Title: An Autonomous Flow Through Salinity and Temperature Perturbation Mesocosm System for Multi-stressor Experiments

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Abstract

The rapid environmental changes in aquatic systems as a result of anthropogenic forcings are creating a multitude of challenging conditions for organisms and communities. The need to better understand the interaction of environmental stressors now, and in the future, is fundamental to determining the response of ecosystems to these perturbations. This work describes an automated *ex-situ* mesocosm perturbation system that can manipulate several variables of aquatic media in a controlled setting. This perturbation system was deployed in Kongsfjorden (Svalbard) where ambient water from the fjord was heated and mixed with freshwater in a multifactorial design to investigate the response of mixed kelp communities in mesocosms to projected future Arctic conditions. The system employed an automated dynamic offset scenario where a nominal temperature increase was programmed as a set value above real-time ambient conditions in order to simulate future warming. A freshening component was applied in a similar manner where a decrease in salinity was coupled to track the temperature offset based on a temperature-salinity relationship in the fjord. The system functioned as an automated mixing manifold that adjusted flow rates of warmed and chilled ambient seawater, with unmanipulated ambient seawater and freshwater delivered as a single source of mixed media to individual mesocosms. These conditions were maintained via continuously measured temperature and salinity in all 12 mesocosms (1 control and 3 treatments, all in triplicates) for 54 days. System regulation was robust as median deviations from nominal conditions were < 0.15 for both temperature (°C) and salinity across the 3 replicates per treatment. Regulation further improved during a second deployment that mimicked three marine heatwave scenarios where a dynamic temperature regulation held median deviations to < 0.036°C from the nominal value for all treatment conditions and replicates. This perturbation system has the potential to be

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implemented across a wide range of conditions to test single or multi-stressor drivers (e.g., increased temperature, freshening, high CO_2) while maintaining natural variability. The automated and independent control for each experimental unit (if desired) provides a large breadth of versatility with respect to experimental design.

1 Introduction

The persistent burning of fossil fuels since the industrial revolution has radically increased atmospheric CO_2. This has led to an enhanced greenhouse effect resulting in a multitude of changing climatic elements such as increasing sea surface temperature (Bindoff et al., 2019). In fjord systems, the confluence of increased fluvial inputs, glacier and permafrost meltwater, stratification and water mass intrusion, as well as increased sea surface temperatures can create periods of extreme physicochemical conditions for nearshore benthic and pelagic marine communities (Bhatia et al., 2013; Poloczanska et al., 2016; Divya and Krishnan, 2017; Bindoff et al., 2019). As ocean changes progress, the need to better understand the effects of combined stressors (e.g., increased temperature and freshening) on marine communities is essential to understand how community function and species richness will be affected while ecosystems adjust to these new environmental conditions (Kroeker et al., 2017; Wake, 2019; Orr et al., 2020). Several methodological approaches have been used to assess and characterize the response of organisms and communities to future ocean changes, such as *ex-situ* experimentation, the use of natural analogues (e.g., CO_2 vents), and space-for-time substitution (using spatial phenomena to model temporal changes) (Blois et al., 2013; Rastrick et al., 2018; Bass et al., 2021). These approaches, however, can be limited from testing the full range and dynamics of present and future environmental conditions. The use of *ex-situ* experimental

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systems that manipulate multiple environmental conditions, such as temperature and salinity, can therefore provide a valuable tool to assess the response to multi-stressors in a future ocean.

The necessity of conducting multi-stressor experiments has become more pressing due to the increasing interactions of environmental drivers within dynamic systems under a changing climate (Kroeker et al., 2020). Nearshore regions can experience amplified modulations of temperature and salinity on short timescales (Evans et al., 2015; Hales et al., 2016; Fairchild and Hales, 2021). Such instances have been observed in sub-Arctic estuaries where water temperature at a depth of 10 m decreased by 1.5°C in < 10 h, and in temperate systems where the magnitude of salinity change driven by high precipitation displayed a decrease of 4 units in < 24 h (Miller and Kelley, 2021; Poppeschi et al., 2021). Changes of this magnitude are particularly pertinent for Arctic fjords, where the variations in salinity from glacial meltwater can influence whether a system exhibits net heterotrophic or autotrophic characteristics (Sejr et al., 2022).

Recent advances in the ability to modulate several environmental parameters at once using *ex-situ* mesocosms have been made via the use of modular programmable systems (Wahl et al., 2015; Pansch and Hiebenthal, 2019). Such systems have demonstrated an ability to apply programmable environmental scenarios as a multifactorial design, or as a delta-change (offset) from ambient conditions that mimic the natural variability of an environment. The advantages of these types of automated systems lie in their ability to overcome the need for capturing and measuring abundant discrete measurements used to regulate experimental conditions, and transcend the logistical difficulties of implementing natural variability to experimental designs. In addition, these systems can reduce the need for constant human observation which may be required to program new regulatory operations or make rapid adjustments to experimentally manipulated conditions.

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Here, we describe an autonomous salinity and temperature experimental perturbation mesocosm system (SalTExPreS) that has the ability to modify, and then regulate, salinity and temperature in real-time. The SalTExPreS can perform similar functions as the *ex-situ* mesocosm systems discussed above (i.e., Kiel-outdoor and -indoor benthocosms), such as applying programmable static or dynamic changes to temperature and salinity, or by replicating natural variability as on offset in real-time, but has the added capability of autonomous control for each experimental unit (e.g., chamber or mesocosm). In the initial deployment of the SalTExPreS, we applied a delta offset (i.e., offset from a measured control) to temperature and salinity as a fractional-factorial treatment design for a two-month long experiment in KongsFjorden, Svalbard, that exposed mixed kelp communities to future temperature, salinity, and irradiance. This study demonstrates the stability and flexibility of the SalTExPreS as an experimental tool to be utilized under extreme and dynamic conditions to test the effects of physicochemical multi-stressors on marine organisms and communities in the context of a multi-month experiment.

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2 Methods

2.1 Operational Concept of the Experimental System:

The SalTExPreS simulates the drivers in a marine or freshwater system such as temperature, freshening, acidification, or hypoxia as either static or as temporally-variable modifications to a reference water source. This is accomplished by mixing manipulated source water, whether it is freshwater or warmed water, with ambient water through automatic flow valves that control the volume and rate of water delivered. This is regulated by the constant monitoring of the mixed water conditions in each mesocosm or chamber via a programmable feedback loop that transmits the opening or closing of the automatic flow valves. The automated ability of the SalTExPreS is

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configured to respond to near instantaneous measurements (several reads per second) to achieve high frequency regulation of the manipulated drivers based on a measured *in-situ* or control reference. The programmable nominal conditions in each mesocosm are easily controllable through an intuitive user interface.

2.2 Site Description and Experimental Design

Kongsfjorden is a fjord system on the west coast of Svalbard (Norway) where the West Spitsbergen Current exchanges warm Atlantic water through sill channels based on differences in density gradients at the fjord mouth. Over the past two decades, a persistent influx of Atlantic water has resulted in the reduction of sea ice and the melting of marine-terminating glaciers causing enhanced freshwater and fluvial input (Luckman et al., 2015; Tverberg et al., 2019). The influx of freshwater is highest in summer and is accompanied by an important sediment loading with the potential to reduce the euphotic zone from 30 to 0.3 m depth (Svendsen et al., 2002). These climatic changes in the Kongsfjorden environment set a relevant context for the inaugural experiment of the SalTExPreS. It was placed on a concrete platform situated ~ 12 m from the shoreline in Ny-Ålesund, which is located on southwestern shore of Kongsfjorden ~ 11 km from the fjord mouth.

The SalTExPreS was utilized to implement three treatment scenarios in a fractional-factorial design to simulate expected future conditions in Kongsfjorden for a 54 d experiment that supervised the productivity, survival, and growth response of mixed kelp communities surveyed at 7 m (maximum depth of collection). The treatments were realized by multi-driver combinations of temperature, freshening, and irradiance, where treatments 1 and 2 differed in the magnitude of temperature increase, salinity decrease, and irradiance decrease (Table 1). Only

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temperature was manipulated for treatment 3. The chosen treatment and salinity perturbations were applied as offset values from *in-situ* fjord conditions, which were measured at an underwater observatory fixed at 11 m depth and captured the natural variability of the fjord system. The applied temperature offsets used for this experiment reflected the projected SSP2-4.5 and SSP5-8.5 scenarios (Meredith et al., 2019; Overland et al., 2019; Table 1). The chosen decreases in salinity were based on correlations between *in-situ* temperature and salinity during summer 2020 in Kongsfjorden (Gattuso et al., 2023), weeks 22 to 35 (Appendix A1 and Fig. A1). These calculated delta salinity values were applied as offsets in treatments 1 and 2 (Table 1). The third treatment scenario applied a temperature change of + 5.3°C as a way to decouple the multi-stressor system and evaluate a temperature only stress. The effect of turbidity for treatments 1 and 2 were simulated as a decrease in surface irradiance (i.e., ~ 25% and ~ 40% reduction from ambient irradiance at 7 m) by applying a combination of neutral light and spectral filters (LeeⒸ Filters) placed as static fixtures over the top of the mesocosms. The response of these kelp community assemblages was determined in part by conducting weekly closed system incubations and assessing the growth and metabolism of the kelp in each mesocosm—details and results of this experiment are discussed elsewhere (Lebrun et al. *in review*; Miller et al., *in review*).

2.3 Experimental System

Water was pumped from Kongsfjorden at a 10 m depth (300 m offshore) using a submersible pump (NPSⒸ Albatros F13T) that was tapped into an underwater intake pipe and that fed a header tank in the Kings Bay Marine Laboratory in Ny-Ålesund, Svalbard. To prevent clogging from sediment, the pump was situated at a 10 m depth ensuring a safe height above sediment

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resuspension from the floor. Pumped ambient seawater from the header tank was then split into three sub-header tanks within the marine lab where ambient water was (1) left unchanged, (2) chilled to 0°C, or (3) warmed to 15°C. Each sub-header tank was plumbed to supply a maximum flow of 6 m^3 h^{-1} for the ambient, 1 m^3 h^{-1} for chilled, and 2 m^3 h^{-1} of warmed water which required a pressure of 0.3 bars for each line to ensure consistent flow rates (Fig. 1). The three control mesocosms received a mix of chilled and ambient seawater in order to properly simulate *in-situ* temperatures. The three experimental treatments (nine mesocosms in total) received a mix of ambient, warmed, and freshwater for treatments 1 and 2, whereas treatment 3 received a mix of just ambient and warmed water (Fig 1). Freshwater was sourced from the tap which is fed by the Tvillingvann reservoir close to Ny-Ålesund. The total flow-through rate of each mesocosm was 0.5 m^3 h^{-1} (i.e., each mesocosm turned over every 2 h) of post-mixed media delivered in an open cycle flow-through system which was the necessary flow rate needed to maintain the target nominal values. Continuous flow was maintained throughout the experiment except for weekly 3 h interruptions (to perform experiments on the community) where the flow to each mesocosm was shut off. In total, there were twelve circular mesocosms (3 treatments and 1 control, each with 3 replicates) with a mean diameter of 1.1 m and a volume of 1 m^3, each equipped with a 12 W wave pump (Sunsunⓒ JVP-132), a temperature-conductivity probe (Aqualabo, PC4E), an optical oxygen sensor (Aqualabo, PODOC), and an Odysseyⓒ light logger. Fiberglass insulation at the outside of each mesocosm reduced unintended changes in treatment water temperature.

Delivery of ambient, chilled, warmed and freshwater first ran through an automated mixing manifold that regulated the flow of each media type assuring that proper volumetric proportions passed through the regulator valves to achieve target conditions (Fig. 1). Each source-water flow line was regulated by an automated 2-way mixing valve (including the

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incoming freshwater line) which then passed through a 3-way mixing valve that was assigned to each mesocosm (12 in total, Fig. 1). This style of regulation ensured that the proper proportions of manipulated media and ambient water were mixed to achieve nominal conditions. Any temperature variation induced by mixing freshwater was immediately compensated for by regulating the flow of the warm water line. Details regarding the programmed regulation are discussed further in the appendix (Section A2). The mixed media then passed through a flow meter which measured the flow rate to each mesocosm. A hand-crank regulating valve was placed directly after the flow meter and was used for making minor adjustments and controlling the overall flow. Measurements by the pressure sensors, the status of open position for the regulator valves, and flow rates were logged every minute and displayed on the user interface (Fig. A3).

2.4 Nominal Regulation

Nominal temperature conditions of + 3.3, 5.3, and 5.3°C applied to treatments 1, 2, and 3, respectively, were offsets from the nominal control temperature. The nominal temperature of the control was updated hourly and programmed to replicate the measured *in-situ* conditions in the fjord logged by the AWIPEV (Alfred Wegener Institute and Institute Paul Emile Victor) FerryBox part of the COSYNA underwater observatory (https://dashboard.awi.de/) situated at a depth of 11 m. Each treatment condition (temperature and salinity offset) was set by manually programming the nominal value of temperature in the software interface (see appendix A3). The salinity offset was coupled to the nominal temperature via the correlation described in appendix A1. The measured temperature and salinity observations from inside each mesocosm were recorded multiple times per minute and used to continuously monitor the regulation of the

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conditions inside each mesocosm. This data transmission was used to program the software controller that performed the automated regulation of mixed media (for details see appendix A2).

2.5 Software

The software application used for the control of the SalTExPreS was developed using Visual Studio Community (2019 edition) with the vMicro extension and Arduino 1.8.13. The program application has a user-friendly interface designed to allow real-time monitoring and parameterization of regulation processes (Fig. A3). The main window displays each mesocosm condition (the parameters measured by a sensor), their piping connections, a connection status for each Programmable Logic Controller (PLC) informing on proper communication, date and time of the last received communication packet from the Head PLC, and the status of the experiment (e.g., started or stopped). The interface also displays the valve opening percentage along with the nominal pressure and the actual measured value for each main source-water inlet. In addition, the *in-situ* data (temperature and salinity) received from the FerryBox is displayed with the time and date of the last logged value utilized to program the real-time nominal value of the control. Sensor readings of flow rate (L min^{-1}), O_2 saturation (%), salinity, and temperature (°C) are shown for each mesocosm in conjunction with the treatment nominal values (i.e., temperature, and salinity when relevant). All measured data are stored through the server connection to the cloud, however, there is a backup microSD card on the Head PLC that logs data from all mesocosms every 5 sec. If communication fails between the Head PLC and the interfaced computer, data will not be retrieved by the PC during the communication break but will be retained by the microSD card.

3 Results

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3.1 Regulation of the Control

The control was able to simulate the ambient fjord temperature well over the experimental period where the average value across the 3 replicates deviated < 0.3°C (Table 2, Fig. 2). The overall quality of the regulation was achieved by the ability of the system to interpret and respond to the measured data from the FerryBox (or to follow a manually programmed nominal value when communication with the FerryBox was interrupted). During the experiment, the FerryBox went intermittently offline 24% of the time, ceasing transmission of real-time data that resulted in a break of communication to the PLCs. This somewhat frequent break in communication resulted in an average nominal deviation that was nearly double for the control compared to the treatment conditions (Table 2). The ability to manually program a new nominal value when communication breaks occurred ensured that the control remained robustly regulated. Over the entire period of the SalTExPreS deployment, the mean temperature of the control increased from ~ 4 to 6.5°C from early July to the end of August (Fig. 3a). The coldest mean temperature of the control occurred when a backup pump situated at 90 m depth in the fjord was used from 2021-07-14 ~21:00 UTC until 2021-07-26 13:49 UTC while the original pump at 10 m depth was repaired. During this period, the control was ~ 1.0 – 1.5°C cooler than the temperature measured by the FerryBox (Figs. 2, 3). Since a warmed seawater inlet was not supplied to the control, the temperature of the control remained cooler than the measured ambient conditions at the FerryBox. Despite the cooler temperature for the control, regulation of flow rates, mesocosm turnover time, and variability across the control replicates was well maintained by the system.

1.2 Temperature and Salinity Regulation

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The regulation of temperature and salinity in the different treatment conditions (Trts. 1 – 3) was maintained by the SalTExPreS for the full planned duration of 54 days (2021-07-03 to 2021-08-26). For the first 6 days of the SalTExPreS experiment, the treatment conditions were held at the control (i.e., no applied offset from the control) before the stepwise increase in temperature began. On 2021-07-10 12:00 UTC a temperature offset of 0.55°C d^{-1} was programmed for treatment 1 while treatment 2 and 3 were programmed to increase by 0.88°C d^{-1} (Figs. 2, 3). The final nominal temperature above the control was reached on 2021-07-15 21:00 UTC. The system needed 4 h to achieve the new temperature conditions (i.e., homogenize the mesocosm to a 0.88°C increase). A manual override was applied to the salinity regulation for treatments 1 and 2 which resulted in the system achieving the final salinity offset value upon the initial temperature increase (Fig. 3b, 4). This was done to ensure the maintenance of salinity regulation as the temperature offsets were applied relative to the control, which was receiving fjord water pumped from 90 m and was colder than the measured *in-situ* conditions. It took the system 4 h to achieve the salinity offset for treatment 2 adjusting the value from ~ 34 to 29.8 (Fig. 3b, 4).

The precision of the temperature and salinity regulation across all treatment conditions was well maintained as the mean difference between the measured value and the nominal value was < 0.2°C and < 0.36 for salinity across the entire deployment (Table 2). The mean deviations observed across treatments did not appear to correlate to the degree of offset. Thus, treatment 3 showed the highest precision for temperature regulation, while salinity regulation was the most robust for treatment 2 compared to treatment 1 (Table 2). During several instances when communication was interrupted between the FerryBox and the Head PLC, the SalTExPreS retained the last measured value at the FerryBox as a contingency protocol. This aided in the ability of the system to maintain a high degree of regulation throughout the entire deployment.

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The largest deviation from the nominal value for all treatment conditions occurred during the single instance in which the last read value from the FerryBox was not retained: this occurred on 2021-08-24 04:47 UTC (Fig. 4). Communication was quickly restored after this incident by cycling the program code, and the average deviation of temperature (°C) and salinity for treatment 1 for the remainder of the deployment was < 0.16, and < 0.25 for treatment 2.

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When adequate flow rates were maintained, the SalTExPreS was able to simultaneously regulate 12 mesocosms at 4 different conditions to deviations in temperature and salinity that were < 0.5°C or 0.5 in salinity from the nominal value ≥ 80% and ≥ 70% of the time, respectively (Fig. 5). Due to an erroneous nominal value for the control during the 90 m pump usage, these times were excluded. If warm water could have been mixed with the ambient water feeding the control mesocosms, then a proper nominal value could have been maintained. Over the full duration of the experiment, effective regulation from the nominal temperature and salinity values were kept to < 1 for all mesocosms 89% of the time for temperature (°C), and 80% for the salinity (excluding the 1st replicate for treatment 2).

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Discussion

The first application of the fully autonomous SalTExPreS demonstrated the capacity of the system to successfully manipulate temperature and salinity as an offset value from the control, thus maintaining, natural, *in-situ* variability for 4 different conditions simultaneously. We utilized this deployment to test the effects of climate change drivers on Arctic kelp communities recognizing the feasibility of the system to perform *ex-situ* experiments on organisms or whole communities (Miller et al., *in review*). The versatility of the system not only allows for the manipulation of temperature and salinity, but can incorporate other factors such as CO_2 or

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hypoxia (Gazeau et al., *in prep*). While this experiment used a control offset approach to produce treatment conditions, programmable parametrization of various treatment combinations can be applied depending on the question and design of the experiment. The automated component of the system reduced the logistical hurdles that can arise when performing high precision replication and regulation of experimental conditions that track real-time system variability. While the use of such a system can reduce user oversight and limitations, there is still a need for diligent operation.

Since the initial experiment, we have implemented a number of changes to improve the performance of the system which have been realized during a second experiment in the summer of 2022 (Fig. 6). In this experiment, the SalTExPreS was integrated to function with a deployable heat pump to simulate multiple scenarios of marine heatwave patterns over a nearly month-long experiment. In this instance, temperature regulation was vastly improved as a result of the programmable modifications made since the initial experiment. During this second experiment, the SalTExPreS mimicked 3 marine heatwave scenarios where a dynamic temperature regulation kept deviations in the 9 different mesocosms at < 0.5°C for 94% of the time. This was an improvement to the % time of temperature regulation by ~ 15% compared to the first experiment. During the first experiment, inconsistent flow rates and communication errors between the FerryBox and the Head PLC were the primary causes of larger deviations (> 2.0 salinity or °C) from nominal values. For example, flow rates of < 2 L min^{-1} accounted for ~ 20% of the large deviations in temperature and salinity regulation. Simple software modifications such as 'pop-up' alert windows that warned when a lapse in communication with the FerryBox occurred (e.g., FerryBox stopped logging), and the addition of contingency coding instructions (i.e., fail-safe instructions) ensuring that the last received *in-situ* data were maintained solved

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most of the issues. Communication errors were easily remedied by cycling the power on a PLC, which is why pop-up alerts were an improvement to the operation. Other extraneous circumstances that could impact flow rates, such as pump failure and clogging of the seawater intake ports, are issues that need to be addressed whenever the SalTExPreS is used. However, these are very manageable situations which can be easily mitigated by an operator.

The novelty of the SalTExPreS lies in its ability to independently regulate experimental conditions in a single experimental chamber (e.g., mesocosm). The operational data produced from this deployment are reliable, easily quantifiable, and provide the highest degree of monitoring frequency for every applied experimental condition. This study has demonstrated the system's ability to replicate dynamic nearshore environments where temperature and salinity can vary at high frequency (e.g., tidally). The system's additional capacity to mimic future scenarios by applying an amplitude offset to the natural dynamics of *in-situ* conditions is an added feature for conducting manipulative experiments. Wahl et al. (2015) described a system with a similar capability, but regulated treatment conditions by monitoring source water and adjusting that media before it was delivered to each experimental chamber. The SalTExPreS differs in that it measures the conditions inside each experimental chamber (i.e., mesocosm) and regulates them independently based on per second measurements. This provides the flexibility to individually modulate each experimental chamber providing a broad range of versatility. The lack of infrastructure needed to set up the SalTExPreS makes it easy to deploy and transport. As long as there is a sufficient supply of ambient water and manipulated media, there is little limit to the versatility of automated control for each mesocosm. Many research endeavors and future implementations by the SalTExPreS have the potential to conduct a large range of experimental settings that pertain to environmental perturbations associated with climate change or other

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anthropogenic forcings. The operation of such a system in extreme environmental conditions has shown the durability of the manifold to endure an adverse Arctic summer and still respond without mechanical failures. With proper operation and user proficiency, this proves to be a highly sophisticated and powerful tool to be utilized for marine and aquatic perturbation experiments.

Acknowledgements

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Author contributions

C.M. and F.G. conceptualized the frame of the paper while F.G, S.C, and P.U. designed the experimental system. P.U. programmed the software. C.M. wrote the manuscript, performed the data analysis, and constructed the figures and tables while P.U. designed schematic figures. All authors participated in the operation of the system and have, thus, commented, and edited during writing.

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This study was conducted in the frame of the project FACE-IT (The Future of Arctic Coastal Ecosystems – Identifying Transitions in Fjord Systems and Adjacent Coastal Areas). FACE-IT

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has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 869154. Logistical and financial support was provided by IPEV, The French Polar Institute and the Foundation Prince Albert 2 of Monaco (project: 3051, http/fpa2.org).

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Competing interest

The authors declare no competing interests exist.

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Tables

Table 1. Experimental treatment conditions with corresponding offsets (as compared to the control) for temperature (°C), salinity and photosynthetically active radiation (PAR; expressed as a percentage). See section A1 and figure A1 for a full description of the temperature-salinity relationship used to calculate salinity offsets.

Treatment	*Temperature*	*Salinity*	*PAR*
1	+ 3.3 °C	- 2.5 – 3.0 - S = 0.546*T + 0.490	- 25% PAR
2	+ 5.3 °C	- 5.0 – 5.5 - S = 0.877*T + 0.089	- 40% PAR
3	+ 5.3 °C	Ambient	Ambient

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Treatment	*Temperatur*
Cntrl.	Ambient
Trt. 1	+ 3.3 °C
Trt. 2	+ 5.3 °C
Trt. 3	+ 5.3 °C

Table 2. Absolute mean difference between measured temperature (T_{meas}; °C) and salinity (S_{meas}) values against nominal values ($T_{nominal}$ and $S_{nominal}$) plus or minus the corresponding standard deviation, in each mesocosm during the experimental period. A weighted average was used for treatments 1 – 3 to account for the initial 5-day incremental increase. Triplicate mesocosms per condition are expressed as a, b and c. Water mixture indicates the types of media supplied to each treatment, denoted with an 'x'.

Treatment	*Mean diff*	*Mean diff*	*Water mixture*			
	Abs($T_{meas.}$ - $T_{nominal}$)	*Abs*($S_{meas.}$ - $S_{nominal}$)	*Cold*	*Ambient*	*Warm*	*Fresh*
Control a	0.275 ± 0.39	–	x	x		
Control b	0.291 ± 0.36	–	x	x		
Control c	0.223 ± 0.36	–	x	x		
Treatment 1a	0.126 ± 0.31	0.116 ± 0.31		x	x	x
Treatment 1b	0.142 ± 0.29	0.148 ± 0.22		x	x	x
Treatment 1c	0.145 ± 0.33	0.171 ± 0.33		x	x	x
Treatment 2a	0.111 ± 0.29	0.357 ± 0.74		x	x	x
Treatment 2b	0.133 ± 0.29	0.149 ± 0.26		x	x	x
Treatment 2c	0.196 ± 0.38	0.128 ± 0.25		x	x	x
Treatment 3a	0.109 ± 0.27	–		x	x	
Treatment 3b	0.112 ± 0.27	–		x	x	
Treatment 3c	0.106 ± 0.28	–		x	x	

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Treatment	*Mean diff* *Abs*($T_{meas.}$ - T_{set})	*Mean diff* *Abs*($S_{meas.}$ -
Cntrl. a	0.275 ± 0.39	–
Cntrl. b	0.291 ± 0.36	–
Cntrl. c	0.223 ± 0.36	–
Trt. 1a	0.126 ± 0.31	0.116 ± 0.
Trt. 1b	0.142 ± 0.29	0.148 ± 0.
Trt. 1c	0.145 ± 0.33	0.171 ± 0.
Trt. 2a	0.111 ± 0.29	0.357 ± 0.
Trt. 2b	0.133 ± 0.29	0.149 ± 0.
Trt. 2c	0.196 ± 0.38	0.128 ± 0.
Trt. 3a	0.109 ± 0.27	–
Trt. 3b	0.112 ± 0.27	–
Trt. 3c	0.106 ± 0.28	–

Figures

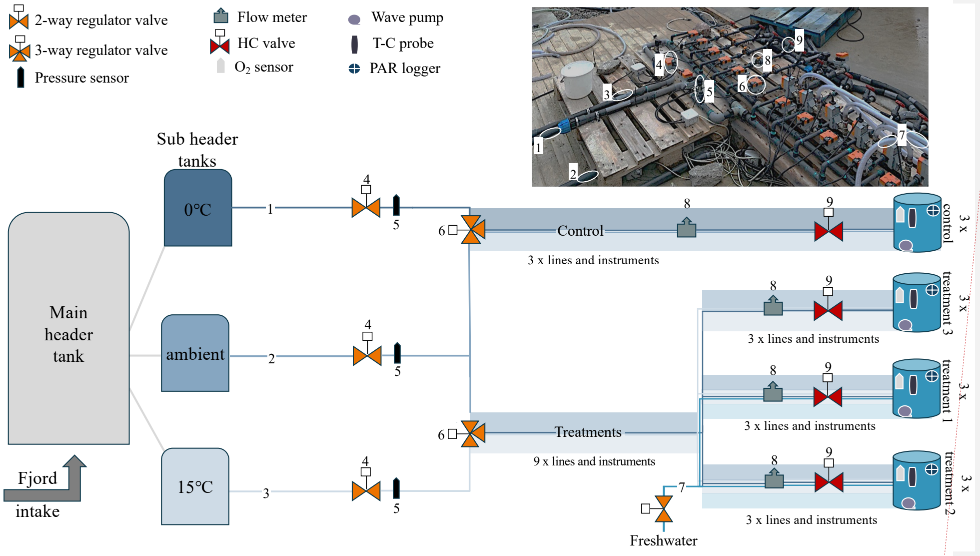

Figure 1. Piping schematic of the SalTExPreS which includes the mixing and regulation manifold. Items 1 – 3 depict the main seawater inlets from the chilled, ambient, and warmed sub-header tanks located in the Kings Bay Marine Laboratory. Seawater from each sub-header tank moves through a 2-way regulator (4) valve followed by a pressure sensor (5) before splitting into individual lines that lead to all 12 3-way regulator valves (6), each assigned to a single mesocosm. For treatments 1 and 2, the freshwater inlet (clear tube; item 7) passes through a 2-way regulator valve before mixing with the ambient and warmed seawater lines. Flow rates are then measured (8) post-mixing, and final flow rates are set using a hand-crank (HC) red valve (9). The shaded regions in the schematic indicate that mixed media lines and instruments occur 3x or 9x times. T-C probe is the temperature-conductivity probe and the PAR logger measures the photosynthetically active radiation. Photos of mesocosms and the sensors inside can be found in the appendix (Fig. A6). Table A1 provides the parts list for the items shown in this figure.

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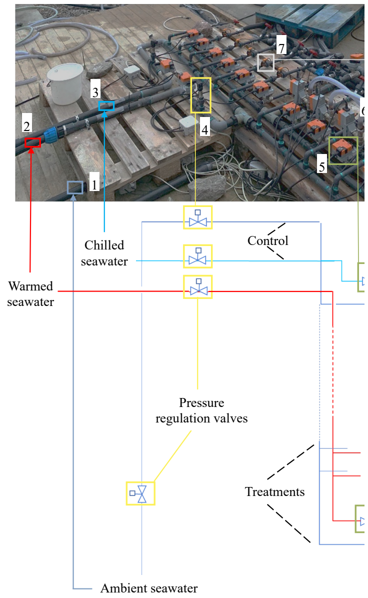

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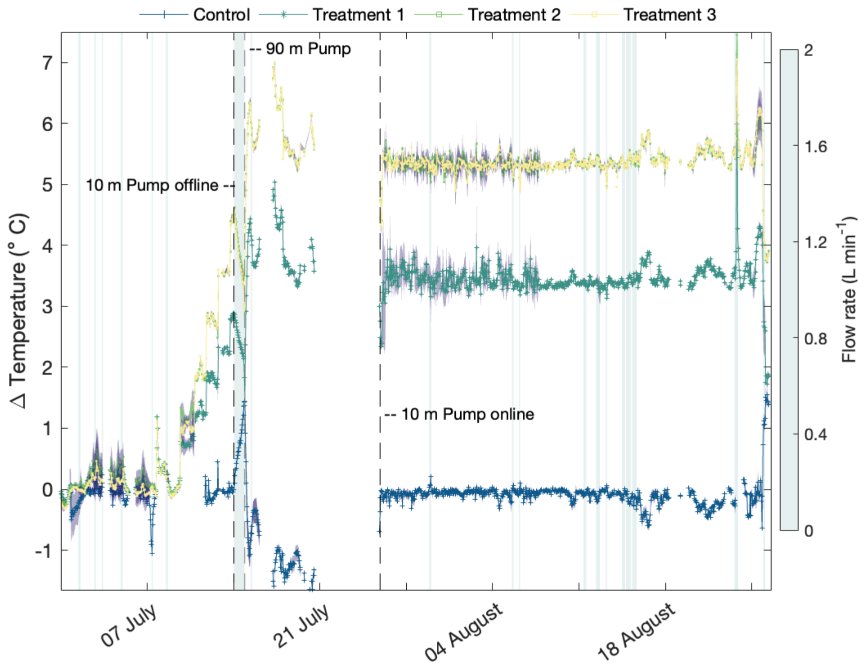

Figure 2. The hourly mean (across triplicated mesocosms) temperature offsets of all applied conditions. For control mesocosms (in blue), offsets were calculated against *in-situ* measurements (FerryBox). For the three experimental treatments (dark green, light green, and yellow for treatments 1, 2 and 3, respectively), offsets were estimated against the mean control values. The purple shaded region around the mean is the standard deviation. The heatmap isoclines (blue-grey shaded regions) are instances when flow rates were ≤ 2 L min^{-1} (threshold to avoid large deviations > 2.0 salinity or °C). Dashed black lines indicate periods when the pump at 10 m depth and 90 m depth were used to feed the sub-header tanks. The time presented is the duration of the experimental deployment.

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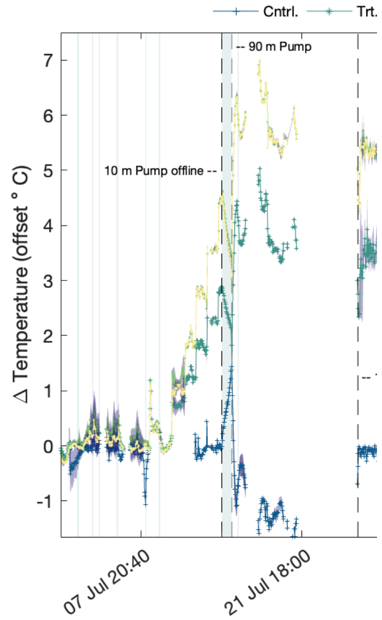

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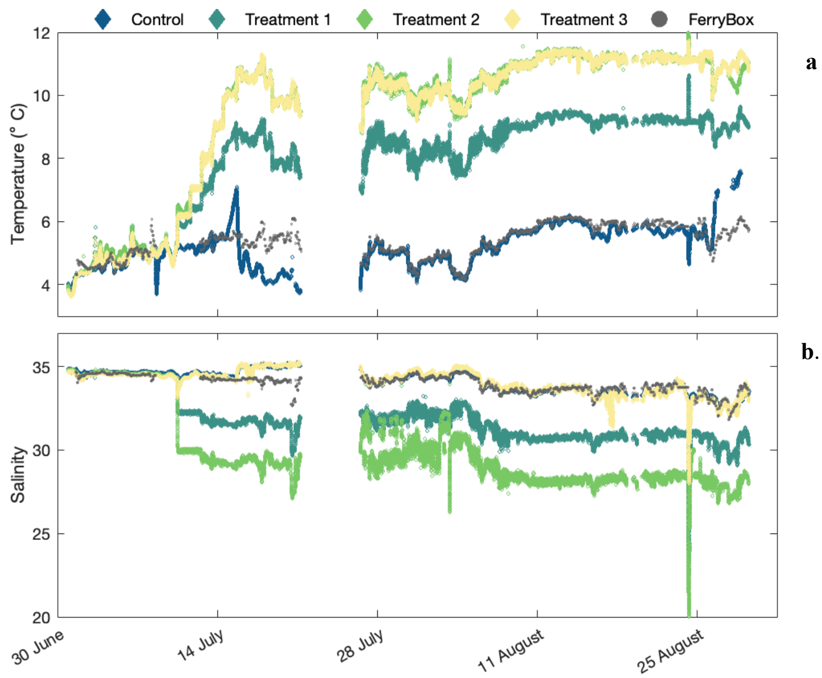

Figure 3. Mean (across triplicated mesocosms) temperature (°C; **a**) and salinity (**b**) values measured every minute over a 60 d period (including 6 day period before the start of the experiment) for the control (blue), and for treatments 1 – 3 (dark green, light green, and yellow, respectively).

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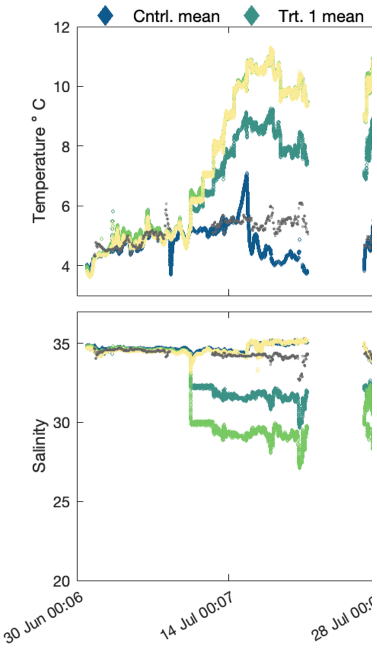

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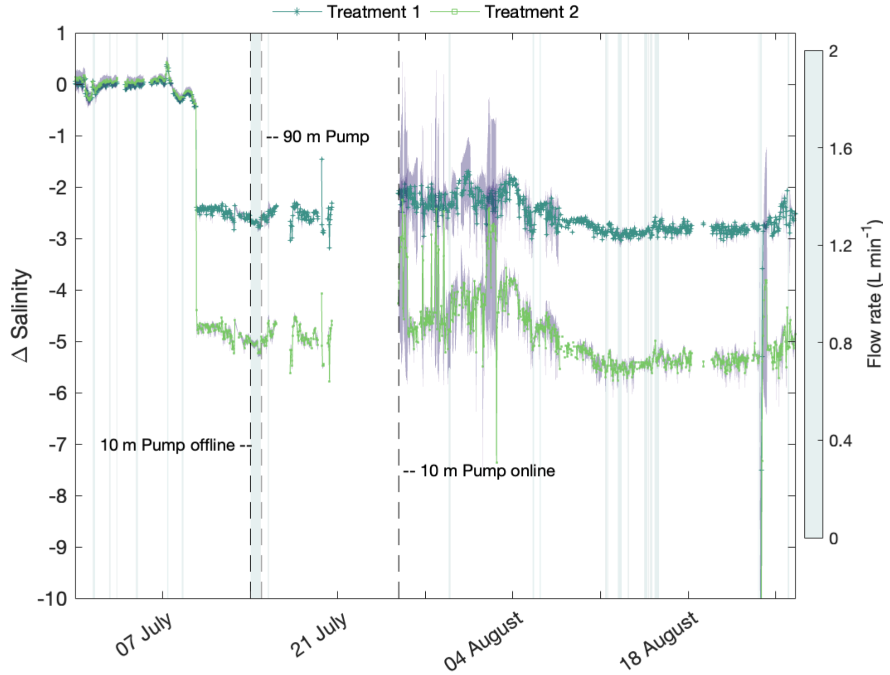

Figure 4. The hourly mean (across triplicated mesocosms) salinity offsets for the experimental period. Dark green is treatment 1 and light green is treatment 2.The purple shaded region around the mean is the standard deviation and the heatmap isoclines (blue shaded regions) are the instances when flow rates ≤ 2 L min^{-1}. Dashed black lines indicate periods when the pump at 10 m depth and 90 m depth were used to feed the sub-header tanks.

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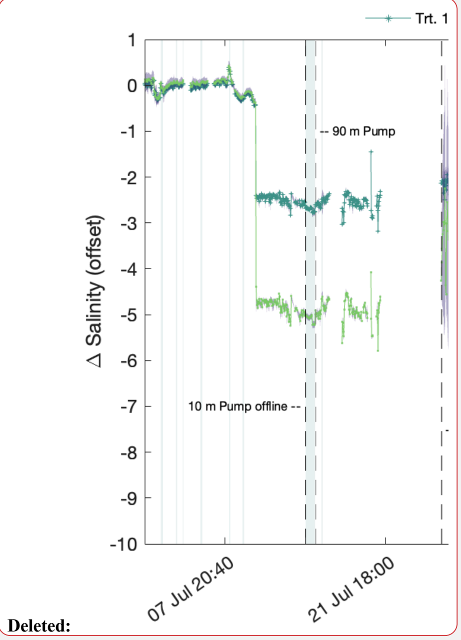

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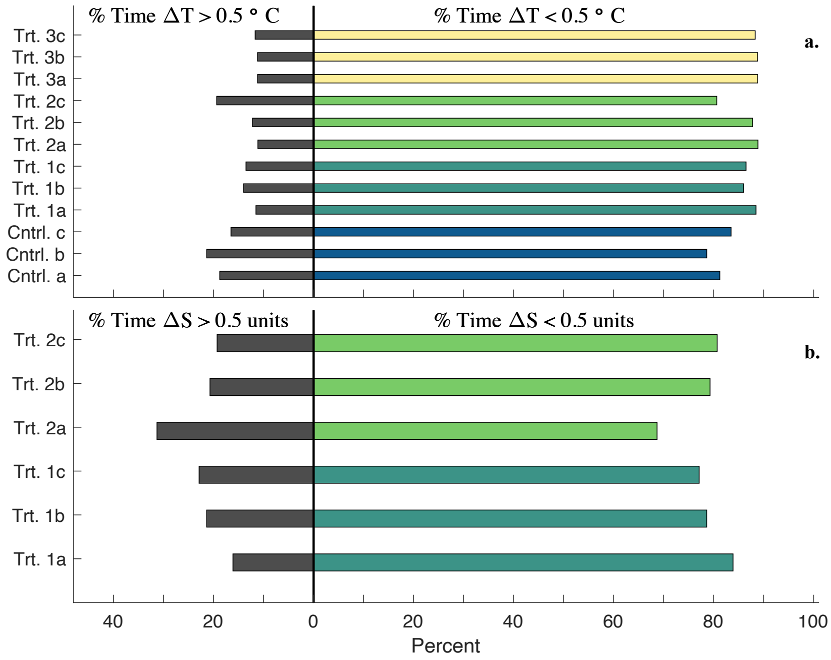

Figure 5. Percent time each mesocosm experienced a deviation > (black bars) or < (colored bars) 0.5°C (ΔT; **a**) or 0.5 in salinity (ΔS; **b**) when flow rates were above 2 L min^{-1}. Cntrl. and Trt. abbreviations are the control and treatments, respectively. This excludes the period when using the 90 m pump (12 d), but accounts for 42 days out of the 54-day experiment. Bar color indicates different treatment groups, as shown on the y-axes.

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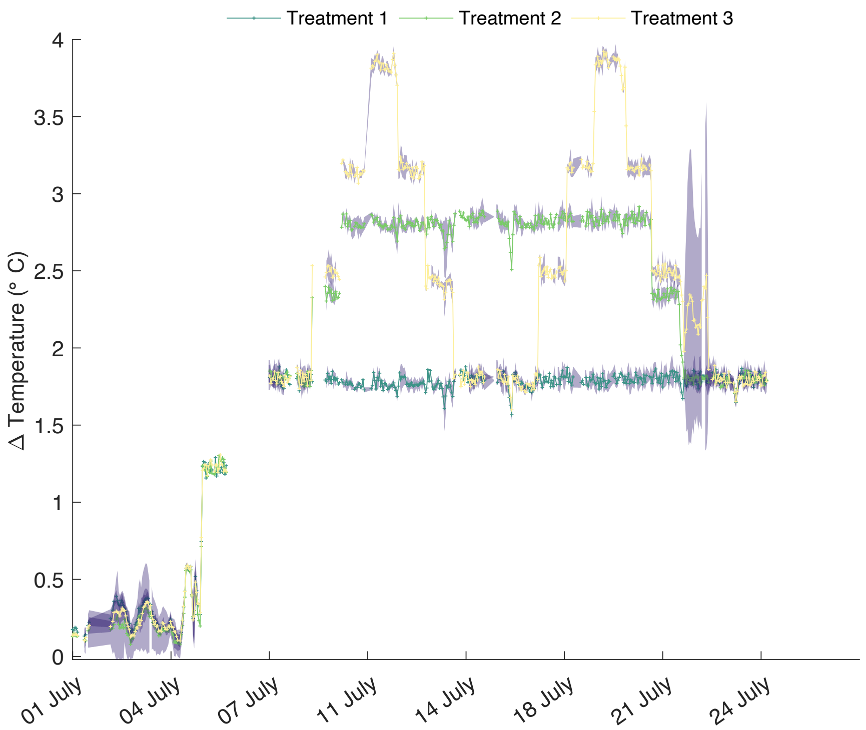

Figure 6. The hourly mean temperature offsets (Δ Temperature) during the 2nd deployment of SalTExPreS in the summer of 2022 in Tromsø (Norway) performing a variation of heatwave scenarios with three experimental treatments 1 – 3. Treatment 1 is a constant high temperature (+ 1.76°C), treatment 2 is a low frequency (1 heatwave) and medium magnitude offset (+ 2.81°C), while treatment 3 is a high frequency (2 heatwaves) and magnitude offset (+ 3.86°C). The purple shaded region around the mean is the standard deviation.

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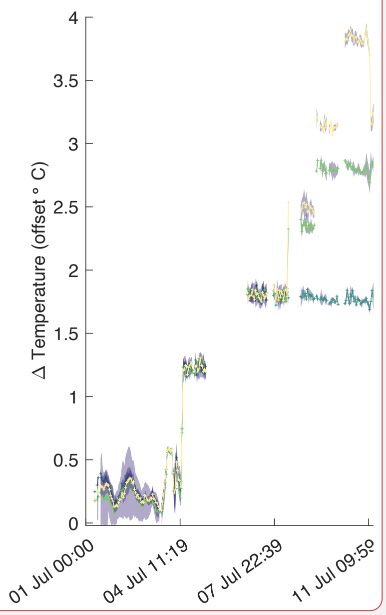

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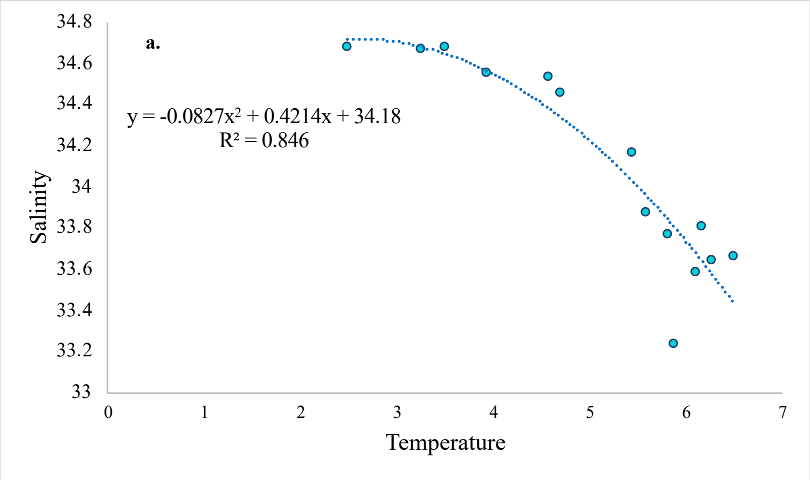
Appendix

A1. Calculation of Salinity Offset

In the summer of 2020—weeks 22 to 35— the mean temperature at 11 m displayed a range from 2.48 – 6.28, with salinity values ranging from 34.67 measured at the minimum 2.48°C and 33.63 measured at 6.28°C (Fig. A1a). The correlation was best fit with a 2nd order polynomial. To project the salinity offset at a future temperature based on this 2nd order polynomial fit, temperatures of + 3.3 and 5.3°C (SSP2-4.5 and SSP5-8.5, respectively) were added to *in-situ* fjord temperatures and salinity was calculated based on the 2nd order polynomial. These estimated salinity values were then subtracted from the mean salinity values observed (y-axis, Fig. A1a) in summer 2020 in order to calculate a delta salinity value for the SSP2-4.5 and SSP5-8.5 scenarios. The relationship between these estimated delta salinity values and the mean *in-situ* temperature (y-axis, Fig. A1a) displayed a robust linear relationship (Fig A1b).



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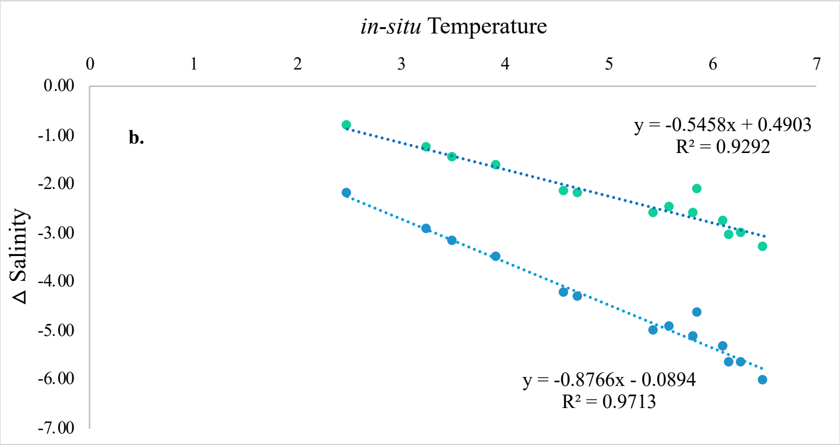

Figure A1. Relationship between temperature and salinity in summer 2020 weeks 22 – 35 in Ny-Ålesund, Svalbard (**a**). Relationship between estimated delta salinity and *in-situ* temperature, where delta salinity was calculated as the difference between the current mean salinity and the salinity estimated at the temperature increase projected for SSP2-4.5 (green dots) and SSP5-8.5 (blue dots) scenarios (**b**).

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Table A1. Parts list with manufacturer model numbers.

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Group	Item	Supplier/manufacturer	Model / details	Quantity
Hydraulic system				
	Mesocosms	home made	1000 L fiber glass	12
	Seawater pump	NPS, BradFord, UK	Albatros F13T	1
	PVC-U tubing and fittings		20mm, 32mm & 50mm diameter	–
	Insulated flexible hose		19mm diameter	100 m
Sensors				
	Conductivity / temperature	Aqualabo, Champigny sur Marne, France	PC4E	12
	Oxygen	Aqualabo, Champigny sur Marne, France	PODOC	12
	Pressure	Siemens, Munich, Germany	7MF1567-3BE00-1AA1	3
	Flow rate	IFM, Essen, Germany	SV3150	12
Actuators				
	Pressure regulation valves	BELIMO, Hinwil, Switzerland	R2025-10-S2 with LR24A-SR motor	3
	Temperature regulation valves	BELIMO, Hinwil, Switzerland	R3015-10-S2 with LR24A-SR motor	12
	Salinity regulation valves	BELIMO, Hinwil, Switzerland	R2015-10-S2 with LR24A-SR motor	6
Automation cabinet				
	Cabinet	Fibox, Espoo, Finland	FIB8120017N	1
	Security switch	KRAUS-NAIMER, Karlsruhe, germany	KNA002245	1
	12 vdc power supply	TDK Lambda, New York, USA	LAMDRL30-12-1	1
	24vdc power supply	TDK Lambda, New York, USA	LAMDRB240-24-1	1
	PLC	Industrial Shields, Barcelona, Spain	Mduino-42+	4
	Ethernet switch	HIRSCHMANN-INET, Neckartenzlingen, Germany	HIR942132002	1

A2. Temperature and Salinity Regulation

Accurate temperature and salinity regulation was managed using the software PID (proportional integral derivative) controller on the corresponding Programmable Logic Controller (PLC). The PLC operated in PoE mode (power over ethernet) which builds a local area network (LAN) enabling use of Ethernet data cables to carry electrical power. The PID controller measures the difference between the measured value and the nominal value (i.e., the error). This calculates the position and adjustment of the valve opening by multiplying the error, the integral of this error, and the derivative of the error over time, by previously determined coefficients K_p (proportional gain), K_i (integral gain) and K_d (derivative gain), respectively. These coefficients were obtained experimentally using the empirical method of Ziegler & Nichols (1943). These coefficient values may differ from one condition to another.

A2.1. Pressure and Flow Regulation

Each sub-header tank inlet line of ambient, chilled and warmed seawater had its own pressure regulation system enabling equivalent pressure levels to be maintained. This regulation process aided in the ability to adjust flow rates for all mesocosms by using the hand-crank valves (Fig. 1). The system consisted of an analog pressure sensor (SiemensⒸ 7MF1567-3BE00-1AA1) and a two-way analog valve (BELIMOⒸ R2025-10-S2 with LR24A-SR motor). The pressure sensors were placed in-line directly after water from each sub-header tank passed through a regulator valve. The sensor ensured that pressure for each line was maintained at 0.3 bars by transmitting data to the system which then regulated the valve opening position of the incoming flow. A nominal pressure for all three sensors was predetermined during flow rate test trials. This

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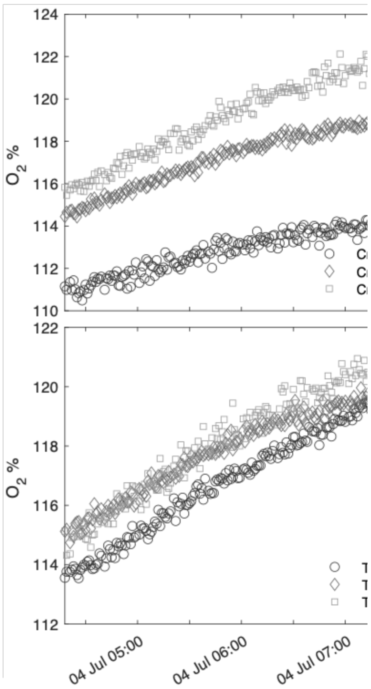

Figure A2. Oxygen evolution for each mesocosm separated by treatment.

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process took place during the setup of the system where the valve opening was adjusted using a PID regulator (see A2) to maintain the defined nominal pressure.

A2.2 Automation

The automation was performed using 4 Industrial Arduino-based PLCs (Industrial shieldsⒸ Mduino-42+), with an individual PLC regulating the control and each treatment 1 – 3, respectively. Each PLC was responsible for logging data and regulating a specific experimental condition. The PLC regulating the control—identified as the Head PLC—was the primary device responsible for communication with the branched PLCs and the monitoring computer (Fig. A2). All monitoring was performed on a PC Windows application (Section A3) and responsible for: (1) reading data received from the PLCs, (2) reading *in-situ* data received from the internet, (3) displaying live data, (4) logging data and sending it to an FTP server, and (5) sending settings and commands to the PLCs. Communication between the PLCs and the PC was ensured using http WebSocket protocol on RJ45 ethernet cables. The communication between the PLCs and the conductivity-temperature and oxygen sensors, flow rate sensors, and regulation valves was executed using a half duplex RS485 (2 wires) protocol, with an analog 4-20mA and an analog 0-10V signal, respectively. All PLCs and wired communication lines were housed in an electrical box installed to an IP68 Fibox enclosure with a 400 V (3P+N+E) 32 A security switch (Fig. A6). All the automation elements use low tension (12 Vdc or 24 Vdc) through circuit breakers and fuses. The electrical box was protected with a 220 V socket.

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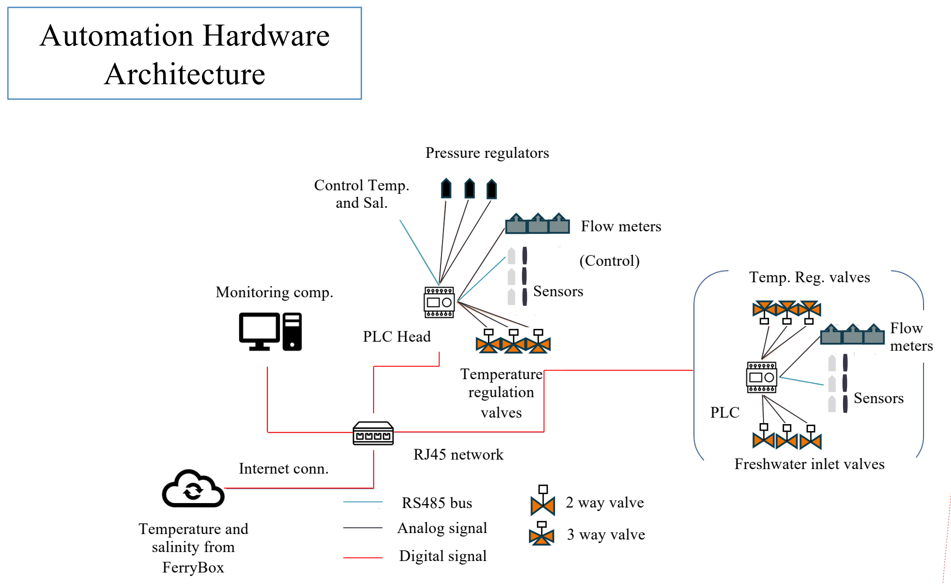
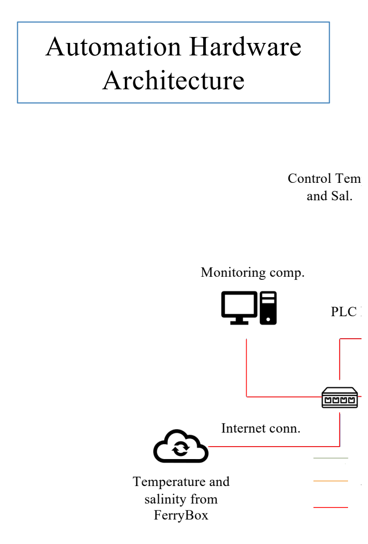


Figure A2. Diagram and flow-chart of the automation system.



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A3. Software Development

The code for the application was written in C/C++. The code uses publicly available Arduino libraries (https://www.arduino.cc/reference/en/libraries/) as well as originally designed libraries. All code is available on Github (https://github.com/purrutti/FACEIT). The code is divided into two pathways: ‘Master.ino’ for the Head PLC, and ‘Regul_condition.ino’ for the Branched PLCs. A description of the main functions applied in the code for programming the system regulation and features are listed in Table A3.

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Table A3. Functions used for programming of software.

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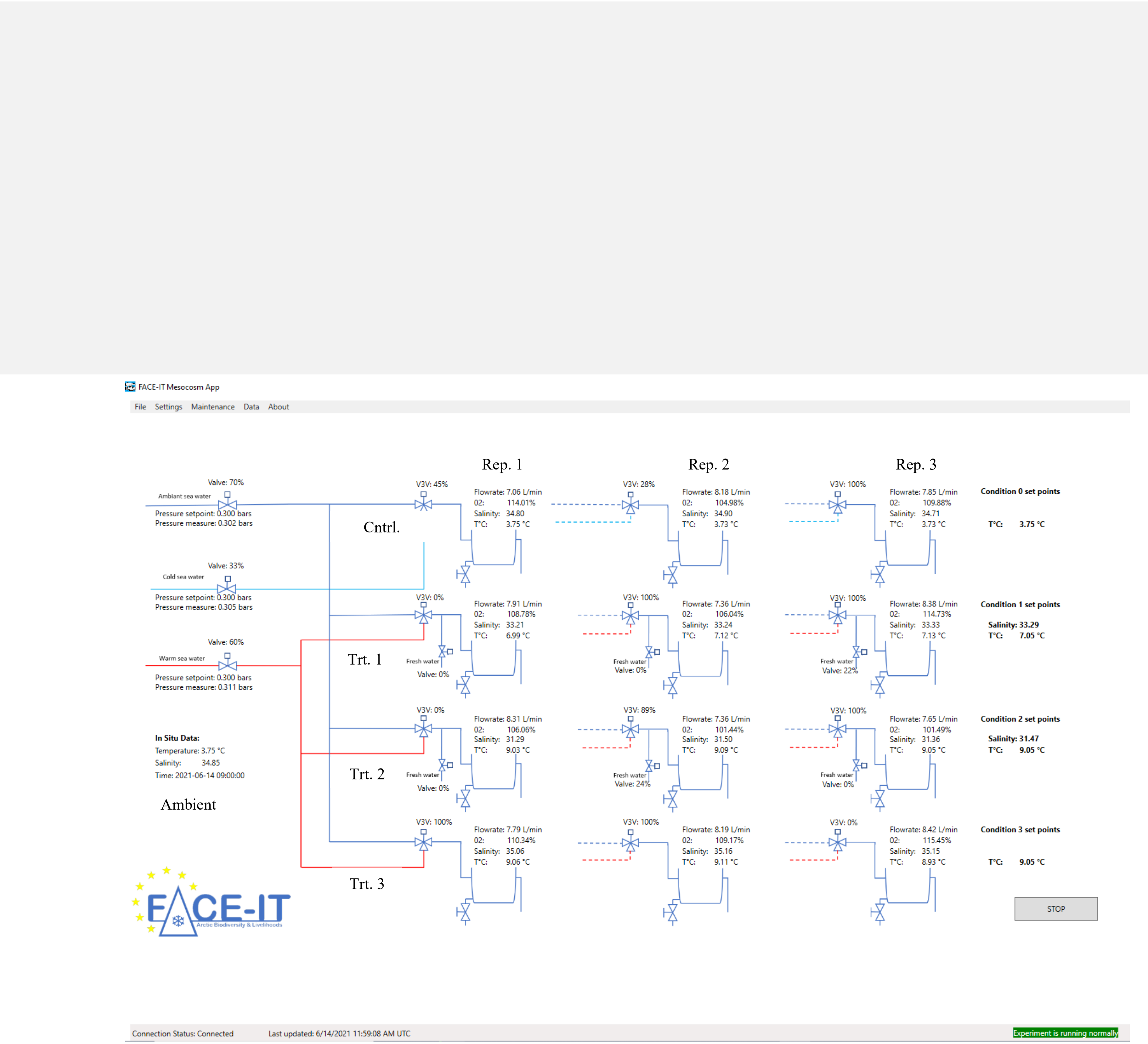
Function	Operation	*Ancillary field* Sender ID	*Ancillary field* Command #
RTC.read()	The PLCs are equipped with a RTC chip and battery to keep track of the date. Once set on commissioning, RTC.read() returns the current date and time.		
readMBSensors()	This functions loops through each sensor connected on the RS485 bus. Each Mesocosm has two sensors (O2 and Conductivity/Salinity), so each PLC has 6 sensors connected on its bus. - O2 sensors have addresses ranging from 10 to 12, for mesocosms 0 to 2 of the scenario, respectively. - PC4E sensors have addresses ranging from 30 to 32, for mesocosms 0 to 2 of the scenario, respectively. - Sensors are requested individually and in sequence. A request is made every 200 ms.		
webSocket.loop()	This is a callback function responsible for dealing with the WebSocket communication. The master PLC is the WebSocket server. It listens to slave PLCs requests and to the monitoring PC requests. Requests are JSON formatted. They always contain *anciallry fields:* senderID (ID of the entity sending the request), condID (ID of the requested entity), command (command type of the request). They optionally can also contain a « time » field: Unix-like timestamp (number of seconds since 01-01-1970)	Head PLC (ID = 0) Branched PLCs (ID = 1–3) Monitoring PC (ID = 4)	Request params: setpoints, PID settings (# = 0) Request data: measurement values, regulation outputs (# = 1) Send Params: response to a « request params » request (# = 2) Send Data: response to a « request data » request (# = 3) Calibrate sensor: request for calibrating sensor to specified value (# = 4) Request Head data: specific data measured by Head PLC (pressure & flowrates) (# = 5) Send Head data: a response to a « request Head data » request (# = 6)
regulationTemperature()	This function is responsible for the temperature regulation of the mesocosm. It sets the corresponding three-way valve position using a 0-10V analog signal. The function first checks if the regulation is in « manual override » mode. If so, it applies the override setpoint. If not, it reads the temperature measure in the mesocosm, compares it with the setpoint, and uses the PID settings to set the valve position.		
checkMesocosmes()	This functions loops through every mesocosm every 200 ms and reads analog signals (i.e., flowrates and pressure readings).		
regulationPression() *Only for HEAD PLC*	This function is responsible for the pressure regulation of the mesocosm. It sets the corresponding three-way valve position using a 0-10V analog signal. The function first checks if the regulation is in « manual override » mode. If so, it applies the override setpoint. If not, it reads the pressure measure in the mesocosm, compares it with the setpoint, and uses the PID settings to set the valve position.		
printToSD() *Only for HEAD PLC*	Master PLC is equipped with a microSD card, on which data from all mesocosms is logged every 5 seconds, in one csv file per day. This is for security only, as the microSD card is not easy to remove from the PLC casing. It should not be removed before the end of the experiment.		
regulationSalinite() *Only for Branched PLCs*	This function is responsible for the salinity regulation of the mesocosm. It sets the corresponding three-way valve position using a 0-10V analog signal. The function first checks if the regulation is in « manual override » mode. If so, it applies the override setpoint. If not, it reads the salinity measure in the mesocosm, compares it with the setpoint, and uses the PID settings to set the valve position.		



Ambiant sea water
Valve: 70%
Pressure setpoint: 0.300 bars
Pressure measure: 0.302 bars

Cold sea water
Valve: 33%
Pressure setpoint: 0.300 bars
Pressure measure: 0.305 bars

Warm sea water
Valve: 60%
Pressure setpoint: 0.300 bars
Pressure measure: 0.311 bars

In Situ Data:
Temperature: 3.75 °C
Salinity: 34.85
Time: 2021-06-14 09:00:00

Cntrl. – Rep. 1
V3V: 45%
Flowrate: 7.06 L/min
02: 114.01%
Salinity: 34.80
T°C: 3.75 °C

Cntrl. – Rep. 2
V3V: 28%
Flowrate: 8.18 L/min
02: 104.98%
Salinity: 34.90
T°C: 3.73 °C

Cntrl. – Rep. 3
V3V: 100%
Flowrate: 7.85 L/min
02: 109.88%
Salinity: 34.71
T°C: 3.73 °C

Condition 0 set points
T°C: 3.75 °C

Trt. 1 – Rep. 1
V3V: 0%
Fresh water Valve: 0%
Flowrate: 7.91 L/min
02: 108.78%
Salinity: 33.21
T°C: 6.99 °C

Trt. 1 – Rep. 2
V3V: 100%
Fresh water Valve: 0%
Flowrate: 7.36 L/min
02: 106.04%
Salinity: 33.24
T°C: 7.12 °C

Trt. 1 – Rep. 3
V3V: 100%
Fresh water Valve: 22%
Flowrate: 8.38 L/min
02: 114.73%
Salinity: 33.33
T°C: 7.13 °C

Condition 1 set points
Salinity: 33.29
T°C: 7.05 °C

Trt. 2 – Rep. 1
V3V: 0%
Fresh water Valve: 0%
Flowrate: 8.31 L/min
02: 106.06%
Salinity: 31.29
T°C: 9.03 °C

Trt. 2 – Rep. 2
V3V: 89%
Fresh water Valve: 24%
Flowrate: 7.36 L/min
02: 101.44%
Salinity: 31.50
T°C: 9.09 °C

Trt. 2 – Rep. 3
V3V: 100%
Fresh water Valve: 0%
Flowrate: 7.65 L/min
02: 101.49%
Salinity: 31.36
T°C: 9.05 °C

Condition 2 set points
Salinity: 31.47
T°C: 9.05 °C

Trt. 3 – Rep. 1
V3V: 100%
Flowrate: 7.79 L/min
02: 110.34%
Salinity: 35.06
T°C: 9.06 °C

Trt. 3 – Rep. 2
V3V: 100%
Flowrate: 8.19 L/min
02: 109.17%
Salinity: 35.16
T°C: 9.11 °C

Trt. 3 – Rep. 3
V3V: 0%
Flowrate: 8.42 L/min
02: 115.45%
Salinity: 35.15
T°C: 8.93 °C

Condition 3 set points
T°C: 9.05 °C

Connection Status: Connected
Last updated: 6/14/2021 11:59:08 AM UTC
Experiment is running normally

Figure A3. Application interface displaying real-time monitoring of ambient conditions as well and control (Cntrl.), and treatment (Trt.) conditions for each replicate (Rep.) in each mesocosm.

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A4. Menu bar of PC application

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From the interface, the user sets the temperature condition and associated salinity offset, IP address and logging parameters, sensor calibration settings, and nominal pressure (Fig. A4). Within the menu bar several tabs permit the setup of the project: file, settings, maintenance, and data. Under ‘file’ the system can be manually connected to, or disconnected from, the PLCs. Connection is usually maintained automatically. The ‘settings’ tab displays the application and experimental setting options (Fig. A4.1 a – c). All the settings of the project are stored on the computer (found in ‘application settings’) that is running the application, which include:

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i. *Master IP address*: The IP Address of the Master PLC (centralizing all the data).
ii. *Data Query Interval*: Frequency of queries from the application to the master PLC.
iii. *Data Log Interval:* Number of minutes between logs to file.
iv. *Data Base File Path*: Directory and base filename of the csv data files.
v. *FTP Username, Password, Path*: FTP settings for sending the data file every hour.
vi. *InfluxDB Settings*: For Live Monitoring and local storage of the data.

Under ‘experimental settings’, the programmed specificities and regulation of the treatment conditions can be adjusted. This includes programming the nominal pressure (all main inflow lines), temperature and the salinity-temperature relational equation (on a different tab selected from dropdown), as well as adjusting the K_p, K_i & K_d coefficients for the regulation (see section 2.3.1). The nominal temperature is provided by the data received from the ferry-box, however this can be overridden if needed. The « Save to PLC » button sends the values to the corresponding PLC and saves the data, while the « Load from PLC » button loads the settings from the PLC. For the purposes of this experiment, the nominal salinity was calculated based on a delta salinity for treatments 1 and 2 which were derived from the linear relationship with

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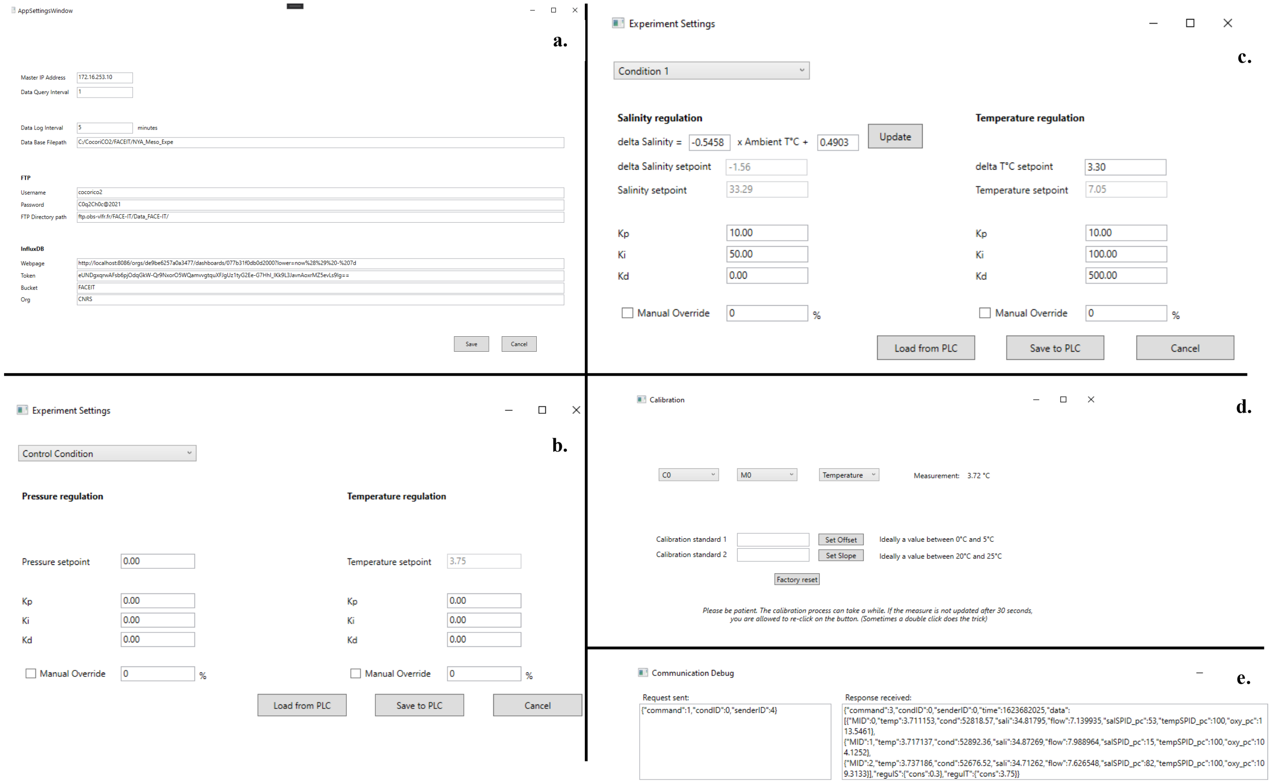
temperature (see section 2.3.1). This can also be overridden if needed by selecting the manual override box.

The ‘maintenance’ tab is where sensor calibration and communication ‘Debug’ operations can be executed (Fig. A4 d, e). Calibration can be performed for each sensor deployed in each mesocosm, and uses a 2-point calibration for temperature and % oxygen. The salinity calibration is done by setting the conductivity value corresponding to a temperature of 25°C rather than the *in situ* measured temperature. The conductivity value is programmed as $\mu S\ cm^{-1}$. The communication process for sensor calibration is between 5 to 10 seconds. The final option in the menu is the ‘data’ tab which displays the historical and live data. The historical data can be interfaced to an html site if desired.



AppSettingsWindow

Master IP Address: 172.16.253.10
Data Query Interval: 1
Data Log Interval: 5 minutes
Data Base Filepath: C:/CocoriCO2/FACEIT/NYA_Meso_Expe

FTP

Username: cocorico2
Password: C0q2Ch0c@2021
FTP Directory path: ftp.obs-vlfr.fr/FACE-IT/Data_FACE-IT/

InfluxDB

Webpage: http://localhost:8086/orgs/de9be6257a0a3477/dashboards/077b31f0db0d2000?lower=now%28%29%20-%207d
Token: eUNDgxqrwAFsb6pjOdqGkW-Qr9NxorO5WQamvvgtquXFJgUz1tyG2Ee-G7HhI_IKk9L3JavnAoxrMZ5evLs9lg==
Bucket: FACEIT
Org: CNRS

Experiment Settings

Control Condition

Pressure regulation

Pressure setpoint: 0.00
Kp: 0.00
Ki: 0.00
Kd: 0.00
☐ Manual Override: 0 %

Temperature regulation

Temperature setpoint: 3.75
Kp: 0.00
Ki: 0.00
Kd: 0.00
☐ Manual Override: 0 %

Experiment Settings

Condition 1

Salinity regulation

delta Salinity = -0.5458 x Ambient T°C + 0.4903
delta Salinity setpoint: -1.56
Salinity setpoint: 33.29
Kp: 10.00
Ki: 50.00
Kd: 0.00
☐ Manual Override: 0 %

Temperature regulation

delta T°C setpoint: 3.30
Temperature setpoint: 7.05
Kp: 10.00
Ki: 100.00
Kd: 500.00
☐ Manual Override: 0 %

Calibration

C0 | M0 | Temperature | Measurement: 3.72 °C

Calibration standard 1: Ideally a value between 0°C and 5°C
Calibration standard 2: Ideally a value between 20°C and 25°C

Please be patient. The calibration process can take a while. If the measure is not updated after 30 seconds, you are allowed to re-click on the button. (Sometimes a double click does the trick)

Communication Debug

Request sent:

```
{"command":1,"condID":0,"senderID":4}
```

Response received:

```
{"command":3,"condID":0,"senderID":0,"time":1623682025,"data":
[{"MID":0,"temp":3.711153,"cond":52818.57,"sali":34.81795,"flow":7.139935,"salSPID_pc":53,"tempSPID_pc":100,"oxy_pc":1
13.5461},
{"MID":1,"temp":3.717137,"cond":52892.36,"sali":34.87269,"flow":7.988964,"salSPID_pc":15,"tempSPID_pc":100,"oxy_pc":10
4.1252},
{"MID":2,"temp":3.737186,"cond":52676.52,"sali":34.71262,"flow":7.626548,"salSPID_pc":82,"tempSPID_pc":100,"oxy_pc":10
9.3133}],"reguIS":{"cons":0.3},"reguIT":{"cons":3.75}}
```

Figure A4. Operation windows for the application and experimental settings (**a-c**). These windows are found under the 'settings' tab. Operation windows for sensor calibration and debugging (**d, e**). These are found under the 'maintenance' tab.

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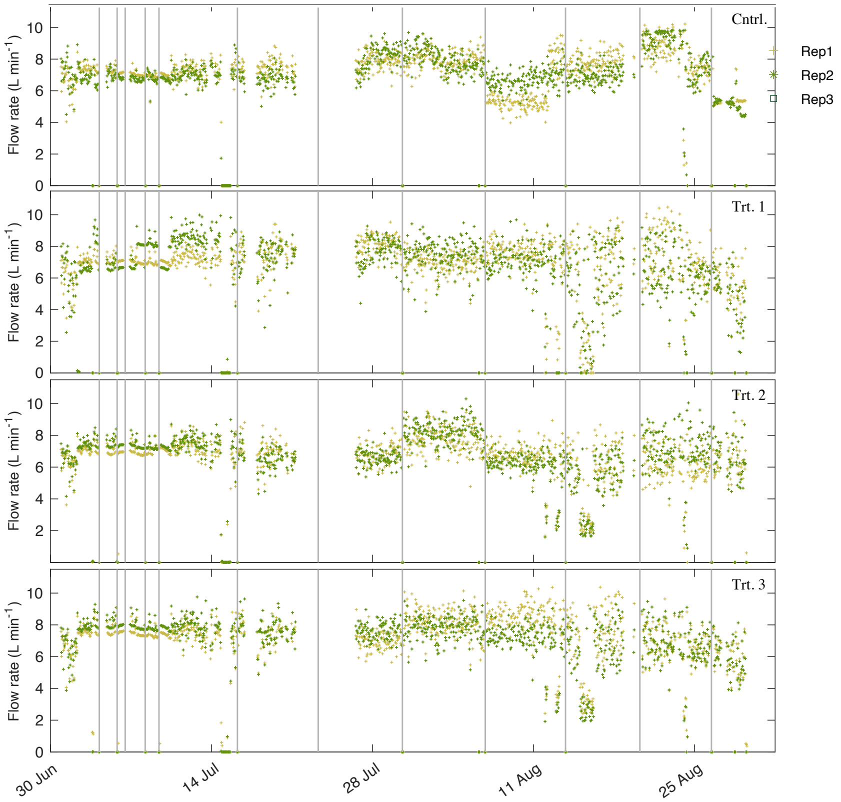

Figure A5. Flow rates for control and treatments 1-3 for the entirety of the system deployment. Black vertical lines are when incubations were performed and the system shut-off for a period of 3 h. Flow rates went to zero at these times.

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Figure A6. All 12 mesocosms are displayed (upper left photo) with the inside of one mesocosm (right photo) showing the oxygen (silver) and temperature/conductivity sensors along with the photosynthetically active radiation (PAR) logger (bottom right photo).

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Figure A7. Electrical cabinet used for SalTExPreS

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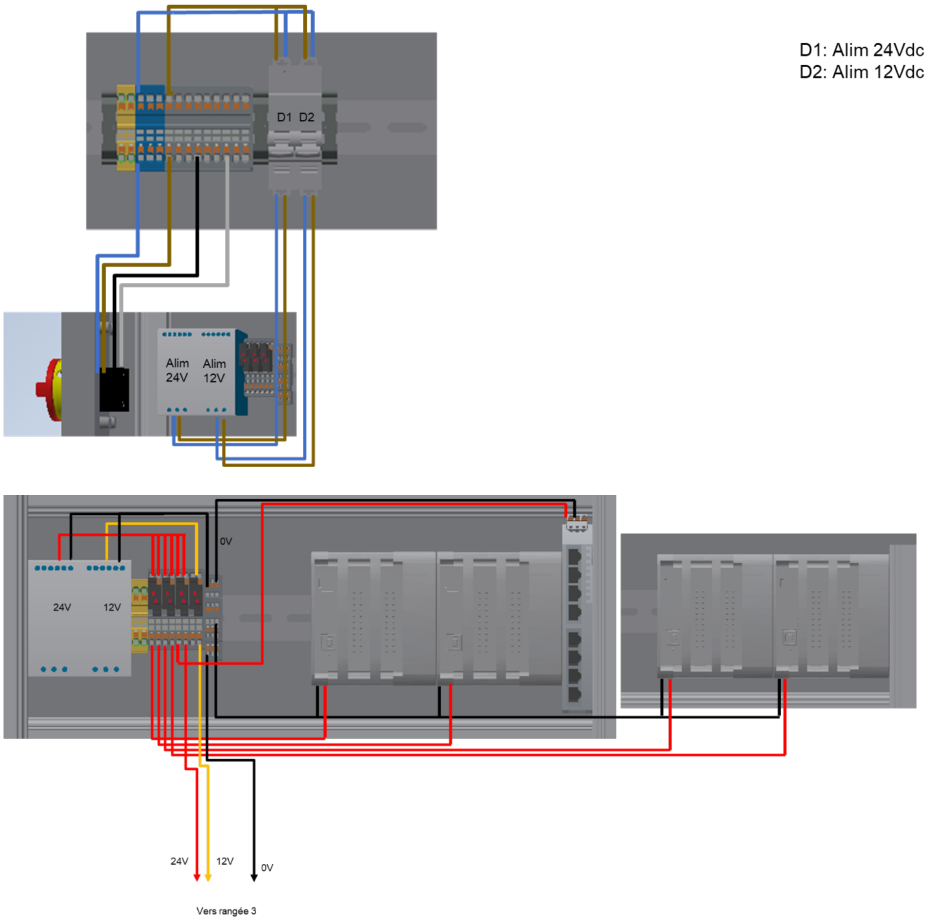

Figure A8. Electrical schematic for wiring within the electrical box.

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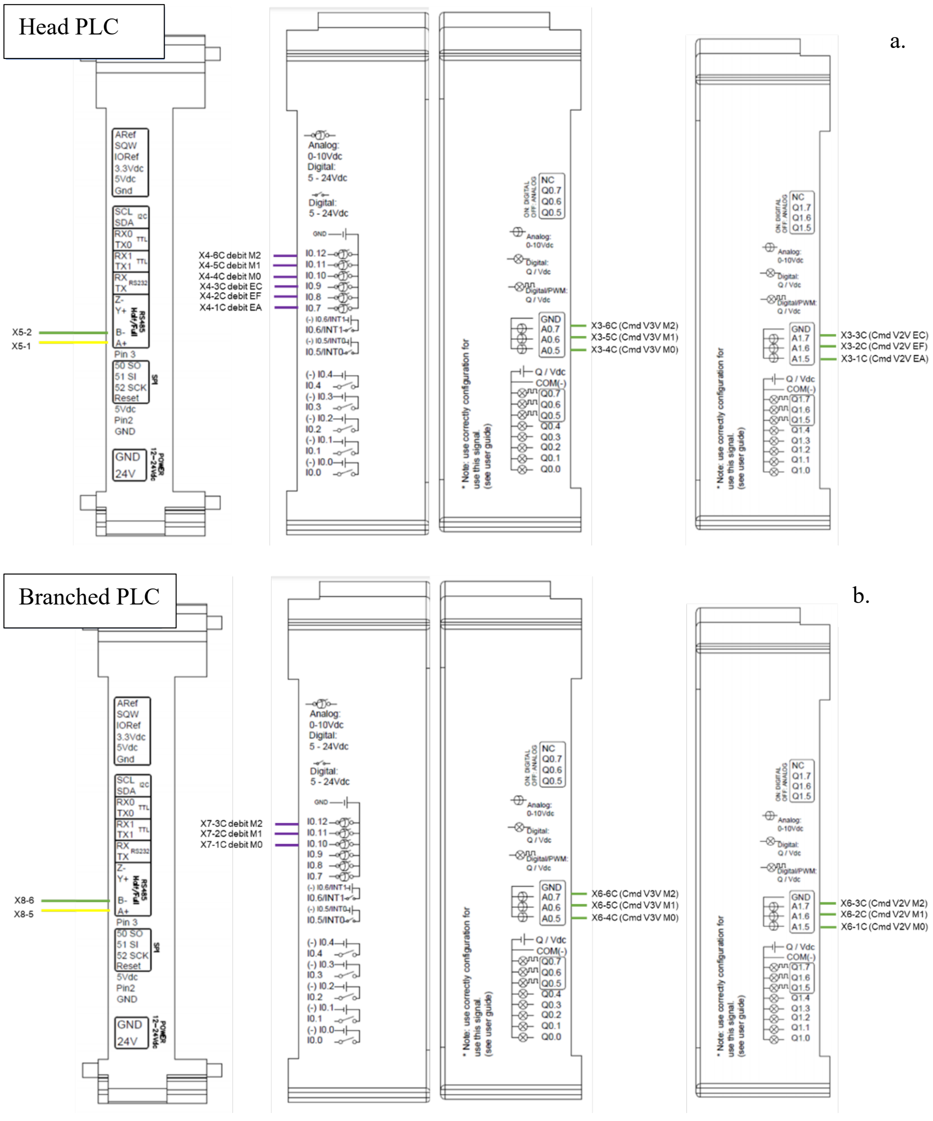

Figure A9. PLC controller diagram for Head (a) and Branched (b) operations.

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Group	Item	Supplier/man
Hydraulic system		
	Mesocosms	home m
	Seawater pump	NPS BradForc
	PVC-U tubing and fittings	
	Insulated flexible hose	
Sensors		
	Conductivity / temperature	Aquala Champigny s Franc
	Oxygen	Aquala Champigny s Franc
	Pressure	Sieme Munich, G
	Flow rate	IFM Essen, Ge
Actuators		
	Pressure regulation valves	BELIM Hinwil, Swi
	Temperature regulation valves	BELIM Hinwil, Swi
	Salinity regulation valves	BELIM Hinwil, Swi
Automation cabinet		
	Cabinet	Fibox Espoo, Fi
	Security switch	KRAUS-NA Karlsruhe, g
	12 vdc power supply	TDK Lar New York
	24vdc power supply	TDK Lar New York
	PLC	Industrial S Barcelona
	Ethernet switch	HIRSCHMAN Neckartenz Germa

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