

Article

Design, Construction, and Application of an Inexpensive, High-Resolution Water Sampler

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Received: 11 July 2017; Accepted: 1 August 2017; Published: 3 August 2017

Abstract: The cost of high-resolution water sampling devices for ecological studies and water quality analyses can be prohibitive. Moreover, the potential for operator error in the use of complicated sampling equipment can lead to inaccuracies. Here we describe the construction and operation of an inexpensive and easy-to-use water sampler that achieves a water column sampling resolution of approximately 1 cm. The device is driven by a peristaltic pump and is constructed entirely of non-corrosive and non-reactive materials. The sampler has no moving parts and was completely reliable in fieldwork on temperate and Antarctic lakes. The device is especially suited for the collection of water samples from calm or stagnant surface waters, such as lakes, ponds, reservoirs, and deep swamps or other wetlands. In addition, because its components are unaffected by corrosive salts and sulfides, the device is suitable for sampling calm inlet waters, including shallow bays and estuaries. Because of its low cost, simple construction, compact design, and precision performance, this water sampler is an excellent option for studying and monitoring shallow to moderately deep (<50 m) natural waters.

Keywords: water sampler; limnology; water column sampling; water monitoring; stratified lake

1. Introduction

Precise, high-resolution sampling of natural waters with depth can be difficult and costly. Most commercially available water samplers suitable for limnological studies are expensive and incapable of the precision water column sampling desirable in many research applications. In an extensive Internet search, we were unable to identify a commercially available water sampler that could match the resolution provided by a device we describe herein. Bottle-type water samplers, such as Van Dorn samplers and Niskin bottles, are essentially elongated tubes that use a spring-loaded, cable-retained triggering mechanism to capture a water sample at a desired depth. However, this action has the disadvantage of significantly disturbing and mixing the water column upon collection of the sample [1]. This compromises sampling resolution, especially when sampling multiple depths through narrow and often highly dynamic thermal or chemical gradients, and may skew physicochemical data collection. The design of these commonly used samplers requires that the bottle be returned to the surface and emptied following each sample taken. In addition, these manipulations are time-consuming and commonly require a winch for lowering and retrieving the sampler.

The cost of a Niskin bottle sampler and its accessories can exceed \$1000 USD. In addition to disturbing the water column, bottle-style samplers—even those oriented horizontally—have a maximum sampling resolution of only about 0.5 m (vertically oriented bottle samplers have resolutions of about 1 m). This limitation can significantly constrain research efforts, especially those whose goal is to study stratified or meromictic bodies of water; in such environments, waters just a few centimeters apart often differ significantly in their limnology and microbiology [2–9].

Here we describe the construction and performance of a peristaltic-pump-driven, limnological sampling device that, due to its design, has a theoretical water column sampling resolution of as little as 1 cm. The sampler performed extremely well when field-tested in Antarctica to retrieve samples from permanently ice-covered lakes in the McMurdo Dry Valleys [6,8] and also for obtaining water samples at high resolution from the limnetic zone of a temperate lake (to be described here). The sampler has no moving parts and is constructed of non-metallic (or plastic-coated) components. This sampler is also more compact (and thus more portable) than commercially available water samplers, and its construction is straightforward and requires only a few tools. Thus, this sampler supports high-resolution water column sampling in a compact and inexpensive package (Table 1).

Table 1. Approximate total cost (in USD) for materials necessary to build the water sampler.

Item	Quantity	Pricing (USD)
Acrylic squares—approximately 15 cm × 15 cm × 2.5 cm	2	\$80
Peristaltic pump with tubing (Global Water SP200) *	1	\$325
12V lawnmower battery with charger	1	\$80
Nylon washers—5/16-inch I.D. (inner diameter) × 1/8-inch thickness	8	\$3
Nylon hex bolts—5/16-inch T.D. (thread diameter)	4	\$5
Nylon wing nuts—5/16-inch T.D.	4	\$6
Nylon fitting (3/8-inch male pipe thread × 5/16-inch hose base)	1	\$1
Total Cost		\$500

Note: * Many limnology laboratories and science departments will already have a peristaltic pump and vacuum tubing on hand, effectively lowering the cost of using the sampler to less than \$200 (USD).

2. Materials and Methods

2.1. Construction of the Water Sampler

To prevent corrosion and/or reactions with chemicals in the water being sampled (e.g., hydrogen sulfide or various salts), the water sampler was constructed of clear acrylic plastic and nylon parts (Figure 1A). Construction of the sampler began with two identical acrylic blocks approximately 15 cm square and 2.5 cm thick (Interstate Plastics, Sacramento, CA, USA) (Figure 1). These may be ordered pre-cut from various online retailers. One of these pieces became the top block of the sampler, which was drilled and tapped in its center to accommodate a straight nylon fitting with a 3/8-inch (~1 cm) male pipe thread on one end and a 5/16-inch (~8 mm) barbed hose base on the other (the latter accommodated a length of vacuum tubing, described below). The threads to accept the nylon fitting were cut into the hole in the center of the top square of acrylic using a standard tap and die set (if necessary, this step can be performed by a technician at a machine shop). To achieve a snug and watertight fit, the threads of the fitting were wrapped with two complete turns of Teflon™ pipe thread tape before screwing the fitting into the block.

The two acrylic squares were aligned and taped together, one on top of the other, and a 5/16-inch hole was drilled approximately 2.5 cm in from each corner (Figure 1B). After drilling and removing the tape from the squares, four nylon hex bolts (4-inch × 5/16-inch) were inserted upward through the bottom acrylic square (Figure 1C). A 1 cm nylon spacer was then slid onto each bolt to separate the squares and provide for entry of the water samples (Figure 1D). (If a single spacer of the required thickness cannot be obtained, stacked nylon washers are also suitable for this purpose.) The top acrylic square was then slid onto the bolts, resting on each of the four spacers (Figure 1E), and secured at each corner by installing a nylon washer and wing nut (5/16-inch) onto each protruding bolt (Figure 1F). The assembled sampler is then ready to be connected to the vacuum tubing and peristaltic pump.

2.2. Specifications and Assembly of the Pump Apparatus

The collection of water using this device requires four basic components: the sampler itself, vacuum tubing of desired length, a variable-speed peristaltic pump, and a power source to drive

the pump. A suitable power source may be either a small gasoline-powered generator or a battery, depending on the type of pump used. Our pump worked well when coupled to a 12 V rechargeable lawnmower battery (shown in Figure 2). Automobile batteries (12 V) will also suffice for this purpose, but they are less portable because of their larger size and greater weight.

The vacuum tubing (1/4-inch (6.35 mm) I.D.) is pushed as far as possible onto the barbed nylon fitting threaded into the center of the top square of acrylic and fixed firmly in place with a hose clamp. It is important that the tubing used be sturdy enough that it will not collapse under vacuum; thin-walled Tygon® tubing is unsuitable. We used polyvinylchloride (PVC) “bartender’s hose” (13-mm O.D.), the rigid (2-mm wall thickness), gastight, and braid-reinforced tubing used to transport water or soft drinks under pressure from remotely stored containers. Note that for some applications, PVC may be unsuitable as a tubing material. For example, for samples in which organochlorine compounds are to be analyzed, reinforced tetrafluoroethylene (TFE) tubing is preferred due to its hydrophobicity and excellent resistance to most chemicals [1], and it also has the advantage of remaining flexible in cold temperatures. Therefore, depending on the application, the sampler tubing can be readily exchanged for tubing of a different material between uses. In addition, many types of tubing are autoclavable, and therefore the use of sterilized tubing can minimize carryover or cross-contamination of chemicals and microorganisms between samplings, a key precaution for metagenomic and culture-based studies.

It is critical that the hose be securely fastened, not only to prevent leakage into or out of the tubing at the point of connection to the acrylic plates, but also to prevent the hose from slipping off and losing the device. For this reason, we used a stainless steel hose clamp for a secure connection rather than a plastic clamp. The other end of the vacuum tubing was connected to the peristaltic pump in the same way. The length of tubing was measured and marked with an indelible Sharpie® marker to indicate depth. The entire sampling kit consisting of the sampler, tubing, pump, and battery is compact and can be transported in a small container (Figure 2).

2.3. Water Sample Collection and Analyses

Using the device described herein, water samples were collected from the water columns of two lakes: Lake Fryxell, a meromictic and permanently ice-covered lake located in Taylor Valley, McMurdo, Antarctica; and Little Crooked Lake, a small dimictic temperate lake located in northern Indiana, USA. Water samples were collected from 7 m (just below the ice cover) to 17 m (in 0.5-m or 1-m increments) in Lake Fryxell and from 0.2 m to 4.8 m (in 0.2-m increments) in Little Crooked Lake. Global positioning system (GPS) coordinates of the sampling sites were 77°36.630'S, 163°08.826'E (Lake Fryxell) and 41.2579° N, −85.4672° W (Little Crooked Lake).

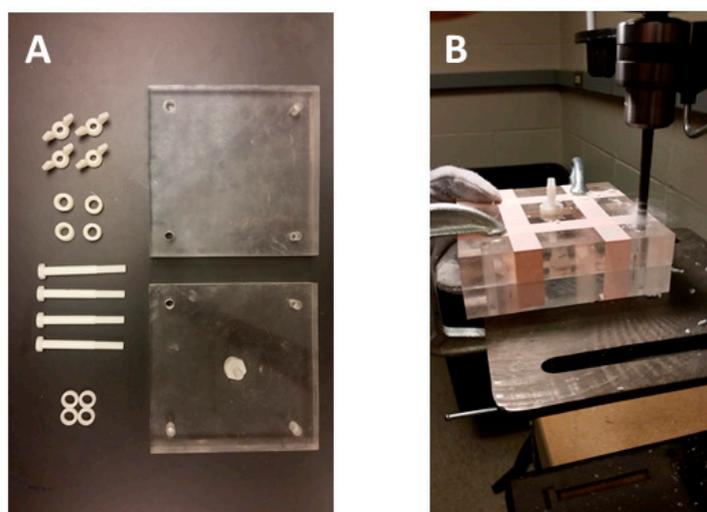


Figure 1. Cont.

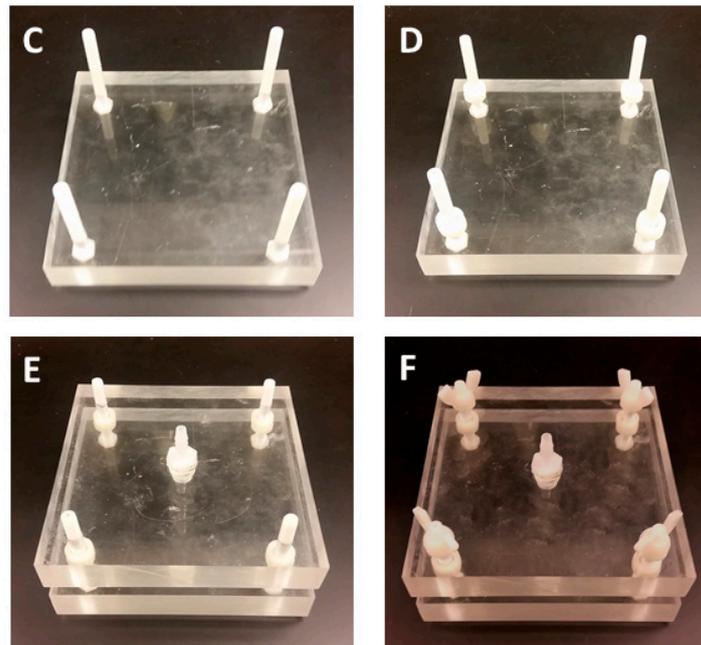


Figure 1. Assembly of the water sampler. (A) Collection of all components. *Clockwise from top right:* bottom acrylic square for sampling device; top acrylic square for sampling device fitted with barbed nylon fitting for attaching tubing; four nylon spacers (each 1 cm tall with 5/16-inch I.D.); four 5/16-inch \times 4-inch nylon bolts; four 5/16-inch I.D. nylon washers; and four 5/16-inch nylon wing nuts. (B) Four holes were drilled at each corner of the acrylic squares using a drill press and a 5/16-inch drill bit. The pieces were taped together to retain alignment of the holes. The holes were drilled slowly to avoid warping or cracking of internal acrylic. (C) The bolts were inserted upwards through each of the four holes in the bottom square of the sampler. (D) 1 cm spacers were slid onto each bolt. (E) The top square of the sampling device was slid into place over the four bolts and rested on the spacers. (F) Washers and wing nuts were secured onto the bolts to complete the sampler.



Figure 2. Transporting the water sampler. The sampler (with tubing), peristaltic pump, and battery all fit into a single container, and the total weight of the kit was approximately 30 lbs (13.5 kg). In this case, the container in which all components were placed was a simple wooden box with dimensions of $16\frac{1}{2} \times 16\frac{3}{4} \times 8$ inches (42 cm \times 42.5 cm \times 20.3 cm). Carrying handles were installed on each side of the box to transport the kit. The cost to build the transporter was less than \$20 (USD).

To retrieve lake water samples, the sampler was lowered by its tubing to the desired depth (Figure 3A), and the pump was turned on. Many peristaltic pumps are fitted with a variable-speed switch, in which case the water samples can be extracted at an adjustable rate. For stratified or meromictic bodies of water, slow but steady pumping rates to avoid splashing minimize dissipation of volatile gases, such as hydrogen sulfide and methane, as the sample containers are filled. The high resolution of the sampler was achieved because water enters the tubing from the 1-cm gap present between the two squares of acrylic (that is, water enters the sampler horizontally from the sides) (Figure 3B).

Unlike conventional water samplers, the device was not brought to the surface after each depth was sampled. Instead, after a sample was retrieved, the device was immediately lowered to the next depth, and sampling was resumed. However, to ensure that the previous sample was completely flushed from the tubing, approximately twice the volume of the tubing (≥ 320 mL for our apparatus; Table 2) was pumped and discarded before collecting the next sample.

Table 2. Specifications and performance of the water sampler: Performance will vary based on the model of peristaltic pump used. The observations recorded here are specific to the use of a Global Water SP200 variable-speed pump driven by a 12 V battery.

Parameter	Measurement
Total length of tubing	4.9 m
Inner diameter of tubing	6.4 mm
Total volume of tubing and pump	160 mL
Time to first drop in collection vessel	19 s
Time required to fill 500-mL collection vessel	60 s
Resolution of sampling device (space between the two acrylic squares)	10 mm

Pumped samples were dispensed into 10% HCl-rinsed glass Wheaton bottles (VWR Scientific) that were filled completely and sealed with TeflonTM-lined, phenolic screw caps; the collection vessels were thus both gas-tight and chemically inert. Upon returning to the laboratory, the sampler was rinsed and the tubing flushed with deionized water and air-dried thoroughly before storage.

Sulfide concentrations in Lake Fryxell were determined using the methylene blue colorimetric method of Trüper and Schlegel, as previously described [3,10]. Chl *a* concentrations in Little Crooked Lake were measured using a standard spectrophotometric method [11] (pp. 10-18–10-20). Briefly, each sample was concentrated by centrifugation and Chl *a* from the pellet was extracted into reagent-grade acetone and saturated aqueous magnesium carbonate (90:10). Chl *a* was quantified as absorbance at 664 nm after correcting for turbidity and Chl *a* degradation to pheophytin *a* [11] (pp. 10-19–10-20).

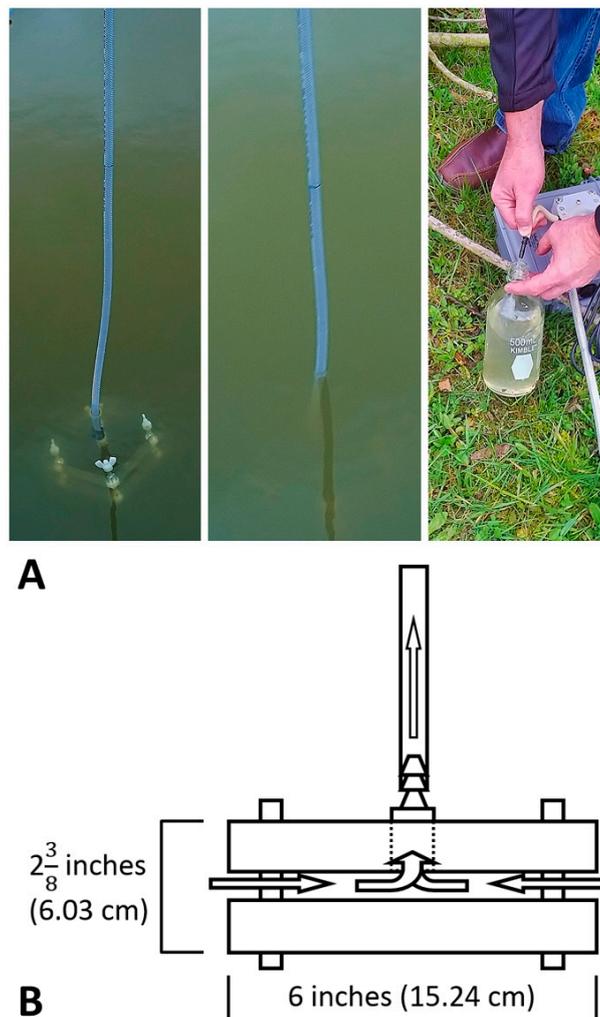


Figure 3. Use and action of the water sampler. (A) Lowering the sampler into the water by its tubing and subsequent sample collection in a rinsed and sterilized bottle. (B) Schematic diagram showing the mechanism of water sample collection (arrows indicate water flow). A major advantage of this design is that the water sample is pulled between the two acrylic squares within a space of 1 cm, allowing for high-resolution sampling and precise data collection.

3. Results and Discussion

3.1. Performance of the Water Sampler

Using a battery-powered Global Water model SP200 peristaltic pump (Cole-Parmer, Vernon Hills, IL) operating at maximum speed, a 500-mL water sample could be collected through a 5-m hose in 1 min (Table 2). However, deeper depths can be sampled using a more powerful peristaltic pump, as we have shown with a prototype of the water sampler in studies of the water column of permanently ice-covered Antarctic lakes [6–8]. Therefore, it is likely that the length of the vacuum tubing used is limited only by the power of the pump to which it is coupled.

During sample collection, additional ballast was necessary to maintain proper vertical orientation of the sampler in the water column. Adding mass to the device ensured that the tubing, which was stored in a coil, was fully straightened and taut during sampling. This may be critical for accurate sampling if the tubing is cold or immersed in cold water, or if conditions are windy at the time of sampling. Ballast can be installed on the sampler by affixing a plastic-coated lead donut (commercially available for anchoring flasks in a water bath, VWR Scientific) to the top square of the

sampler using plastic-coated wires secured under the wing nuts on the sampler, as shown in Figure 4. The wires can be clamped to the tubing to ensure that the sampler is securely attached under the added weight (Figure 4). The plastic coatings on ballast components are necessary to prevent corrosion, especially in saline or sulfidic waters.



Figure 4. Water sampler fitted with additional ballast. The mass of the lead donut weight adds ballast to the sampler to ensure proper vertical orientation when lowered into the water column. Plastic coatings on the weight and wires prevent corrosion.

Because it was unnecessary to bring the sampler to the surface upon the acquisition of each sample, the retrieval of lake water from a variety of depths in the water column was remarkably convenient and efficient. For example, all 24 samples collected from Little Crooked Lake (1 L each) were obtained with ease in less than 1.5 h. Our 12 V battery—fully charged at the start of sampling—maintained strong, even performance over the entire sampling period. In addition, unlike bottle-style samplers, the use of the apparatus allowed for minimal disturbance of the water column and, thus, more accurate and precise sampling.

3.2. Field Results Verification: Chlorophyll *a* and Sulfide Measurements

Confirmation that the added lead weight ballast provided proper vertical positioning of the sampler in a water column came from a comparison of sulfide concentrations in highly stratified Lake Fryxell, Antarctica. The sulfide data were obtained in different years using two different sampling methods: a traditional Niskin bottle sampler (2001 and 2003) and the pump-driven sampler described here (2005) (Figure 5A). Because of its thick (5–6 m), permanent ice cover and a pronounced salinity gradient, the water column of Lake Fryxell is extremely stable, with physicochemical properties differing only slightly from year to year [7,12,13]. The congruence of the sulfide data from different sampling seasons shows that not only did the new sampler provide accurate sampling of the Lake Fryxell water column, but it also allowed for finer resolution sampling at key depths (8.5 m to 12.5 m) wherein oxygen-rich upper waters transition to an anoxic, sulfidic monimolimnion (Figure 5A). Because of the ice cover, strong winds (or an unsteady boat) were not an issue in retrieving the Lake Fryxell samples. However, in sampling unfrozen lakes by boat, windy conditions could influence high-resolution sample collection.

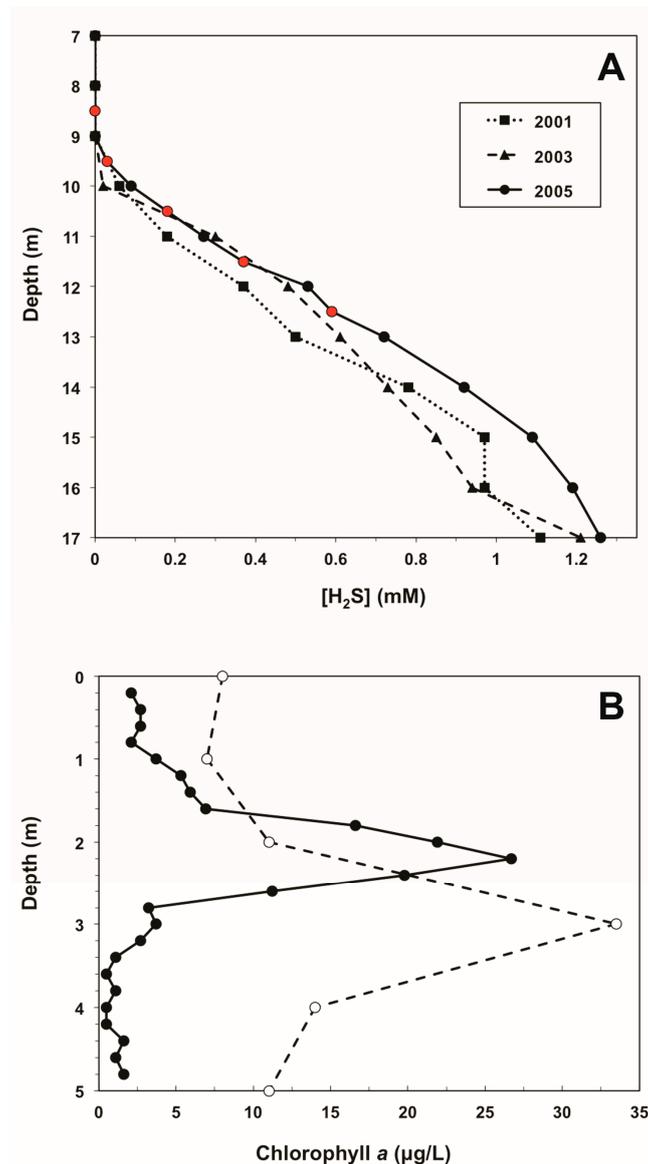


Figure 5. Field results using the pump-driven water sampler. **(A)** Comparison of sulfide concentrations in meromictic Lake Fryxell, Antarctica from samples obtained using a Niskin bottle (2001 and 2003) versus the pump-driven sampler (2005). A general consistency in the concentrations in each profile, as well as the especially smooth curve from the 2005 samples, shows the accurate and precise performance of the new sampler. Data points in red indicate samples taken in 0.5-m increments through the biologically dynamic chemocline of the lake, thus providing a sampling resolution not possible with the Niskin bottle. **(B)** Comparison of Chl *a* concentrations in the water column of Little Crooked Lake, Indiana, from samples obtained using a Van Dorn sampler (dashed line, adapted from [14]) with those obtained using the pump-driven sampler (solid line). Sampling dates for **(B)**: 19 July 1982 [14]; 19 June 2017 [this study].

To provide additional evidence for the accurate, high-resolution performance of this sampler, we measured Chl *a* concentrations at each depth sampled in a temperate freshwater lake, Little Crooked Lake, Indiana. Little Crooked Lake is a relatively shallow (maximum depth, 15 m) hard water marl lake with significant biogenic and abiogenic turbidity; light intensity at a depth of 3 m is less than 10% of surface irradiance and the lake supports a metalimnetic cyanobacterial bloom during summer stratification [15]. Limnological studies of this lake and the adjoining Crooked Lake were published

over 30 years ago. Specifically, Lovell and Konopka [14] measured levels of Chl *a* with depth in Little Crooked Lake, providing a useful standard for our determinations. The distinguishing feature between their work and our study is that their samples were obtained in 1-m intervals, the maximum resolution that could reliably be achieved using a Van Dorn sampler. By contrast, because of the design of our sampler, we could easily and accurately obtain samples at much finer resolutions, and we chose 0.2-m intervals to demonstrate this. The two Chl *a* datasets are compared in Figure 5B.

Our results showed a gradual increase in Chl *a* from 0.2 to 1.6 m followed by a sharp increase to a depth of 2.2 m and an equally sharp decline down to 2.8 m (Figure 5B); measurements of Chl *a* remained low in all deeper samples. Our data differ a bit from those of Lovell and Konopka [14], in which slightly higher Chl *a* concentrations were recorded throughout the same depths of the water column. This, along with the slightly deeper Chl *a* maximum reported in Reference [14], is likely due to seasonal factors associated with differences in sampling dates between the two studies (Figure 5B).

As is clearly apparent from the data of Figure 5, our water sampler allowed for more precise and higher-resolution water column sampling than is possible with a bottle-type sampler; our Chl *a* profile included 24 data points obtained across 4.6 m of water (Figure 5B). This can be compared with the six data points obtained across 5 m of water in the study by Lovell and Konopka [14] (Figure 5B). The performance of our sampler thus significantly exceeds that of other water samplers currently available for limnological studies.

Although high-resolution sampling may be unnecessary for many applications, for some studies, for example, limnological studies of the water column of amictic or stratified lakes, high-resolution sampling is exactly what is needed to precisely define the spatial distribution of chemical gradients and their associated microorganisms. For example, the ability to retrieve samples along a steep oxycline at centimeter-level resolution could reveal the nutrient and microbial community structure of waters that quickly transition from oxic to anoxic [7,8]; such discoveries would likely be unobtainable in analyses performed at meter-level resolution. This improved resolution could significantly refine studies of the diversity or metagenomics of aquatic microbial communities that catalyze major nutrient cycles, such as those of nitrogen and sulfur.

4. Conclusions

A high-resolution, limnological sampler is a key apparatus for monitoring natural waters and an essential tool for any limnology department. The water sampler described and demonstrated here allows for easier and more precise sampling of calm surface waters than does the use of bottle-type water samplers. A sampling resolution on the order of centimeters can be achieved with this device, which for some studies may be a necessary feature for accurate geochemical and microbiological measurements at specific depths in natural bodies of water. Moreover, this method of water sampling is easier, significantly faster, and less disruptive to the water column than sampling using bottle-style samplers. For teaching lab activities, water quality monitoring, and research applications, this compact water sampler provides rapid and precise water collection at an affordable cost.

Acknowledgments: We thank the Indiana Wesleyan University Division of Natural Sciences for financial support for this project. We also thank John C. Priscu, Montana State University, for helpful advice in the design of our water sampler, John P. Buffat for assistance in its construction, and Larry Cramer for kindly providing convenient access to Little Crooked Lake. Use of the prototype of this sampler in Antarctica was supported by U.S. National Science Foundation grants OPP008581 and MCB0237576 to Michael T. Madigan.

Author Contributions: W. Matthew Sattley and Michael T. Madigan designed the water sampler (with suggestions from John C. Priscu (see acknowledgments)); Brad M. Burchell and W. Matthew Sattley ordered the components, built the water sampler, and assembled the carrying case and kit components; W. Matthew Sattley and Michael T. Madigan collected and analyzed the water samples from Lake Fryxell, and W. Matthew Sattley and Stephen D. Conrad collected and analyzed the water samples from Little Crooked Lake; Brad M. Burchell and W. Matthew Sattley wrote the first draft of the paper, and Stephen D. Conrad and Michael T. Madigan provided critical reviews and edits during the final draft stage.

Conflicts of Interest: The authors declare no conflict of interest.

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