinoflagellates are unicellular plankton that can reach high abundance during bloom events and are common sources of luminescent displays observed from ships and along the shore (Fig. 1). In nature, dinoflagellate bioluminescence serves as a predator defense strategy to startle a potential predator, and as a “burglar alarm” to attract the predator of the dinoflagellate predator. Triggered by the mechanical force imparted by a predator contact, any flow condition with sufficient force levels will stimulate bioluminescence, including the swimming of fish and dolphins, and the motion of ships, surge, and breaking waves (Latz and Rohr 2005). My own research over the past 35 yr has investigated the level of mechanical forces that stimulate bioluminescence, first using populations of cells experiencing fully characterized flow fields, and more recently by studying the mechanosensitivity of individual cells using microfluidics and atomic force microscopy (Latz et al. 2008; Tesson and Latz 2015). In our investigation of the bioluminescence mechanotransduction signaling pathway, we have identified signaling proteins that have been conserved in the force sensing pathways of higher organisms including humans (Lindström et al. 2017). So in a sense, we have a connection to dinoflagellates, whose bioluminescence can provide insights into the origins of mechanical sensing in eukaryotes.

Bioluminescence is also produced by a myriad of other marine organisms, including bacteria, radiolarians, cnidarians, ctenophores, polychaetes, gastropods, cephalopods, bivalves, chaetognaths, crustaceans, echinoderms, tunicates, fish, and sharks. The light helps them to lure or see prey, attract mates, and distract or hide from predators.

Bioluminescence is not only a beautiful display of nature, it is also a wonderful tool for public outreach and education. To explore whether art could contribute to communicating the science of bioluminescence to the public, my Artist in Residence program offers artists the opportunity to collaborate in developing creative approaches for displaying bioluminescence. The artist brings a creative perspective for a project idea, and I provide mentoring and resources including living organisms and camera equipment. The results of these collaborations have included photography, video, and live installations in Paris, Los Angeles, Venice (Italy), and London (Latz 2017).

So when Iyvone Khoo, inspired by her magical experience with bioluminescence in Mexico, contacted me with interest in a bioluminescence installation, I invited her to visit Scripps as an artist in residence to film in my laboratory, which she did in 2014. She obtained video of dinoflagellate bioluminescence that was incorporated into a “light altar” consisting of Venetian glass with video projection of bioluminescence. Iyvone was so inspired by her experience working with bioluminescence that she returned as a Mead Fellow through the University of the Arts London for a second residency in 2015, filming for 6 weeks using innovative approaches including high magnification ultra-high resolution imaging without use of a microscope (Fig. 2). This footage was ultimately incorporated into Infinity Cube.

At the time, we did not have specific plans for the footage. But it so happened that at the end of Iyvone’s residency, we had the opportunity for a “meet and greet” with Harry Helling, who at the time was the incoming Executive Director of the Birch Aquarium at Scripps (BAS). That initial meeting lasted 1.5 h, with Harry challenging Iyvone to brainstorm on ideas for a BAS exhibit. That started the creative design process; 1 yr later, the contract was signed and 6 months later, on 07 April 2017, Infinity Cube opened to the public. By the time it closed on 09 September 2018, hundreds of thousands of guests had the opportunity to experience the exhibit for themselves.
Infinity Cube is a multimedia installation consisting of an 8 ft × 8 ft reflective cube with projections, reflections, and sound (Fig. 3). According to the artist, *Infinity Cube* is "a sensorial space" of visual and sound stimuli, a space where one can experience the otherworldly phenomenon of bioluminescence, created by video projections accompanied by soundscapes. The viewer is immersed inside a luminous realm of electric blue; an illusion of endless space stretches beyond the imaginary dimensions of an infinity cube."

The *Infinity Cube* experience is much more complex than just viewing simple videos of dinoflagellate bioluminescence. The projections, involving three video projectors, incorporate as many as 24 video streams that are creatively superimposed on one another, and physically mapped onto the projection space in even more creative ways. The 7-min video loop includes three modes of stimulating the bioluminescence of *Pyrocystis fusiformis*, a large robust dinoflagellate that is amenable to creative manipulation. As described by the artist:

"Luminous blue waves trickle from the side walls onto the floor creating a waterfall of lights. Glowing ripples projected above the ceiling reflect an expanding, infinite universe of light and sound."

*Infinity Cube* is accompanied by interpretative graphics and text designed by a creative team that included education and exhibit staff at the BAS. The main message of the exhibit, "The mesmerizing language of light is key to survival in the dark ocean" has three subthemes: (1) the diversity of luminescent systems, (2) the chemistry of bioluminescence, and (3) "beauty and the beast," highlighting the importance of bioluminescence in predator prey interactions (Fig. 4). Just as nature uses bioluminescence as a form of communication, we use light to communicate, whether for high-speed telecommunications or driving down the street.

For several hours a day, an interpreter in the exhibit space displayed preserved specimens of bioluminescent fish, squid, and pyrosomes, and was available to provide additional information about bioluminescence and to answer questions. Also available were blue flashlights that made for an interactive experience in lighting up the glow-in-the-dark ink of graphics and text mounted on the walls.

**Using haiku to explain the science concepts**

Unique to the exhibit was the use of haiku, a form of Japanese poetry primarily about nature, beauty, or love, to communicate the science concepts. The National Science Teachers Association has embraced the use of haiku for science education and creative writing (Rillero et al. 2011; Burrow 2016).

The exhibit welcomes you with Phil Hart’s spectacular image of bioluminescence from Australia, along with a haiku about night lights of nature:

*Fig. 1.* Dinoflagellate bioluminescence. A bloom of the dinoflagellate *Noctiluca scintillans* occurred in Gippsland Lakes National Park, Australia, during summer 2008/2009. Copyright: Phil Hart. Published with permission. Inset: *N. scintillans* cells, approximately 500 µm in size. Copyright: Ana Amorim. Published with permission.

*Fig. 2.* Artist Iyvone Khoo. Innovative approaches in filming dinoflagellate bioluminescence included high magnification ultra-high resolution imaging.
stars above shine bright
living glow sparkles below
equally wondrous

After the immersive Infinity Cube experience, a haiku explains that the light you observed comes from living organisms, and invites you to peer into a video box to view high magnification video of live dinoflagellate cells expressing bioluminescence:

A major function of bioluminescence in the deep ocean is for predator avoidance. Accompanying graphics of predator prey interactions, a haiku introduces the problem that light in the perpetual darkness may indicate something good to eat, or a lurking predator:

see my light, come close
catch my signal in the dark
am I friend or foe?

Bioluminescence occurs as a result of a chemical reaction in which a substrate molecule luciferin is oxidized in a reaction that is catalyzed by a protein called luciferase. This haiku accompanying the chemical structure of coelenterate luciferin provides the meaning of luciferin and the importance of the chemical reaction that produces the light:

‘light bringer’ by night,
full of energy so blue.
it’s the chemistry.

In fact, green fluorescent protein (GFP), involved in the bioluminescent chemistry of the hydromedusa Aequorea victoria, has developed into such an important tool in biomedical research that the 2008 Nobel Prize in Chemistry was awarded to three scientists “for the discovery and development of the GFP.” Marine chemist Osamu Shimomura, of the Marine Biological Laboratory in Woods Hole, Massachusetts, was the scientist who first isolated GFP from Aequorea collected from the University of Washington’s Friday Harbor Laboratories, located in Puget Sound, Washington. Roger Chalfie of Columbia University and Roger Tsien of UC San Diego also shared the Nobel Prize.

Dinoflagellates blooms are typically intermittent; in San Diego coastal waters only about two dozen have been recorded since 1902, when researchers started tracking their occurrence. Furthermore, it is impossible to predict when they will occur and how long they will last. But, there are places where dinoflagellate blooms persist throughout the year, such as the so-called bioluminescent bays of the Caribbean. Bioluminescent bays are small and few in number, with the five major bioluminescent bays of the Caribbean having a combined total area less than 5 km². The bays are mangrove fringed tropical coastal ecosystems in which the phytoplankton are dominated by the dinoflagellate Pyrodinium bahamense.

Framing the exit of the exhibit is a spectacular image by Frank Borges Llosa of bioluminescence from Mosquito Bay in Vieques, Puerto Rico, one of the most spectacular bioluminescent bays in the world. Bioluminescent bays are rare and unique ecosystems; the associated haiku brings attention to the need for conservation of these ecological wonders:

little bay so rare
will you stay bright forever?
we must keep you safe
On 17 April 2017, International Haiku Poetry Day, the BAS opened a haiku creation station, where guests created their own haiku inspired by Infinity Cube. By the time the exhibit closed, more than 1000 entries had been submitted, for example:

Ballerinas of
The blue, the ocean their stage
Dancing in the night – Elise, age 8

Drifting rings of light
Bright blue dots like ripples of
Water stuck in time – Danica, age 16

Intermittent flash
One glimpses eternity
The fade to wonder – Karen, age 65

The guest experience

Guests found the space and visuals to be a tranquil relaxation spot, often spending time just sitting and observing. The video projection associated with the cube provided a fun opportunity for selfies and creative photos that were often shared on social media (#infinitycube). When an interpreter was present, guests enjoyed using flashlights to explore the haiku and animal graphics; little ones enjoyed running around lighting up the glow-in-the-dark ink of the graphics. The specimens of preserved bioluminescent animals were a big hit as they helped bring the story of bioluminescence to life. Guests were astounded by the beauty of nature and the diversity of life that produces bioluminescence. Most guests did not realize that angler fish and other deep-sea animals were so small, and they enjoyed hearing about the pressures, both literal and figurative, of life in the deep sea.

Evaluating the exhibit

During the more than 17-month life of Infinity Cube, more than 700,000 guests visited the BAS. Interpreters who were in the exhibit space for only a few hours a day engaged with 57,866 guests, averaging 80 guests per 1.5 h interpretation, discussing exhibit content, and answering questions.

The San Diego Exhibits Evaluator Group, a team of museum professionals, viewed Infinity Cube and completed the FRAMEWORK: Assessing Excellence in Exhibitions from a Visitor Centered Perspective. This framework evaluated how comfortable, engaging, reinforcing, and meaningful was the exhibit. In a subsequent discussion with the exhibit creative team, group participants responded to three elements of the exhibit: science, art, and emotions. Evaluators liked how the haikus led to questions, not answers; exhibit interpreters and additional content outside the exhibit were means to get more information. Evaluators enjoyed the cube experience and watching the actions of children within the cube and elsewhere in the exhibit space. They would have liked the room darker with a louder soundtrack, but those conditions were limited by BAS concerns about safety and not disturbing animals in nearby display tanks. The group brainstormed on ways to make the exhibit even more interactive.

Reflections by the artist

As described by artist Iyvone Khoo, “I learned so much about the organisms. When I started the project, I thought they would glow on command, but that wasn’t the case. I thought the project would take six months to finish but that wasn’t the case; it took two years. I learned a lot from this project. It was the first time I had actually worked with living organisms, so that definitely shaped my art making process. The timeline wasn’t defined by me, it was defined by the process and the living organisms. I had to learn about the organisms and the science behind them. I ended up producing work that I never would have been able to produce otherwise. The science influenced my art practice and opened up an endless possibility of inspiration for my work.”

Final thoughts on the artist-scientist collaboration

As with all good collaborations, both partners were enriched by the experience. I was reminded of the esthetic beauty of bioluminescence, which we normally study using instruments that keep us one step removed from direct observation. I agree with artist Iyvone Khoo who stated, “Through this process of capturing the fleeting light of bioluminescence, I found an increased appreciation and awareness of the fragility, beauty, and ecological importance of these microscopic organisms.” The synergy between science and art creates an incubator for inspiration and exploration. Science and art can create a magnificent union; art embodies the esthetic beauty of nature that science seeks to understand. Art also offers a creative means to communicate science without the jargon and technical details. Infinity Cube is an expression of this science-art collaboration (Fig. 5).

Acknowledgments

Infinity Cube was generously funded by Rick and Patty Elkus. Interpretative components were funded by the National Science Foundation through grant 1205930 to MIL. Thank you to BAS Executive Director Harry Helling for the

FIG. 5. Artist Khoo and scientist Latz within the reflective cube. An effective collaboration between artist and scientist, working with the BAS design team, was essential to the success of Infinity Cube. Copyright: Birch Aquarium at Scripps. Published with permission.
opportunity to bring *Infinity Cube* to the public; the BAS staff and volunteers for their assistance and enthusiastic support, including Daniel Beckwith who provided material for this article including Fig. 4; and Iyvone Khoo for thoughtful comments about the manuscript. Visit http://siobiolum.ucsd.edu for more information about bioluminescence, and http://www.iyvonekhoo.co.uk to learn more about the artist.

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_Michael I. Latz,* Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA; mlatz@ucsd.edu_
Every year in early summer, we forecast the extent of hypoxia and harmful algal blooms in the Gulf of Mexico, the Chesapeake Bay, and Lake Erie. This year the outlook was not good (http://scavia.seas.umich.edu/hypoxia-forecasts/), and unfortunately most of the forecasts were born out. Gulf hypoxia approached record size at roughly 18,000 km\(^2\). Chesapeake Bay’s July hypoxic volume of 8.2 km\(^3\) was in the top 20% of the past 20 yr. And Lake Erie is likely to reach or surpass its previous record of over 40,000 metric tons of potentially toxic algae (Fig. 1).

The key drivers of this year’s outcomes are winter and spring rainfall considerably above normal. This winter was the wettest on record, and May was the second-wettest month on record. More rain means more flooding and run-off carrying heavy loads of nutrients fueling algal blooms and hypoxia. This end result often includes fish kills, closed beaches, drinking water alerts, and loss of coastal property value. This July was also the warmest on record, and as the climate continues to warm the problem is likely to get worse. Most climate models forecast increased precipitation, especially intense spring rains, for most of the Midwest, the Great Lakes basin, and the mid-Atlantic. It is also clear that this problem extends well beyond these three iconic systems and has been around for decades (NRC 2000).

As limnologists and oceanographers, we spend most of our careers exploring how oceans and lakes respond to drivers, and for hypoxia, harmful algal blooms, and other symptoms of eutrophication, the drivers come from land. Yet, we spend most of our time with our backs to the land. This viewpoint suggests more of us should look to both proximate and ultimate causes of these problems, and advocate for solutions.

TREADING WATER

After decades of upgrades in municipal and industrial treatment, nutrient loads now come primarily from diffuse sources, often dominated by industrial row crop agriculture, especially corn. The main policy tool currently available to combat nutrient losses from agricultural lands is the Farm Bill, enacted about every 5 yr, that funds voluntary conservation. Between 1995 and 2015, it provided almost $32 billion in conservation incentive payments. While water quality would likely be worse without these programs, both nutrient loads and their impacts have increased or held grudgingly steady in these three systems (Fig. 2).

REPLACING INDUSTRIAL CORN

While these conservation programs are important, and some new practices like two-stage ditches could improve nutrient management, watershed models suggest that these conservation practices would have to be implemented at unprecedented—and unlikely—scales to be effective (e.g., Scavia et al. 2017). The challenge is even more daunting when recognizing that, in many cases, agricultural soils are already laden with excess nitrogen and phosphorus. This is not to say that we should abandon implementing best management practices where they will do the most good. But as concerned scientists, we need to step back and look at the larger system within which these watersheds operate, and advocate for broader change.

For example, if making industrial corn production more efficient and implementing programs to reduce runoff are not likely to be enough, then perhaps there is just too much corn. Simple math suggests that reducing and/or replacing industrial corn production with less leaky crops would help. But one cannot expect farmers in these watersheds to forgo income to others, which given current markets, would certainly happen.

So, reducing or replacing industrial corn requires a national, multipronged agenda. In my view, we should be advocating a shift away from industrial-scale corn production through partnering in three integrated national movements.

First, we should support policies that stop putting food in our gas tanks. Current U.S. energy policy calls for so much ethanol that it consumes 40% of the U.S. corn production. This large-scale diversion of corn has raised prices, distorted markets, and had serious negative impacts on food choice and availability globally. This change would, of course, be politically difficult as long as presidential primaries start in Iowa. But, coupled with other strategies, it should be a component.

The second strategy is to encourage the private sector to use its influence over the agricultural supply chain to demand corn raised through more sustainable practices. While the marketplace does provide healthy alternatives and food from sustainably grown crops, these are not generally within reach, geographically and financially, to the vast majority of consumers. So, we need mass market leaders to help make them more available. Some progress is already being made. For example, Walmart, the country’s largest grocer, collaborated with food and beverage suppliers and their supply chains to reduce the impact of fertilizer on

FIG. 1. Lake Erie cyanobacteria bloom on 25 August 2019. Color spectrum based on satellite detection of cyanobacteria. Gray indicates clouds or missing data. The estimated threshold for cyanobacteria detection is 20,000 cells mL\(^{-1}\). Taken from NOAA Lake Erie Harmful Algal Bloom Bulletin, 26 August 2019, Bulletin 17.
14 million acres of U.S. farmland, albeit a small fraction of the 915 million acres. Companies including General Mills, Cargill, Kellogg, and Coca-Cola partnered within the Field to Market Alliance of grain suppliers, agronomic experts, and farmers to measure fertilizer use and identify opportunities for improvement. While it is not clear how much these efforts can shift the supply chain toward more sustainable agriculture at national scales, it is a start, and we should support it professionally and through our individual purchasing power.

The third strategy—probably the most difficult, but arguably the most effective—involves our diet. We need to join environmental and human health advocate efforts to change the American diet. A federal advisory board on nutrition standards recommended food labels that address the environmental impact of food production in 2015, but Congress squelched that proposal. At the same time, the one-two punch of ubiquitous high fructose corn syrup and animal feed for the increasingly meat-consuming population, these diet choices not only drive the nutrient pollution problem. And because over 40% of U.S. corn goes to corn syrup and animal feed for the increasingly meat-consuming population, these diet choices also drive the nutrient pollution problem.

If Americans were to move closer to the lower-meat Mediterranean diet, there would be a dramatic reduction in the demand for fertilizer (Townsend et al. 2003). While a stretch at first, this idea has gained momentum with the growth of the alternative meat industry. The success of startups like Beyond Meat and Impossible Foods is luring giants like Tyson and Perdue into the game. One recent market analysis suggests that plant-based “meat” will surpass animal sources globally by 2040 (Gerhardt et al. 2019), and some producers are even struggling to keep up with demand for plant-based meat alternatives, particularly in China (Vigdor 2019). Recent analyses connecting reduced meat consumption to both positive environmental effects and improved health (Willett et al. 2019) should provide additional incentives for change, and others are laying out comprehensive global pathways to more sustainable agriculture designed to both feed the world and protect and restore natural ecosystems (Clark et al. 2018; Searchinger et al. 2018).

**CALL TO ACTION**
As oceanographers and limnologists who study and care deeply about rivers, lakes, estuaries, and oceans, it is incumbent upon us to advocate for better policies to protect them. A comprehensive plan that addresses energy policy, health and nutrition, environmental protection, and market-shaping initiatives from the private sector is not a quick or easy process. But little else has worked over the past decades, and working with advocates for sustainable energy and healthier diets on this combined agenda could improve the health of both people and the environment.

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ASLO ASM 2021 IN PALMA, SPAIN

Tips to Enjoy the Amazingly Beautiful Spots while on the Island of Mallorca and Surroundings

Eva Sintes, Nona Sheila R. Agawin, Iris Hendriks, Eva Alou-Font, Maria Capa, Lluís Gómez-Pujol, Manuel Hidalgo, Hilmar Hinz, Gabriel Jordà, and Núria Marbà

The next Aquatic Sciences Meeting will be held in Palma, Spain. We anticipate that the topic “Aquatic Sciences for a Sustainable Future: Nurturing Cooperation” and the location of the meeting will incite researchers from all continents working in all aquatic fields to come over, communicate, interact, and share. While attending the meeting for the stimulating science, one has the opportunity to enjoy the astounding beauty of Mallorca, the larger island of the Balearics archipelago, located about 200 km (~125 miles) off the mainland Spain. The archipelago is bathed by the transparent waters of the Mediterranean Sea, harboring some of the best preserved endemic Posidonia oceanica seagrass meadows (Fig. 1) including those declared as UNESCO World Heritage between Ibiza and Formentera. The small Cabrera Archipelago, off the coast of Mallorca, was the first declared “Sea and Land National Park” in Spain, and shelters a diversity of sea life, including the last Spanish catalogued specimens of the highly endangered pen shell, Pinna nobilis (Fig. 1).

Along the coasts of Mallorca are sandy, pebble, and rocky beaches with turquoise waters (Fig. 2), nestled between cliffs or surrounded by the astonishing Serra de Tramuntana, a UNESCO World Heritage, spanning the northwestern coast. Traveling through the scenic coastal road from the Serra, one can make stopovers in beautiful mountain villages such as Valldemossa and Deià where world renowned artists such as Frederick Chopin and Robert Graves, captivated by the island, were hosted. One can also go on hiking excursions through amazing gorges, such as Torrent de Pareis and Sa Calobra, and enjoy other privileged sightseeing spots in the mountains, such as the estates of the former Archduke Ludwig Salvator of Austria. A singular journey through the spectacular Serra landscapes can be made with the vintage wooden train that connects Palma to Sóller village, where one can visit the emblematic Natural History Museum and Botanic Garden and learn about this Mediterranean archipelago’s fauna and flora.

The Serra also boasts two embayments (Gorg Blau and Cúber), the largest freshwater bodies in Mallorca. Numerous underground streams and lakes form in the calcareous terrain of the island, some sculpturing impressive cave systems such as the Drach and Campanet caves. The largest wetlands in Mallorca are in the protected areas of Albufera de Alcudia and Albufereta de Pollença, a natural stop for migrating birds between north of Europe and Africa.

Through an extended stay or early arrival, the other islands from the archipelago can be visited, each one with its own character. Menorca, declared a UNESCO Biosphere reserve, is a quiet island with well-preserved natural and cultural facets; Ibiza, known for its party atmosphere in summer, is also known for its white charming constructions, hippie culture, and enchanting sunsets; and Formentera, the island off Ibiza, is famous for its beautiful pristine white sand beaches.

We hope that the exciting science and topic of the meeting will incite one’s scientific interest and creativity, while the natural land and sea wonders that can be explored, before and after the intense scientific sessions, will complete an unforgettable meeting. Mark your calendar!

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I like to think Richard Brautigan envisioned our current scientific era in his poem entitled “All Watched Over By Machines of Loving Grace.” As in the first stanza quoted above, Brautigan paints an idealized world where machines and nature beautifully coexist. One interpretation of the poem is as a satire about human technology being a source of connection and solution. Another interpretation is as an earnest vision of a better world. We cannot ask the poet. He has been dead since 1984. So I will take the liberty to argue that this poem is, for limnologists and oceanographers, a paean that we are now realizing as we instrument the aquatic world. However, if we are to achieve “grace” with our exploding capabilities, we need to sustain the values and possibilities that scientific inquiry requires. And therein is a big reason for scientific societies to endure.

I suppose over every scientific career there are impressive advances in technology. Early on when I wanted to measure diel oxygen dynamics in lakes, I had the choice of trying frequent measurements with oxygen sensing electrodes, or less frequent but more accurate, measurements with Winkler titrations. Both approaches were arduous and neither worked well when the daily excursions of oxygen concentrations, up during the day and down at night, were modest. This changed with the availability of continuous oxygen measurements incorporating data loggers and has changed further with the optical detection of oxygen. These improvements were paralleled by many others such that sensors with wide capabilities are now available. As I write this message, I can check the evolving conditions of a variety of sensor measurements in an experimental and a reference lake up to the most recent day—never mind that I am in Virginia and the lakes are in Michigan. My point here is that these capabilities were unheard of when I started as a researcher, but now many types of environmental data are easily collected at high frequency over extended temporal and spatial scales.

I could write a similar paragraph about improvements in computation but I will spare you except to say I occasionally wave old punch cards at my students and say, “see what I had to go through.” For those who do not know, a punch card was a line (one line!) of computer code, and along with the rest of the cards that made up a program, was put through a card reader (euphemistically called the “card eater” for reasons you can imagine) to transfer the program code to the computer. The degree of computational change in my time is boggling.

Armed with technical and computational capability, the threshold which we have either gone over or are rapidly approaching is the ability to truly grapple with the complexity of marine and inland water systems. You may have at hand genomes, thousands of chemical observations, second-by-second recordings of temperature, pressure, salinity, oxygen. Our machines are indeed watching over the aquatic world. What do we do with all our data, with all our computing power? Although methodologies like artificial intelligence and other advanced analysis techniques will likely proliferate, I contend that they will not be sufficient.

“Algorithmia” alone will not satisfy our scientific aspirations nor explain environmental complexity to the public. We are and we will be dependent on the same processes of developing questions, analysis, refinement, debate, presentation, and publication. We will need new ideas and means for expressing those ideas. These processes of conducting science are fostered by the interactions we have at meetings, in the journals we publish, and in the educational activities we promote. Just consider the role of an ASLO meeting in your scientific life, you listen to colleagues present their latest findings and you encounter and even think of new questions. You see new ways of analyzing data. There are debates that stimulate further research. You exchange ideas and develop collaborations in conversations. You discern new directions. I belabor these benefits because I worry about the future of scientific societies. It is possible that new means of communication may prevail and largely bypass organizations like ASLO. Publication could go away from society journals. The discussions and debates fostered by meetings might go to social interaction platforms. Reason for membership could diminish.

Thus the challenge for ASLO is to both stay the course of fundamental scientific activities, long our business, while seeking new directions. In my view, those directions need to be about thinking of new ways to foster ideas and advances in our science, promoting opportunities and enriching experiences for students and early career researchers (ECR), and increasingly providing actionable scientific work to help address social-environmental systems. The ASLO Board will be working on how we move forward as we start to reconsider the ASLO Strategic Plan over the next couple of years (current plan is at https://www.aslo.org/page/strategic-plan-2015). We are also definitely going to need to confront publication and open access (see my earlier message on this topic Limnol. Oceanogr. Bull. 28: 31–32). As examples of efforts for students and ECR, we are currently promoting international research exchanges through our LOREX program (https://www.aslo.org/page/lorex), promoting diversity through our long-standing ASLO Multicultural Program (https://www.aslo.org/page/aslomp) and providing editorial experiences through the Cole Fellowships. How can we sustain and possibly increase these kinds of activities in a future where membership or publication revenues might decline? In addition if you sense as I do that even more of our future work will revolve around actionable research that addresses environmental problems, how should ASLO participate? One benefit of greater engagement with these problems will be that ASLO might attract a broader range of professionals who see our society as fundamental to their concerns. Overall, the above questions on our path forward require continuing thought and effective action from ASLO members as well as those of us in leadership. Please get involved through the many activities ASLO provides!

I like to think that ASLO will be sustainable in the world of rich data and powerful computation. Harmony will come with advancing and evaluating novel ideas and engaging more widely, per poet Brautigan, with our fellow “mammals” not to mention benthos, plankton, and fish.

Michael L. Pace, ASLO President (2018–2020), Commonwealth Professor, Department of Environmental Sciences, University of Virginia, Charlottesville, VA; president@aslo.org
ASLO has been very proactive in bringing together art and science, realizing the connection between the two. This has been demonstrated at our meetings in various forms. We have brought in cultural activities, art exhibitions, artisans, music, and visual art experiences. At our 2018 Summer Meeting in Victoria, BC, Canada, we partnered with The Story Collider to present science in a verbal, informal format.

Appalachian State University (ASU) in Boone, North Carolina is using storytelling to express and respond to the climate change crisis. Following a talk by climate change activist and author Jeff Biggers, in which he called for more climate storytellers, an educator met the challenge. Laura England, senior lecturer in the ASU Goodnight Family Department of Sustainable Development, established the Climate Stories Collaborative (England 2019). This soon became a university-wide initiative with the mission to expand among faculty and students via a variety of creative media to tell stories about climate change. The goal was to engage people in meaningful dialog and action to address climate change. The outcome has been the collaborative efforts as students, faculty members, and departments across the campus work together and learn from each other.

Media used went beyond storytelling—painting, sculpture, theatrical performances, videography and photography, narrative stories, and so on. This endeavor has also become a path for the community to raise the profile, sharing concerns, and calling for change. These outreaches also made climate change personal and understandable.

The complete history and current developments of the Collaborative are available via https://climatestories.appstate.edu/.

Think about what ASLO, your department, your university, and your community can do by considering creative ways to present our science.

We hope to see you in 2020 at either the Ocean Sciences Meeting or the Joint ASLO-SFS Meeting. Both will have science and art as one of their components.

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MESSAGE FROM THE EXECUTIVE DIRECTOR
Interview with Jim Cloern, Editor-in-Chief, L&O Letters
Teresa Curto

On August 1, Jim Cloern became Editor-in-Chief of L&O Letters. Pat Soranno, Founding EIC of the journal, accepted a temporary position at NSF that precludes her from serving as EIC during her stint at the agency. As announced to the membership by President Mike Pace in July (https://www.aslo.org/blog/jim-cloern-to-serve-as-eic), Jim is serving as interim EIC for the next three years. Jim has been a Senior Editor at L&O Letters since the journal launched in late 2016. I sat down with Jim to talk about his background, the current status of the journal, and his plans for the next three years.

ED: WELCOME, JIM. AND CONGRATULATIONS ON YOUR APPOINTMENT AS EIC OF L&O LETTERS. YOU HAVE A LONG ASSOCIATION WITH ASLO, INCLUDING AS A FREQUENT AUTHOR, REVIEWER, ASLO SUSTAINING FELLOW, AND 2015 RECIPIENT OF THE RUTH PATRICK AWARD. YOU HAVE ALSO SERVED AS EIC OF ESTUARIES AND COASTS. TELL US A LITTLE BIT ABOUT YOUR BACKGROUND AND THE PERSPECTIVES YOU BRING IN YOUR NEW ROLE WITH L&O LETTERS.

JC: Thank you Teresa. I’ve been warmly welcomed by the ASLO community and am now fully engaged as Editor while Pat is at NSF. I guess the number one perspective I bring is that of an author. I’ve been publishing scientific papers for 44 years (scary to say that) and as an author I’ve had both positive and disappointing experiences. I hope that those who submit to L&O Letters will continue to have positive experiences with the review and production processes. I see my primary job is to work hard at making timely, fair and objective editorial decisions. Woody Allen said that 80% of success is showing up. I intend to show up by paying close attention to the editorial progress of each submission, quality and relevance of reviews, workload of Associate Editors, and so on—the day-to-day tasks of a journal editor. My personal goal is to see repeat submissions from authors because they thought the editorial process was fair and improved their papers. If we can build a reputation of this journal as one that treats authors fairly, then things like growth of submissions and increasing impact factor will take care of themselves. We serve the authors first.

ED: UNDER PAT’S LEADERSHIP, THE JOURNAL HAS BEEN AT THE FOREFRONT OF IMPLEMENTING OPEN SCIENCE INITIATIVES, WELL BEYOND THE OBVIOUS OPEN ACCESS FORMAT OF THE JOURNAL. WHAT ARE YOUR GOALS FOR THE JOURNAL OVER THE NEXT THREE YEARS? ARE THERE ANY NEW DEVELOPMENTS AUTHORS AND READERS CAN EXPECT IN THE COMING YEAR?

JC: I am excited to be part of a journal that not only requires data to be published, but also follows through to ensure that all data reported in an article are published in a repository. There are strong views within the scientific community about the open-data mandate. Since early in my career as a government scientist, I felt a responsibility to make publicly funded data available to the public. We’ve put all of our USGS data from decades of measurements in San Francisco Bay on a web page, beginning soon after the “world wide web” was created. Last count, that site has been visited from over 80 countries and used by teachers, students, NGOs, the regulatory community, and scientists around the globe. That’s been as meaningful to me as any paper we’ve written from the data ourselves.

ED: L&O LETTERS RECENTLY INTRODUCED A NEW ARTICLE TYPE, DATA PAPERS. TELL US ABOUT THIS ARTICLE TYPE, WHAT PROMPTED ITS DEVELOPMENT, AND WHAT YOU ARE LOOKING FOR FROM AUTHORS WISHING TO SUBMIT DATA PAPERS TO THE JOURNAL.
JC: Purely by coincidence, Pat Soranno and I thought we should answer that question as a news piece in the ASLO Bulletin. Readers will find it in this issue at https://doi.org/10.1002/lob.10341. This was Pat’s idea and I’m enthusiastic because, as we explain, it is an important step toward a fully open science enterprise. Data articles make our published data sets discoverable, available, understood, and ready for use or reuse by others. They are indexed, citable, and give authors the professional credit they merit for the hard work that went into their data production. We’re looking for descriptions of published data that have a substantial information content that has not yet been fully extracted, and a high likelihood of being used by others.

ED: OVER THE LAST YEAR, THE JOURNAL GAINED INCLUSION IN A VARIETY OF INDEXES AND DIRECTORIES INCLUDING DIRECTORY OF OPEN ACCESS JOURNALS (DOAJ) AND EMERGING SOURCES CITATION INDEX (ESCI), AND ARTICLES ARE NOW DISCOVERABLE ON THE WEB OF SCIENCE. THESE ARE VITAL STEPS TO BEING EVALUATED AND ACCEPTED INTO THE SCIENCE CITATION INDEX EXPANDED (SCIE) AND ACHIEVING THE IMPORTANT JOURNAL IMPACT FACTOR (IF). WHILE THE JOURNAL IS ON AN ACCELERATED PATH TO GETTING AN IF, HOW DO YOU APPEAL TO AUTHORS TO PUBLISH IN THE JOURNAL NOW? I UNDERSTAND A SIGNIFICANT NUMBER OF EARLY CAREER RESEARCHERS HAVE AUTHORED PAPERS IN THE JOURNAL. THIS IS A HIGHLY POSITIVE DEVELOPMENT, BUT DOES IT SURPRISE YOU?

JC: Launching a new scientific journal takes courage and patience. It takes time for a new journal to become established and for its performance to be assessed with metrics like online views, downloads, and citations. Our patience is being rewarded because we recently learned that L&O Letters has been accepted for indexing in the Science Citation Index Expanded. Acceptance means that our newest journal has met 28 quality and impact criteria used to identify the most influential scientific journals. Papers published in L&O Letters will be indexed in Web of Science, and the journal will have its first impact factor when the next Journal Citation Report is released next year in June. These advances reflect the inspiring leadership from Founding Editor Pat Soranno. They should give prospective authors the confidence they need to submit, knowing that L&O Letters is on track toward recognition as one of the high-impact journals in the aquatic sciences. No, I’m not surprised that ECRs are submitting because they embrace the new faster than us codgers. Now we need to bring them into the fold of peer reviewers.

ED: L&O LETTERS’ FIRST SPECIAL ISSUE ON CARBON CYCLING IN INLAND WATERS WAS VERY SUCCESSFUL AND GENERATED A HIGH LEVEL OF INTEREST BASED ON FULL-TEXT DOWNLOADS AND CITATIONS. I UNDERSTAND YOU HAVE A SECOND SPECIAL ISSUE IN DEVELOPMENT ON MICROPLASTICS IN MARINE AND FRESHWATER ORGANISMS. TELL US ABOUT THAT, AND THE ROLE THAT SPECIAL ISSUES PLAY IN THE JOURNAL. ARE YOU SEEKING OR SOLICITING IDEAS FOR FUTURE SPECIAL ISSUES, AND ARE THESE MARINE OR FRESHWATER FOCUSED?

JC: Pat Soranno served as Editor-in-Chief of the first special issue published in 2018 (https://aslopubs.onlinelibrary.wiley.com/toc/23782242/2018/3/3), and she will continue to serve as Editor of the second that we expect to appear in early 2020. The last two papers I published in an ASLO journal were unplanned until I saw announcements of special issues of L&O on “Headwaters to Oceans” and “Long-term Perspectives in Aquatic Research.” This illustrates how special issues can be strong attractors for submissions. L&O Letters is still a young journal, and we will continue to use special issues to attract submissions and grow interest in and awareness of our newest journal. Special issues are also invaluable resources on focused topics. I’m using papers from the special issue on carbon cycling in my own research and looking forward to learning about the emerging topic of microplastics in the upcoming issue. And, YES. We are just beginning to explore topics for the next special issue of L&O Letters and welcome suggestions from the scientific community. If readers have a topic in mind, or would like to lead production of a special issue, please contact me (loletters-eic@aslo.org).

ED: AUTHORS ARE ALWAYS SEEKING THE BEST VENUE TO PUBLISH THEIR WORK. ARE THERE ANY TOPICAL AREAS YOU ARE SPECIFICALLY TARGETING FOR INCLUSION IN THE JOURNAL?

JC: The main message I have for readers is that, from my perspective as Editor, the scope of L&O Letters is broad and extends well beyond our core research areas of ecology and biogeochemistry. I want to find ways to recruit papers in fields that are under-represented in ASLO journals, such as physical limnology/oceanography. One of my colleagues received comments from a reviewer that his submission was not acceptable in an ASLO journal because “it wasn’t an ecology paper.” This perception is wrong. L&O Letters will consider submissions across all domains of aquatic sciences including studies of sediment dynamics, changing water chemistry, aquatic socioeconomic systems, viruses, chemical ecology, science to support decisions, discoveries from new technologies and observing systems, forecasting, mixotrophy, large rivers, ecosystem-based management, extreme environments, genetic diversity and its meaning, disturbance, the sedimentary record, air-water-land connectivity, as well as currents, waves, mixing, and stratification. I would also take great personal satisfaction if we could expand the geographic range of papers published in L&O Letters by publishing more studies from outside the northern temperate zone. If authors have any questions about the scope of L&O Letters, I encourage them to contact me directly.

ED: YOU HAVE A HIGHLY SKILLED AND PROMINENT GROUP OF SENIOR EDITORS AND ASSOCIATE EDITORS (AEs) WORKING WITH YOU TO ENSURE THAT THE JOURNAL PUBLISHES THE BEST OF SHORT-FORMAT ARTICLES ACROSS THE SPECTRUM OF LIMNOLOGY AND OCEANOGRAPHY. ARE YOU SEEKING NEW ASSOCIATE EDITORS AND REVIEWERS IN ANY PARTICULAR SPECIALTY AREAS? HOW SHOULD INTERESTED INDIVIDUALS CONTACT YOU IF THEY ARE INTERESTED IN SERVING AS REVIEWERS OR ASSOCIATE EDITORS?

JC: One of the important roles of Editor-in-Chief is to build a talented and dedicated group of Associate Editors. Pat Soranno has built an exceptional editorial board. However, she and I agree that we need to add (AEs) with areas of expertise (e.g., physical oceanography) and from geographic regions (e.g., South America, Asia) currently under-represented on that board. Editors are always looking for ways to add talent and diversity to the team of (AEs) who make the critical evaluations of submissions and recommendations for editorial decisions. And, (AEs) are always looking for members of the scientific community who are ready, willing and qualified to review submissions but aren’t being asked. So, YES. I am looking for nominations, including self-nominations, for Associate Editors and reviewers. I especially encourage experienced students, postdocs, and early-career scientists to let me know of your interest in serving as a reviewer. We need you.

ED: WHAT DO YOU SEE AS THE CHALLENGES, NOT JUST FOR L&O LETTERS, BUT FOR ALL SCIENTIFIC JOURNALS IN THE NEXT FEW YEARS? HOW IS THE JOURNAL POSITIONED TO MEET THESE CHALLENGES?

JC: From an Editor’s perspective, the biggest challenge is finding timely and constructive...
ASLO TAKES A NEXT STEP TOWARD OPEN SCIENCE

Introducing Data Papers, a New Article Type in Limnology & Oceanography Letters

James Cloern and Patricia Soranno

Science is moving quickly toward open access of peer-reviewed scientific articles and the data they report. This change began in the early 1990s with publication of digital editions of articles accessible freely to anyone with an internet connection. Today, different models of Open Access exist. Publication of the most common (Direct Open Access) has grown 30% annually since 2000, and exceeded 190,000 articles in 2009 (Laakso et al. 2011). ASLO has recognized this important trend and embraced Open Access publication by making open-access options available to authors in two of its journals (Limnology and Oceanography and Limnology and Oceanography Methods), while also launching a fully open-access journal, Limnology and Oceanography Letters, in 2016. In 2018, 36% of papers in L&O and 38% of papers in L&O-Methods were published OpenOnline, while all of L&O-Letters articles were open access.

However, another equally important component of open science—online publication of the data reported in our papers—is a work in progress. The rationales for publishing data are compelling, and include: (1) making publicly funded research available to the public, (2) allowing others to ask new questions of our data, (3) advancing research and innovation through synthetic analyses across studies, and (4) fostering reproducibility of research (Borgman 2012). ASLO is strongly supportive of open data. For example, publication in L&O-Letters requires that authors place the data and metadata associated with all of its publications in a “public repository that issues a DOI so that future readers can access the exact version of the dataset used in the study.” To guide authors in this relatively new practice in science, one of us recently published a step-by-step guide for placing data and metadata in a public data repository that can be used for any research article or journal (Soranno 2019).

Open data will become the norm, not only because of mandates from government funding agencies and push from scientific societies and publishers (Michener 2015), but also because it leads to a more robust and reproducible science. Although data publication leads to increased visibility and citations of our work (Piwowar et al. 2007), members of the scientific community have not universally embraced the open-data mandate. A survey of 500 papers published in high-impact journals found that only 9% deposited the full data sets required by journal policy (Alsheikh-Ali et al. 2011). Resistance comes partly because of uncertainty about how our data will be used. Borgman (2012) explains the conundrum: “The farther removed from the data collection activity, the harder it is to make use of someone else’s data. Thus, it is not surprising that concerns for the misinterpretation and misuse of data are common reasons that researchers give for not sharing.”

Publishers have addressed this concern through the creation of a relatively new article type—the data article, an article that thoroughly describes a noteworthy, valuable, or novel data set, as well as entire journals devoted to publishing data articles. For example, Nature Research launched Scientific Data in 2014 to publish data articles (“descriptors”). Authors also have other outlets for publishing detailed descriptions of their published data in journals devoted to data papers, such as Geosciences Data Journal (Wiley), Data in Brief (Elsevier), and Earth System Science Data (Copernicus Publications). More recently, journals that publish traditional research articles have also begun to publish data articles.

Data articles provide an opportunity for us, as data producers, to share essential information to minimize the likelihood that our published data will be misinterpreted, misrepresented, or misunderstood by others who use them. They also provide data producers with an avenue for getting credit for the major effort involved in not only collecting data, but in describing them effectively for reuse. Data articles describe the essentials of who produced the data; when, where, and how they were produced; the purposes for which they were produced; detailed and thorough descriptions of the methods used; and steps of quality control and assurance. Data articles are peer-reviewed, have unique digital identifiers, are indexed (e.g., in Web of
Science, Scopus, Google Scholar, and PubMed), and are cited. For example, the impact factor of Scientific Data was 5.9 in 2018 (https://www.nature.com/sdata/about/faq#q6). Therefore, data articles give us professional credit on par with that we receive for publishing traditional scientific articles.

Our purpose here is to announce that the ASLO Board of Directors has accepted founding Editor-in-Chief Patricia Soranno’s proposal that L&O-Letters publish Data Articles as a new article type. We have begun the process to open the journal for submissions of data articles by the end of 2019. As far as we are aware, this will provide the first dedicated outlet for publication of data articles in the aquatic sciences. We encourage you to begin thinking now about submissions to attract and facilitate use or reuse of your data sets. Stay tuned for an upcoming editorial in L&O-Letters that will provide more detail about the structure of Data Articles, criteria for publication, and how they will advance ASLO’s commitment to open science.

We welcome questions and comments to loletters-eic@aslo.org.

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RONALD P. KIENE
Major League Pitching Prospect, Avid Sports Fisherman, and Biogeochemist Who Probed the Mysteries of the Oceanic Organosulfur Cycle
Ronald S. Oremland, Gary King, Pieter Visscher, and Douglas G. Capone

The marine and environmental microbiology science communities lost one of its star players, Ron Kiene, at the untimely age of 59. Ron passed away from complications associated with battling a squamous cell carcinoma, first diagnosed in 2016. The cancer had metastasized, but he only learned of it after returning from a research cruise in 2018. He underwent a debilitating course of further surgery, radiation, and chemotherapy treatments in late 2018 and early 2019, all while still teaching his course load. Ron was always a powerful, heads-on fighter, never one to quit, but the cumulative treatments proved too harsh even for him to bear. He succumbed to heart failure during the night of 19 January 2019.

Ron was born on 06 July 1959 in the city of New York, the borough of Brooklyn, the neighborhood of Bay Ridge. He arrived a year after the beloved Dodgers departed for LA, the same year in which construction of the Verrazano Narrows Bridge began, which when completed in 1964 bisected Bay Ridge. To those who grew up in those southern reaches of Brooklyn by the sea like Bay Ridge or Coney Island, two things were “in the blood” so to speak: baseball and fishing. The loss of the Dodgers (dem Bums) was particularly galling to the denizens of Bay Ridge because many of the players, in those years before free agency and outrageous salaries, dwelt among the hoi polloi. The arrival of the Mets in 1962 only rubbed salt into the open wound, as until 1969 they were horrible, and moreover the Mets settled into Shea Stadium in Queens rather than Brooklyn. Something had to be done to rectify the borough’s lost glory, perhaps someday by one of Bay Ridge’s native sons?

The southern reaches of Brooklyn border the Atlantic Ocean via the New York Bight and its estuarine extensions, like Jamaica Bay and the lower Hudson River. While the rest of the city swelters in summer, these regions are cooled by onshore sea breezes. The salt air that wafts ashore beckons young boys to the littoral for adventures in the exploration of tidal life, swimming in summer, and of course watching the fishermen make their casts. As one grew older, shoreline fishing become a pastime, and Ron started indulging this nascent passion along stretches of Shore (Belt Parkway) Boulevard than circumscribed his neighborhood. When older and more adventurous, there were party boats to be had from nearby Sheepshead Bay that would venture further out to sea for catching giant fluke, pogies, mackerel, cod, stripers, and bluefish. This was the milieu (baseball and fishing) into which Ron grew up and was well ensconced in by the time he entered public high school.

And it was not just any city high school: it was Stuyvesant High in lower Manhattan, a free prep school for the city’s gifted, competitive kids. You had to be smart just to get in, and very smart to get out 4 yr later with your diploma in hand. Mixed in with his academics, came spring Ron played baseball for “Stuy” and became their starting pitcher. So much so that the Dodgers drafted him after graduation, and a future in Los Angeles beckoned, but he balked. Maybe it had something to do with an inkling of shoulder issues arising as a harbinger of a short career in the majors, or maybe it had something to do with feeling a traitor to Brooklyn and deserting the memory of “dem Bums” for the frivolities of the west coast’s LA-LA land, but he chose a cerebral path instead. He went to college at St. John’s University in Queens, where he continued to pitch on a baseball scholarship, and the team heading twice to the nationwide College World Series over the 4 yr he matriculated (and pitched). To get into the CWS is a big deal, and to give you an idea of what the quality of his team was like, two other pitchers on St. John’s at the time were Frank Viola and John Franco, both of whom headed to the major leagues. Ron graduated with a B.S. in biology in 1981, but by then his shoulder truly ached and he gave up the idea of major league baseball. After all, he could always fall back on his second passion: fishing!

Well, sort of…….Ron’s initial interest was zoological, dealing with marine sediment invertebrate in-fauna like worms and clams (aka: live bait), but this changed when he arrived at SUNY Stony Brook’s Marine Science Research Center (MSRC) and tied in with his mentor, Doug Capone. Doug steered him toward sediment microbiology, focusing on methanogenesis and sulfate reduction. Ron’s passion and enthusiasm for science was unleashed and unbridled during graduate school. During his graduate tenure at MSRC, Ron insisted (against his advisor’s advice) to obtain his M.S. degree along the way. His rationale was to show his parents and grandparents that he was making progress. An early indication of Ron’s potential was the awarding of a regular NSF grant from the Ocean Sciences/ Biological Oceanography research section to fund his Ph.D. research. Three of the present writers (RO, GK, and DC) remember fondly gathering on a very blizzardly February day in 1985 for Ron’s qualifying exam at Stony Brook. The event was coincident with the arrival of Doug’s second daughter, adding to the chaos of the weather for Ron’s first major academic hurdle (which he sailed over). He also found time to mentor his mentors, for example, infecting Doug with his love of the music of Mark Knopfler and Dire Straits.

Bill Dennison at UMES/Horn Point, then a Postdoctoral Fellow at Stony Brook, remembers Ron’s pitching prowess: “I very much enjoyed playing catch with Ron behind the Discovery building at MSRC. He could throw a curve ball that I found difficult to catch and a fastball (with his left arm) that I could catch, but it left my hand stinging. Ron would have me hold a glove in front of me with two hands as a target and invariably he would hit the target. He was impressive. I also recall introducing Ron to a chemist friend from MIT when Ron was still a graduate student and he said that his demeanor completely changed when the subject switched from chemistry to baseball. Ron was tentative with him about chemistry, but his confidence noticeably increased when talking about baseball. I loved picking Ron’s brain when I would see him a meetings, as he was such a good synthesizer and explainer. He could distill hotly debated topics into understandable bits.”

A brief sojourn at Ron Oremland’s lab in California got him interested in dimethyl sulfide (DMS) as a precursor substrate for methanogenesis, and from there he never looked back. He finished his Ph.D. in 1986, and while working in Capone’s lab, met one of Doug’s master’s students (Julie McDaniel) whom he wed in 1987. From the MSRC they headed south to Rosenstiel School of Marine & Atmospheric Sciences (RSMAS) of the University of Miami, where he worked with Barrie F. Taylor (mentor to Oremland and Capone) also tying in while there with Pieter Visscher (who had first worked with Ron at MSRC), another Taylor postdoc. As a
Sapelo offered an opposite world of Brooklyn beach under the heavy load. With shrimp or when the moon and tide were favorable, on a}

and coastal waters and even microbial mats. Spartina continued work on offshore wilderness of Sapelo Island and lived at the University of Georgia. DMSP.  

2006 research at Palmer Station. 

FIG. 2. Ron driving a zodiac in Antarctica during a 2006 research at Palmer Station.

FIG. 1. Ron pitching during his senior year at Stuyvesant High School in 1977.

bona fide member of the “Miami Mafia” Ron delved into microbial metabolism of the DMS precursor, dimethyl-sulfiniopropionate (DMSP). From there, a faculty position opened up at the University of Georgia’s Marine Institute. In February of 1988, Ron and Julie moved to the offshore wilderness of Sapelo Island and lived in the shadow of the R.J. Reynolds estate. Ron continued work on Spartina but expanded his research to include volatile sulfur in estuarine and coastal waters and even microbial mats. Days in Sapelo were either spent in the lab or when the moon and tide were favorable, on a road bike loaded with fishing rods, cast nets and buckets, its narrow tires digging into the beach under the heavy load. With shrimp or fresh caught fish on the table, dolphins in the surf, and sea turtles laying eggs on the beach, Sapelo offered an opposite world of Brooklyn and Miami for Ron and Julie. This also meant that hurricanes found the island in their path. A nervous father-to-be, Ron had to evacuate Julie during category five storm Hugo, just days before Andrew Devon was born on 01 October 1989. Exciting times persisted, especially when Ron attempted to relocate a big reptile from his property to keep young Andrew out of harm’s way, finding out first hand that even a small gator tail can whip ferociously.

A few years later, in December 1992, the Kienes, moved to Mobile, AL, where Ron took a faculty position at the University of South Alabama (USA) and its Dauphin Island Sea Lab (DISL) where his lab was located. A little over a year later, Julie and Ron’s second son Dylan was born; both Andrew (Physics professor at Nova Southeastern) and Dylan (Ph.D. candidate in Fisheries) followed in Ron’s science footsteps, but Dylan is the one who got Ron's baseball and fishing genes.

During Ron’s 26-yr career at U.S.A. and DISL, he touched many. Upon his arrival, Ron immediately made an impact on the research culture at the lab, which until that point was mainly focused on marine ecology and fisheries. In his first graduate Chemical Oceanography class, he introduced the course as the “ecology of elements in the ocean.” This is indeed how Ron looked at the world as a connected Earth system from macro to microscales. He hooked many of us on this way of thinking, and his generosity with his knowledge and skills allowed us to follow in his footsteps.

Ron was a dedicated mentor to the younger faculty who began their careers at DISL and who looked up to Ron for advice in navigating the tenure process and establishing their labs. Ron’s effectiveness as a mentor was born out of his child-like curiosity about the natural world. This was infectious for both students and colleagues. Brief exchanges of niceties at the coffee pot often turned into long and in depth dissections of some topic that he had been mulling over or of some problem of your own that piqued his interest. These conversations would often lead to proposals or pilot studies to flesh out ideas and methods. As important were the conversations about his boys’ recent successes or the latest political outrage, as we loved Ron’s passion for making the world a better place and how proud he was of his family.

Ron was clearly the most accomplished member of the DISL faculty, and his outstanding research brought students and postdocs from all over the world to work in his lab and learn from him.

Gelling discussions with Maureen Keller and Pieter Visscher, Ron started organizing the First International Symposium on DMSP and Related Onium Compounds shortly after arriving in Alabama. In early June of 1995, 64 scientists from 12 countries gathered for a week in Mobile to discuss the present and future of odorous sulfur compounds. A year later, Ron et al. published a 400-page book on DMSP, with contributions of most of the prominent organosulfur researchers. The breadth of topics covered in this 36-chapter publication is further evidence for Ron’s impact on the field and interest in virtually all aspects of sulfur biochemistry and microbiology. A recent article details the impact Ron work had on the organosulfur biogeochemical research community (Boden 2019).

Ron won the most important awards at U.S.A. for his scholarship and was widely recognized for his many successes and accomplishments at his home institutions, as well as nationally and internationally. Ron taught Chemical Oceanography to many students who went on to their own distinguished careers, and it is fair to say that Ron was a success in everything he attempted during his long and productive career at U.S.A. and DISL. In 2015, Ron was made a Fellow of the Association for the Sciences of Limnology and Oceanography.

Ron’s prowess on the baseball diamond is well known. He anchored the U.S.A./DISL intramural softball team that competed in the league for many seasons. Ron’s abilities were far above everyone else but he cheerfully played with his amateur teammates. Ironically, at the very first game that Ron participated in, not knowing that he was such a talented athlete and mainly going by his laid-back appearance as a young chemical oceanographer, Ron was positioned in right field thinking that was the place where he would do the least harm. He turned in a stellar game in the field and at the plate and thereafter Ron patrolled the outfield at most games because his ability to chase down balls and quickly throw them back to the infield was beyond compare. In one memorable game, a particularly well-hit ball was flagged down by Ron near the outfield fence and he quickly turned and threw the ball on a straight line all the way from the fence to home plate. Unfortunately, our catcher was inexperienced and not looking for the missile Ron had sent his way. Just as he turned in Ron’s direction, the ball struck him in the chest with a sickening thump. The catcher slowly fell over November 2019 ASLO | 145
backward and lay still. Everyone on the field rushed to him, thinking he might be unconscious or even worse. He was conscious, but badly shaken and he had the clear imprint of a softball on his chest in what was becoming a huge bruise. We helped him off the field and sat him down to rest. But he never returned to play another game after that encounter with Ron’s throwing arm.

Because he was so passionate about science, Ron loathed antiscientific politics and policies especially regarding global warming and associated changes. He was an ardent supporter of activism to support and bolster the scientific enterprise. He was active in the March for Science and regularly voiced his concerns and opinions as a scientist in op-ed pieces for the local Mobile, AL newspaper. He could be a very tough critic of both ideas and people, but his criticism was tempered with thoughtful and constructive feedback.

As a friend and colleague, he was one of a kind and irreplaceable. We shall miss the days of research, play, fishing, laughing about the ones that got away, and planning the next adventure.

Much has been said and written about Ron’s scientific accomplishments, his athletic prowess, and his passion for fishing. During his all too short lifetime, he packed enough success in each of these realms to fill the lives of numerous others. Yet even though he will long be remembered for his discoveries, his baseball championships, and the big ones that did not get away, it is the successes in his personal life that arguably mattered the most and will be remembered the longest.

What always stood out about Ron in all of his endeavors were his modesty, humility, patience, and compassion. Those who worked with him experienced those traits often. They were an ideal complement to his drive, his focus, his competitiveness, and his desire for perfection. In all that he did, Ron set the bars for success high, and he worked very hard to clear them, even though he made it seem effortless.

Yet he worked equally hard to help others clear their own bars. Remarkably, he did so with a generous and selfless spirit, not expecting a quid pro quo for his efforts, but understanding that contributing to the successes of others meant building a bigger and better team for all. Thus, as much as his colleagues and students applauded his scientific acumen, they paid even greater tribute to his humanity. Perhaps it is as fitting to think of him as the highly regarded Coach Ron as it is to think of him as the much admired Professor Kiene.

Outside of the walls of academia, Ron was also a coach, both literally and figuratively, again with much success. But he was a listener and learner as well, who built strong, nurturing, and lasting relationships with his beloved wife, Julie, and his two sons, Andrew and Dylan, of whom he was “button bustin’” proud, and bragged often. Julie and the “boys” carry on now with plans to create a summer home in Alaska, the focus of Ron’s retirement dreams. Yet they are not merely following in Ron’s footsteps or trying to imitate him. Ron’s gift was providing both examples of good life choices and the space in which to make them or not. Ron lives on through his family and the many he influenced, who seek to create good lives in their own way for themselves and others, with his memory as a firm foundation. He would be very pleased.

A Research Scholarship is being established in Ron’s name at the University of South Alabama memory (https://giving.southalabama.edu/kiene, active August 2019). All donations will be matched 1:1 from the Moulton–Mitchell Fund at the University of South Alabama.

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FIG. 3. Ron and family in August 2018 on the river trail at Morgan’s Landing on the Kenai Peninsula.
CLAIRE L. SCHELSKE (1932–2019)

Daniel J. Conley

The aquatic science community lost an eminent scholar and prominent researcher with the passing of Claire L. Schelske on 20 August 2019. Claire was a leader in the international limnology community, who made substantial contributions to phytoplankton ecology, aquatic biogeochemistry and paleoecology, and provided insightful and sound advice for addressing the problem of lake eutrophication.

Claire L. Schelske was born in Fayetteville, Arkansas, U.S.A. on 01 April 1932. He was raised in Peabody, Kansas. Claire excelled in both academics and athletics in high school, where he lettered in four sports and graduated as class valedictorian in 1950. He worked during the summers at the Peabody Gazette Herald as a typesetter, where he developed his uncanny ability to read text upside down and backward.

Claire graduated with a B.A. in 1955 and an M.S. in 1956 from Kansas State Teachers College in Emporia, Kansas (now Emporia State University). It was during his time working as a teaching assistant at Emporia that he met his future wife and lifelong partner, Betty. They married in 1957 and have three children and six grandchildren. Claire finished his Ph.D. underadvisor David Chandler at the University of Michigan in 1960, where he studied the role of iron availability as a factor that limited primary productivity in a marl lake. His doctoral research was published in Science in 1962.

Claire carried out postdoctoral studies at the University of Georgia Marine Institute on Sapelo Island, GA (1960–1962) where he worked with Eugene P. Odum, on the mechanisms that maintain high productivity in Georgia estuaries. From 1962 to 1966, he researched the environmental distribution of fallout radioactivity at the Bureau of Commercial Fisheries in Beaufort, NC, and then took a position as a Technical Assistant at the Office of Science and Technology, Washington DC (1966–1967).

In 1967, Claire was hired at the University of Michigan, Great Lakes Research Division. Soon after arriving, he teamed up with Eugene (Gene) F. Stoermer, with whom he worked on a project collecting baseline environmental data, prior to construction of a nuclear power plant on the shore of Lake Michigan. The information they gathered became an invaluable database in later years, which could be compared with data collected in subsequent studies and enabled evaluation of biochemical changes in Lake Michigan. Gene insisted on including silica in nutrient bioassays, which led to formulation of the “Silica Depletion Hypothesis,” published by Schelske and Stoermer in Science in 1971. Their research and Claire’s expert testimony played an essential role in requiring the city of Milwaukee, WI to reduce raw sewage discharges into Lake Michigan. A later collaboration with Gene on diatom microfossils in the sediments of Great Slave Lake, Canada was one of the first studies to suggest that atmospheric transport of nutrients could impact relatively remote, pristine lakes, as likely happened during the early history of the North American Great Lakes.

Claire’s fruitful collaborations with Gene continued until the end of their careers, with numerous classic studies on diverse lake types (large and small, deep and shallow, oligotrophic and eutrophic) in many places, for example, Great Slave Lake in Canada and Lake Apopka in Florida.

Claire accepted an appointment in 1987 as the Carl S. Swisher Eminent Scholar and Professor of Water Resources at the University of Florida, Gainesville. He continued to address the causes and consequences of eutrophication in lakes using a variety of tools and collaborated widely. Claire frequently applied paleoecological approaches to study how and why ecosystems responded to past nutrient inputs. His pioneering investigations of the carbon and nitrogen isotope composition of autochthonous organic matter with David Hodell and Mark Brenner have become standard tools for reconstructing lacustrine paleoproductivity. In addition, Claire made sustained contributions to the use of nutrient enrichment bioassays to test for spatial and temporal differences in the factors that limit phytoplankton dynamics. Upon retirement in 2001, he moved to the Department of Geological Sciences at the Land Use and Environmental Change Institute, University of Florida, where he continued his research activities. In 2010, he published his last first-author paper, in Limnology and Oceanography, the venue for 20 of some of his most well-known papers.

Throughout his career, Claire was a very active member of the American Society of Limnology and Oceanography (ASLO), as an Associate Editor, Editor, society Secretary, and last, President (1988–1990). His work for the society as Secretary (1976–1985) was a family affair. His wife Betty and their children would stuff envelopes, attach address labels, then seal and stamp envelopes for journal mailings.

Claire received the Ruth Patrick Award from ASLO in 2003 for elucidating the biogeochemical consequences of cultural eutrophication in large lakes and developing a comprehensive understanding of the recovery of anthropogenically disturbed aquatic ecosystems. He was also awarded the Edward S. Deevey Award from the Florida Lake Management Society for his contributions to the understanding of Florida’s waterbodies.

Claire Schelske was highly productive and a key contributor to many notable publications. He published 161 articles in peer-reviewed journals, edited one book, 16 book chapters, and more than 30 conference proceedings and primary reports. He supervised three Ph.D. students, 12 Postdocs, numerous M.S. students, and took numerous others under his wings throughout his career.

Claire was a distinguished scientist, a great educator, and a true gentleman who projected decency and fairness. He played a huge role in the academic development of many and served as a wonderful mentor, leading by example, especially about how to conduct oneself professionally. He was an unparalleled role model and affected many of us profoundly and positively. We miss him dearly.

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HOW TO BE A BETTER SCIENTIST

Christopher T. Filstrup  

FOCUS OF THIS EDITION

For this edition of the column, I want to revisit the topic of resources on undergraduate and graduate student mentoring. I am writing this column as I return from the annual ASLO—Wiley Strategy Day, where we briefly discussed this topic. In my last column, I posited that either there is a lack of resources on this topic, or they exist but we simply do not use them because we are already experts on mentoring. Participants at the meeting indicated that there are a lot of existing resources on this topic, so I guess that narrows things down a bit. The following list contains recommendations from participants at the Strategy Day meeting, as well as those contributed by the ASLO Community.

Lee, A., C. Dennis, and P. Campbell. 2007. Nature’s guide for mentors. Nature 447: 791–797.

I came across this article early on in my career as a new professor on the year that I was preparing my tenure application. With just a little bit of mentoring experience under my belt, the article resonated with me especially the words “enthusiasm,” “positivity.” My approach to mentoring has closely mirrored those words and the advice and recommendations of this article.—Maggie Xenopoulos, Trent University, Peterborough, Ontario, Canada.

Another great approach to improve your student mentoring skillset is by surrounding yourself with great mentors and colleagues, and emulating their approach (i.e., learn by example). This advice begins as an undergraduate or graduate student when selecting an advisor and continues throughout your career. While the next set of recommendations specifically apply to graduate students, the advice should also be informative to mentors reflecting on what characteristics are considered and sought by students.

Barres, B. A. 2013. How to pick a graduate advisor. Neuron 80: 275–279.

It is axiomatic that we need good mentors. How do you find one? This essay from a neuroscientist discusses how a prospective graduate student can find their advisor. Barres says look for a good scientist and a good mentor. On the first point, read a prospective mentor’s papers, look at their productivity and the impact of their work, and check to see if they have research funding. On the second point, know that mentors work with their students to develop strong scientific questions and then help them design research to answer those questions. Mentors must also be attuned to needs and opportunities allowing flexibility both personal and professional. My favorite line in this essay is, “I feel that the advisor’s job is to provide a fun and exciting environment, to set a good example, and the rest must come from the heart of the student.” That is the environment you want to be in.—Michael L. Pace, University of Virginia, Charlottesville, Virginia.

Stearns, S. C. 1987. Some modest advice for graduate students. Bulletin of the Ecological Society of America 68: 145–150.

Huey, R. B. 1987. Reply to Stearns: Some acynical advice for graduate students. Bulletin of the Ecological Society of America 68: 150–153.

Thompson, J. N. 2015. On being a successful graduate student in the sciences. Version 8.6. Available at: https://bit.ly/2kuZ7ND

There is a consistent theme that runs through the three essays of advice listed above. That theme—graduate students need to develop into independent thinkers and there is a diversity of paths given toward achieving that end. One important suggestion is to surround yourself with people who are excited about what they are doing. That community will carry you along in tough times. Beyond these points, there is much in these pieces for discussion and debate. The re-creation of the performance of Stearns and Huey which lead to the first two essays is entertaining. Unfortunately, also in these two essays, there is an overuse of the word “he” and an over orientation to academic careers, a lamentable sign of earlier times. The final essay by Thompson is a sound description about becoming a professional—good for any career—not least your graduate one!—Michael L. Pace, University of Virginia, Charlottesville, Virginia.

Finally, in my last column I included At the Helm by Kathy Barker as an additional resource and inquired if anyone has used it in the past. As anticipated, the ASLO Community did not disappoint, and I received the following recommendation.

Barker, Kathy. 2010. At the Helm: Leading Your Laboratory. Second Edition. Cold Spring Harbor: Cold Spring Harbor Laboratory Press.

As a mentor and PI, I have been using At the Helm by Kathy Barker for years. It is an excellent resource to get insights on all aspects of leading a research lab, from mentoring to holding lab meetings to employment related issues. At times, I find the recommendations are a bit too formal, for example, there is frequent encouragement to formalize everything in writing, in forms of signed contracts. Personally, I use a softer style, but it is useful to see different perspectives. Especially when I started my lab, it was useful to see all the aspects a PI deals with and that are typically not dealt with formally in graduate education. In essence a PI leads a small to medium-sized company and thus skills far beyond research and communication are required. A book cannot replace training in these many areas, but At the Helm is a great guide and continues to be for me personally.—Susanne Menden-Deuer, University of Rhode Island, Narragansett, Rhode Island.

NEXT EDITION

For the next edition, I am still undecided on the specific aspect of being an effective scientist upon which I want to focus. While I have several potential topics in mind, I would love to receive your suggestions. Feel free to contact me using the information below.

This column is appearing as a trial run in 2019 issues of the L&O Bulletin. If you have any thoughts or critiques of this column, or suggestions for additional resources on this topic or for topics to cover in future issues, please feel free to contact me. You can email me at filstrup@aslo.org or tweet me @ctfilstrup. Please be sure to tag the L&O Bulletin (#ASLO_Bulletin) in your tweets.

Christopher T. Filstrup, Natural Resources Research Institute, University of Minnesota Duluth, Duluth, MN; filstrup@aslo.org
Policy fellowships have been launching the careers of newly minted masters and Ph.D.s for decades. Having worked in the U.S. Senate as a Sea Grant Knauss fellow at the end of graduate school, I can attest to the power of these programs which place scientists in government offices for a period of time (typically 1–2 years). With policy engagement being more of an accepted and encouraged activity for scientists than it was when I did my fellowship, I was curious if the experience for policy fellows was similar today. Two recent ASLO Science Communication Interns recently completed policy fellowships—Lushani Nanayakkara was a Mitacs Canada Science Policy Fellow and Britta Voss was a AAAS Science and Technology Policy Fellow—so I took the opportunity to ask them about their experiences. Thinking of applying to a policy fellowship? You can learn more about both fellowships on the ASLO website!

AS: How did the experiences you have prior to the fellowship prepare you (or not) for the realities of working in a government position?

LN: In addition to analyzing the food-web dynamics of Prairie lake ecosystems, my Ph.D. research included a human dimensions component. This interdisciplinary approach really helped me focus on the need to consider and communicate the broader implications of my research, and how it can be useful in a decision-making context. I had always had a budding interest in policy, but honing in on this interdisciplinary perspective cemented my decision to apply for the fellowship, especially as a way to test out what is was like to work for the government. Professional development opportunities like the ASLO science communication internship, and writing for various science communication platforms boosted my communication portfolio and helped develop skills critical to working in government. Being able to articulate your position in a simple, straightforward manner without any technical jargon is sometimes a challenge for scientists, so I rely heavily on the skills learnt through these experiences. But you can only prepare so much in advance, and switching from academia to government was a bit of a culture shock for me initially. You really hit the ground running, especially if your job is connected to a piece of legislation making its way through Parliament, as was the case for me. It was a steep learning curve at the beginning, but an exciting one! So instead of relying on my content expertise, I had to really utilize my transferable skills to navigate this new landscape. My research and previous policy experience had taught me to have an open mind and try to learn something from every new experience; this approach helped me become comfortable relatively quickly.

BV: The science communication and outreach activities I engaged in during grad school were some of the most useful things for preparing me for a science policy fellowship. They forced me to think about my research in a broader context and how to explain scientific concepts to non-scientists. This flexibility and perspective is critical for working in science policy or government in general because you will likely be working with people with a much wider range of expertise and technical training within and outside your office, and your success depends on being able to effectively communicate with some combination of people with backgrounds in business, economics, law, public policy, or other fields, members of Congress and their staff, members of the public, and others. Thinking of applying to a policy fellowship? You can learn more about both fellowships on the ASLO website!

AS: Did your fellowship change your thinking about how science (and scientists) can be part of the policy process?

LN: Yes absolutely! One of the purposes of the fellowship is to expose us to the role science plays in government operations. Generally speaking you have (1) policy for science, which deals with things like research funding and (2) science for policy, which is the role science plays in policy-making. I think many scientists tend to have a bit of tunnel vision on science and the central role it should play in decision-making. However, my thinking on this was quickly challenged. Yes, science is an absolutely critical cornerstone of evidence-informed decision-making but it’s not the only consideration. The decision-making environment is extremely complex and science is often only one of the factors that must be taken into account. This reality demonstrates why it’s important for scientists to communicate their research findings to policy decision-makers in a manner that is applicable to that issue, and have productive relationships with this policy决策-makers so this can be done proactively. This is not to hold scientists solely responsible for cultivating these types of networks and relationships, but to emphasize the need to reach across the science-policy divide to ensure their science has a meaningful impact on the policy process.

BV: My time as a science policy fellow really opened my eyes to the vast range of federal policy that is impacted by science and, ideally, scientists. Far more than just decisions about research funding allocation, federal science policies in Congress and the executive branch grapple with international diplomacy, agriculture subsidies, space exploration strategy, nuclear energy research priorities, facilitating progress on diversity, equity, and inclusion in STEM, and countless other issues that have a nexus with science. The variety of issues each individual federal agency works on is also much wider than I appreciated before my fellowship. I was placed at the National Institute of Standards and Technology, which I quickly learned supports standards development in areas quite far from what I had previously known them for—chemical concentration standards. For example, I learned first-hand how my office, which manages a funding program to accelerate research and development of communication technologies for emergency first responders, is connected to broader issues like federal artificial intelligence policy and wireless spectrum management.
Something the AAAS program tries very hard to instill in fellows when they arrive in DC is the reality that science is one of many considerations policymakers weigh when making decisions, and that is okay. Coming from research and academic backgrounds, many of us feel (if subconsciously) that if science points to a particular policy solution to a problem, then it is the only correct choice. Policymakers (whether they are politicians or decision-makers at agencies), however, evaluate policies against multiple factors including feasibility, cost, justice, the preferences of their stakeholders, and many other issues. While sometimes these other considerations may not be scientifically or democratically justified, the fact that science is one of a variety of influences on policy decisions is appropriate as a general principle. Science policy decisions have impacts on people, which means people (not just scientists) should have a voice in the decision-making process. The role of science policy is to try to make sure that relevant data and analysis are included in that conversation, presented to the right people at the right time and in the right way to clearly convey the most important messages to non-experts. Scientists aren’t traditionally trained in the methods of building relationships with decision-makers and communicating for non-experts (that’s where programs like science policy fellowships come in), but by combining those skills with their technical knowledge, scientists can help ensure that science gets a fair shake in policy debates.

AS: What advice would you give current students who are interested in policy fellowships (about preparing a strong application, making the transition easier, when to do such a fellowship, etc.)?

LN: Diversify your portfolio. This cannot be stressed enough, step outside your research silo and develop transferable skills, communication being a key one. Even if you are not at the stage where you can commit to a fellowship, start exploring your options. It is never too early to start looking, do some initial research to identify some options that are interesting/relevant to you. Consider where you would like to work, what kind of work you find interesting, etc. Reach out to those organizations and ask if they can put you in touch with current/past fellows or what opportunities are available for you to gain some experience in this field. If someone reaches out to you in response, ask them about their experience and questions that will help you decide whether this is a good option for you. This may sound cliché but don’t underestimate the power of networking!

BV: Reach out to your peers and colleagues (or seek out new connections through science policy groups or career centers at your institution or professional societies) who have engaged in policy in some way. Whether they are someone who spent time working in government in some capacity or have met with elected officials or written op-eds, these people will be able to offer advice and guidance from a perspective of some familiarity (common scientific or policy interests, institutional affiliation, or whatever your connection is). If you are in an early stage of considering science policy, these conversations will help you understand what science policy is and what opportunities exist to make it part of your career path. And of course if you have already decided you plan to pursue science policy, building relationships with experienced science policy practitioners will help you develop your plans for getting there.

Another great way to prepare for a science policy fellowship is to dip your toes into science policy work! Write an op-ed, schedule a meeting with your Congressional representatives, write a policy brief and publish it as a blog post, organize a science-themed roundtable discussion for a local school or civic group on an issue of local importance. Activities like these will allow you to hone your communication skills and demonstrate your policy interests and acumen. If your institution has a group for scientists interested in policy, join them and get involved—or if they don’t have one, start your own! Many scientific societies and nonprofit organizations have policy toolkits, trainings, and events to help you get started and offer activities to join (like Congressional Visit Days) so you don’t have to start completely from scratch or go it alone.

AS: How did participating in the fellowship impact your plans for your future?

LN: The fellowship had a significant impact on my plans for the future. Having a year to explore a career in government was invaluable. It allowed me to experience first-hand what a government career entails, the work-life balance it offers, the impact you can have on environmental issues, and the challenges and rewards of being in a policy program. Ultimately it reinforced my interest in pursuing a career outside of academia.

BV: The fellowship experience confirmed for me that I want to pursue a career that bridges scientific research and social impacts. It equipped me with hands-on training in communication and the federal policy process and introduced me to a whole community of other scientists who are passionate about putting their technical skills to work for policy. It also broadened my awareness of the multitude of different forms that science policy work can take. The federal government is just one piece of the science policy universe. Scientific expertise is also needed at nonprofit organizations, think tanks, state and local government agencies, and many other areas. As I transition to my next opportunity, it’s actually hard to narrow down the types of work I can see myself being excited to work in. My fellowship experience both exposed me to types of work that I hadn’t previously heard of, but also made me see more
connections between research and scientific inquiry and social challenges. In many ways, it reinvigorated my excitement for science while pivoting my specific career trajectory.

AS: Anything else you would like to add?  
LN: Trying to veer off the traditional path academia may be scary and challenging, especially if all your mentors are academics. So have an open mind and explore what kinds of science policy activities are feasible for you. As stated above, don’t underestimate the power of networking. Reach out to people and try to get their perspective on various career options. Don’t get discouraged if something doesn’t fit within you content expertise, consider what transferable skills you possess and how they may be applicable to this opportunity. Remember, there is no universal formula on how to get involved in science policy. So try to participate in as many diverse experiences as possible so you are making the most informed decision possible about your career path.

BV: Aquatic scientists curious about policy shouldn’t be intimidated by the notion that fellowships in DC are the only way to get involved in science policy or get the experience you want to launch a science policy career. First, there are a range of science policy fellowships out there—some are less than a year long, some are not in DC. Second, there are lots of non-fellowship opportunities in science policy, as described in question 3. To try to minimize the amount of this work that takes the form of uncompensated labor, look for ways to incorporate policy into your existing research and institutional programs and colleagues or mentors that can help you formalize this. For example, you may be able to collaborate with a colleague in a non-STEM field to write a policy analysis or design a science policy course on a topic related to your research. Experiences both formal and informal can build a portfolio of policy expertise that can help you incorporate more policy focus into your existing career or prepare you for a new policy-focused career path.

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