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Review

Can drones be used to conduct water sampling in aquatic environments? A review

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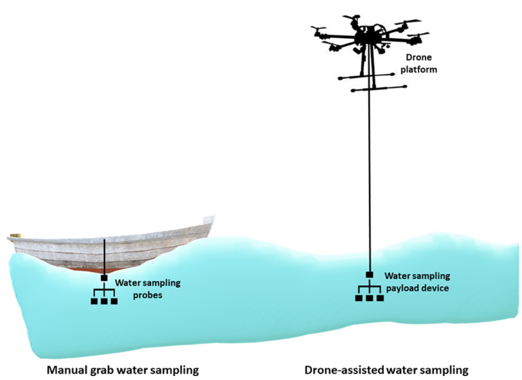
HIGHLIGHTS

- Previous research has demonstrated the potential of drone-assisted water sampling.
- Advancement in off-the-shelf probes allows for real-time data collection.
- Reported sample volumes of 330 ml may be insufficient for water sampling programmes.
- Research needs to compare the precision and accuracy of data collected via drones.
- Cost-benefit analyses are required before water sampling programmes utilise drones.

GRAPHICAL ABSTRACT



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ABSTRACT

Advancements in drone technology have seen the development of drone-assisted water sampling payloads resulting in the ability of drones to retrieve water samples and physico-chemical data from aquatic ecosystems. The application of drones for water sampling provides the potential to fulfil many aspects of the biological and physico-chemical sampling required to meet large-scale water sampling programmes. This paper reviews the achievements made in the development of drone platforms; advances in specially designed water sampling payloads; advances in incorporating off-the-shelf probes and the ability of drone-assisted water sampling payloads to capture water and physico-chemical data from freshwater environments. However, drone-assisted water sampling is still in its infancy and several key limitations include the small volume of water captured via drones to date, the low rate of successful sample capture and the legislative restrictions limiting the distance drones can be flown from the operator. Of critical importance, however, are the clear inconsistencies observed between water chemical parameters obtained using drone-assisted and traditional water sampling methods. Consequently, water samples and physico-chemical data obtained using drones may not provide the level of reliability and accuracy needed to meet the needs of large-scale water sampling programmes. Solutions aimed at addressing these limitations and developing the potential of drones to conduct water samples include: modifying larger drones with greater payload capacity, facilitating the capture of greater volumes of water; technological developments to increase success rates of water capture; planning fieldwork for operation beyond visual line of sight (BVLOS); employing real-time physico-chemical probes; and integrating robust statistical experimental designs.

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In addition, detailed cost benefit analyses are required to investigate if drones would result in a meaningful financial saving to water sampling programmes. However, it is envisaged that drone-assisted water sampling will act as a pivotal supporting tool if such current limitations can be addressed by future research.

Contents

1. Introduction

Over the last decade, unmanned aerial vehicles (UAVs), also known as unmanned aerial systems (UAS), unmanned vehicle systems (UVS), remotely piloted aircraft systems (RPAS), small unmanned aircraft (SUA), and commonly referred to as drones (Chapman, 2014; Chabot, 2018) have emerged as novel, versatile, adaptable and flexible technologies capable of gathering high resolution data for monitoring and assessing the natural environment (Wich and Koh, 2018; Fráter et al., 2015). Thus, drones have quickly become a prominent methodological tool in terrestrial, freshwater and marine ecosystems. The use of drones has been key in bridging the gap between field observations and traditional air and space-borne remote sensing predominantly in habitat mapping and land cover change (Flynn and Chapra, 2014; Klemas, 2015; Pajares, 2015; Watts et al., 2012; Whitehead and Hugenholtz, 2014). However, the adoption of drones has also been decisive in monitoring and assessing river and floodplain monitoring (Bandini et al., 2017; Flener et al., 2013; Rhee et al., 2018), invasive species distribution (Alvarez-Taboada et al., 2017; Michez et al., 2016), species conservation biology (Hodgson et al., 2016; Koh and Wich, 2012) and precision agriculture (Hogan et al., 2017; Zhang and Kovacs, 2012) to name a few applications (see Wich and Koh, 2018 and Chabot and Bird, 2016 for more comprehensive lists of drone applications). The use of drones has increased safety and accessibility to otherwise hazardous or inaccessible terrestrial, freshwater and coastal ecosystems (Manfreda et al., 2018; Rhee et al., 2018; Terada et al., 2018; Watts et al., 2012) and developed capacity to collect data in less-optimum weather conditions such as cloudy or hazy conditions when compared to satellite images (Van der Wal et al., 2013). In addition, data can be collected from low altitudes in a rapid, repetitive and affordable way (Manfreda et al., 2018; Pajares, 2015).

Further advancements in drone platforms and mounted sensor technology will increase their potential application in environmental monitoring of terrestrial and aquatic ecosystems by allowing rapid access to environmental data (Wich and Koh, 2018). Of the impending advancements, the most noteworthy is the potential opportunity to retrieve physical, chemical and biological data from aquatic ecosystems such as collecting water samples and physico-chemical data from large open waterbodies. The increased capabilities of drone platforms (payload weight capacity, flight time, battery endurance etc.) and development of bespoke attached payloads offers a new and unique opportunity to potentially deploy drones in large-scale water sampling programmes (Vergouw et al., 2016). Such large-scale programmes (e.g. the United Nation Global Environment Monitoring System for Freshwater (GEMS/Water) (UN Environment, 2019); European Union Water Framework Directive (EC Environment, 2016) and Marine Strategy Framework Directive (EC Environment, 2017); and United States National Aquatic Resource Surveys (US EPA, 2018)) typically require considerable field personnel, are very expensive to run while also posing both health and safety in addition to biosecurity risks that require significant attention. In addition, the use of boats can lead to problematic issues regarding site access particularly in remote regions (Tierney et al., 2015). The application of drones provides the potential to fulfil some aspects of the biological and physico-chemical sampling required to meet large-scale water sampling programmes in an efficient and cost-effective manner.

This review aims to i) evaluate the use of drones to collect water samples and in-situ physico-chemical data in freshwater environments, synthesising and reviewing the current literature on this topic; and ii) identify knowledge gaps and technological developments needed to advance the use of drones to conduct water sampling in aquatic environments in the coming decade.

2. Current use of drones to conduct water sampling in freshwater environments

The application of drones to collect in-situ hydro-chemical data and water samples from freshwater environments is relatively new, with the first publication of such research by Ore et al. in 2013. Advancing the use of drones in the field of water sampling is highly desirable as current water sampling and data collection programmes worldwide necessitates considerable numbers of field personnel and is hence very expensive, while also posing health and safety and biosecurity risks. The use of drones could offer a safer, easier, more reliable and accurate assessment of water chemistry parameters compared to using traditional water sampling techniques.

Over the past decade, a combination of off-the-shelf drones (e.g. Ascending Technologies Firefly hexarotor and six rotor LAB645 UAV) (Detweiler et al., 2015; Ore et al., 2013, 2015; Song et al., 2017; Terada et al., 2018) and custom-built platforms (Koparan and Koc, 2016; Koparan et al., 2018a, 2018b) (Table 1) have been deployed along with specially designed water sampling payloads (Table 2). Key developments in water sampling payload design has seen payloads advance from complex custom-built chassis systems with three spring-lidded chambers operated by a servo-rotated 'needle' where water fills a glass sampling container via a micro submersible water pump (Detweiler et al., 2015; Ore et al., 2013, 2015) to "thief-style" water sampling systems (Koparan et al., 2018a). More recently these designs have evolved to deploy high-density polyethylene (HDPE) bottles consisting of a hollow tube structure which allows water to freely enter when lowered into the water (Terada et al., 2018). Advancements in incorporating off-the-shelf multi-meter probes (temperature, dissolved oxygen, conductivity and pH) (Koparan et al., 2018b; Song

Table 1
Specifications of drone platforms used to conduct water sampling.

Platform type	Maximum payload weight	Flight time	Communication software	Source
Off-the-shelf Hexarotor - Ascending Technologies Firefly	600 g[a]	Total flight time = 15–20 mins per battery with full payload[a]	Robot operating system - low level communication with the UAV, risk management, mission control, navigation & altitude estimates On board custom microcontroller – operates aerial sampling system, reads sensors & status of water sampling system	Detweiler et al., 2015; Ore et al., 2013, 2015; Song et al., 2017
Off-the-shelf Six-rotor LAB645	12,000 g[a]	Maximum flight time = 40 mins[a]	Operator controlled during take-off and landing Autonomous flight via GPS waypoints	Terada et al., 2018
Custom built hexacopter with floatation attachments	750 g[b]	Theoretical flight time = 8 mins[c]	Radio controller (Turnigy 9X) – manual control of hexacopter Autonomous flight & ground control station - Pixhawk autopilot (GPS receiver, radio telemetry) – provides information on flight conditions Mission planner software	Koparan and Koc, 2016; Koparan et al., 2018a, 2018b

[a] Manufacturers specification.
[b] Weight of components used to develop the custom-built payload.
[c] Flight time based on 80% battery life.

et al., 2017) and the ability of some sensors to autonomously relay real-time data back to nearby ground stations (Song et al., 2017) has greatly increased the capacity of drones with water sampling payloads to monitor in-situ water chemistry parameters.

A significant achievement of these water sampling payloads has been the capability to capture water from the freshwater environment, with recent studies demonstrating the ability of the water sampling payload to take 330 ml of water (Terada et al., 2018) (Table 2). Field trials demonstrated a successful water capture rate of 60–83% (Koparan and Koc, 2016; Koparan et al., 2018a; Ore et al., 2013, 2015) with issues predominantly associated with faulty lid mechanisms, variations in the altitude of the pump, pump not priming correctly, silt intake in the pump, environmental conditions (i.e. increase in wind speed) (Ore et al., 2013, 2015); and issues associated with the messenger on the “thief style” water sampler such as the sampler not triggering or the servo-motor malfunctioning (Koparan and Koc, 2016; Koparan et al., 2018a). Nevertheless, a clear proof of concept that drones can be used to take water samples from aquatic environments has been demonstrated.

Before drones can be consider for use in obtaining water samples and physico-chemical data under water sampling programmes, it is critical that the method of sampling and data collection does not influence the quality of data collected. The comparison of water chemical parameters obtained using drones-assisted water sampling with those of more traditional methods (e.g. handheld probes and manual grab samples from land or boat) (Table 3) highlight clear inaccuracies. This in part is due to variations in water sampling payloads used, the manner in which drones were deployed to capture water samples and physico-chemical data, and limited experimental design. Ore et al. (2013, 2015) and Detweiler et al. (2015) reported similar trends for physico-chemical variables collected using drone-assisted and manual water sampling methods. However, dissolved oxygen (DO) levels were higher and temperature levels lower in waters collected using the drone-assisted water sampling method. Differences were attributed to interference by the pump and transit through the tubing, agitation during flight, and in some instances changes in water properties between water collection and analyses (Detweiler et al., 2015; Ore et al., 2013, 2015). In comparison, sulphate and chloride levels were lower from waters collected using the drone-assisted water sampling method when compared to simultaneously collected manual grab water samples. Differences were pronounced, values were deemed to be due to sampling variation (Detweiler et al., 2015; Ore et al., 2013, 2015). Comparative statistical studies by Koparan et al. (2018a) found drone-assisted water samples to be significantly higher for DO, pH and chloride. However, the percentage difference between water chemistry parameters was deemed small, highlighting minimal error between the sampling methods. Despite this, it should be noted that prior to analyses, drone-assisted and manual grab water samples were poured from their respective collection vessels into beakers on the bankside. This procedure would not be standard practice during large-scale water sampling programmes in which data collected via probes usually involves immersion of the meter probe into the waterbody. The pouring of the water sample from the collection container into a beaker most likely impacts

Table 2
Specifications of water sampling payloads attached to drones to conduct water sampling.

Sampling location	Water sampling payload	Physico-chemical sensors attached to drone	Quantity of water captured	Water sampling times using drone	Physico-chemical variables monitored	Source
Holmes lake (Nebraska, USA)	Custom built chassis - spring-lidded chambers operated by a servo-rotted ‘needle’ with tube and micro pump	None	60 ml	Total time = 2 h Estimate 20 min using the drone alone	Temperature, dissolved oxygen (DO), sulphate & chloride	Detweiler et al., 2015; Ore et al., 2013, 2015
Mesocosms, Uni. of Kansas' Biological Field Station (Kansas, USA)	As above	Temperature (GP103J4F NTC Thermistor) & conductivity (Atlas Scientific) sensors	As above	Total time = 40 mins 10 min per reading per mesocosm	Temperature, conductivity & chloride	Song et al., 2017
Yugama crater lake (Japan)	Custom built metal free high-density polyethylene sampling bottle	None	250–330 ml	Not given	Conductivity, pH, chemical conc. (chloride, sulphate, aluminium, calcium, iron, potassium, magnesium, manganese, sodium, silicon-dioxide) & stable isotope ratios (δD & $\delta^{18}O$)	Terada et al., 2018
Lamaster Pond, Clemson Uni. (South Carolina, USA)	Custom built “thief-style” water sampler	pH, conductivity, temperature and DO (Atlas Scientific) sensors	130 ml	Total time = 1 h Estimate 20 min using the drone	DO, temperature, pH, conductivity & chloride	Koparan and Koc, 2016; Koparan et al., 2018a, 2018b

Table 3
Comparison of water sampling methods and experimental design employed within freshwater environments.

Sources	No. of sampling sites	Replication	Methods Compared	Total sample size	Statistical comparison
Ore et al. (2013, 2015) Detweiler et al. (2015)	5	3	Manual grab sample & use of hand-held probes from Kayak versus drone-assisted water sampling from Kayak	30	None
Song et al. (2017)	9	3	Manual grab sample & use of hand-held probes versus HOBO in-situ sensors versus drone-assisted water sampling	81	None
Koparan et al. (2018a)	3	3	Manual grab samples & use of hand-held probes from Kayak versus drone-assisted water sampling	18	Paired *t*-tests

on DO concentration of the samples. Song et al. (2017) also reported no direct comparison in the levels of chloride between drone-assisted and manual grab water samples. Disparities were attributed to interferences within the water column from using a boat and differences in the volume of water collected. The small volume of water collected using the drone-assisted sampling method may have been less representative of the chloride levels. Further research investigating if such discrepancies between sampling methodologies is obviously required to identify if sample treatment post capture, level of precision within each sampling method has a significant impact on these parameters or if the manner in which samples are collected (drone versus manual sample) is responsible for such significant inconsistencies.

Overall, limited sample size and replication, and poor water capture rates may have prevented robust statistical comparison between water sampling methodologies in many of the reviewed studies (Table 3). In addition, water chemical parameters varied between water sampling methods. At this time there is no clear indication that water samples and physico-chemical data obtained using drones would provide the level of reliability and accuracy needed to meet the needs of large-scale water sampling programmes, therefore creating a short-term limitation to their use.

3. Knowledge gaps and technological advances needed to future-proof the use of drones for water sampling

The studies reviewed here highlight the potential use of drones to conduct water sampling and obtain physico-chemical data from freshwater environments and are considerable and noteworthy studies in the development and application of drones in water sampling. However, several key limitations must be addressed before the application of drone technology can be applied as an alternative to traditional water sampling on large-scale aquatic sampling programmes worldwide.

Consideration should be given to the type and payload capacity of off-the-shelf drones, as many new large drones (<25 kg) have payload carrying capacity of at least 10 kg, for example the DJI Agras drone series (DJI, 2019). These drones, while not designed for water sampling, could be modified allowing larger volumes of water (minimum 1–2 l) to be collected. While current drone-assisted water sampling devices can capture between 60 and 330 ml of water (Detweiler et al., 2015; Koparan and Koc, 2016; Koparan et al., 2018a, 2018b; Ore et al., 2013, 2015; Song et al., 2017; Terada et al., 2018), larger drones (10–25 kg) with greater payload capacity provides an opportunity to match the quantities of water typically required for collection in large-scale sampling programmes. Careful consideration will need to be given to obtaining a greater volume of water as this will have a knock-on effect on the ability of the drone to successfully complete flights in less optimum weather conditions. Furthermore, use of larger drones and associated payloads could result in increased costs, longer set up times on site and greater requirements for increased permissions, licencing and/or insurance which will have a knock-on impact of the drone selected for use in drone-assisted water sampling. Sampling success rate must also increase, if larger volumes of water are to be captured every time. A solution used by Song et al. (2017) involved monitoring the status of the pump (is it in the water, is it pumping water etc.) and ability to control filling of the sampling vials from the ground station. This allowed issues to be highlighted early in the sampling procedure and feed information back to the drone operator on the status of the water sample.

As the development of drone and payload technology advance and these systems become more integrated into and complement water sampling programmes a major limitation of their use will be obtaining samples beyond the visual line of sight (BVLOS) especially on large open waterbodies (>2 ha). Currently, international, European and national drone regulations (Table 4) typically only allow drones with a maximum take-off mass (MTOM) of <25 kg to operate within the visual line of sight (VLOS), which is typically no further than 300 m, to avoid problems arising with manned aircraft and ensure safe flights (EASA, 2015, 2018; ICAO, 2011; JARUS, 2013). Drone-assisted water sampling within the VLOS (300 m) places restrictions on the ability of the drone to collect multiple water samples from across a waterbody from the same ground station. For large waterbodies (>2 ha), this could result in several ground station locations and more time spent setting up and packing up a large drone platform and payload than spent sampling. Therefore drone-assisted water sampling BVLOS will be necessary if drone-assisted water sampling is to be practically applied to large waterbodies. Where planned flight operations are expected to be BVLOS operators will need to seek permission from their local authorised authority for special operating permission (SOP). This may result in additional costs, both in terms of time and financially, associated with the use of drones for water sampling. Although it is anticipated that the legal requirements associated with operating drones will become less cumbersome in the future, but this remains to be seen.

Technological advancements in water sampling payload design are required if accurate and reliable statistical comparisons of water chemistry parameters are to be determined. In-situ, real-time data transfer of physico-chemical parameters specifically temperature, dissolved oxygen, conductivity and pH is necessary if meaningful comparisons between drone-assisted and hand-held probes is to occur. Song et al. (2017) used real-time conductivity and temperature probes and incorporated these into the water sampling payload design, allowing real-time monitoring of data. Nonetheless, use of the same probes (from same manufacturer) when comparing drone-assisted and hand-held water chemistry data is important if clear, transparent, and consistent comparisons are to be made. In addition, allowing sampling probes sufficient time to take readings (up to 3–4 min) when in the water is important especially when comparing values obtained from hand-held probes which are likely to have more time to settle (>5 min). Enthusiasm surrounding the use of drones as a faster sampling method cannot compromise how the data are obtained.

While it is accepted that many of the studies presented in this review demonstrate proof of concept that drones can be used to capture water samples and physico-chemical data; there is now a need for future drone-assisted water sampling studies to adapt more robust statistical experimental designs to examine the variability and precision of data collected. In addition, comparing sampling methodologies across a range of hydromorphological types to ensure the use of drones does not impact on the quality of data collected. This could be achieved by incorporating a greater number and diversity of types of water bodies, increased number of sampling sites per waterbody and greater replication of samples per sampling site per waterbody. In addition, a wider selection of water chemistry parameters (nutrients, suspended solids & heavy metals) and comparisons across various water sampling

Table 4
Comparison of New Zealand (Civil Aviation Authority (CAA) of New Zealand Part 101), North American (Federal Aviation Administration (FAA) Part 107), Irish (Irish Aviation Authority (IAA) (Small Unmanned Aircraft (Drones) and Rockets) (S.I. No. 563 of 2015)) and new European (EU Basic Regulation) legislation pertaining to the operation of drones.

	CAA Part 101	FAA Part 107	IAA S.I. No. 563		EU Basic Regulation	
	≤25 kg	≤25 kg (55 pounds)	4–25 kg	25–150 kg	Open (1–25 kg)	Specific
Register drone platform		✓	✓	✓	✓	✓
Operate within VLOS or max. Distance of 300 m	✓	✓	✓	✓	✓	✓
Maintain max. Height of 120 m (400 ft)	✓	✓	✓	✓	✓	✓
Cannot fly within 5 km of an aerodrome	✓		✓	✓	✓	✓
Cannot fly at speeds >100 mph		✓				
Distance of 30 m from people, vessel, vehicle or structure			✓	✓		
Distance of 120 m from a group of 12 or more people (IAA) or structure (FAA)		✓	✓	✓		
Distance of 50 m from large obstacle					✓	✓
Requirement to partake in ground safety school, undergo a flight exam and/or hold a certificate of competency	✓	✓		✓	✓	✓
Maintain height of 3 m above uninvolved persons					✓	✓
Prohibited from operating over nonparticipants		✓				
Maintain height of 20 m above private property where permission is not sought					✓	✓
No autonomous drone flight operations					✓	
No modifications to be made to the commercially purchased drone					✓	
No excessive or continuous recording (visual/audio) of people during drone flight operations					✓	✓
Develop operations manual & record flight logbook						✓
Undertake risk assessments						✓
Consent must be obtained for flying over persons and property	✓					

VLOS: visual line of sight.

methodologies (manual grab samples & hand-held probes versus drone-assisted water sampling versus in-situ sensors) should also be included for analysis.

Finally, despite the anticipated cost and time savings of using drone-assisted compare to manual grab water sampling, evidence to date is limited. Ore et al. (2015) noted that manual grab water sampling took between 10 and 15 h per day per lake in comparison to approximately two hours to collect replicate manual and drone-assisted water samples (Detweiler et al., 2015; Ore et al., 2013, 2015). However, Koparan and Koc (2016) and Koparan et al. (2018a) documented that is took approximately the same time (1 h) to conduct both drone-assisted and manual grab water sampling from a kayak. Detweiler et al. (2015), Koparan and Koc (2016), Koparan et al. (2018a), and Ore et al. (2013, 2015) all estimated that drone-assisted water sampling alone would take approximately 20 min per flight mission to collect water samples and take physico-chemical data highlighting the potentially rapid pace of drone-assisted water sampling. Future drone-assisted water sampling research should incorporate a detailed cost benefit analysis including capital costs of drone, payload and sensor investments, sampling times, personnel resources, health and safety risks and biosecurity risks, and clear all-inclusive comparisons of water sampling methods employed enabling informed decisions regarding sample collection methods to be based on careful cost estimates (Wich and Koh, 2018). In some circumstances, regardless of the estimated high set up and running costs, drone-assisted water sampling will provide water samples and physico-chemical data from inaccessible and hazardous regions (Terada et al., 2018).

It is anticipated that developments in platforms, payloads, sensors and regulatory environment will facilitate the widespread adoption of drones for water sampling. Such a scenario will provide detailed, long-term evidence of the use and application of this technology to complement water sampling programmes worldwide.

4. Concluding remarks

Over the last decade, advancement in drone technology has seen the development of drone-assisted water sampling payloads resulting in the ability to conduct water sampling and retrieve physico-chemical data from aquatic ecosystems. The application of drones in this context provides the potential to fulfil some aspects of the biological and physico-chemical sampling required to meet large-scale water sampling programmes in a safer, efficient and more cost-effective manner.

This review documents the range of uses of drones to conduct water sampling and obtain physico-chemical data from freshwater environments. Significant achievements include the application of off-the-shelf drones (Detweiler et al., 2015; Ore et al., 2013, 2015; Song et al., 2017; Terada et al., 2018); advances in specially designed water sampling payloads in particular the type of water sample bottle used and collection mechanism (Detweiler et al., 2015; Koparan et al., 2018a; Ore et al., 2013, 2015; Terada et al., 2018); and advancements in incorporating off-the-shelf multi-meter probes (Koparan et al., 2018b; Song et al., 2017) capable of real-time data transfer to ground stations (Song et al., 2017). These achievements in drone-assisted water sampling payload design now enable the capture of water (up to 330 ml) and physico-chemical data from freshwater environments.

However, drone-assisted water sampling is still in its infancy and hence is not currently without drawbacks yet to be resolved with several key limitations highlighted in this review. Of critical importance are the clear inconsistencies observed between water chemical parameters obtained using drone-assisted and traditional water sampling methods, limited evidence of the ability of drones to sample a sufficient volume of water, and inconsistent sample retrieval success rates. Consequently, there is no clear indication that water samples and physico-chemical data obtained using drones would provide the level of reliability and accuracy needed to meet the needs of large-scale water monitoring programmes, creating a short-term limitation to their use.

Key recommended solutions aimed at addressing these limitations and future-proofing the application of drones to conduct water sampling include:

- Modifying large, off-the-shelf drones (<25 kg) with payload carrying capacity of at least 10 kg, allowing larger volumes of water (minimum 1–2 l) to be collected;
- Capturing comparable volumes of water (1—2l) for analysis using drone-assisted and manual grab water sampling;
- Increasing success rates of water capture by incorporated a communication system allowing the operator to monitor the status of the pump and sampling bottles from the ground station;
- Planning fieldwork well in advance of sampling on large waterbodies and obtaining permission from local authorised authorities to conduct drone-assisted water sampling BVLOS;
- Employing in-situ, real-time physico-chemical probes is necessary if meaningful comparisons between drone-assisted and hand-held probes is to be made;

- Comparing the same probes (from same manufacturer) and allowing sampling probes sufficient time to take readings is necessary when comparing drone-assisted and hand-held water chemistry data if clear, transparent, and consistent comparisons are to be made;
- Critical need for robust statistical experimental designs to examine the variability and precision of data collected;
- Conducting drone-assisted water sampling on large open waterbodies; and
- Incorporating detailed cost benefit analysis enabling informed decisions regarding sample collection methods based on careful cost estimates.

Despite the current limitations, this review demonstrates that water samples can successfully be captured using drone-assisted water sampling from aquatic environments. It is envisaged that drone-assisted water sampling technology will act as a pivotal supporting tool in the future if such current limitations can be addressed by future research.

Declaration of interest

None.

CRediT authorship contribution statement

H.T. Lally: Conceptualization, Formal analysis, Funding acquisition, Investigation, Project administration, Writing - review & editing. **I. O'Connor:** Conceptualization, Funding acquisition, Writing - review & editing. **O.P. Jensen:** Conceptualization, Funding acquisition, Writing - review & editing. **C.T. Graham:** Conceptualization, Funding acquisition, Writing - review & editing.

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