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SyPRID sampler: A large-volume, high-resolution, autonomous, deep-ocean precision plankton sampling system

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ABSTRACT

The current standard for large-volume (thousands of cubic meters) zooplankton sampling in the deep sea is the MOCNESS, a system of multiple opening–closing nets, typically lowered to within 50 m of the seabed and towed obliquely to the surface to obtain low-spatial-resolution samples that integrate across 10 s of meters of water depth. The SyPRID (*Sentry* Precision Robotic Impeller Driven) sampler is an innovative, deep-rated (6000 m) plankton sampler that partners with the *Sentry* Autonomous Underwater Vehicle (AUV) to obtain paired, large-volume plankton samples at specified depths and survey lines to within 1.5 m of the seabed and with simultaneous collection of sensor data. SyPRID uses a perforated Ultra-High-Molecular-Weight (UHMW) plastic tube to support a fine mesh net within an outer carbon composite tube (tube-within-a-tube design), with an axial flow pump located aft of the capture filter. The pump facilitates flow through the system and reduces or possibly eliminates the bow wave at the mouth opening. The cod end, a hollow truncated cone, is also made of UHMW plastic and includes a collection volume designed to provide an area where zooplankton can collect, out of the high flow region. SyPRID attaches as a saddle-pack to the *Sentry* vehicle. *Sentry* itself is configured with a flight control system that enables autonomous survey paths to low altitudes. In its verification deployment at the Blake Ridge Seep (2160 m) on the US Atlantic Margin, SyPRID was operated for 6 h at an altitude of 5 m. It recovered plankton samples, including delicate living larvae, from the near-bottom stratum that is seldom sampled by a typical MOCNESS tow. The prototype SyPRID and its next generations will enable studies of plankton or other particulate distributions associated with localized physico-chemical strata in the water column or above patchy habitats on the seafloor.

1. Introduction

Distributions of zooplankton in deep water and processes controlling these distributions and their dynamics remain poorly known, in part due to the challenges of sampling these systems with adequate spatial precision and sample size. Towed plankton-net sampling systems have been in use in oceanography since the 1970s to map the depth-stratified distribution of pelagic organisms with simultaneous collection of information about the physico-chemical environment (Wiebe et al., 1976, 1985). The MOCNESS (Multiple Opening–Closing Net Environmental Sensor System) has been a gold standard for decades and was recently used extensively by the international Census of Marine Zooplankton program (Bucklin et al., 2010). MOCNESS has also been used for distributional studies of deep-sea larvae at hydrothermal vents (Mullineaux et al., 1995) and methane seeps (Arellano et al., 2014). For a typical full-water-column sampling program, the MOCNESS is towed obliquely from the lowest safe limit of bottom approach (typically 50–100 m above bottom) to 100 or 200 m below the surface. A large (0.25–10 m^2, depending on the system) net opening ensures that a large volume of water (up to thousands of cubic meters, depending on towing speed and time a net is left open) is processed through each net, but each sample is necessarily integrated over large vertical and horizontal distances (Fig. 1A), obscuring information on finer-scale spatial distributions and processes. Because nets produce bow waves, some strongly swimming animals, including crustacean larvae, may be able to detect and avoid the net opening. Furthermore, the towed character

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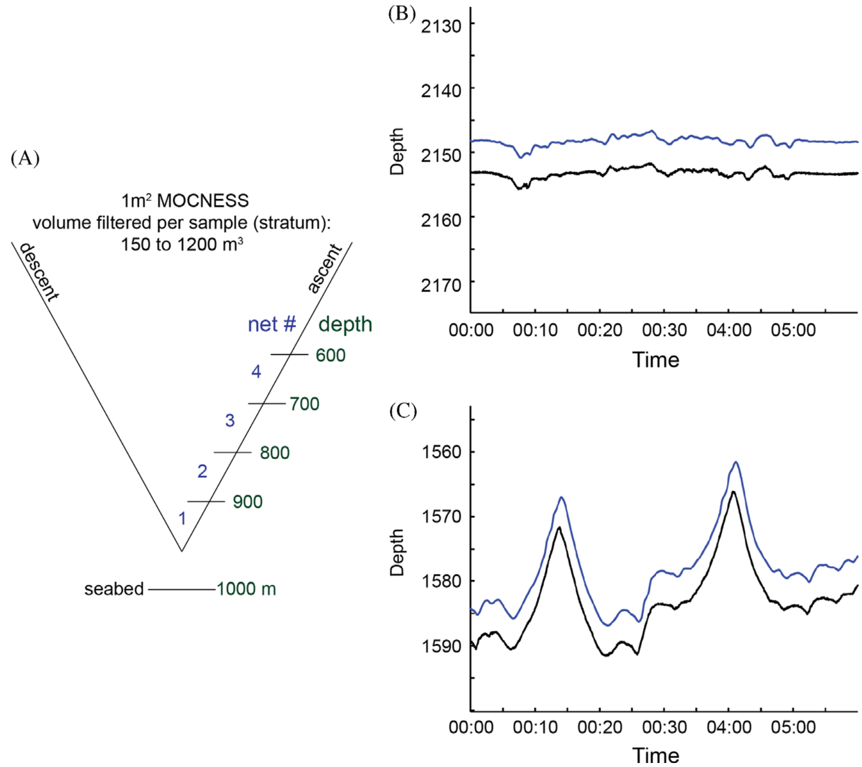

Fig. 1. Comparison of MOCNESS and *Sentry* abilities to sample depth strata. (A) Oblique water-column sampling mode of MOCNESS. Illustrates the absence of sampling capability close to the seabed (< 50 m) and the broad depth strata over which plankton abundance and distribution is integrated in any given net; from Wiebe et al. (2006). (B) *Sentry* 322 bottom tracking with SyPRID, flat terrain (< 5-m relief). (C) *Sentry* 326 bottom tracking with SyPRID, more rugged terrain (up to 25-m relief). (B) and (C): black line, seabed depth; blue line: *Sentry* depth.

of the net system precludes the possibility of sampling effectively the near-bottom (< 50 m) strata. To complement MOCNESS sampling, net-based sampling methods for deep-submergence vehicles (e.g., *Deep Tow* and *Alvin*) have been developed and deployed in multiple settings (Wishner, 1980; Wishner and Gowing, 1987; Kim and Mullineaux, 1998; Metaxas, 2011, among others).

In addition to MOCNESS and similar opening-closing net systems, a variety of other plankton sampling systems have been used to build our understanding of plankton distributions, including imaging systems such as the Video Plankton Recorder (Davis et al., 1996), the Underwater Vision Profiler (Stemmann et al., 2012), and the Lightframe On-Sight Keyspecies Identification (LOKI) system (Hirche et al., 2014). For near seabed systems, *in situ* large-volume (e.g., ~41,000 L) plankton pumps and sediment/larval traps are a proven method of sampling zooplankton, including larvae, and have the valuable capability of time-series sampling (Beaulieu et al., 2009). Prior results with larval traps at chemosynthetic ecosystems suggest that abundances of larvae are significantly higher within 5 m of the seafloor than 50 m above the seafloor (Mullineaux et al., 2005, 2013, CM Young, pers. obs.).

Autonomus Underwater Vehicles (AUVs) have the potential to sample plankton with precision relative to 3D space, but to date, sample volumes have been low. The SUPR pump sampler (Breier et al., 2009) with the AUV *Remus* were successful in sampling abundant larvae from surface waters in coastal areas (Govindarajan et al., 2015). The low pump rate ($\sim 2\ \mathrm{l\ min^{-1}}$) did not sample a volume large enough to capture any larvae on extended *Sentry* surveys in deeper waters, where larvae are more scarce (at altitudes of 20 m, 5 m, 3.5 m, 2 m, and 1.2 m above bottom; Kaiser, Young, Van Dover, pers. obs. from R/V *Atlantis* AT26-15).

There remain critical gaps in our plankton sampling and environmental sensing capabilities, including precision sampling at variable, narrow, and spatially constrained depth strata in conjunction with a suite of remote sensing and sensor packages. There is also a need for near-bottom sampling in regions of chemosynthetic seeps and vents, cold-water corals, sponge gardens, and other patchy benthic habitats, where larval densities are reported to be maximal (Baker et al., 2010). For these and other benthic ecosystems, including cold seeps and coral and sponge gardens, our understanding of how populations are maintained will benefit from knowledge of details of larval distributions in space and time and with regard to geochemical and geophysical characters of water strata (Young et al., 2012).

Our goal was to design a large-volume plankton sampler compatible with the autonomous underwater vehicle *Sentry* and other deep-submergence assets. *Sentry* routinely conducts mission-specific surveys with precision horizontal and vertical navigation to within 5 m of the seabed, and with co-registered geochemical, geophysical, photographic, and acoustic sensor data collection. *Sentry* missions 248, 249, and 251 in the Gulf of Mexico (R/V *Atlantis* AT26-15, CL Van Dover, Chief Scientist; May 2014) demonstrated a new survey capability for precision, three-dimensional flight at 120 cm above the seabed. This capability pre-adapted *Sentry* to attempt plankton-sampling missions with a new type of plankton sampler in the critical, high-larval-density regions near the seafloor in chemosynthetic and other benthic habitats, and subsequent missions demonstrated the low-altitude terrain-following capability of the Sentry/SyPRID system in flat (< 3 m relief) and in more rugged (> 25 m relief) terrain (Fig. 1B,C). In this paper, we summarize the design of a novel deep-ocean plankton sampler,

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