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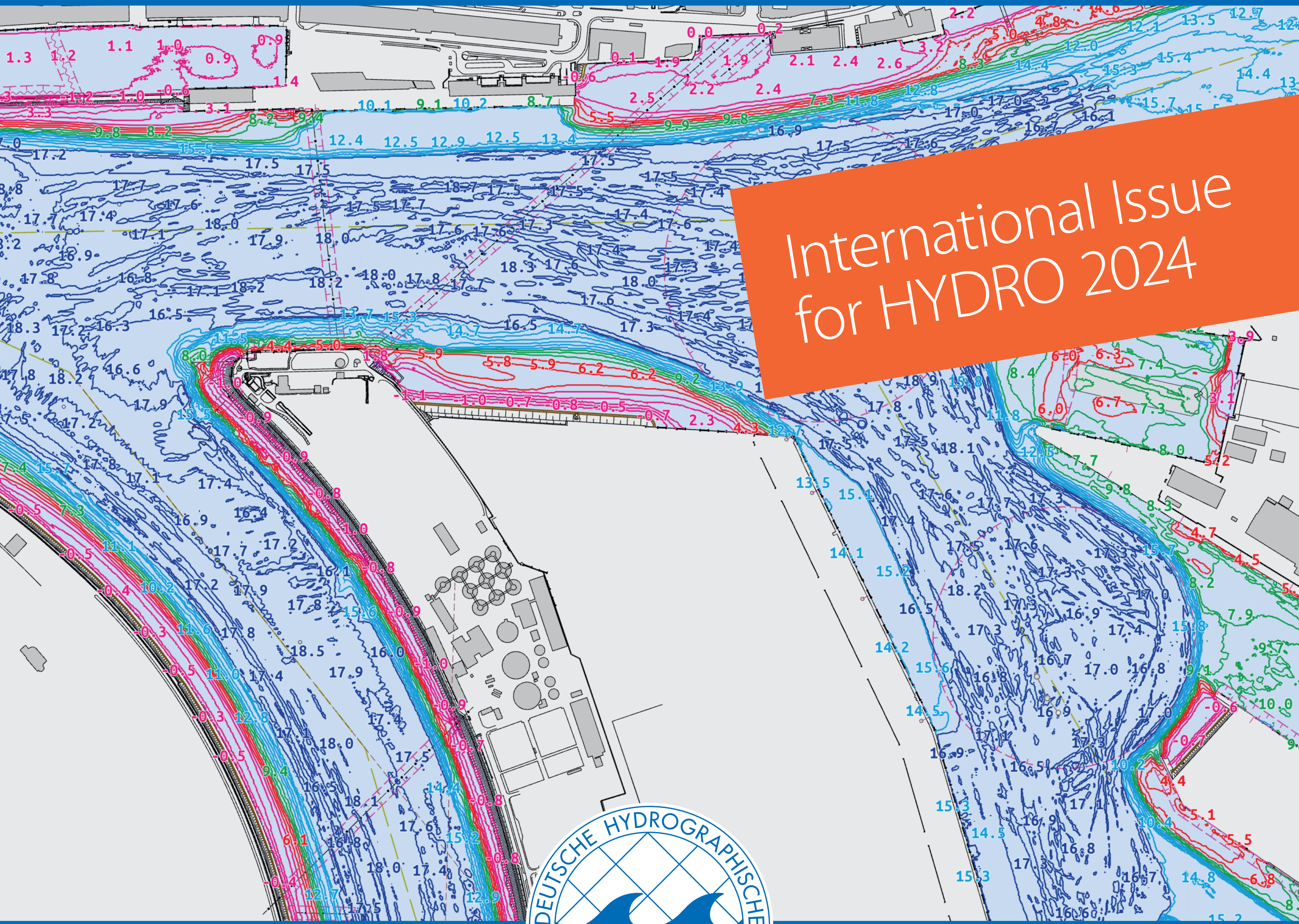

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HyFiVe: hydrography on fishing vessels

A new monitoring system enables cost effective and scalable ocean monitoring

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Whether for modelling climate change or understanding fish stocks, ocean data is essential across many disciplines. Traditionally, such data has been collected by research vessels, which are costly and limited in scope. To enhance data resolution, the concept of ships-of-opportunity presents a scalable alternative, utilising vessels originally financed for non-scientific purposes. Fishing vessels, in particular, offer unique advantages as they operate in deep waters, allowing access to the entire water column for attached measuring systems. We developed a highly flexible, autonomous measuring system within the HyFiVe project over the past three years. This system comprises three main components: a sensor carrier mounted on fishing gear for underwater data collection, a deck unit for geo-referencing and data transfer, and an onshore server for automatic quality control and data storage. In this article, we provide an overview of the HyFiVe measuring system, summarise the results of measurement campaigns to date, and discuss the system's benefits to the community.

hydrography | monitoring system | ships of opportunity | open source | citizen science | future fishery
Hydrographie | Überwachungssystem | Nicht-Forschungsschiffe | Open Source | Bürgerwissenschaft | Fischerei der Zukunft

Ob für die Modellierung des Klimawandels oder das Verständnis von Fischbeständen – Meeresdaten sind für viele Disziplinen unerlässlich. Traditionell werden solche Daten von Forschungsschiffen gesammelt, die kostspielig und in ihrer Reichweite begrenzt sind. Um die Datenauflösung zu verbessern, stellt das Konzept der Ships of Opportunity eine skalierbare Alternative dar, bei der Schiffe eingesetzt werden, die ursprünglich für nicht-wissenschaftliche Zwecke finanziert wurden. Insbesondere Fischereifahrzeuge bieten einzigartige Vorteile, da sie in tiefen Gewässern operieren und den Zugang zur gesamten Wassersäule für die angebrachten Messsysteme ermöglichen. Im Rahmen des HyFiVe-Projekts haben wir in den vergangenen drei Jahren ein hochflexibles, autonomes Messsystem entwickelt. Dieses System besteht aus drei Hauptkomponenten: einem Sensorträger, der an einem Fanggerät für die Datenerfassung unter Wasser angebracht ist, einer Deckseinheit für die Georeferenzierung und Datenübertragung sowie einem Server an Land für die automatische Qualitätskontrolle und Datenspeicherung. In diesem Artikel geben wir einen Überblick über das HyFiVe-Messsystem, fassen die Ergebnisse der bisherigen Messkampagnen zusammen und diskutieren den Nutzen des Systems für die Gemeinschaft.

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1 Introduction

The ocean is a crucial resource for humanity, serving various purposes such as transportation, food supply, and recreation. However, human activities have increasingly exerted anthropogenic pressure on marine ecosystems, a situation exacerbated by climate change. This is particularly true for sensitive ecosystems like those in coastal and marginal seas with limited water exchange, such as the Baltic Sea. The Baltic Sea is a unique but fragile environment where the impacts of pollution, fishery pressure and climate change are more pronounced (HELCOM 2018; ICES Advice 2024).

Hydrographic parameters, which include salinity, temperature and dissolved oxygen levels, are critical indicators for assessing the health of such marine environments. Traditionally, these data are collected by research vessels or moored platforms. To acquire more extensive data from the open oceans, gliders and floats are also utilised (Freeland et al. 2020; Queste et al. 2012). While these methods provide high-quality data, their high operational costs limit their spatial and temporal coverage.

To overcome these limitations and enhance data resolution, the concept of »ships of opportunity« (SoO) has been proposed. SoO leverages vessels not primarily intended for scientific research to collect valuable environmental data. This approach is particularly promising for increasing the frequency and coverage of data collection, especially in regions like the Baltic Sea, where extensive monitoring is crucial.

However, SoO systems are usually limited to surface water monitoring (Rosa 2021). In this context, fishing vessels offer a unique advantage as they deploy gear in deep water, making them ideal platforms for deploying hydrographic sensors that can collect data throughout the entire water column. Recognising the absence of suitable commercial systems for this purpose, we initiated the HyFiVe (Hydrography on Fishing Vessels) project in 2021 to develop a flexible and autonomous monitoring system.

2 HyFiVe in the Baltic Sea

The HyFiVe system was initially intended for use in trawl fisheries. However, the situation in the Baltic Sea has deteriorated dramatically in recent years, with key fish stocks, such as cod and herring, collapsing. This decline has led to the closure of significant portions of the fishery, with little hope of recovery in the near future due to persistent adverse water conditions that hinder reproduction (HELCOM 2018; ICES Advice 2024; Lewin et al. 2023). The collapse of these stocks has placed traditional coastal fishing, recognised as an intangible cultural heritage, under severe threat (Lasner and Barz 2023).

With the fishery largely closed, the HyFiVe system cannot currently contribute to increasing data density through trawl fisheries. Yet, paradoxically, more data is now needed than ever to develop and justify appropriate conservation measures. In response, the HyFiVe system has been adapted for use in small-scale fisheries. This adaptation aligns with efforts to provide fishermen with alternative sources of income by involving them in environmental monitoring and the protection of the Baltic Sea ecosystem. Initiatives like the Sea Rangers programme exemplify this approach, where fishermen contribute to citizen science and environmental stewardship (de Graaf et al. 2023).

3 HyFiVe system overview

3.1 System design and modularity

The HyFiVe system is designed with a focus on flexibility, modularity and ease of use. Its autonomous nature is underpinned by three core components: a data logger, a deck unit and an onshore server (Fig. 1).

- Data logger: The data logger is mounted on fishing gear, such as trawls or nets, and collects essential hydrographic data, including salinity, temperature and dissolved oxygen levels. Designed for autonomous operation, the system requires minimal interaction from the vessel's crew.
- Deck unit: The deck unit is responsible for georeferencing the data and facilitating its transfer to the onshore server. It ensures that the data is accurately associated with its geographical location and time of collection.
- Onshore server: The onshore server manages the automatic quality control, visualisation and storage of the data. It also makes the data accessible to users via a web server and integrates it into international databases.

The modularity of the HyFiVe system allows it to be easily adapted to measure different chemical and physical ocean parameters, making it suitable for a variety of vessels and fishing operations. The system's design incorporates process routines and bidirectional communication capabilities, enabling seamless data acquisition, transfer, post-processing, visualisation, remote servicing and reconfiguration of devices. All components and developments are published at GitHub under open-source licenses, allowing the public to use and modify the system according to their needs (https://github.com/HyFiVeUser/HyFiVe).

The system operates in three distinct phases and employs established Internet of Things (IoT) protocols for wireless communication:

Preparation: Configurations for loggers are prepared on the server and transferred to all deck boxes, allowing for remote maintenance and reconfiguration. The loggers synchronise their configuration parameters and clocks with the deck box at regular intervals.

Acquisition: The deck box collects GPS data and stores it for later geo-referencing. While submerged, the logger controls the attached sensors and collects measurement data throughout the deployment.

Transmission: After each deployment, the logger wirelessly transmits the stored data to the deck unit, which geo-references and visualises it. The complete datasets are then transmitted to the onshore server, where they are processed for further applications.

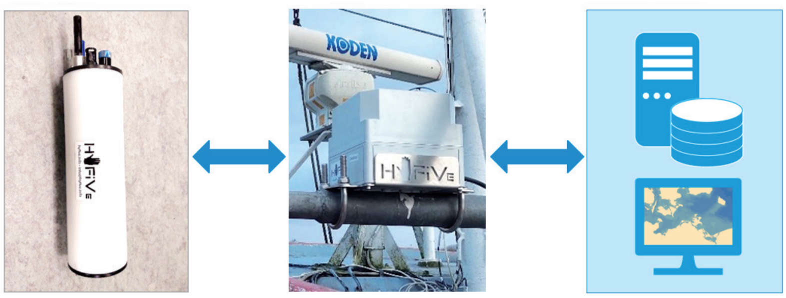

Fig. 1: HyFiVe system components (from left to right): data logger, deck unit and onshore server

3.2 The sensors

The data logger is designed with one interface board that connects to the mainboard for each integrated sensor, allowing for the integration of nearly any OEM sensor into the system. The current system, optimised for the Baltic Sea, measures conductivity (C), temperature (T), depth (D), and dissolved oxygen (DO) levels. The complex selection process for the chosen OEM sensors will be described in detail soon. Finally we use an Atlas Scientific K1.0 conductivity probe, a BlueRobotics Celsius Fast Response temperature probe, a Keller PAA-20D pressure sensor and a Pyroscience Pico-O2-Sub oxygen sensor.

3.3 The data logger

The data logger is a self-sufficient measuring system that controls the sensors via a mainboard based on an ESP32 controller (Espressif Systems Co. Ltd). Interface boards are available for various communication protocols, including I2C, UART, RS232, RS485, and analog input signals. The interface boards allow power supply programming for each sensor to values of 3.3 V, 5 V and 12 V. The logger uses WiFi for communication with the deck unit and features a battery management system (BMS) with external contacts for fast recharge. The battery with a capacity of 133 Wh uses twelve Li-Ion cells aggregated to a 4S3P cylinder block with a diameter that fits inside the housing tube and provides power for continuous measurement of parameters at 1 Hz for 30 days. In commercial fishery operations, where the logger predominantly operates in power-saving mode, this battery life can extend to several months. The underwater housing is made from polyoxymethylene (POM) and can accommodate up to six sensors. It has a depth rating of 300 metres at a diameter of 90 mm and a length of 285 mm without sensor heads. In the current sensor configuration the total length is 340 mm. An optional steel mounting bracket provides additional mechanical protection for installation on trawl doors. Fig. 2 illustrates the latest version of the data logger.

The logger's firmware manages all internal tasks and applies SD card settings, including sensor data, network credentials and thresholds. To extend deployment time, the microcontroller stays mostly in deep-sleep mode, with sensors either off or in power-saving mode. At regular intervals, a Real Time Clock RTC wakes the microcontroller to take a sensor reading (e.g. conductivity or pressure) and checks if the logger is submerged. If not in water, the system stays in standby mode, periodically checking the wireless connection to sync the RTC and the configuration from the deck unit.

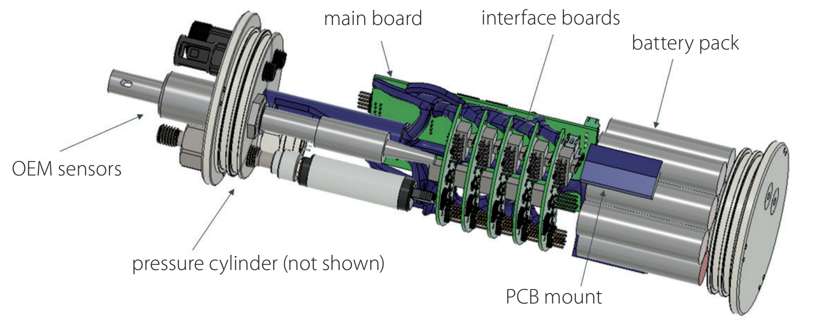

Fig. 2: Inside view of the latest data logger with its modular system components

3.4 The deck unit

The deck unit serves as the communication hub for all subsystems, providing a local wireless network, mobile connectivity and GPS reception. The main components include a Teltonika RUT955 router and a Raspberry Pi 4B single-board computer (SBC). The SBC processes measurement data and geo-references it using the visual programming tool Node-RED, storing it locally in an InfluxDB time series database. Additionally, it provides a webserver to visualise the local measurement data. The deck unit is powered externally and can operate on either 230 VAC or 9 to 30 VDC.

The router provides a wireless LAN for the Raspberry Pi, the logger and other field devices. It also offers a network time protocol (NTP) server for time synchronisation, an MQTT broker for data transmission, a GPS receiver and a gateway to the onshore server via LTE. Regularly, a Node-RED application reads the InfluxDB deployments, adds scientific metadata and creates NetCDF files for transmission to the onshore server.

A standard IP67-rated housing (180 mm × 180 mm × 150 mm) was selected for weather protection. Antennas for GPS, WiFi and LTE are placed inside to avoid cable feed-throughs. Components are secured with 3D-printed mountings. The box can be attached on deck (Fig. 3) using a steel plate mount, water-cut, and clamped to the vessel's railing with U-shaped bolts of different sizes.

3.5 The onshore server

The onshore server is the central component for data management and transfer, featuring a relational database (MariaDB), a VPN server and a web interface for data visualisation and remote configuration. It stores all relevant metadata and configuration data for the subsystems in operation, their integrated sensors and the respective fishery vessels. The database also maintains sensor specifications and calibration histories, ensuring the traceability of measured values – an important feature for autonomously acquired data with no manual editing. The system automatically checks all stored measurements for outliers, incorrect coordinates and irregular timestamps.

A configuration interface allows for remote management of the loggers and deck boxes in

Fig. 3: Mounting of the data logger on the trawl doors and the deck unit of the roof

the field. It visualises the last known position of the systems, their state of charge and memory capacity. New configuration files can be created remotely and automatically picked up by the deck units in the field.

Currently, the system interfaces with the Beluga Navigator of Geomar Helmholtz Centre for Ocean Research Kiel (https://beluga.geomar.de/hyfive), with plans to integrate additional databases in the future.

4 Field deployments: Trawling and coastal gillnet fishery

So far, the existing systems have been tested in over 150 deployments in fisheries and various citizen science applications. The results for two important use cases are presented in more detail below.

4.1 Trawling test deployment

The HyFiVe system was used during trawling operation on the FFS *Clupea* in the Warnemünde area. The mounting of the deck unit and the data loggers is shown in Fig. 3. The system successfully collected and transmitted data on salinity, temperature and dissolved oxygen while the vessel engaged in routine fishing activities (three trawls on December 6, 2022 and four trawls on December 14, 2022).

All data were transmitted to the onshore server, where they can be accessed at the webserver http://hyfive.info:4001. Within this measurement campaign, 140 minutes of underwater data were collected at a 1 Hz measurement frequency (>18,000 parameter sets) over a period of eight days in a coastal area extending three nautical miles along the coast. This underscores the potential of this measurement method to significantly enhance the spatial and temporal resolution of data density.

Fig. 4 illustrates screenshots from one selected deployment showing a table with metadata, graphs with measurement data for each parameter and the underwater track in a map.

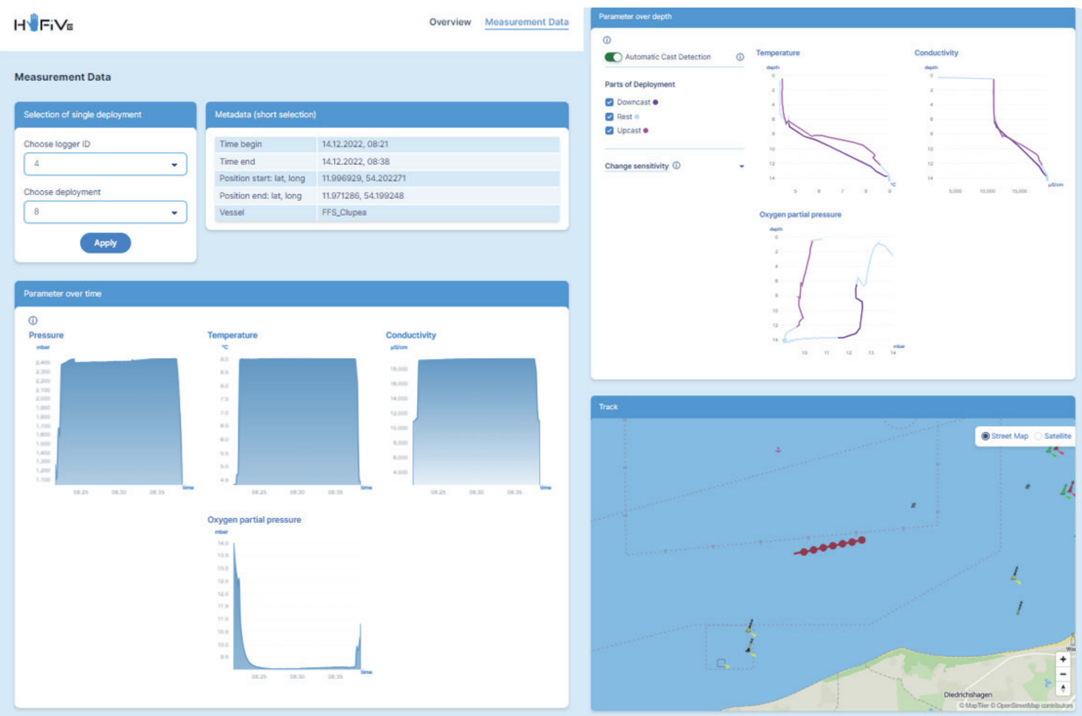

Fig. 4: Screenshots from one selected deployment at December 6, 2022, showing a table with metadata, graphs with measurement data for each parameter and the underwater track on a map

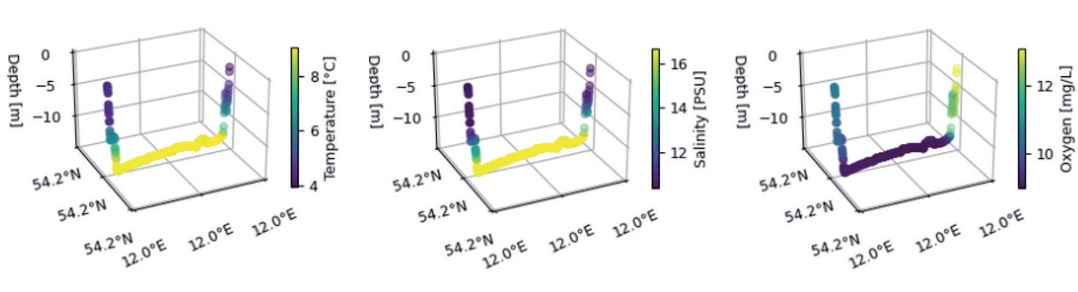

Fig. 5: Processed values by depth: temperature, salinity and dissolved oxygen (left to right)

Upon submersion, the logger successfully detected the start of each deployment and measured all parameters at a frequency of 1 Hz until the deployment's conclusion. After surfacing the logger automatically transmitted the data to the deck box where the corresponding coordinates were added. The 3D plots of latitude, longitude and depth in Fig. 5 display the processed values for temperature, oxygen and salinity from the selected trawl in Fig. 4.

Temperature and salinity increase with depth, while dissolved oxygen slightly decreases, which is typical for this region in winter. Even near the bottom, with approximately 10 mg/l of dissolved oxygen, there is sufficient oxygen for fish to survive, making this information also valuable for fisheries.

4.2 Coastal gillnet fishery deployment

The system was also deployed in coastal gillnet fisheries, demonstrating its versatility in nearshore environments. Over the past year, two systems were tested by coastal fishermen from Travemünde and Kühlungsborn area. These fishermen, who typically operate gillnets on their own vessels, used the system to measure profiles from the surface to the seafloor at specific positions along transects (Fig. 6). The transects which start in deep waters and extend towards shallow waters close to shore are about 2 km long and provide valuable data on the water column's hydrographic properties. For the Kühlungsborn transect a zoom is integrated in Fig. 6 as well as a picture showing the fisherman monitoring one station. This is done by slowly lowering the data logger by hand on a rope from the surface to the ground and back.

The mission of this campaign is to conduct regular transect measurements (weekly), particularly during periods when oxygen deficiency zones are expected (June to November), in order to obtain meaningful data for observing this phenomenon. The future plan is to define similar transects along the entire German Baltic Sea coast and have them sampled by fishermen.

A closer examination of the monitoring results in Fig. 7 reveals the presence of two distinct water masses separated by a halocline at a depth of

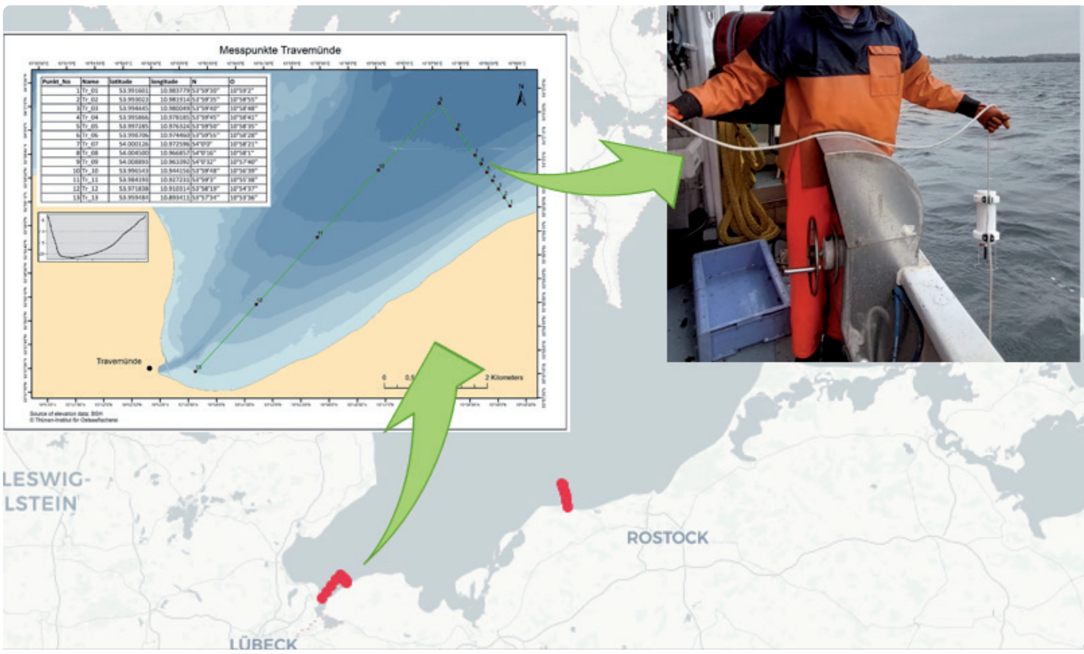

Fig. 6: Small scale fishery monitoring campaign

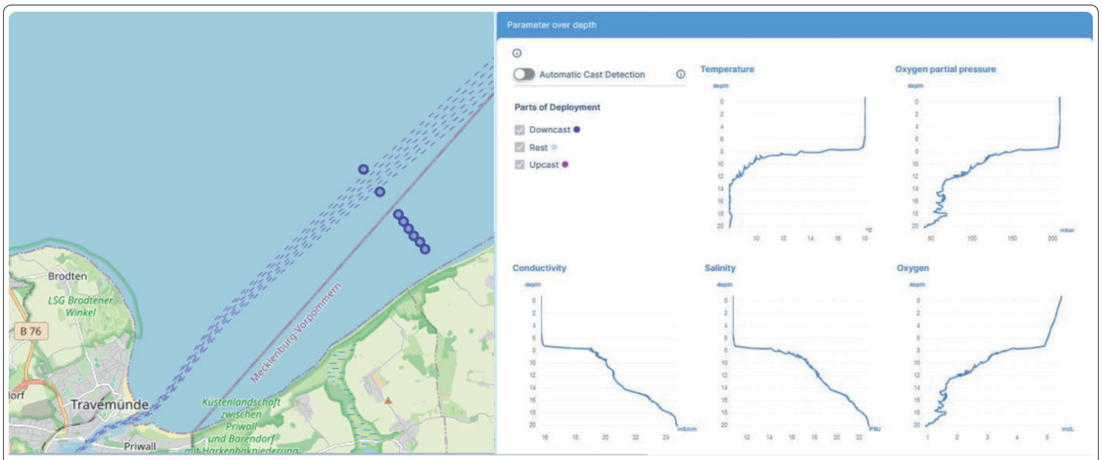

Fig. 7: Measuring results (4.7.24, 12:50) close to Travemünde indicate hypoxia below 11 m depth

approximately 9 metres. The lower water mass exhibits higher salinity and lower oxygen levels, with oxygen concentrations dropping below 2 mg/l at depths greater than 11 metres which indicates hypoxic conditions (Rosa et al. 2021) in which fish could not stay. Setting a gillnet here would have no chance of success.

5 Discussions and limitations

The HyFiVe system represents a significant advancement in autonomous hydrographic monitoring, but its current limitations need addressing to achieve full potential. The primary issue is that only ten systems have been deployed so far, restricting extensive testing across varied environments. This limited deployment hampers the identification and correction of weaknesses or hidden errors that may affect system robustness.

Limited deployment and testing

With the current systems primarily tested in the Baltic Sea, broader deployments are needed to evaluate performance in different geographic locations and conditions. Without this, potential issues in sensor integration, data processing and hardware durability might remain undetected, which could compromise the system's reliability over time.

Hidden errors and system robustness

The system's modular design introduces flexibility but also risks hidden errors, particularly in integrating various sensors and maintaining long-term operational stability. These issues must be identified and resolved to ensure consistent performance across diverse conditions.

Scaling and continuous improvement

To overcome these limitations, expanding the number of deployed systems is essential. More extensive use would provide valuable data for rigorous testing and iterative improvement, helping to eliminate persistent issues. Feedback from users will be crucial in guiding these enhancements.

Long-term reliability

The long-term reliability of HyFiVe must be validated through extended use. This includes assessing the durability of components, the stability of data transmissions, and the consistency of sensor performance. Developing effective maintenance strategies and field repair options, will be critical.

In summary, while HyFiVe is a promising tool for oceanographic monitoring, addressing these limitations through broader deployment, ongoing testing and continuous refinement is essential to fully realise its potential.

6 Perspective and conclusion

The HyFiVe system marks a significant advancement in autonomous hydrographic monitoring, offering exceptional flexibility and modularity that make it applicable across diverse domains, from citizen science initiatives to environmental monitoring by small-scale and commercial fisheries. By embracing an open-source approach, with all resources and documentation available on GitHub, HyFiVe not only promotes transparency but also encourages widespread adoption and adaptation, including commercial reuse. To date, ten systems have been successfully developed and deployed, contributing to small-scale fisheries like SeaRanger (de Graaf et al. 2023), contributing to citizen science projects and supporting the development of early warning systems for marine hazards such as hypoxia, blue-green algae and Vibrio bacteria through initiatives like the Prime-Prevention project (AWI 2024). We warmly invite collaboration from the scientific community and other interested parties to utilise, enhance and expand the capabilities of the HyFiVe system, with all necessary tools and resources available through our GitHub repository.

7 Funding

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