The Sea Core Sampler: a simple water sampler that allows direct observations of undisturbed plankton

THOMAS KIØRBOE*
DENISH INSTITUTE FOR FISHERIES RESEARCH, KALELGÅRDEN 6, DK-2920 CHARLOTTENLUND, DENMARK

*CORRESPONDING AUTHOR: tk@difres.dk

A simple water sampler that brings undisturbed water samples to the deck-laboratory and that allows video recording of plankton and small-scale plankton phenomena directly in the sampler is described. Using the sampler, it is possible to follow individual plankton organisms and marine snow aggregates for longer periods of time in an environment where the original three-dimensional organization of particles and chemical gradients have been retained. The sampler has been used to film sinking marine snow, the microbial life on a snow flake, and the behaviour of delicate zooplankters that are otherwise difficult to collect live. Video clips demonstrating the utility of the sampler are available online.

INTRODUCTION

The small-scale world of the plankton is not directly accessible to humans and important characteristics of this world cannot be perceived by our senses. The sticky nature of water at small scales and the very heterogeneous distribution of solutes, for example, are not part of our sensed experience. Conventional sampling may destroy delicate organisms and marine snow aggregates, erode chemical gradients, and obscure the three-dimensional organization of organisms and particles. Most of our present understanding of the biology, behaviour and ecology of plankton organisms is still based on morphological and chemical examinations of (dead) individuals, quantitative field samples to reveal abundances and distributions, incubation experiments to estimate production rates and observations of behaviour in artificial laboratory environments. One may argue that these limitations have biased our understanding of the ecology of the plankton and thus constrained our comprehension of the functioning of pelagic food webs (Smetacek and Pollehne, 1986).

Several attempts have been made to circumvent these limitations and to visualize plankton organisms and phenomena in a natural setting. The most direct approach is to dive and to directly observe, photograph and experiment with plankton in situ (Hamner et al., 1975; Alldredge, 1981). This, of course, is limited to plankton organisms that are visible with the naked eye, but has revealed important insight into such diverse phenomena as larvacean feeding biology and sinking rates of marine snow aggregates. A second approach has been to deploy underwater cameras to obtain still pictures or video recordings in situ (Davis et al., 1992; Tiselius, 1998, Malkiel et al., 2006). Due to the high magnification required to observe small plankton, and the high water velocity past the camera, also when mounted on a free floating device, even video recording provides only still pictures, albeit many of them. Such still pictures have been used to quantify plankton and particles and to reveal the three-dimensional organization of particles, either qualitatively (Tiselius and Kiorboe, 1998) or quantitatively using holographic techniques (Holm et al., 2000; Malkiel et al., 2006). Here I suggest a third and very simple approach, i.e. to bring an undisturbed water column into the shipboard laboratory and directly follow plankton organisms and marine snow aggregates for extended periods of time in an...
METHOD

The Sea Core Sampler: design and use

The core of the water sampler is a 1-m high and 23 by 23 cm wide rectangle, build of transparent PVC and with a capacity of 50 L (Fig. 1). The sampler is closed by means of PVC butterfly valves in each end (Fig. 1B and C). The openings of the valves are circular and with diameters just slightly less than the sides of the corer, which minimizes the turbulence generated inside the corer as it is lowered through the water. The closing mechanism of the sampler is external, thus allowing for an undisturbed view into the sample volume. Each valve is closed by the turning of an arm mounted on the centre axis of the valve. The two arms are connected by a flat bar, thus synchronizing the closure of the two valves. The closing mechanism is released by a messenger. When open, the sampler is attached to the wire by which the device is deployed by means of a ring mounted on the wire (Fig. 1B). When the release mechanism is hit by the messenger, the ring is released, and the sampler falls about 3/4 m, until it hangs in the arm that closes the sampler (Fig. 1A). An extra weight (8 kg lead) is mounted below the sampler to provide enough force for the closing of the sampler. On deck, the valves are locked in the closed position and the sampler falls about 3/4 m, until it hangs in the centre axis of the valve. The two arms are connected by a flat bar, thus synchronizing the closure of the two valves. The closing mechanism is released by a messenger.

A video camera is positioned opposite the sampler (Fig. 2). The camera is mounted on a small platform that can be moved in the vertical over the entire height of the sampler as well as horizontally. Vertical movement is provided by a hand driven worm gear, horizontal movement by mounting the set-up on two carriages that run on metal slides. In addition, the camera can be turned in two dimensions, allowing the camera to cover the entire water sampler. An IR-sensitive B/W CCD camera (Watec WAT-535EX) is used with infrared illumination, and a colour CCD camera (Panasonic AW-E300) is used with dark-field illumination. Various lenses can be fitted to the cameras; the best results were obtained with a manually focused 55 mm macro lens (Computar TEL-M55), which at the closest distance (13 cm) allows a 6.3 × 8.5 mm² view and visualization of particles down to 10–20 μm diameter. Size calibration depends on the distance to the object, which can be monitored only approximately in the present set-up. In practice, most recordings were made at object-distances between 15 and 17 cm, which provide a view area of 80–110 mm². In addition, objects can be searched from a further distance, up to 45 cm, where the view area is 800 mm². With dark-field illumination and adequate aperture opening, the depth of view is about 2 mm at the highest magnification, 3 mm at the typical magnification and 33 mm furthest away, yielding view volumes of 0.1, 0.3 and 25 mL, respectively.

Sampling

The sampler was tested during a cruise in the Indian Ocean, off the coast of NW Australia between 7–16 November 2006. Trial casts were conducted at 10 stations along a 325 km long transect running off the coast, between 17.46.489 S, 121.51.924 E and 16.01.174 S, 119.21.144 E. A Dr Haardt fluorometer (Dr Haardt Optik-Mikroelektronik, Kleinbarkau, Germany) with depth sensor was mounted below the water sampler to allow for exact vertical positioning of the sampler. The coastal stations were shallow (40 m) and rich (0.5 μg chlorophyll L⁻¹), the offshore stations deep (1.7 km) and meagre (0.1 μg chlorophyll L⁻¹) but with a distinct sub-surface fluorescence maximum (0.5 μg chlorophyll L⁻¹), where all samples were taken. Water temperature in the upper mixed layer was 26–30°C, and I attempted to keep this temperature range in the onboard laboratory.

RESULTS AND DISCUSSION

One immediate consequence from the use of this equipment is that one can observe planktonic organisms in a near natural environment and get an impression of, for example, concentrations of particles, larger...
phytoplankton cells and micro- and mesozooplankton (see example videos in Appendices 1–4 online at http://plankt.oxfordjournals.org). Below I consider two examples in some detail.

**Marine snow**

Marine snow aggregates are very difficult to collect intact as they easily disintegrate to their component particles when handled. All pictures of natural marine snow and measurements of individual sinking rates have consequently been taken in situ (e.g., Alldredge and Gotschalk, 1988; Shanks et al., 2002). In contrast, most rate measurements made on diver-collected aggregates are conducted on disintegrated particle ‘slurries’, where chemical gradients have been destroyed (Brzezinski et al., 1997). Similarly, most of the insights of heterotrophic plankters colonizing and utilizing aggregates, from bacteria to mesozooplankton, are based on experiments with artificial aggregates (Kiørboe, 2001; Kiørboe et al., 2003) or derived from quantitative sampling (reviewed by Kiørboe, 2000). The Sea Core Sampler offers new opportunities to study natural marine snow aggregates under near-natural conditions.

At the coastal stations, the concentration of particles was high and marine snow quite abundant. The typical marine snow aggregates here were loose, porous and elongated structures, with linear dimensions of a few mm (Fig. 3A). The aggregates were sinking (see movie Appendix 1 online at http://plankt.oxfordjournals.org) and despite the occurrence of convective currents when applying darkfield illumination, one can describe fluid flowlines around the sinking aggregate by tracking the positions of particles in its vicinity using the ‘manual

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**Fig. 1.** The Sea Core Sampler. (A) Hanging in the wire in closed position. (B) Top part with close-up of release mechanism in top. The sampler is open. (C) Top part of sampler in closed position.
The type of marine snow aggregates shown in Fig. 3A is presumably formed by coagulation; i.e. by component particles that collide due to turbulence and stick together upon collision. Another important source of marine snow is discarded larvacean houses (Fig. 3B, Appendix 2 online at http://plankt.oxfordjournals.org). These occurred in sufficient concentration at station 3 to be found in the Sea Core Sampler. This type of aggregate was found in all stages of collapse and degradation, and with different types of particles attached, including appendicularian faecal pellets. The recently discarded house (Fig. 3B) is a very open structure that does not sink or sinks only very slowly. Over time, the mucus house either collapses or is degraded by microbes, such that eventually it becomes a compact structure with higher sinking velocity. Appendix 2 (online at http://plankt.oxfordjournals.org) illustrates this development.

One intention with the Sea Core Sampler is to examine how meso- and microzooplankton colonize and degrade snow aggregates. Micro-organisms, mainly protozoans, were abundant on the surface of the discarded larvacean houses (Appendix 2 online at http://plankt.oxfordjournals.org). The swimming behaviour of the protozoans in the vicinity of the aggregate, i.e., with frequent tumbles (direction shifts), is similar to what one may observe in artificial aggregates, and suggests a steep chemical gradient in the vicinity of the aggregate.
Leakage of dissolved organic matter from sinking aggregates due to bacterial activity on the aggregate surface has been suggested from experimental observations (Smith et al., 1992) and theoretical considerations (Vetter et al., 1998), and the present observation confirms this in a qualitative way. Such leakage attracts heterotrophs with chemosensory capability (copepods, other protozoa, bacteria) and thus accelerates aggregate degradation. The sinking and leaking aggregate also leaves a chemical trail in its wake and generates significant heterogeneity in the distribution of dissolved organics in the water column (Azam and Long, 2001; Kiørboe et al., 2001).

**Delicate zooplankters**

A number of quantitatively important zooplankters are difficult to study experimentally because they are fragile
or otherwise easy to disturb. This includes gelatinous zooplankters, such as doliolids and larvaceans, copepods with long, breakable setae and arrow worms. Such species are difficult to collect alive and difficult to maintain in the laboratory. The Sea Core Sampler collects these animals in a good condition and offers an opportunity to examine their behaviour.

Doliolids (*Doliolum denticulatum*) were abundant at station 3 and many individuals occurred in the sampler (Fig. 3C, Appendix 3 online at http://plankt.oxfordjournals.org). I found phorozooids and gonozooids as well as a single nurse stage individual with an attached trophozooid. The two former stages swim more or less continuously due to the feeding current generated by ciliary action. The muscle bands only contract occasionally generating a jet that shoots the animal through the water. Prey particles enter through the frontal buccal siphon and the screened water leaves the animal again through the rear atrial siphon. In one instance, on encountering a too large particle, the feeding current was reversed and the particle thus rejected before getting into physical contact with the animal. In five cases with animals (phorozooids and gonozooids, average body length 3.5 mm) swimming perpendicular to the camera view direction I tracked particles that eventually entered through the buccal siphon with the feeding current (Fig. 3A). This allowed estimates of swimming velocity (ca. 3 mm s$^{-1}$) and feeding current velocity (ca. 11 mm s$^{-1}$) and, eventually, clearance rate. The latter can be estimated as the cross-sectional area of the buccal siphon (diameter 1 mm) times the feeding current velocity. This calculation assumes that the velocity is uniform across the siphon opening, which is approximately true at the entrance (Vogel, 1993). The resulting estimate, 750 mL day$^{-1}$, is substantially higher than previously reported clearance rates measured in incubation experiments in similarly sized *Doliolitta gegenbauri*, 20–200 mL day$^{-1}$ at 15–25°C (Deibel, 1982; Crocker *et al.*, 1991; Gibson and Paffenhofer, 2000), even when considering differences in temperature. Deibel and Paffenhofer (1988) used a similar approach as here to estimate clearance rates in tethered *D. denticulatum* of about 100 mL day$^{-1}$. The smaller size (2.2 mm) of these animals and the lower experimental temperature (20°C) make their estimates more comparable with the present ones. The difference between direct estimates and estimates derived from incubation experiments may be due to a species difference, but may also be caused by the latter measurement being made in small containers. When encountering a wall doliolids stop filtering for a few to a few 10’s of seconds, an observations also made by D. Deibel (Memorial University of Newfoundland; personal communication). This means that time-averaged clearance rates from measurements made in small containers

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**Fig. 4.** (A) Flow lines around the marine snow aggregate shown in Fig. 3A. The position of the aggregate and of various particles in its environment were tracked during up to 4 s (200 video frames) at a frequency of 25 Hz. The wiggling of the flow lines reflect the inaccuracy of the tracking. The outline of the aggregate (grey shading) has been shown. (B) Profile of fluid velocity (relative to aggregate) along the transect line shown in panel A. The full line is the theoretical velocity profile assuming Stokes’ creeping flow around a solid sphere with diameter equal to the width of the aggregate (0.75 mm) and a sinking velocity of 0.8 mm s$^{-1}$.
(0.25–2 L in previous studies), where the animals will encounter a wall frequently, may be an underestimate of the true rate in nature. The technique presented here can be improved by seeding the water with particles; in the present case, the concentration of visible particles was too low to make a more detailed description of the feeding current.

Other delicate zooplankters that were found quite abundantly in the sampler were larvaceans and chaetognaths (Fig. 3D). For the former, one can examine tail beat frequency and feeding currents (as above), and for the latter one can describe the behaviour. The chaetognath species found here (unknown) seems to lead a rather inactive life (Appendix 4 online at http://plankt.oxfordjournals.org): it hangs vertically in the water column and jumps upwards once every 2 s and sinks between jumps. This alternating jump/sink results in a net upward movement. Occasionally, the animal turns around and swims downward, just to initiate another jump/sink cycle. One should be able to directly observe prey encounter and attacks. However, feeding rates in small chaetognaths are on the order of a few prey per day (e.g. Saito and Kiørboe, 2001) and it thus requires patience or luck to observe a prey attack. I had neither.

**CONCLUSIONS**

The Sea Core Sampler brings into the laboratory small pieces of the water column that appear almost undisturbed, and fragile marine snow aggregates and zooplankters are collected in a very good condition. First and foremost, this allows a view into the microscopic plankton world which is normally not accessible. Such a view will reveal the beauty of the plankton which together with qualitative information on plankton life forms and behaviour may be a very important source of inspiration. The sampler also allows more directed studies, which are otherwise difficult or impossible to conduct, as demonstrated by the few examples given here. Various modifications for special purposes may be made easily, for example adding tracer particles and shining a laser sheet into the sampler to improve the precision of particle tracking.

There are several limitations to the sampler. One is the 50-L sampling volume. Larger organisms are rare and are only occasionally collected by the sampler. Also, the likelihood of getting anything of interest in the sampler decreases in oligotrophic water. Thus, the sampler worked better at the rich coastal stations than at the poorer offshore stations. I had hoped to study how mesozooplankters like *Oncaea* spp. and *Microsetella norvegica* colonize marine snow aggregates, but these organisms were simply too rare in the study area to have enough colonization events in the sampler. Similarly, larger copepods, like *Rhincalanus* spp, which were collected quite abundantly in plankton nets, never occurred in the sampler. One possible way of compensating for the limited sampling volume includes selection of areas and periods where target organisms occur in high concentration and to collect many samples that are rapidly scanned until target organisms have been found.

Although particles and organisms in the sampler appeared undisturbed, conditions in the sampler do...
deviate from those in situ in several ways. Illumination, both infra red or dark field, is different from light conditions in the ocean, which may influence phototactic organisms and water motion in the sampler deviates from the turbulence in situ. Particles will eventually settle on the bottom of the sampler, and other conditions will change over time, such that the best observations are obtained within 1–2 h after collection of the sampler.

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SUPPLEMENTARY DATA

Supplementary data can be found online at http://plankt.oxfordjournals.org

REFERENCES


