et al., 2011; Barton et al., 2012; Gobler and Talmage, 2013). Designing an observational plan for an OA experiment requires researchers to consider many factors, including the variability of the system or process, the necessary observational temporal frequency, spatial variability (horizontal and vertical), and the accuracy and precision of measurements.

In order to address the complex OA research questions and measurement requirements, the OA eld has broadened to include scientists from a variety of disciplines with a need for CO_2 measurements but without backgrounds in the arcane techniques and technologies of the discipline (Dickson et al., 2007). us, the oceanography community faces the challenge of providing non-experts with access to cost-e ective, high-quality CO_2 system measurements, as well as training opportunities and information on best practices. Community surveys are essential for identifying the current status and technology needs of the growing OA

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- 50% of respondents use autonomous and underway pH and pCO_2 systems.
- Few respondents use autonomous and underway systems for DIC and TA.
- Periods of operation reported for autonomous and underway systems were distributed evenly from days to years.
- ere is room for continued development to improve sensors and instruments. Although instrument failure rate was relatively low, the frequency with which unusable data were collected was relatively high. Responses in every category re ected user frustration. Many sensors and instruments present operational di culties and/or don't work as well as people would prefer.
- It is critical to have continued access to Certi ed Reference Materials (CRMs). Many researchers rely on the use of CRMs for data quality control. e majority of all instrument and sensor users carry out some form of instrument calibration (e.g., routine measurement of CRMs on benchtop instruments) or eld validation (e.g., comparison of sensor data with data obtained for bottle samples using benchtop instrumentation). Most respondents did not rely on factory calibrations.
- ere was a general consensus that reference materials serve a critical need for identifying dri in all forms of instrumentation. Particular needs in this area include reference materials covering a broader range of CO_2 properties and salinity (e.g., for estuarine work), in addition to puri ed indicator dyes for spectrophotometric pH measurement.
- Biofouling of autonomous sensors is a pressing issue; all sensor designs need improvement.
- Intercomparison exercises such as those carried out for benchtop instruments (Bockmon and Dickson, 2015) should be extended to autonomous systems.

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Recommendation 1: Establish Best Practices

Best practices in the form of standard operating procedures (SOPs) for benchtop CO_2 instruments were meticulously documented during the World Ocean Circulation Experiment/Joint Global Ocean Flux Study (WOCE/JGOFS) era in the late 1980s through the 1990s (Dickson et al., 2007). More recently, OA experts assembled a set of best practices for OA experiments (Riebesell et al., 2010). With the exception of underway pCO_2 systems (Pierrot et al., 2009), there are currently few best practices analogues for automated and autonomous systems. Most recently, Bresnahan et al. (2014) reported a set of best practices speci c to ISFET pH sensors deployed for autonomous use in situ. Others have reported thorough assessments of in situ pCO_2 instruments that could likely be transformed into a set of best practices (Fietzek et al., 2013; Jiang et al., 2014). In a manner similar the present manuscript (Johengen et al., were at an advanced state 10 years ago (Bellerby et al., 1995; McNeil et al., 1995) or that were made available through existing company expertise (Fietzek and Körtzinger, 2010). Nonetheless, these companies have clearly made impressive progress by developing complex equilibrator and detector systems in house and commercializing them in less than a decade. ese nal three sensors may therefore represent the closest exception to the ten-year rule of the systems listed in Table 1.

In addition to sensor development trajectories, the breakout group was also asked to discuss the possibility of developing or enhancing sensor networks, particularly with an eye toward coordination and intercomparison. Networks for observing, research, and collaboration exist (e.g., observing systems such as the NOAA OA mooring system, the Ocean Observatories Initiative, and Argo), as do data repositories (Biological and Chemical