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Research Article

AquaticVID: a low cost, extended battery life, plug-and-go video system for aquatic research

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Abstract

AquaticVID is a low-cost, long battery life video camera system for use in a wide-range of aquatic research applications. The system can be deployed for multiple day recording on a single charge, is submersible to depths of down to 950 m and can be constructed quickly using easily sourced off-the-shelf materials. The system is essentially ‘plug-and-go’, as assembly and preparation for deployment takes < 30 minutes without the need for technical build or programming skills. All of the electrical components are interchangeable with parts from multiple manufacturers and the camera system can be adapted to fit a variety of waterproof enclosure sizes depending on power and data storage requirements. Here, we describe three versions of the AquaticVID in detail and give examples of above and below water research undertaken with the system. The small size and extended battery times, coupled with ease of use and low cost (US$ 268–540) make the AquaticVID a useful option for numerous aquatic research applications.

Keywords

underwater video, electronic monitoring, fisheries, BRUVS, conservation, ecology, marine ecology, fish behaviour, bycatch

Introduction

Remotely deployed video camera technology is now widespread in aquatic research (Bicknell and Godley 2016). Waterproof video cameras (or video cameras combined with waterproof housings) are used in numerous research and monitoring applications, including; remote observations of underwater biota (e.g. baited remote underwater video systems; reviewed in Whitmarsh and Fairweather (2017)), interactions with fishing gear (e.g. Ljungberg and Lunneryd (2016)), electronic monitoring of fisheries catch (see Helmond and Mortensen (2020) for review), assessing fishing effort (e.g. Lynch and Foster (2020)) and compliance with regulations (e.g. Harasti and Davis (2019)). Remote video cameras have numerous advantages, they are non-destructive, non-intrusive (and, therefore, less likely to influence study animal behaviour), allow safe sampling of deep-water environments which humans cannot easily access safely and can detect species or behaviour that would not otherwise be detected (Favaro and Lichota 2012, Fetterplace and Turnbull 2018). Since the first early underwater video-based research, scientists have continuously been developing and custom building camera systems to reduce costs, improve available systems or to fit specific study requirements (Bicknell and Godley 2016).

Deploying video cameras underwater or in the ‘splash’ zone creates additional challenges compared to terrestrial applications (Bergshoeff and Zargarpour 2017). Cameras need to be waterproof or placed in a waterproof housing. The availability of power is often lacking or limited on-board boats and in remote locations (Fujita and Cusack 2018). In addition, multiple video systems are often deployed simultaneously (e.g. Rees and Knott (2021)), which further limits the ability to use cabled power. When battery power is used, battery run-time is often a major limitation (Madsen and Pedersen 2021), both because video sample length has to be relatively short and because batteries must be recharged frequently which often requires a reliable power source. Depending on study-specific requirements, the need to withstand water pressure at depth, salt-water corrosion, within-housing moisture, heat on exposed vessel decks and limited space are just some of the additional factors that need to be managed. All of these factors increase complexity and cost.

Ease of build, setup and deployment are important considerations for a cheap general use aquatic video system. Conversely, complicated builds and or the need for specialist skills likely limits wider uptake. Likewise, equipment cost and repair continue to be a major impediment in video-based aquatic research and monitoring. To increase efficiency and reduce high labour costs in many video sampling studies and monitoring programmes, multiple cameras are deployed simultaneously at the local scale (i.e. deployed at the same location to gather multiple samples) (e.g. Sih and Cappo (2017), Rees and Knott (2021), Clementi and Babcock (2021), Cáceres and Kiszka (2022)) and, in some cases, multiple camera sets are also deployed at wide spatial and temporal scales (i.e. multiple sets of cameras are deployed at different distant locations rather than sending cameras between locations, for example, MacNeil and Chapman (2020), Knott and Williams (2021)). However, the number of systems that can be deployed at one time is often limited by equipment costs and equipment size. The availability of a small cheap, easy to use and effective video system allows more samples to be collected, providing advantages in both cost efficiency and sampling power.

There remains a need for affordable, small, long battery life remote video systems that are also simple to build with readily available components. Current systems usually only meet a subset of these needs or require programming and build skills that often are not available. Here, we describe AquaticVID, a low-cost, long battery life video camera system that can be utilised in a wide-range of aquatic research applications. The system was developed and improved over time in response to a need for a cheap and easy-to-use camera that could be adapted to a number of research situations and that could also be used as a stand-in for more expensive and specialised systems (e.g. should they fail in the field and need a quick replacement or when more expensive systems have been delayed during the production process). To provide a representative overview of the system variations in use, we describe three of the latest versions of the AquaticVID configurations in detail and also give examples of above- and below-water research undertaken with the system to date.

The AquaticVID System

Requirements and need:

The AquaticVID system was created at the Swedish University of Agricultural Science (SLU Aqua) to fill the need for a cheap, long battery life (i.e. multiple day recording) video system that could be used across multiple projects and modified to fit each project's requirements. It was important that anyone could put the system together quickly, at any of our field stations or on-board our fishing and research vessels, using easily sourced off-the-shelf components. Other key requirements were multiple day recording time, waterproof down to 100s of metres, portable with small size, configurable frame rate and resolution, easily modifiable to suit each project needs (e.g. can be used with different-sized housings and batteries dependent on project requirements) and had components that were able to be widely sourced or equivalents swapped in easily.

System description:

The AquaticVID system consists of a single camera in a watertight housing that can be used underwater or modified for use above water in electronic monitoring on boats or other applications where a waterproof system is needed. When used above-water, a cheap external GPS unit can also be included when position data are required.

The system is designed to:

1. Record video remotely and autonomously for multiple day recording using battery power.
2. Be small and lightweight to minimise space and allow deployment by one person.
3. Have configurable settings that allow the user to decide on video quality and frame rate. This includes allowing low frame rates and resolution where needed to reduce data and storage needs.
4. Be modular; has optional components for specific research applications and can be downsized further or up-scaled depending on battery requirements.
5. Have as few components and cables as possible to minimise the chances of failure in the field and to minimise build complexity. Components are interchangeable with other brands/models and all the components have off-the-shelf easily sourced options.
6. Fast to build and short preparation time: With the parts in hand, the base system for use underwater can be assembled in very short time (< 30 minutes).
7. Be easy to put together for non-experts and be built with off-the-shelf components that are plug-and-go, so there is no need to have electronics, soldering or coding/ programing skills.

Here we describe three versions of the AquaticVID in detail: A '**Micro**' (2 inch housing), '**Mini**' (3 inch housing) and a '**MiniAir**' (3 inch housing) option that has modifications for long-term deployments above-water environments. All three versions consist of the same base components (camera, miniSD, keep-alive load) and have differing waterproof enclosure sizes and power supply components (Table 1, Fig. 1).

Table 1.

Bill of materials outlining the base components required for all versions of the AquaticVID system and the components specific to each version.

Version	Part	Component	Qty	Unit Cost (USD)	Total cost (USD)	Source of materials
All versions	A	Mobius 1080p HD action camera + C2 wide angle lens	1	90	90	mobius-cam.com
	B	USB cable	1	0	0	NA
	D	Camera holder	1	1	1	See S2 Section
	E	USB battery pack keep-alive load	1	20	20	Sotabeams
Micro (2")	C	Micro SD card 64GB	1	10	10	24.se
	F1	Powerbank (2600 mAh)	1	12	12	See S1 section
	G1	Dome port 2" Series	1	24	24	BlueRobotics
	H1	Aluminium O-ring flange 2" Series	2	27	54	BlueRobotics
	I1	Cast acrylic tube 2" Series	1	34	34	BlueRobotics
	J1	Acrylic end cap 2" Series	1	14	14	BlueRobotics

Version	Part	Component	Qty	Unit Cost (USD)	Total cost (USD)	Source of materials
	K	Enclosure pressure vent	1	9	9	BlueRobotics
				Total Cost Micro: 268		
Mini (3")	C	Micro SD card 400GB	1	55	55	24.se
	F2	Powerbank (30,000 mAh)	1	35	35	See S1 section
	G2	Dome port 3" Series	1	32	32	BlueRobotics
	H2	Aluminium O-ring flange 3" Series	2	35	70	BlueRobotics
	I2	Cast acrylic tube 3" Series	1	179	179	BlueRobotics
	J2	Acrylic end cap 3" Series	1	15	15	BlueRobotics
	K	Enclosure pressure vent	1	9	9	BlueRobotics
				Total Cost Mini: 506		
MiniAir (3")	C	Micro SD card 400GB	1	55	55	24.se
	F2	Powerbank (30,000 mAh)	1	35	35	See S1 section
	G2	Dome port 3" Series	1	32	32	BlueRobotics
	H2	Aluminium O-ring flange 3" Series	2	35	70	BlueRobotics
	I3	Cast acrylic tube longer 3" Series	1	215	215	BlueRobotics
	J2	Acrylic end cap 3" Series	1	15	15	BlueRobotics
	L	One way valve (above-water only)	1	6	6	Biltema
				Total Cost Mini Air: 539		
Above-water optional	M	External on/off switch	1	6	6	Kjell & Company
	N	GPS unit	1	55	55	Conrad.com

Hardware Description

Electronic Components

The electronic components in the AquaticVID consist of an action camera with internal battery, miniSD card, type A male-to-male mini-USB cable, a keep-alive load (these components are the same in all versions of the AquaticVID) and a power bank (the power bank size and capacity varies depending on AquaticVID configuration) (Fig. 1, Table 1).

Camera: The Mobius action cam 1 is used as a base camera as it is cheap, reliable, takes good quality video footage and has a wider range of easily configurable settings than other action cameras (the camera can be swapped with alternatives with no modifications to the system needed; see S1). Spare parts, alternative lens types and add-ons are low cost and easily sourced. Technical camera details: Mobius 1080p HD action camera 1 (three resolution settings 848x480(WVGA)–1920x1080, frame rate 5–60fps, MP4, MOV, AVI, video codec h.264) with 130-degree wide-angle C2 lens (170-degree diagonal FOV). Camera and lens 68 mm(L) x 35 mm(W) x 18 mm(H). Weight 41 grams (see

MobiusActionCam (2017) for recording instructions). Mobius provides a windows application with a simple graphical user interface for adjusting the camera settings. Alternatively, users can use a text file to enter settings (MobiusActionCam 2017). Camera settings and setup are available via the Mobius manual. Note that, while the cameras are reported to have good sound recording capabilities, we disable the sound function primarily to maximise battery life when recording video and because we do not generally require sound data in our camera-based studies. As a result, we have not field-tested sound recording or sought to optimise sound recording in the AquaticVID systems.

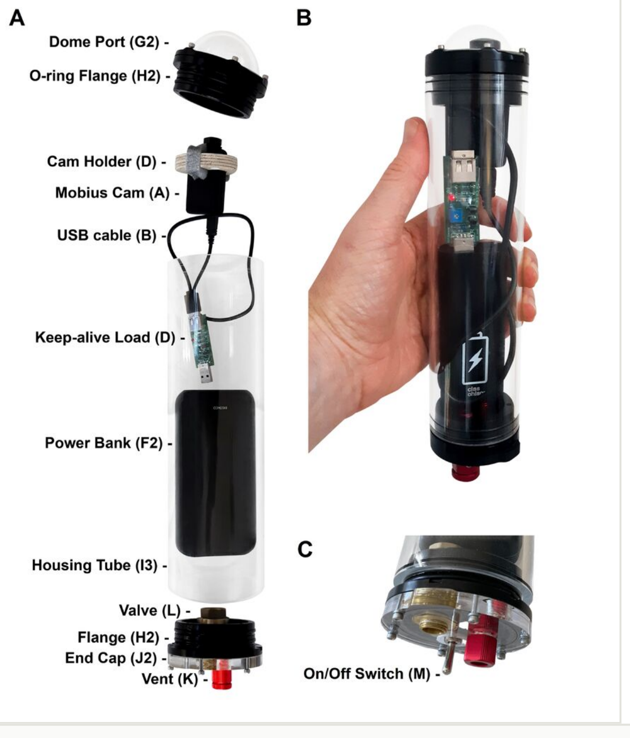

Figure 1. doi

Two AquaticVID variations: **A)** the Mini Air with components labelled (value in brackets matches Table 1 designator), **B)** the smaller Micro setup for underwater deployment (no valve) and **C)** end cap with optional on/off switch alongside a valve and vent. The tube and end cap can also be swapped over with aluminium tubes, from the same manufacturer which will increase the depth rating substantially.

Data Storage: Mobius recommends the use of 128 GB miniSD cards as a maximum; however, we tested up to 400 GB cards and some models (formatted to FAT32 or exFAT32 in camera) were compatible (Suppl. material 1). Today, power supply is often the limiting factor, particularly in the smaller system versions, so storage capacity should be based on power and settings used (see Suppl. material 1 for power and storage capacity test outcomes), so that power runs out before the data capacity fills (include a small buffer as power use and data size vary based on light conditions).

Keep-alive Load: Sota beams variable load 6–150 mA with adjustable current level. Most modern power banks have an automatic sleep mode (they switch off if the current being drawn stops or is too low after a short time period) that cannot be turned off. This means that when charging a camera with an internal battery, the power bank will charge the camera battery once and then turn off when the camera battery is full despite having the capacity to charge the camera battery multiple times. Adding a component that maintains a low constant current draw that keeps the battery back 'alive' prevents power bank low-current shut-down. The keep-alive load uses a USB type A female connector for incoming power supply.

Power supply: The Mobius standard battery is 520 mAh which gives roughly 90 minutes battery life on default 1920 x 1080p at 30fps (can be upgraded to 820mAh = 130 minutes). In the AquaticVID systems, additional battery supply is added: In the AquaticVID MICRO version, generally we use an additional off-the-shelf power bank of 2600–5200 mAh and the MINI and MINI Air have an additional off-the-shelf power bank of 30,000 mAh (see Suppl. material 1 for detailed specifications). Note: Although we use a power bank in the example here, as they are easy to source in most locations and simple to ship via postage compared to batteries, a single battery or banked batteries can be used in the system.

Cables: To interconnect the Mobius camera with the keep-alive load, a type A male to type mini male USB cable is used. To interconnect the keep-alive load with the power bank, a USB cable with a type A male connection is used, while the other end is power bank specific.

Camera holder: a simple camera holder made of easily available material – we use plywood offcuts with foam padding points or foam holders (any lightweight wood or 3D printed plastic versions can be used). See Suppl. material 2 additional details.

GPS: When used above-water, an external portable GPS unit (sold as Renkforce gp102 in Sweden that is a house brand rebadged G-Porter CANMORE-gp-102) can be added to the system to collect position data (Table 1, Fig. 1) Output file is .FIT (Flexible and Interoperable data Transfer) format and contains position, altitude, distance and speed information.

Watertight Enclosure

The standard watertight enclosure used for the AquaticVID consists of a dome, a cast acrylic tube and acrylic end cap, two O ring-flanges (these come standard with six O-rings) all made by and distributed by BlueRobotics (Table 1, Fig. 1). In the Mini and Micro AquaticVID versions, a single enclosure vent with plug is inserted into the acrylic end cap (Table 1, Fig. 1). Closing the watertight enclosure compresses the air inside and the pressure can begin to push the enclosure open. The vent lets you release the pressure and reseal the enclosure before deployment. Double O-rings in the vent combined with screw threading prevent water entry. In the MiniAir used above-water, an additional one-way air valve is inserted into the acrylic end cap (Table 1, Fig. 1). Adding an air valve overcomes issues with air inside the housing warming when in sunlight and the air expanding and popping the endcaps off the enclosure and prevents overheating of the camera system when using power banks. Recently BlueRobotics released a new locking version of their watertight enclosure and the tubes in the 3 inch size increased in price significantly. In Table 1, we give the higher prices of the newer locking versions of the tubes and associated flanges and end caps. However, the cheaper tubes that we currently use are stock tubing that is available from a number of plastic manufacturers, for example, Eplastics and the design files for components that match these stock tubes are available open source at BlueRobotics to be utilised should the early versions be preferred for a project. For the Mini and Mini Air, we generally purchase an acrylic tube length of 400 mm (15' 6") and for the micro, an acrylic tube length of 300 mm (11.8"); however, if shorter powerbanks or battery packs are used, then the acrylic tube can be cut shorter to further streamline the system if needed. Where deep deployments are needed, the tubes can be directly swapped over with BlueRobotics aluminium components, which can be sent down to 950 m.

Optional additions:

It is easy to remove the endcap and turn the camera on and off; however, in some cases, for example, wave and splash zones, where users need to maintain the water seal, the above-water version can be modified to include an on/off switch (Fig. 1C).

Mounting options:

The AquaticVID system can be mounted or deployed in various ways to suit different applications. The small size and weight of the system make it well-suited for ad-hoc field deployments, such as using cables or tension ties to attach it to vessel fittings or fishing gear. The system is not built with a standardised deployment mount and we tend to adapt a mount to each research situation (see Suppl. material 3 for examples).

Example Applications

The AquaticVID system has various aquatic and above-water applications and has been used in a large number of research and monitoring projects in Sweden. Some examples of projects that the system has been used in include:

Underwater behavioural studies around fishing gear

New fishing gear development requires in-situ studies evaluating the behaviour of target and non-target species around the gear, so that catch efficiency can be maximised and unwanted bycatch minimised (Thomsen and Humborstad 2010). Cameras are a widely used and effective non-intrusive means of undertaking these evaluations. For example, Ljungberg et al. (Ljungberg and Lunneryd 2016) in Sweden and Hedgärde et al. (Hedgärde and Berg 2016) in Denmark investigated the behaviour of Atlantic cod (*Gadus morhua*) entering fishing pots, with different entrance modifications designed to increase catch efficiency. Atlantic cod behaviour around fishing gear in the Baltic Sea has also been recorded to study which modification on cod pots can prevent seal raids (Stavenow and Ljungberg 2016). However, newer models of action cameras (for example GoPros, with their increasingly better quality images and faster frame-rates in each new model), are not always well suited to these types of studies, because they have greater data storage requirements, require more battery power and often cost more. In addition, lower frame-rates and quality settings have been phased out, restricting the ability to input custom settings that could overcome some of these issues. These issues are particularly problematic when wanting to deploy multiple systems and for extended periods, whilst minimising data.

The AquaticVID has been used for fishing gear-related behavioural studies (e.g. Fig. 2), primarily to overcome the cost and battery life issues associated with more expensive action cameras mentioned earlier. The key system features allowing the success of these studies have been the extended deployment times and the low frame-rate settings that minimise data storage requirements. In the Baltic Sea, the behaviour of cod entering pots was studied using an AquaticVID variant, with deployments lasting up to 76 hours using WVGA setting with 10 fps (Nyquist 2019). Similarly, when assessing the behaviour of Atlantic cod around a newly-developed pontoon trap (Ljungberg and Lunneryd 2018) and gear modification's ability to reduce seal interactions with catch (Lunneryd and Björklund 2018), an AquaticVID system was used and deployments times at 5 fps in WVGA resolution lasted up to 6.5 days. In the Bothnian Bay, Östman et al. (Östman and Sundblad 2023) used the system to observe salmonids moving through an open-ended pound-net as a way to corroborate catches in nets set by small-scale fishers. On the west coast of Sweden, the influence of competition between European lobster (*Homarus gammarus*) on catch in lobster traps (Haffling 2023; Fig. 2c) and the effectiveness of wide-scale fishing with pots for cod (Königson and Hedgärde 2023; Fig. 2b), was also demonstrated using AquaticVID. Since passive gears in some areas must be soaked several days before fish swim into the gear, the AquaticVID with its long recording time was particularly suited.

Electronic monitoring for catch estimates and evaluations in commercial fisheries

Electronic monitoring (EM) of fisheries catch and bycatch, using video camera and GPS-based systems, has been successfully implemented all over the world (Helmond and Mortensen 2020). There are several different EM systems developed that are used for monitoring of protected species bycatch (e.g. Kindt-Larsen and Dalskov (2012)Needle and Dinsdale (2015), Plet-Hansen and Bergsson (2019), Glemarec and Kindt-Larsen (2020), Tide and Eich (2022)). These systems are designed for long-term installation on a single vessel, require specialist technicians to setup and must be connected to the vessels power supply. They are not always suitable for small vessels with no, or limited, battery supply or where cameras need to be quickly moved between boats in a fleet. A small and portable system, such as the AquaticVID Mini Air version (with GPS addition), is useful because it is cheap, comes with its own power supply and it can be quickly installed and operated with no specialist EM skills by commercial fishers themselves. For example, the AquaticVID Air has been used as an EM system in bycatch monitoring of small-scale lumpfish gillnet fisheries along the Swedish west coast fisheries between 2018 and 2020 (Sara Königson, unpublished data; Fig. 3). Four fishermen where responsible for collecting data on catches and bycatches from their vessels using the camera system. The fishermen handled operation of the cameras (turning the system on and off, cleaning, off-loading data to an external hard drive and charging the batteries). Over 180 fishing days, 500 hauled nets were monitored and a wide range of bycatch recorded (Fig. 3). The AquaticVID Air system has also been used for collecting data on trials conducted in collaboration with commercial fishermen evaluating whether acoustic deterrents (pingers) decrease the bycatch of harbour porpoises and harbour seals in gillnet fisheries (Björklund Aksoy 2020, Fonseca-Pilzecker 2023, Königson and Naddafi 2023) and for comparisons between camera and observer records of catch (Häberle 2021). The footage from the AquaticVID system is compatible with the commercial EM analysis programme "Blackbox Analyser" which allows rapid processing of collected EM data.

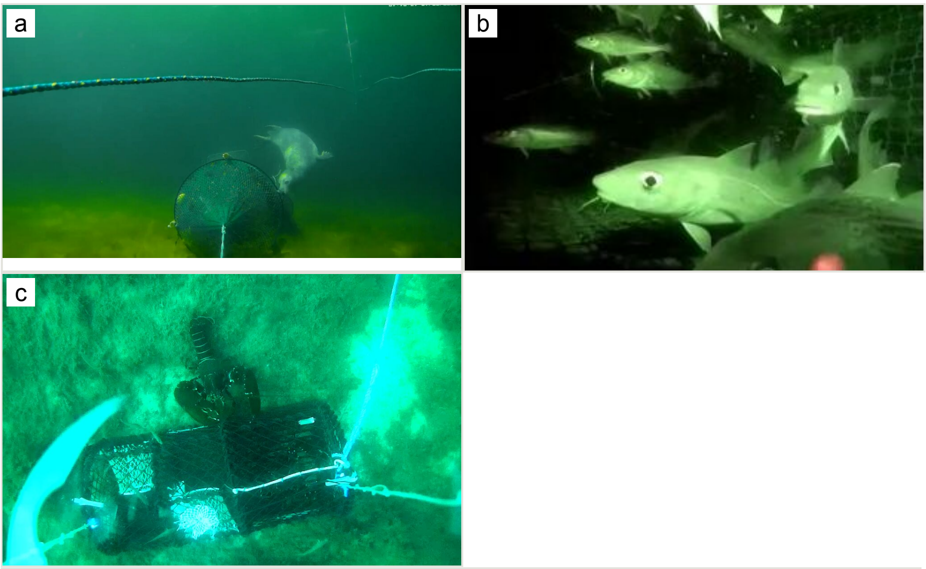

Figure 2.

AquaticVID variants have been used by SLU Aqua researchers and students, to look at animal behaviour around fishing gear. Image a: A grey seal looking for an easy meal investigates a fyke-net: filmed in ongoing research into grey seal behaviour around fyke-nets in the Baltic Sea. Image b: Atlantic Cod trapped in a cod pot filmed as part of a study on fish behaviour in relation to light, different types of bait and fishing gear effectiveness (Königson and Hedgärde 2023). Image c: A European lobster approaches a lobster trap in a study looking at size-driven competition between lobsters (Haffling 2023).

Remote underwater video sampling

Battery power is often a limiting factor in deployments of baited remote underwater video systems (BRUVS) (Gore et al. 2020). BRUVS samples generally only last for 30–90 minutes (e.g. Sih and Cappo (2017), Fetterplace (2018), De Vos (2021), Becker and Taylor

(2022), Cáceres and Kiszka (2022)). However, each system is usually deployed multiple times per day until battery power is exhausted (Fetterplace, pers. commun). In addition, in some cases, long deployment times are needed, requiring various modifications to cameras and housings (e.g. Stobart and Díaz (2015) (7 h), Harasti and Lee (2017)(5 h), Gore and Ormond (2020) (2 h+), Torres and Abril (2020) (24 h)). The cost of many commercially made BRUVS is a limiting factor in setting up BRUVS studies and the extent of sampling possible within studies. To maximise efficiency, BRUVS are almost always deployed simultaneously, in sets of 4–10, at a study site (e.g. Cáceres and Kiszka (2022), Coleman and Wood (2023)) and multiple sets may be required at different regional sampling sites (e.g. Knott and Williams (2021)) which saves labour, time and vessel costs, but means the initial outlay on camera equipment and repairs/replacements can be high. The AquaticVID system with its very long battery life, small size and low cost is a useful BRUVS option to overcome some of these issues. In Sweden, the AquaticVID system has been used in comparisons of bait types in the Baltic Sea (Königson and Strömberg 2018, Königson and Hedgärde 2023; Fig. 4) and in ongoing student thesis BRUVS projects. Although the use of BRUVS in Sweden only began relatively recently, there is increasing impetus to undertake BRUVS studies and we expect there will be increased use of the AquaticVID system in these types of studies.

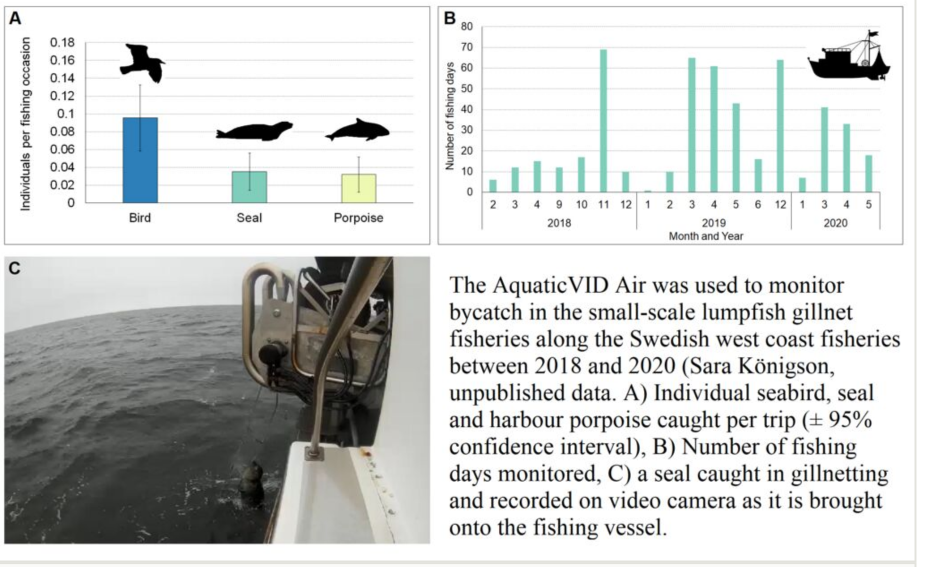

Figure 3. doi

Electronic monitoring of fisheries bycatch in Swedish small-scale fisheries using AquaticVID.

Figure 4. doi

AquaticVID was used in a Swedish BRUVS bait comparison study to evaluate the number of fish attracted to various bait types, with deployments lasting up to 36 hours of continuous filming (Königson and Strömberg 2018, Königson and Hedgärde 2023).

Conflicts of interest

The authors have declared that no competing interests exist.

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Supplementary materials

Suppl. material 1: S1 doi

Authors: Fetterplace L, Rooth D and Benavente Norrman E
Data type: Battery and SD card test results - Table S1
Brief description: Power bank and SD card specifications, camera alternatives and validation and characterisation of batteries and SD Cards.
Download file (127.28 kb)

Suppl. material 2: S2 doi

Authors: Fetterplace L
Data type: Images and text
Brief description: Description of camera holders and additional photos. Description of pressure vent and one-way air valves and additional photos.
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Suppl. material 3: S3 doi

Authors: Fetterplace L and Rooth D
Data type: Images and descriptive text
Brief description: Examples of some camera mounting options.
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