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Scientific Research Diving: Engaging Students with Unique STEM Training Opportunities and Place-Based Field Experiences

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Abstract

The USC Environmental Studies place-based field program uses scientific research diving as an experiential learning tool to engage undergraduates with novel STEM training opportunities and marine conservation and management issues. Scientific diving is a vital skill for marine resource managers and scientists. Given USC's coastal location, it is critical that the university invest in Southern California's next generation of STEM professionals to advance skills that make them competitive in underwater research and the conservation workforce. We have designed a dive-based, field experience to provide students with a better understanding of the complex issues that are required to implement coastal zone sustainability strategies in a real landscape. Undergraduate science divers learn skills needed to survey, monitor, and conduct research in temperate and tropical environments. Research methods include quantitative surveys of macroalgae, invertebrate, and fish indicator species, photogrammetric mapping methods for investigating protected areas, and the effects of water flow on subtidal organisms. The scientific diving and research skills our students learn provide an important boost in advancing their professional and academic careers, as well as increase their ability to communicate with both specialized and general audiences.

Keywords: experiential learning, field studies, marine science, STEM education, undergraduate research

Introduction

Scientific diving is an experiential learning tool that engages students using hands-on activities in the natural environment. The incorporation of scuba into undergraduate research training programs in Science, Technology, Engineering and Math (STEM) fields provides a unique undergraduate experience that encourages critical thinking and the use of scientific methods to solve real-world problems. The skills that students learn also provide an important boost in advancing their future professional and/or academic careers. Specialized training in underwater research and marine science makes students more attractive to many graduate programs (Pearse et al., 2013).

Scientific diving may also serve to retain students in STEM fields while they are still in college. To keep up with the projected growth in demand for STEM jobs, the United States will need ~1 million additional college graduates with STEM training by the year 2023 than the country is set to produce (National Academies of Sciences, Engineering, and Medicine, 2017). However, higher education institutions are often challenged to recruit and retain students in STEM fields. For example, fewer than 40% of students who enter college with the intention of pursuing a STEM major go on to

complete a STEM degree. One reason for this is that conventional educational methods may fail to excite and engage them on a level necessary to maintain their interest in a given field.

Unlike teaching within a traditional classroom, hands-on activities enable more learners to be successful by engaging them in authentic research and experiences (Freeman, et al., 2014). Students understand topics more fully by actively engaging in a specific activity rather than by simply reading about a concept. New approaches to train STEM students include field-based training and research experiences to allow students to gain expertise as emerging STEM professionals (National Science and Technology Council, 2013). Place-based immersive field experiences and early exposure to hands-on science and data-rich activities help students to strengthen their quantitative skills and confidence in using technology to perform as scientists, which are key factors that impact job retention and performance (Manduca and Mogk, 2002; Seymour et al., 2004; Gagnier et al., 2016).

Here, we present an overview of the scientific diver program for Environmental Studies majors and minors at the University of Southern California (USC). This program, comprised of two separate courses, fulfills all American Academy of Underwater Sciences (AAUS) Scientific Diver training requirements and offers students the opportunity to participate in an upper division elective course focused on temperate and tropical coastal zone sustainability. Courses are designed to investigate environmental issues such as ecologically sustainable development, fisheries management, protected-area assessment, and natural resource governance issues. These topics are presented to students in terms of their application to local issues within the Los Angeles region and to more remote (and biologically diverse) areas of the world, such as tropical ecosystems in The Bahamas.

Scientific Diver Program and Training

A founding member of AAUS, the USC Wrigley Institute for Environmental Studies (WIES) facilitates all scientific diving activities at the university and operates the Wrigley Marine Science Center (WMSC) on Santa Catalina Island (Figure 1). More than 2,000 dives are completed annually under the auspices of both the USC Diving Safety Officer (DSO) and Diving Control Board, which are responsible for the oversight of more than 100 active scientific divers.

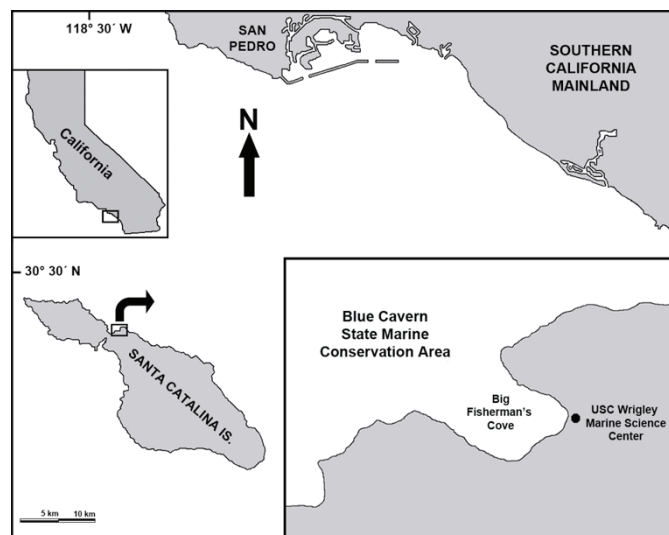


Figure 1. Map showing the location of Santa Catalina Island relative to the southern California mainland. The WMSC is adjacent to Big Fisherman's Cove (inset), which is part of the Blue Cavern State Marine Conservation Area, a no-take marine reserve. Map adapted from Froeschke et al. (2006).

Located ~35 km off the coast of Southern California, Catalina Island is an ideal location for underwater research and offers convenient access to nearshore and blue water environments. The waters adjacent to WMSC are part of the Blue Cavern State Marine Conservation Area (designated as a no-take marine life refuge) and include a wide variety of fauna, flora, and habitat types that are representative of Southern California's coastal ecosystems.

Scientific diver training is a multistep process for students in the USC Environmental Studies program. Students with a diving certification from an internationally recognized scuba training agency and who have an interest in STEM topics are invited to enroll in *Introduction to Scientific Diving*. Ginsburg and the USC DSO with the help of faculty, staff, and students who volunteer to assist with dive training activities teach this course during the spring semester. The introductory course covers the physics, chemistry, biology, and physiology fundamental to scientific diving, as well as sampling protocols used to perform surveys and collect data underwater. Additionally, students are encouraged to become certified as Reef Check California divers, which is a science-based monitoring program designed to assess the health and status of nearshore ecosystems (Hodgson, 2000). Subsequent to receiving their scientific diver certification, students are eligible to continue their dive and experiential research training in a second course (*Tropical Coastal Zone Sustainability*) taught as a 3-week summer course by Ginsburg and Heidelberg. In this class, students engage in field-based and mentored research projects performed underwater off Santa Catalina Island and in The Bahamas.

Scientific Diving for Training Students in Research Methods

We use scientific diving projects as a way to engage students in science-based, experiential learning. Research shows that students who have early exposure to hands-on, data-rich activities gain confidence and identity as scientists (Laursen et al., 2007), aspects that are critical to recruitment and retention in science. Our program is designed to allow students to gain hands-on field experience and skill sets. Student divers learn skills needed to survey, monitor, and conduct research in temperate and tropical environments. Examples of three types of underwater research methodologies taught and practiced in the USC Environmental Studies introductory scientific diver course and summer field program are briefly outlined below. These methods include underwater surveys of key indicator species, photogrammetric mapping protocols for investigating protected areas, and techniques for measuring the effects of water flow on subtidal organisms.

Transect Surveys

Benthic transect surveys of subtidal marine life are used to gauge the spatial and temporal patterns of abundance of key indicator species present in a given location. Students are trained to use three different types of survey protocols (i.e., swath, uniform point contact, fish sampling methods) in order to quantify the density of benthic macroalgae, seagrasses, invertebrates, and fishes. Surveys are performed using standardized sampling protocols established by the California Department of Fish and Wildlife's Cooperative Research and Assessment of Nearshore Ecosystems (CRANE) program, which were developed in cooperation with the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) (reviewed by Gillett et al., 2012). Visual survey techniques along a benthic transect line are frequently used to monitor subtidal marine life off Southern California (Pondella et al., 2006; Gillett et al., 2012; Coates et al., 2018). At a given reef location, key indicator species of algae, invertebrates, and fishes are surveyed visually by divers along a 30-m benthic transect line (Figure 2). The total area surveyed along each transect is determined by the type of protocol implemented. Assessments of student learning are conducted through group-based, comparative data analysis of underwater surveys performed by different student dive teams.



Figure 2. Student diver performing a transect survey of eelgrass in Big Fisherman’s Cove, Santa Catalina Island. Eelgrass abundance was recorded using the uniform point contact method in which the total number of leaf shoots were counted directly under each meter of the 30-m transect line. Photo: Tom Carr.

Photogrammetric Mapping

Photogrammetry is a scientific documentation and visualization technique that is used around the world to transform 2D digital images into 3D immersive virtual reality environments or augmented reality interactions. Underwater photogrammetry enables targets and terrains to be measured, counted, described, and monitored over time. Such methods have been successfully tested and used in Australia’s Great Barrier Reef Marine Park for evaluating coral reef habitat and the diversity of benthic environments, as well as for the quantification of coral health (Figueira et al., 2015; Raoult et al., 2016) and surveys of underwater archaeological sites (McCarthy and Benjamin, 2014). Given the popularity of high resolution, low cost digital action cameras (e.g., GoPro HERO[®]), photogrammetric mapping tools are widely accessible. Using this technology, student divers are introduced to cutting-edge efforts to survey and visualize archaeological and biological features underwater, as well as a means to provide scientific assessments of protected area health, and facilitate the use of these data for the management of subtidal resources.

Measurements of Water Flow

Water flow is an important metric for determining effects of currents and mixing on subtidal marine flora and fauna. For example, a variety of organisms rely on water flow as a source of nutrients or prey, or for gamete and larval dispersal. Thus, an understanding of hydrodynamics is valuable for estimating nutrient availability, as well as to predict dispersal distances of an organism’s reproductive propagules. This activity teaches student divers how to compare differences in water motion in and around kelp forests and in different regions of coral reef habitats. We deploy pre-weighed ice cube-sized plaster of Paris blocks to estimate integrated water movement in different benthic habitats (Coyer et al., 1999; Maney and Genovese, 2000; Sebens et al., 2003; Figure 3). After 48-72 hours, the blocks are retrieved, dried, weighed again, and compared to a set of control blocks placed in a bucket of seawater at a similar average temperature over the same time period. The change in weight from the dissolving plaster blocks serves as a proxy for mass water flow in the study area.



Figure 3. Plaster of Paris bricks (bottom, right) with temperature and relative light level data logger (Onset Computer Corp.) placed next to a barrel sponge by divers at Eleuthera Island, Bahamas. Photo: David Ginsburg.

Discussion

Scuba diving has led to profound contributions to underwater science by providing access for direct observation and experimental manipulation of organisms in their natural environment, which can yield synergistic insights into animal behavior and functions (reviewed by Witman et al., 2013). When combined with other approaches, students are likely to gain a better understanding of the specific behaviors and ecology of organisms within their natural environments using hypothesis driven experiments (Resasco, 2013). Data collected by scientific divers also are important tools to validate different remote sensing metrics (Ferrari et al., 2016) on a global scale. Illustrative of this, high impact scientific journal papers resulting from projects involving scuba have increased exponentially over the past 60 years (Figure 4).

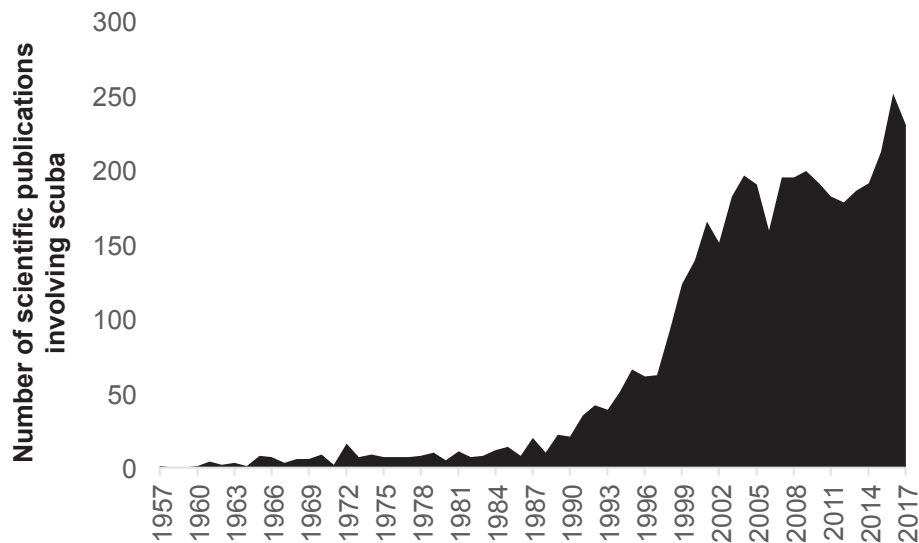


Figure 4. Scholarly articles published over the past 60 years resulting from data and/or samples collected underwater by scuba divers (Clarivate Analytics, 2017).

The primary goal of the USC Environmental Studies scientific diver program is to provide students with a better understanding of the interdisciplinary complexities of implementing coastal zone sustainability and management strategies in a variety of real landscapes. For nearly a decade, we have used experiential learning and mobile technology tools at WMSC off Santa Catalina Island and in remote field locations, such as The Bahamas, to introduce undergraduates to the importance of underwater science methodology in different ecosystems, as well as to help them to better understand the complexities and challenges of designing scientific experiments *in situ*.

Our program was established on the premise that place-based research training, paired with strong mentoring, increases success for students who want to pursue careers related to environmental and ocean sciences. Field program participants are typically freshmen and sophomores who have taken few of the university-level STEM courses required for traditional majors in the natural sciences. Given the experiential context of the hands-on training activities required for AAUS scientific divers, we are able to deliver unique STEM course content, as well as help to advance national undergraduate science learning goals and outcomes. Early training and focus on skills development also helps build student confidence, which has been shown to further contribute to persistence and success in the sciences (Manduca and Mogk, 2002; Seymour et al., 2004; and Gagnier et al., 2016). An unexpected outcome of the summer field program is the gender split amongst students, in which women outnumbered men by 56-90% each year (2010-2018; n = 172, $70.6 \pm 4.2\%$, mean \pm SE) the course has been offered. These findings agree with previous studies that suggest project-based learning experiences may increase women's interest in STEM fields (Benderly, 2010; Klawe, 2014; Vaz et al., 2013). However, for many of our students (women and men), participation in the summer field experience has significantly altered their educational trajectory to pursue additional STEM coursework. For example, as a field course comes to an end, it is not uncommon for new plans to be made for graduate studies, study abroad programs, and applications to marine-coastal themed internships such as the National Science Foundation's Research Experience for Undergraduate programs.

Informal assessments of student outcomes suggest that the USC Environmental Studies place-based field program is successful at providing an appreciation for coastal zone sustainability, and that our students feel the initial scientific diver training was essential to this success. Given USC's coastal location, it is important that we invest in Southern California's next generation of student scientists to advance skills that make them competitive in underwater research and the conservation workforce. Alumni of the summer field program are accomplished scientific divers with expertise in underwater methodologies, experimental design, and coastal zone monitoring. Amongst this group, ~30% of students (2010-2016 graduates; 132 students total) have gone on to either an academic or professional career in environmental science. In summary, we believe this program has a direct benefit to students who seek STEM-focused graduate training opportunities with dive-related projects or careers with various Non-Governmental Organizations and universities across the globe working in marine conservation, management, and coastal sustainability.

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as scientific divers have participated in the USC Wrigley summer coastal ocean sustainability research program (NSF OCE #1559941) or other summer research programs.

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