UNDERWATER DRONES FOR WATER QUALITY MONITORING – A SURVEY ON THE IMPACTS OF FLOATING STRUCTURES ON WATER QUALITY AND ECOLOGY

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DRONES SUBAQUATIQUES POUR LE MONITEUR DE LA QUALITÉ DE L'EAU - LES IMPACTS DE STRUCTURES FLOTTANTES SUR LA QUALITÉ DE L'EAU

MOTS CLEFS: drones subaquatiques, qualité de l'eau, l'oxygène dissous, l'urbanisation flottante, changement climatique

I INTRODUCTION

Urban delta areas are facing problems related with land scarcity and are impacted by climate change and flooding. To meet the current demands and future challenges, innovative and adaptive urban developments are necessary [de Graaf, 2009]. Floating urban development is a promising solutions, as it offers the flexibility and multifunctionality required to efficiently face the current challenges for delta cities [de Graaf, 2013]. It provides flood proof buildings and opportunities for sustainable food and energy production [Roeffen, et al., 2013].

In order to wisely infer about the best solutions for the sustainability of delta areas, it is important to understand how these projects affect the environment. In particular for floating developments, the possible positive or negative impacts are currently largely unknown and often disregarded as a priority for research. This knowledge gap complicates the task of water authorities and municipalities to create a policy framework, in order to regulate and facilitate the development of new floating projects [de Graaf, et al., 2014].

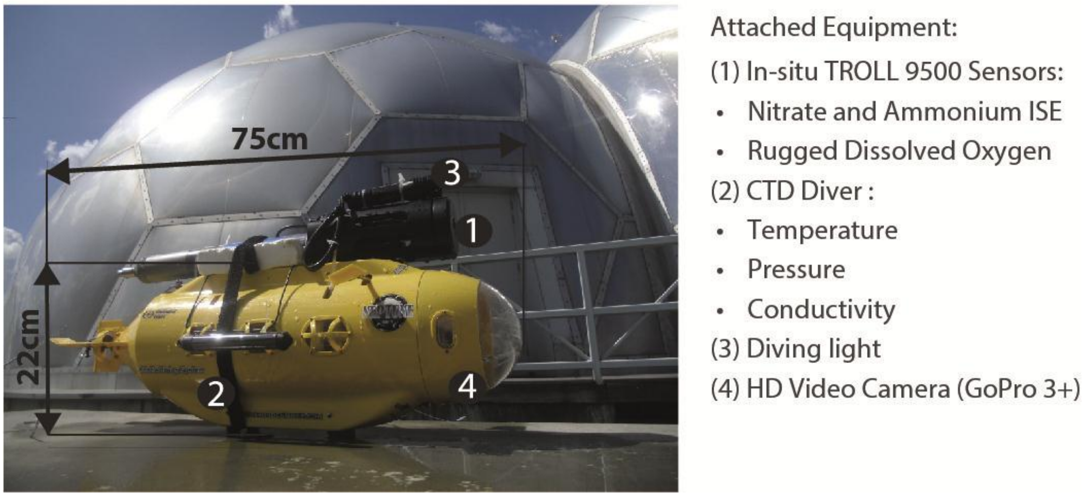
Eventual impacts of floating structures in the water quality are linked with the coverage of the water surface, which has an influence on the air-water interactions and on the penetration of light [Foka, 2014] [Hartwich, 2014] However, there isn’t much literature available on this topic, and further research is necessary. There has been some monitoring [e.g. Kitazawa, et al., 2010; de Buck, et al., 2014] but the research methods used are usually ineffective and do not include the water underneath the structures. In addition, monitoring these effects have been difficult until now because of the poor accessibility of the water body underneath the floating structures (e.g. in some locations the freeboard under the houses is lower than 0,5 m).

In order to overcome this limitation, the ongoing research project “Impacts of Floating Urbanization on water quality and ecology” [Boogard, et al., 2014] is currently using a remote controlled underwater drone to perform water quality measurements and ecological monitoring close to floating buildings/platforms. Underwater drones allow to easily collect data in zones near and under floating structures where, in the past, it would be troublesome and expensive for other methods to access (e.g. human divers). Some of the locations could even be unsafe for human divers to enter, due to the frequent small layer of water available between the structure and the ground (sometimes less than 50 cm), and due to high water turbidity.

In addition to the main research question regarding the study of the impacts of floating structures, this research also aimed at understanding if a drone could be useful to surpass the referred limitations, and whether it has potential for future research developments for applications in water quality and ecology. This study was also part of a preliminary research for a possible PhD research topic, and was conducted with a low budget.

II METHODOLOGY:

To know more about the water quality around and under floating structures, a remote-controlled underwater drone, equipped with several water quality sensors and a video camera, was used to go under floating structures to collect data (Figure 1). The sensors allow to monitor water quality parameters such as pressure (depth), temperature, conductivity, nitrate, ammonium, dissolved oxygen and turbidity.



Attached Equipment:

(1) In-situ TROLL 9500 Sensors:
- Nitrate and Ammonium ISE
- Rugged Dissolved Oxygen

(2) CTD Diver :
- Temperature
- Pressure
- Conductivity

(3) Diving light

(4) HD Video Camera (GoPro 3+)

Figure 1 – View of the underwater drone with all the attached equipment (near the Floating Pavilion, Rotterdam).

The underwater remote-controlled drone used for the measurements (Thunder Tiger - Neptune SB-1) [Thunder Tiger, 2012] is an underwater R/C model designed by Thunder Tiger (Figure 2). The transparent dome at the front allows the placement of a camera. It has been developed to allow the exploration of the underwater world. Figure 2 shows a picture of the submarine and some of its components, whereas its full specifications can be consulted in Table 1.

Figure 2 – Thunder Tiger Neptune SB-1 (adapted from REF), and Thunder Tiger Ace remote-control (right).

The water quality sensors are presented in Figure 3 and 4. The Troll 9500, CTD and a Mini-Diver were attached to the underwater drone. The second mini-diver was placed on land, nearby the water, to work as a barometer and thus to allow posterior compensation for the atmospheric pressure in depth computations. The full specifications, including accuracy, are presented in the Appendix. As an example, the concentrations of dissolved oxygen could be measured with an accuracy of ± 0.1 mg/L. Although most sensors allow a sample rate of 5 seconds, data was collected every 10 seconds, due to the requirement of the dissolved oxygen sensor. The sensors, in particular the Ion-Selective Electrodes (ISE – Nitrate and Ammonium) require frequent calibration, in order to provide accurate measurements [In-Situ Inc, 2009].

Figure 3 - CTD-Diver DI261 (left), Mini-Diver DI501 (center) and Micro-Diver DI601 (right) [Schlumberger, 2014].

Figure 4 - In-situ Multi-Parameter TROLL 9500 (with Rugged Dissolved Oxygen and Ion Selective Electrode sensors installed) [In-Situ Inc, 2009].

To pursue the research objectives, it was necessary to access the zone underneath floating structures to collect water quality data. As a control, data was also collected from zones far away (>8 m) from the floating structure (same water body), and thus unaffected by the blockage caused by it. Figure 5 illustrates these procedures and measuring locations. Due to uncertainty regarding the position of the drone, and corresponding times, data collected on the surface, near the structure, was also included in the under/near category. Because GPS tracking is not easy/possible underwater, and other tracking options [Leonard, et al., 1998] were not available, knowing the position of the drone was challenging. In order to know the location of the drone (crucial for the success of the analysis of the data), the sequence of events was registered in a logbook and video during the measurements. This contributed to better understand the depth profile from the divers, and to identify the period of time when the drone was under the structure. The footage obtained with the video also contributed to identify where the measurements were taken.

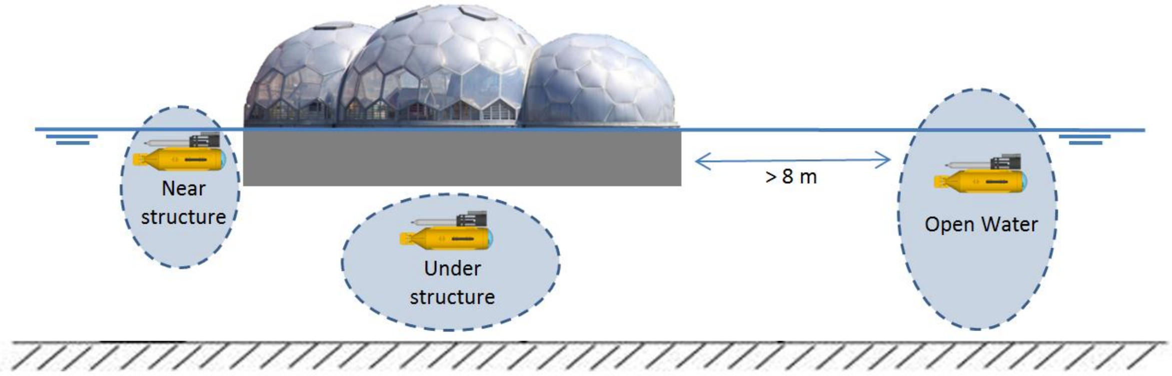


Figure 5 - Schematization of the zones of collection of data.

III RESULTS

III.1 Data from water quality sensors

After collecting water quality data in both open water and under/near floating structures, the data is extracted and the multiple parameters can be represented in graphs (Figure 6). In this figure, the two graphs in the first column (open water) are plotted against the data collected under/near the structure, in the column on the right. It can be observed that the thicker black line represents the depth where the measurements were taken, and that the other parameters present significant fluctuations, which in most cases can be associated to the variations in depth.

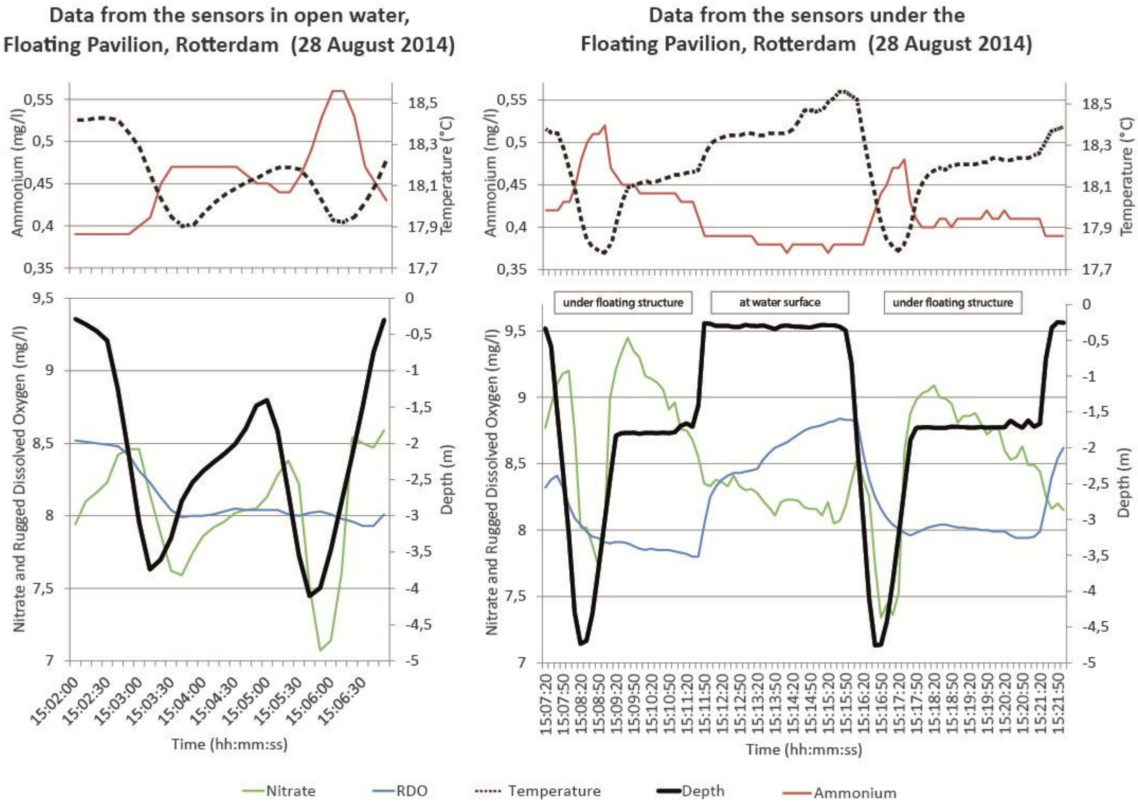


Figure 6 – Representation of water quality parameters in open water (left) and under the Floating Pavilion (right).

Therefore, due to the complexity of water quality assessments, with not only temporal (e.g. daily, seasonal) and spatial variability of parameters, but also with variability with depth and temperature, it is not easy to understand and analyze how the water quality parameters vary under floating structures. Therefore, in order to allow an easier comparison, the profile was divided in depth ranges and then the averages for each depth were computed. As can be seen in Figure 7, this allows to evaluate and compare results from the two zones, and to quantify the effects the floating body may cause, regarding water quality chemical parameters. In the case of dissolved oxygen, it can be visible that the dissolved oxygen is always slightly lower under the floating structure, than in open water, for the same depth.

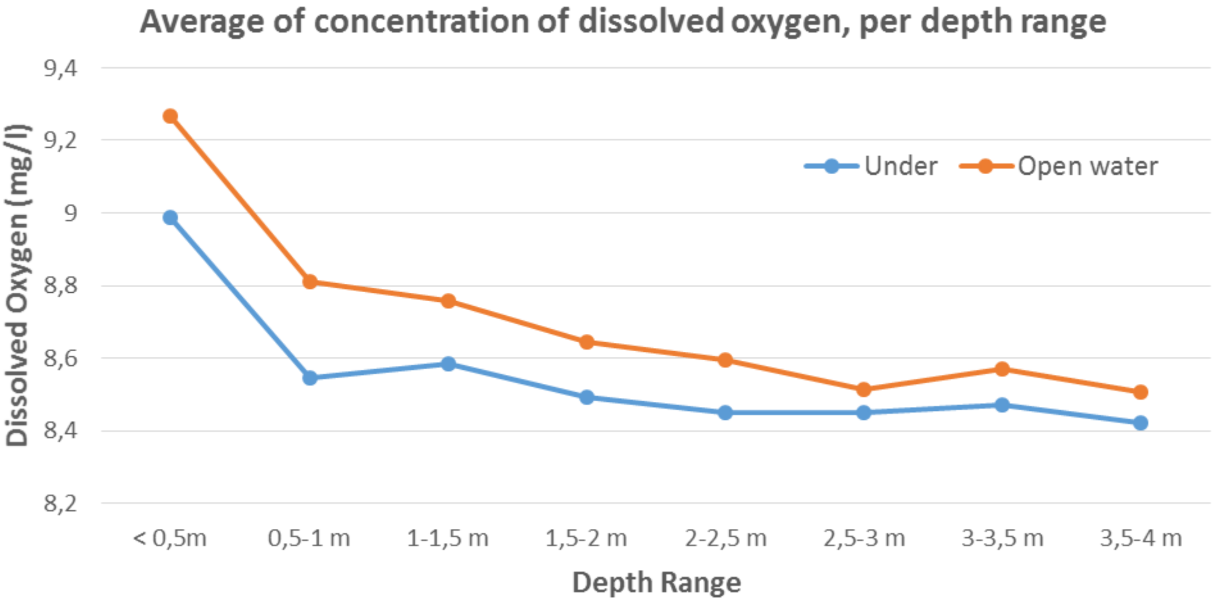


Figure 7 – Comparison between the averages of the concentration of dissolved oxygen under/near floating structures and in open water, per depth range (Floating Pavilion, Rotterdam, 13 August 2014).

III.2 Underwater footage

In addition to the water quality data from the sensors, a high definition video camera was used to collect underwater footage. However, in some locations the water presented high turbidity, which resulted in poor video quality or even made it impossible to see more than a few centimeters ahead of the camera. However, when the water was clear enough, it was possible to identify many fish swimming under and near these floating structures, along with many other organisms (e.g. mussels) attached to the structures (Figure 8). The presence of fish and other aquatic life forms are, per se, a good water quality indicator. The underwater footage gave some insight into what happens under floating structures. It was observed that a whole new habitat is created, where, otherwise, wouldn't exist much biodiversity and activity.

Figure 8– Examples of underwater footage with aquatic life under floating houses in Maasbommel and Lelystad (NL).

III.3 Underwater drone

With the available equipment for this study, some limitations regarding the use of the drone were identified. There are still some challenges to overcome, such as the lack of knowledge of the exact position of the measurements (GPS does not work under water), gradual decrease on the autonomy of the drone (battery initially lasted for around 4 hours, whereas in the last measurements it was only lasting for around 1 hour), lack of underwater visibility under certain turbidity conditions.

This design was only a first pilot, and further research on how to improve the drone is planned. The implementation of improvements to the existing drone (e.g. additional equipment), or the development of a more advanced drone will allow to surpass most of the referred limitations, and to obtain better spatial information, thus opening further research opportunities. Some examples are the inclusion of a positioning system (e.g. acoustic positioning system, inertial navigation system), enhanced visuals on the drone (sonar imaging, live underwater camera), possibility for water and benthic sediment samples collection, additional sensors (pH, phosphate, algae), or an improved Illumination system. The possibility of scheduling and defining automatized routes for the drone to follow is also an interesting possibility for future developments of the drone.

IV CONCLUSIONS

A submerged drone can be very useful in scientific research to gather information with sensors and visuals. This research delivered good feedback regarding the use of underwater drones as environmental monitoring tools. It was understood that drones are suitable to use for water quality measurements, as they are capable of performing fast water quality monitoring tasks that otherwise would be rather complicated and less efficient. Considering their versatility and potential applications, enabling several possibilities such as tasks of routine measurements, inspections or ecological scans.

The simplicity of execution of general surveys to underwater environments with drones is attractive for other types of water monitoring tasks. Using drones could contribute to the enhancement of the monitoring of water resources, as they enable to quickly perform measurements in any location without requiring any complex pre-installed water quality monitoring stations and equipment (subject to theft and sabotage). The drones are easy to transport, setup, and can easily swim to the desired locations.

In this specific application where the effects of floating structures on water quality and ecology are studied, the submerged drone allowed to collect a considerable amount of valuable data and underwater images. Based on this information, the current small scale floating structures do not have a significant influence on water quality. The detected differences in the concentration of water quality parameters (e.g. dissolved oxygen) between open water and under/near the structures parameters was low, and most parameters remain at acceptable levels. Regarding the ecology, footage from the video camera revealed a multitude of organisms attached to these structures, in addition to fish swimming underneath them. This shows that floating constructions can even have a positive effect on the environment, by creating new habitats and providing shelter for smaller fish.

All the findings, collected data and videos from floating structures from several locations around The Netherlands are available in an online knowledge management tool (www.climatescan.nl). This website aims at promoting knowledge transfer among stakeholders, and to help gaining insight on the environmental impact of floating solutions, and can be accessed by anyone interested in the topic.

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VI APPENDIX – EQUIPMENT SPECIFICATIONS

Table 1 - Technical Specifications of Thunder Tiger Neptune SB-1 (Thunder Tiger, 2012).

Model name	Thunder Tiger - Neptune SB-1 Submarine RTR
Developer	Thunder Tiger
Displacement	7.7kg surface, 7.95kg submerged
Overall length	30.5" (774mm)
Beam (width)	11.4" (290mm)
Draft	7.9" (200mm)
Height	11.2" (285mm)
Propulsion motor	12V
Propeller:	Three blade, outer diameter 40mm, pitch/41mm
Speed (surfaced):	1.45 knots/ 2.7km/h
Speed (submerged)	1.08 knots/ 2km/h
Diving technology	Dual diving system: static and dynamic (ballast tank and motor drive system)
Steering system	Full elevator and rudder controls.
Operating diving depth	5m
Max. diving depth	10m (mechanical limit)
Body	High impact ABS plastic hull, yellow in color
Battery	12V sealed Lead-Acid battery with 12V wall charger
Remote	Thunder Tiger Ace RC 6-channel FM radio transmitter
Safety feature	Auto-detect electronic protection system (surfaces submarine in case of low battery power, weak radio signals or leakage).
Price	Around 600€ (July 2013)

Table 1 - Technical Specifications of divers - including CTD (Schlumberger, 2014).

	i) CTD-Diver DI261	**ii) Mini-Diver DI501**	**iii) Micro-Diver DI601**
Dimensions:	Ø 22 mm x 183 mm	Ø 22 mm x 90 mm	Ø 18 mm x 90 mm
Sample rate:	0.5 sec. to 99 hours	0.5 sec. to 99 hours	0.5 sec. to 99 hours
Housing material:	Ceramic (ZrO2)	RVS 316L	RVS 316L
Battery life:	Up to 10 years	Up to 10 years	Up to 10 years
Weight:	150 grams	70 grams	60 grams
Memory:	16,000 measurements	24,000 measurements	48,000 measurements
Temperature			
Range:	-20 °C to 80 °C	-20 °C to 80 °C	-20 °C to 80 °C
Accuracy:	± 0.1 °C	± 0.1 °C	± 0.1 °C
Resolution:	0.01 °C	0.01 °C	0.01 °C
Pressure			
Range:	10 m H2O	10 m H2O	10 m H2O
Accuracy:	± 1 cm H2O	± 0,5 cm H2O	± 1 cm H2O
Resolution:	0.2 cm H2O	0.2 cm H2O	0.2 cm H2O
Conductivity			
Range:	0 to 80 mS/cm	-	-
Accuracy:	± 1% of reading	-	-
Resolution:	0.1% of reading	-	-

Table 1 - Technical Specifications of In-Situ Multi-Parameter TROLL 9500 Sensor (In-Situ Inc, 2009).

	Data logger : In-Situ Multi-Parameter TROLL 9500 general specifications
Wetted Material:	PVC, titanium, Viton®, acetal, 316L SS
Operating Temperature:	- 5°C to 50°C
Storage Temperature:	- 40°C to 80°C
Pressure Rating:	350 psi
Dimensions:	Ø 47 mm x 57.7 cm
→with RDO adapter	Ø 88.4 mm x 57.7 cm
Weight (without cable):	1.4 Kg
Battery type:	2 standard alkaline D-cells (1.5 V), or 2 lithium D cells (approx. 3.6 V)
External power input:	9-12 VDC (optional)
Memory type/size:	4 megabytes flash data storage, about 1,000,000 individual readings
Logging rate (max)	5 seconds (10 seconds with RDO)

	Sensors		
	Dissolved Oxygen (optical, RDO)	**Ammonium (NH4+)**	**Nitrate (NO3–)**
Type:	Optical, fluorescence quenching	PVC membrane sensing (Ag/AgCl)	PVC membrane sensing (Ag/AgCl)
Range:	0 to 20 mg/L, 0 to 450% saturation	0.14 to 14,000 ppm N 0.1 to 18,000 ppm NH4+	0.14 to 14,000 ppm N 0.4 to 62,000 ppm NO3–
Pressure Rating:	300 psi	20 psi	20 psi
Operating Temperature:	0°C to 40°C	- 5°C to 40°C	- 5°C to 40°C
Accuracy:	± 0.1 mg/L @ 0-8 mg/L; ± 0.2 mg/L @ 8-20 mg/L	± 10%	± 10%
Resolution:	0.01 mg/L	0.01 ppm	0.01 ppm

	Temperature	**Turbidity**
Type:	Platinum resistance thermometer	Nephelometer, 90° light scattering, 870nm LED, solid-state
Range:	- 5°C to 50°C (23°F to 122°F)	0-2000 NTU
Accuracy:	± 0.1°C	± 5% or 2 NTU
Resolution:	0.01°C	0.1 NTU