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Development and field testing of a portable eDNA water sampler

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ABSTRACT

One of the methods currently revolutionizing biodiversity assessment is the analysis of environmental DNA (eDNA). Here we present a prototype of a semi-automatic sampler for water eDNA collection. The sampler is a portable, affordable, battery-powered device that supports hands-free filtration using peristaltic pumps and allows for the processing of multiple water samples under field conditions.

The prototype system consists of commonly available components including an ESP32 microcontroller, a 3D-printed battery adapter, voltage converters, and two peristaltic pumps. The system is controlled by a simple push-button starting a 20-minute sampling cycle. The filtration setup ensures that contamination is avoided by placing the filter before the pump in the water flow path.

Initial field testing was conducted at Lake Silbersee in Carinthia, Austria, where successful filtrations were carried out using different filters. Concentration measurements of extracted eDNA samples ranged from 9.8 to 24.0 ng/µL, confirming that the device can collect eDNA for water biodiversity assessment. Tests also revealed that filters became clogged after 1 L of filtration in the given water source, supporting the decision to limit operation time.

Future improvements to the prototype may be possible by adding further pump capacity, a display, data logging, and a web-based interface to further increase usability and automation.

KEYWORDS

- eDNA
- environmental monitoring
- water sampler
- portable device

Entwicklung und Felderprobung eines tragbaren eDNA-Wasserprobenehmers

ZUSAMMENFASSUNG

Eine der Methoden, die derzeit die Bewertung der biologischen Vielfalt revolutionieren, ist die Analyse von Umwelt-DNA (eDNA). Hier stellen wir den Prototyp eines halbautomatischen Probenehmers für Wasser-eDNA vor. Der Probenehmer ist ein tragbares, erschwingliches, batteriebetriebenes Gerät, das eine freihändige Filtration mit peristaltischen Pumpen unterstützt und die Verarbeitung mehrerer Wasserproben unter Feldbedingungen ermöglicht.

Der Prototyp besteht aus handelsüblichen Komponenten wie einem ESP32-Mikrocontroller, einem 3D-gedruckten Batterieadapter, Spannungswandlern und zwei peristaltischen Pumpen. Das System wird über einen einfachen Druckknopf gesteuert, der einen 20-minütigen Probenahmezyklus startet. Der Filteraufbau stellt sicher, dass Verunreinigungen vermieden werden, indem der Filter vor der Pumpe im Wasserflussweg platziert wird.

Erste Feldversuche wurden am Silbersee in Kärnten, Österreich, durchgeführt, wo erfolgreiche Filtrationen mit verschiedenen Filtern stattfanden. Die Konzentrationsmessungen der extrahierten eDNA-Proben reichten von 9,8 bis 24,0 ng/µl und bestätigten, dass das Gerät eDNA für die Bewertung der biologischen Vielfalt im Wasser sammeln kann. Die Tests zeigten auch, dass die Filter nach 1 Liter Filtration in der gegebenen Wasserquelle verstopft waren, was die Entscheidung, die Betriebszeit zu begrenzen, bestätigte.

Zukünftige Verbesserungen des Prototyps könnten durch weitere Pumpenanwendungen, ein Display, Datenprotokollierung und eine webbasierte Schnittstelle möglich sein, um die Benutzerfreundlichkeit und Automatisierung weiter zu erhöhen.

INTRODUCTION

Environmental DNA (eDNA) sampling is an increasingly important method in biodiversity monitoring, allowing the detection of organisms based on genetic material present in environmental samples, including water or soil [1], [2]. eDNA sampling techniques mostly rely on manual filtration using syringes, which can be labor-intensive and prone to contamination [3]. The growing demand for reliable, efficient, and field-deployable systems has led to the development of portable eDNA samplers [4], [5]. However, these devices are often large, difficult to transport, reliant on specific filter systems, and expensive, making them inaccessible to many users.

In this paper we present a semi-automatic, battery-powered sampler developed as part of a research internship during the MSc Study program System Design at Carinthia University of Applied Sciences. The project was initiated in response to the need for a lightweight, user-friendly, and robust device that can operate without external infrastructure in remote locations. The aim of the project was to develop a system that supports hands-free filtration via peristaltic pumps and is capable of processing multiple water samples in parallel. The sampler should allow the use of various filter types and include features such as predefined operation times to prevent overloading or clogging of the filter.

The development of the portable eDNA sampler followed a structured, iterative process. First, a functional concept was designed based on the requirements for autonomous eDNA sampling in remote environments. The system was planned to operate with minimal user interaction, using a microcontroller, two peristaltic pumps, and a standard 18 V power tool battery. Splash protection, field portability, and ease of use were also considered in the design.

Based on this concept, the first prototype was assembled. 3D printing was used for selected components of the prototype. All electronic components were installed in splash-resistant housing, providing adequate protection against light rain and moisture during fieldwork. Initial functionality was tested step-by-step on the workbench.

Before field deployment, preliminary tests were carried out in a controlled aquarium environment populated with fish and aquatic plants. These tests verified the system's basic performance under realistic conditions and helped optimize tubing layout and flow rates.

The completed prototype was then tested under natural conditions in the field. Water samples were collected using both the automated sampler and a manual syringe method for comparison. The filtered samples were analyzed in the laboratory to assess DNA concentrations and evaluate the performance and sample quality of the system.

METHODS

The core system consists of an ESP32-WROOM-32E microcontroller, two peristaltic pumps, a toggle switch, two push-buttons, relay modules, and two voltage converters. Power is supplied by an 18 V Makita battery via a 3D-printed adapter. The voltage converters reduce the voltage to 12 V for the pumps and 5 V for the controller. All components are mounted in a splash-resistant plastic housing, providing protection against light rain and moisture during field use. A modular internal layout and a prototyping board with screw terminals allow for easy access and future modifications.

A schematic overview of the wiring setup is provided in Supplementary Figure 1, and a photo of the assembled prototype is shown in Figure 1.

Each pump is controlled independently by pressing a corresponding button, which starts a 20-minute filtration cycle. This duration is based on preliminary tests that showed filter clogging after pumping of approximately 1 L of lake water. Water is drawn through a filter placed upstream of the pump to prevent contamination of internal tubing. After sampling, filters are removed and stored on ice.

The microcontroller is programmed using Arduino IDE software. The control logic includes a simple timer function for automated pump shutdown after 20 minutes.

Field testing took place on March 27, 2025, at Lake Silbersee (Villach, Austria), a freshwater lake located in the Alps-Adriatic region. Four water samples were collected using glass fiber filters with a pore size of 0.7 µm and the sampler prototype: three water samples were filtered using the peristaltic pumps, and one sample was processed manually

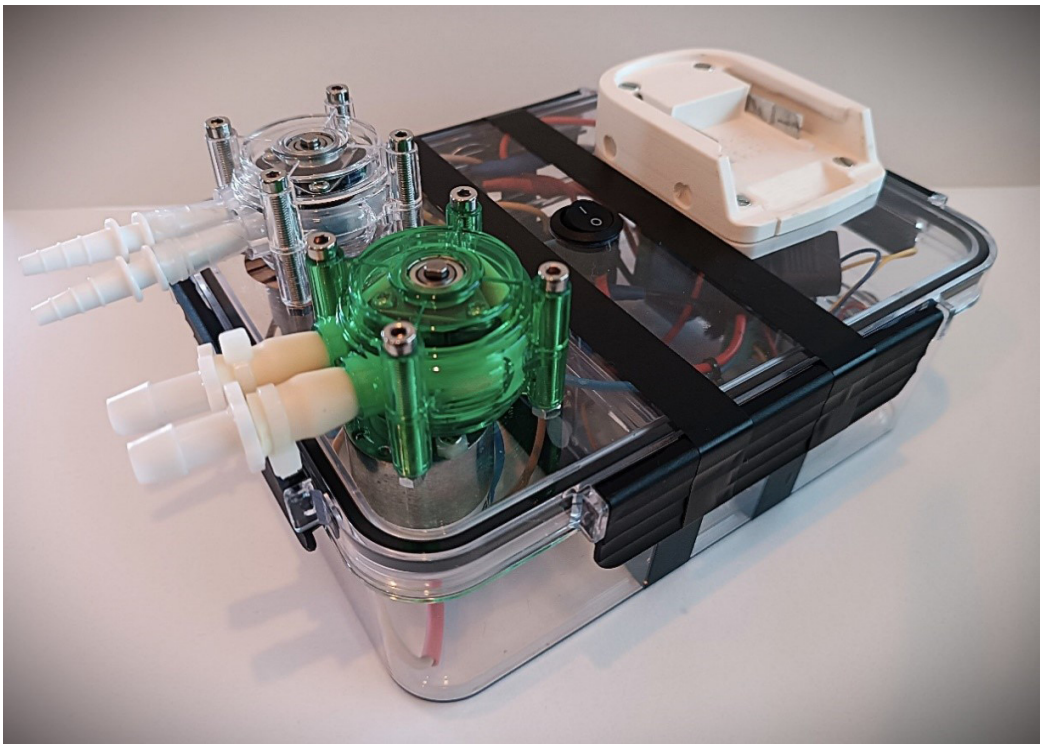

Fig. 1

Figure 1:
Prototype of the portable eDNA water sampler in housing. Source: Own image

Abbildung 1:
Prototyp des tragbaren eDNA-Wassersamplers in einem Gehäuse. Quelle: Eigenes Bild

with a syringe for comparison. After the filtration process, the filters were stored in tubes containing 1.5 µL ATL extraction buffer (Qiagen, Hilden, Germany). Two control samples were included: a negative field control and a DNA extraction blank using only the extraction buffer. DNA was extracted from all filters on April 17, 2025, using the DNeasy Blood & Tissue Kit (Qiagen, Hilden, Germany) with a 2 h Proteinase K incubation step, and the final sample elution volume was 100 µL (2 × 50 µL). For all samples and controls containing filters, 500 µL were used for the extraction; for all controls that did not contain filters, 200 µL were used. An inhibitor removal step was performed according to the manufacturer's instructions using the Inhibitor Removal Kit (Zymo Research, CA, USA). All samples and final DNA extracts were stored at –20 °C prior to and post analysis. DNA concentrations were measured using a Qubit fluorometer (Thermo Fisher Scientific, MA, USA).

RESULTS

The field test demonstrated that the prototype is capable of filtering approximately 1 L of lake water within 20 minutes using standard eDNA filter cartridges. During operation, the peristaltic pumps functioned reliably under battery power. All four filtered samples (three using the device, one using a syringe) yielded measurable amounts of eDNA. Filter clogging occurred consistently after pumping around 1 L of filtered water.

Tab. 1

Sample code	Filtration method	Starting volume (µl)	Concentration (ng/µl)
P1	Pump	500	9.8
P2	Pump	500	24.0
P3	Pump	500	17.0
S4	Syringe	500	24.0
K5	Sampling control	500	0.0
EK	Extraction control	200	0.0

Table 1:
Overview of filtered samples and corresponding eDNA concentrations

Tabelle 1:
Übersicht der gefilterten Proben und entsprechenden eDNA-Konzentrationen

The concentration of extracted DNA varied between 9.8 ng/µL and 24.0 ng/µL (Table 1). Notably, the highest concentrations were recorded in samples P2 and S4, both reaching 24.0 ng/µL. The concentration of DNA measured in the samples was of the same order of magnitude for the syringe and the pump samples. Syringe-based filtration performed comparably to the automated system. No significant difference was observed between the pump-filter combinations in terms of sample yield, suggesting that the system works reliably across different filter types, provided they are compatible in size and flow resistance. The negative controls (field control and extraction blank) showed 0.0 ng/µL, indicating the absence of contamination during sample handling and processing.

DISCUSSION

The major advantage of the system is its portability and ease of use. Unlike most commercial systems, which require supervision and often depend on external power sources, the prototype operates autonomously for a predefined time and is powered by a common 18 V tool battery. This makes the system especially suitable for fieldwork in remote areas with limited infrastructure.

The results of the field tests confirm that the developed eDNA sampler can successfully collect environmental DNA from freshwater environments. The measured DNA concentrations are within the expected range for aquatic eDNA studies and demonstrate the system's practical usability under field conditions. The agreement between automated and manual filtration (syringe) further supports the validity of the approach and confirms that the prototype is suitable for producing high-quality samples. In addition to DNA yield, user observations during field deployment confirmed that the handling of the prototype can be done without significant previous experience, and the splash-resistant housing protects the electronics from the elements. However, filter clogging occurred consistently after around 1 L of filtered water, justifying the decision to limit pump operation to 20 minutes per cycle.

The absence of contamination in the control samples indicates that the upstream filter placement is effective. This design choice reduces the need for internal cleaning and simplifies reuse. However, the current version lacks advanced features such as data logging or sample tracking, which could enhance traceability in large-scale sampling efforts.

Despite the successful performance of the sampler, the field test also highlighted practical challenges associated with the transport and handling of additional sampling equipment. Items such as filters, gloves, tweezers, waste bags, and cooling containers need to be transported and accessed efficiently under varying weather and terrain conditions. The current housing of the sampler itself is a functional but provisional prototype and could be further optimized to enhance waterproofing, durability, and usability in rugged environments.

Potential further improvements include adding a user interface (e.g., LCD display), implementing real-time monitoring of flow rates or pressure, and introducing remote connectivity (e.g., via Wi-Fi) for device control and data access. These features could be integrated in future iterations depending on field testing feedback and specific use case requirements.

The lack of an integrated or standardized transport solution for all required components was a limiting factor during field use. In response, a theoretical concept for a modular transport system—based on a hard plastic case with backpack straps—was developed. This approach could significantly improve handling efficiency and operational readiness in

the field. Future iterations of the project should explore optimized storage and organization solutions that support rapid deployment and help minimize the risk of contamination or equipment loss.

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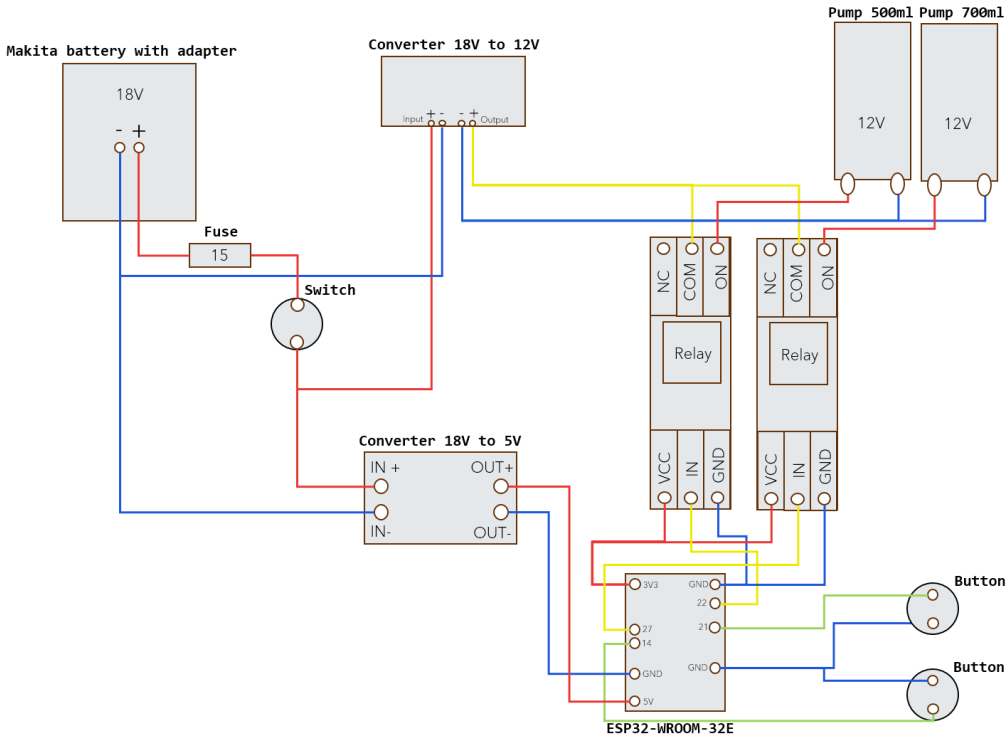

Supplementary Fig. 1

Supplementary Figure 1: Wiring diagram of the portable eDNA sampler. Source: Own image Ergänzende

Ergänzende Abbildung 1: *Schaltplan für den tragbaren eDNA-Probenehmer. Quelle: Eigenes Bild*

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