Chapter S10. Environmental Monitoring Technologies and Techniques for Detecting Interactions of Marine Animals with Marine Renewable Energy Devices

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S10.1. INSTRUMENT CLASSES USED FOR MONITORING MARINE RENEWABLE ENERGY DEVICES

A suite of environmental monitoring instruments has been used to monitor the potential environmental effects of marine renewable energy (MRE) devices. The most common instrumentation used to document interactions of marine animals and habitats with MRE devices include passive acoustic instruments, active acoustic instruments, and optical cameras. Here, we overview the different classes of instrumentation used for monitoring marine animal interactions with MRE devices[1].

Marine sound monitoring

Passive acoustics

Two review papers published in 2013 provided a comprehensive assessment of all published acoustic environmental monitoring activity for MRE devices up to that time (Copping et al. 2013; Robinson and Lepper 2013). Table S10.1 below provides an update and expansion of those works and summarizes the various PAM efforts used to characterize i) ambient noise baseline measurements, ii) operational noise, iii) construction and installation associated noise, and iv) and planned transmissions. For each noise measurement campaign at the 17 sites outlined in Table S10.1, the methodology used is classified generally as i) boat drifting, ii) buoy drifting, iii) bottom moored/mounted, or iv) turbine mounted single hydrophones, pairs or larger (vertical, horizontal, and two-dimensional) arrays. The objectives of the ensemble of studies outlined in Table S10.1 at each site are characterized as i) background, ii) construction, or iii) operational noise measurements, and are accompanied by selected publications describing the results.

Table S10.1. Summary of deployment locations, passive acoustic measurement (PAM) equipment configurations employed, acoustic measurement type, and related references for various tidal energy noise monitoring campaigns.

Location	Methodology used	Objectives	References
Lynmouth, UK	Drifting boat hydrophone	Operational noise	(Parvin et al. 2005; Maunsell Faber and METOC 2007; Richards et al. 2007)

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[1] Mention of commercial instruments or other equipment and software throughout this chapter is meant to illustrate the gear in use and does not constitute endorsement of those commercial products.

Strangford Lough, UK	Drifting boat hydrophone	Operational noise	(Nedwell and Brooker 2008; Gotz et al. 2011; Keenan et al. 2011)
Fall of Warness, Orkney, UK	Drifting boat hydrophone Drifting buoy hydrophone	Background noise Construction noise Operational noise	(Aquatera 2010; Beharie and Side 2011; Wilson et al. 2011, 2014)
Cobscook Bay, Maine, USA	Drifting buoy with pair of vertically separated hydrophones	Operational noise	(CBTEP 2012)
Kvalsund, Western Finnmark, Norway	Drifting boat hydrophone	Operational noise	(Akvaplan-niva 2009)
East River, New York, USA	Towed hydrophones	Operational noise	(Ocean Energy Systems 2013)
Admiralty Inlet, Puget Sound, USA	Bottom mounted hydrophone Drifting buoy with vertical pair of hydrophones Drifting boat hydrophone Drifting vertical line array	Background noise Operational noise Planned transmissions	(Bassett 2010; Polagye et al. 2012; Xu et al. 2012; Bassett et al. 2013, 2014; Copping et al. 2013)
Minas Passage, Bay of Fundy, Canada	Drifting buoy hydrophone Bottom moored system Turbine mounted system Moored subsurface float Boat deployed horizontal array	Background noise Free-spinning turbine noise	(Martin and Vallarta 2012; Tollit and Redden 2013; Martin et al. 2018; Auvinen and Barclay 2019)
Schottel, Queen's University Belfast Tidal Test Site in Portaferry, Northern Ireland	Drifting buoy hydrophone	Background noise Operational noise, including free-pinning and braking	(Schmitt et al. 2015)
River Turbine, Iguigig, Alaska, USA	Drifting spar buoy hydrophone	Operational noise	(Polagye and Murphy 2015)
Site Expérimental Estuarien National pour l'Essai et l'Optimisation Hydrolienne (SEENOH), Bordeaux, France	Drifting boat hydrophone	Background noise Installation noise Operational noise	(Giry et al. 2018)
Cook Inlet, Alaska, USA	Moored directional array Moored hydrophone	Background noise Beluga whale monitoring	(Worthington 2014)
Ramsey Sound, UK	Boat deployed partial drifting hydrophone with subsurface float and weight 12 element turbine mounted array	Background noise Cetacean detection and localization	(Broudic et al. 2012a, 2012b; Willis et al. 2013; Malinka et al. 2018)
Grand Passage, Canada	Bottom moored hydrophone Drifting buoy hydrophone	Background noise Planned transmissions	(Malinka et al. 2015; Wilson and Martin 2019)

	Turbine mounted hydrophone		
West Scotland (Sound of Islay, Scarba, the Great Race, Gulf of Corryvreckan, Kyle Rhea, the Sound of Sleat)	Moored C-PODs Drifting C-PODs Moored vertical line array Bottom mounted hydrophone Towed hydrophone array Drifting hydrophone	Porpoise detection and localisation Baseline noise Construction noise Operational noise	(Harland 2013; Wilson et al. 2013; Benjamins et al. 2016, 2017; Macaulay et al. 2017)
Mississippi River, Memphis, Tennessee, USA	Moored hydrophone Drifting hydrophone	Background noise Operational noise	(Bevelhimer et al. 2016b)
Sequim Bay, Washington, USA	Bottom mounted vector instrument array	Test tones	(Raghukumar et al. 2019)
Meygen demonstration array, Scotland	High frequency 12 hydrophone array mounted on turbine support structure	Marine mammal localisation and tracking	Gillespie et al. (2020)

Active Acoustics - Imaging sonars

The use of imaging sonars for environmental monitoring of MRE devices are spread across a range of applications that may be categorized by deployment type (i.e., downward looking from a surface vessel, mounted on a subsea platform, or integrated into turbine substructure), deployment duration (i.e., <1 day to several months), target monitoring goals, and method of data acquisition (often continuous) and processing (i.e., a combination of manual review and automated approaches). The most appropriate sonar for each application varies with the goals of the monitoring program, and the technical specifications for different sonars effects their suitability for achieving those goals. The specifications that have the greatest impact on the capabilities of monitoring sonars includes i) the operating frequency, ii) field of view or swath angles, iii) functional range, iv) I/O trigger option, and v) software development kit (SDK). A summary of the technical specifications for the six most common imaging sonars used for monitoring MRE devices and examples of specific applications are provided in Table S10.2.

Table S10.2. Summary of the six most commonly used imaging sonars for monitoring marine renewable energy devices with general specifications.

Sonar	Frequency (kHz)	Field of view (°)	Range (m)	I/O trigger	SDK	Applications
Tritech Gemini	720	120 x 20	<120	Yes	Yes	Vessel surveys, SeaGen, AMP
Teledyne BlueView	900/2250	130 x 20	<100/ <10	Yes	Yes	AMP, vessel surveys
Kongsberg Mesotech	500	120 x 3, 7, 15, 30	<150	Yes	No	AMP, vessel surveys
Blueprint Subsea Oculus	i) 375 ii) 750/1200 iii) 1200/2100	i) 130 x 20 ii) 70 x 12 iii) 60 x 12	i) <200 ii) <120/<40 iii) <30/<10	Yes	Yes	Vessel surveys
Imagenex Delta T	260	120 x 10	<150	Yes	Yes	FLOWBEC
Sound Metrics Aris	i) 1200/700 ii) 1800/1100 iii) 3000/1800	i) 28 x 14 ii 28 x 14 iii) 30 x 15	i) <80/<35 ii) <35/<15 iii) <15/<5	No	No	ORPC, Verdant RITE

Video cameras

This section provides a brief description of the types of components that can be used to monitor fish distribution and behavior, determine species and sizes using optical video and still imagery. Use of optical video is often needed to assess marine fish/mammal observations as they approach tidal turbine systems, record fish blade interactions, determine fish species impacted or to assess operation of the turbine system. Typical equipment configurations can include the use of multiple cameras, paired stereo cameras, paired lasers, light-emitting diodes (LED) lighting, onboard memory or cabled cameras connected to a digital video recording (DVR) system and autonomous, stationary or traversing data collection platforms. Additional components that aid in the collection of data include remote positioners, various types of undersea lighting and power supplies.

Camera Systems

Optical video systems are an important tool for collecting data at remote locations. Cameras have the ability to document fish behavior and fish interactions with various manmade structures and their natural environment (Booth and Beretta 2002; Mueller et al. 2006). There are many vendors who specialize in optical video systems for oceanographic research for both optical video and still imagery with the majority tailored for the ROV industry. There is a wide range of options available from low resolution standard video to ultra-high HD at resolutions exceeding 16 megapixels (Table S10.3). A standard video camera may have 300 to 400 lines of resolution (SD) with high end models exceeding 2000 horizontal lines (4K or 4000 pixels). Recording resolution on higher grade cameras normally consists of 4K, UHD, 720, 960 and 1080p with variable frame rates. Cameras can range from inexpensive action cameras (< $1000; Struthers et al. 2015) to very expensive 4k UHD cameras in high pressure rated housings (> $4000).

Table S10.3. Standard types of optical cameras and related components available to conduct nearshore fisheries and marine mammal related observations studies.

Camera Type	Application	Cost (US$)	Benefits/Limitations
Action Cameras	Nearshore, short term recording.	300 - 800	Small size, flexible recording, low cost.
Low End Monochrome	Mid-high definition, long term	1,000	Low cost, low light sensitivity.
High End HD	High definition, long term.	5,000	Species ID
High End HD Optical Zoom	High definition, long term.	7,000	Variable and close-up viewing region.
IP Cat 5	Mid-high definition, long term.	3,000 - 6,000	Extended cable length.
COTS (digital still)	High resolution, color enhancements.	500 - 1,000	Waterproof housing needed, small size, flexible recording.
Machine Vision Video (CMOS/CCD)	Variable framerate, small size, low power requirement, Flexible interfaces (fire wire, USB, GigE, IP) variable control for camera recording parameters, can select a specific ROI.	Variable	Waterproof housing needed, temperature range, cable length for high frame rate systems.
Accessories			
LED Sea Lighting	Nocturnal viewing	1,500	24-hour observations,
Laser and Housing	Close range scaling/sizing	1,000	Fish/object sizing,
Pan and Tilt	Increased viewing area	3,000 - 4,000	Sector viewing,
Linear Motion Rail	Predetermined sector viewing.	5,000	Increase observation region, programmable.
Motion trigger mechanisms	Enabling camera when marine animal comes into frame of view	1,000	Enables use of camera and compilation of video data only when target is detected, decreasing data storage and analysis costs.
UV lights, copper rings, wipers	Decrease biofouling around optical instruments.	1,000 - 2,000	Deters and slows growth of biofouling organisms that decrease quality and obscures optical images.

The HD cameras will normally have a 1/3 or 1/2 in. CCD or CMOS image sensor. Wide angle field of view (FOV) cameras are best suited for mounting close to structures to capture the largest viewing region. These cameras normally have lens of focal length of 2 - 4 (mm) or 35 mm equivalent lens. Most commercial grade cameras have a max depth rating of 4000 m and made from titanium, Delrin, and aluminum material.

The dome or lens can be flat (less distortion) or curved/domed which is best for pan/tilt and zooming cameras. The lens material is normally sapphire or glass. Many higher-grade cameras have pixel resolutions (H x V) of at least 2k x 1k and if higher resolution is required imagers capable of 4k x 2k are available. Some systems support automatically switching to monochrome under low light conditions such as Sony® Super HAD CCD imagers, have auto white-balance or allow users to manually adjust the images. Systems using 4k UHD or HD real-time streaming ability with on board memory (512 GB) is best suited for short term recording periods (four to five hours on a memory card, up to several days). The most common recording rate is 30 fps and several cameras can be incorporated into a stand-alone recording system using an encoder, which converts analog camera signals into streamed IP video data. Most common video compression includes h.264, h.265, and MJPEG with a 4 Mbps bit rate.

The camera lens size is dependent on the type of survey to be conducted. A wide-angle (2 - 3 mm) lens can be used for fish detection close to the camera, and a 5 to 8 mm fixed or zoom lens is often used for imaging objects at further ranges. Some camera systems have zooming capability (12 - 50x) which can be a benefit if the water is clear and sufficient lighting is present. The light gathering capability of a lens is described by the minimum f-stop which is focal length divided by the aperture. A lens with a relatively large maximum aperture or low f-stop (e.g., f/1.6) is capable of gathering more light than one with a higher minimum f-stop (e.g., f/3.5).

Monochrome video cameras are best suited for operating at low light conditions; color cameras are less sensitive with lower resolution due to the presence of a color overlay filter. Monochrome cameras generally have better resolution which increases the detail of objects and are more sensitive to specific wavelengths (e.g., green or red). If conditions are optimal, color cameras can be used to help distinguish species. Cameras are rated for minimum scene illumination, also known as the lux value; the lower the specified lux value, the less light is required to obtain optimal images. Manufacturers often use different methods to determine the lux value, which is measured at a specific f-stop (normally f/1.4).

Some commercially available optical cameras have built-in pan and tilt mechanisms, eliminating the need to retrieve the camera at the water surface for repositioning. The units also can be programmed to search zones during long-term monitoring which increases the coverage region. The drawback is that pan and tilt systems are two to three times more expensive than a standard camera and require additional power. Another option is a separate pan and tilt rotator. These are normally constructed with a stainless-steel enclosure, operate on input voltages of 10 to 50 VDC, have power requirements of up to 750 mA, and can be remotely controlled using ASCII or Windows GUI. Another option is to use multiple cameras and record using a video multiplexer to obtain a composite image of a larger area. Alternatively, the camera(s) can be part of an ROV, which can be positioned with cable and joystick (e.g., Bergström et al. 1992). Disadvantages of the ROV include cost, additional manpower, larger size, increased data accumulation (storage and processing) and higher power supply requirements. Some vendors offer a remote controller which can be used for focus, zoom, iris, gain, white balance, shutter speed, frame rate, autofocus, audio level, and recording trigger.

An alternative to purchasing a camera already in a waterproof housing is to purchase an off the shelf camera and place in a housing. The benefits include the ability to select a variety of cameras, which are available for security and surveillance industry, and machine imaging, which often have variable recording rates, variable lens configuration and imagers and variable control over with image acquisition. One drawback is the additional connection cables needed to interface with the wet bulkhead connector on the outside of the housing and possible issues with condensation. Camera housings typically are filled with dry air or other inert gases to prevent the lens from fogging, and a desiccant pack can be placed inside the housing if space allows. Commonly used housing materials for freshwater and marine applications are marine-grade aluminum, PVC, Delrin, or acrylonitrile butadiene styrene (ABS) with acrylic or glass lenses. Camera housings are generally pressure-tested to between 60 and 100 m, although marine-grade underwater cameras are placed in housings that are rated up to 300 m or >15,000 psi. Stand-alone housings also allow for various types of wet mate-able bulkhead connectors for cabling.

Still photography can also be utilized to assess fish/turbine interactions. One common method is to select time intervals at which snapshots can be taken or preselected periods of the day (time-lapse recording) and then, using computer software, process the images to determine fish abundance. This option can significantly extend the amount of data that can be stored on the internal memory cards as found in many types of action cameras. Other options include subsampling of image streams and extrapolating if there are time constraints.

Applications

Systems to Measure Object size and Swimming Speed

Paired Camera Systems

Fish size and swimming speed can be determined using stereo-video systems. This method incorporates two cameras positioned side by side at a set distance and then inwardly converged at 4-7° depending on the separation. Images are synchronized via computer by using a LED light placed at a set distance and seen on both images (Harvey et al. 2002; Langlois et al. 2012; Lines et al. 2001; Trudel and Boisclair 1996). When objects move through the camera's fields of view, exact locations (x, y, z coordinates) in three-dimensional space can be determined as well as object sizes. Camera spacing varies for each application but one recent application had 0.8 m spacing with a maximum range of 5−6 m wide horizontal field of view (FOV) (Hammar et al. 2013). Using this method required a video multiplexer or recording directly to a computer system so that paired camera images can be stored simultaneously and have separate calibration files which are used by specialized software (SeaGIS) for each camera, where objects can be sized in 3D (Harvey et al. 2002). Another option is using the camera calibration Toolbox for MATLAB (Bouguet 2015). In another study, camera spacing was 1.4 m, which was used to image objects from 2-10 m from the cameras depending on visibility and was more accurate when objects were in less than 50° from the central axis of the cameras (Harvey and Shortis 1995, 1998). Depending on water clarity, these systems can be effective at determining behavior interaction with tidal turbine blades, species composition, estimating speeds of currents, swimming speeds of fish, fish size and distance of fish to blade interactions (Harvey et al. 2002).

Stereo camera applications require calibration prior to data collection. This can provide in-situ challenges in high energy locations. Performing calibrations in a laboratory setting is easier but the transfer of the cameras and mounting apparatus to the field site can be challenging because the cameras must remain in the same positions from calibration. In the field, real time tilt sensors can be attached to the cameras to ensure they stay at the predetermined location.

To give researchers some information on data acquisition rates and disk storage capacity, with a typical 1k by 1k camera recording at 30 fps, a 1 TB hard disk would be needed to store 8 days of recording using MPEG-4 compression. The same camera using H.264 encoding would fill the 1 TB hard disk in 14 days.

Lasers

As an alternative to the use of paired cameras, paired parallel mounted lasers can be incorporated with a single camera to determine object sizes and these systems are commonly incorporated for use on ROVs. This system is somewhat limiting in that measurements can only be made when lasers appear on the object (fish) in contrast to stereo imaging where more objects can be measured per image. Lasers are mounted on specialized brackets, which hold them parallel to each other so that the laser dot separation is consistent with the variable range to objects. The lasers shine onto fish, substrate, or other structures and allow for scaling of these objects during later analysis. After video images are taken in conjunction with the lasers, the size of the fish and other objects can be determined using imaging software. Depending on the spectral response of the cameras used, it is recommended that laser color is near the maximum spectral response curve for the sensor. Red (650 nm) and, to a lesser degree, green (550 nm) are commonly used colors for lasers because they fall within the higher regions of the spectral response curves of typical monochrome and color cameras. Some fish species may be repelled or attracted by colored lasers emitting in their visual spectrum. Projecting laser dots on natural or manmade surfaces may cause certain fish species to act aggressively and chase the object, possibly mistaken for a prey item (Haddock and Dunn 2015). If the spectral response of a species of interest is known, then selecting lasers that operate at the lower or higher spectrum of the wavelength is recommended.

A typical underwater laser suited for use in shallow water environments consists of a Class III A diode, with a power output of 5 to 20 mW at a wavelength of 635 nm and a beam size of 0.8 to 1 mm. The laser spot or line diameter can be adjusted and focused at a desired range. The range of the lasers in clear water varies depending on the power output; for example, 1 m for a 5-mW laser and 8 m for a 15-mW laser. Lasers are sealed in waterproof housings, typically made from aluminum or Delrin, with optically transparent Lexan or acrylic lens and wet-mate able connectors. The current draw for a single 10-mW laser is approximately 50 mA (Mueller et al. 2006). See Table S10.3 for common camera types and associated components.

Systems for Long-Term Recording and Storage

For long-term continuous recording (more than a few days), cabled systems with a dedicated recording location on shore or stationary platform have several advantages. These include the ability to view live video feeds, contain a dedicated power supply, use more robust recording gear including DVR or other recording media, have easy access to recording equipment, and have remote access via internet. Some drawbacks include added cost for cable, possible cable damage from fish, marine mammals, or other marine life, possible damage from ocean conditions. Live video can be transferred over Gigabit Ethernet, and uncompressed HD video over HD-SDI. Typical cable options include standard coax, min-coax, HD coax, Ethernet, IP (Cat 5e). Adding a strength member (normally Kevlar) is often used to increase the breaking strength and increase durability. Turbine operators may have power available near the turbine and incorporate dedicated cable systems to facilitate various operations of the unit. Research agencies who are contracted to study fish/blade interactions for permitting and assessment of any impacts to sensitive or listed fish/marine mammal species can often utilize these existing cables in order to conduct experiments. If several systems are to be incorporated, a power over Ethernet converter can be utilized. Many cable suppliers have minimum cable length order, which is normally 200-300 m. See Table S10.4 for a list of common cable types used in the near shore region for optical camera observations.

Table S10.4. Specifications of standard types of cables used for nearshore to deep water optical video applications.

Cable Type	Application	Conductors	Cost/m US$	Depth Range
Coax/Mini Coax	Subsea monitoring, ocean observatory, robotics, fisheries.	6	8 to 12(a)	7 km
6 G SDI/HD Coax	Use with SD/HD video.	6	9(a)	200 m to 7 km
Fiber Optic	Inspection systems.	10	21(a)	300 m
IP Cat 5e	High-speed network data, video, and sensor equipment.	6	22(a)	200 m
USB3.1	Bulk transfer, high bandwidth, high transfer rates (10 Gbps).	34	20	3 m cable length limitation.

[a] Cost includes Kevlar strength member and a minimum cable order of 200 m.

DVRs offer many advantages including greater recording resolution, extended recording ability, long-term storage, video overlays, multi-camera inputs, internet streaming ability and greater image reproduction capabilities. The DVR uses software to control external cameras and is very flexible in that cameras can be programmed to record at certain intervals or record only events in which motion is detected (i.e., object detection). Additionally, triggered systems can be incorporated where other sensors (e.g., echosounder) can be used to trigger the camera recording. This can help decrease overall data accumulation for long-term deployments. Some common video overlay types include date/time and recording timers, serial data-based position coordinates, graphical overlays (altimeter, compass, depth), shapes and other superficial objects for custom themes, adjustable position, color, size and opacity, images and logos, and various other features.

Challenges

Lighting

Nighttime viewing may be required as observations limited to daylight viewing when ambient light levels are sufficient may not yield representative results of fish interactions (Hammar et al. 2013). If nighttime recording is required, cameras may be augmented with various types of white, red/green, or infrared (IR) filtered lights. The most common type of light used for underwater viewing are LEDs, which have benefits of a broad light spectrum, long life and cooler operation. Infrared lights operating at wavelengths longer than 800 nm can be useful for identifying fish in low light or during the nighttime as most fish species are unaffected by IR because it falls beyond their spectral response range (Lythgoe 1988). An important consideration is that illuminating light has to travel twice the object distance, and objects close to the lens will be illuminated brightly. In addition, high-intensity underwater IR lights are expensive and have increased power requirements. Some manufacturers incorporate white, colored, or IR light in the form of LEDs surrounding the lens of the camera. Due to the small size of the LEDs, the light intensity is generally low and most applicable at close-range viewing.

When conducting fish behavior or enumeration studies, researchers should verify that the light source will not deter or attract fish or plankton which could interfere with the video observations (most impacts would occur during nocturnal periods). The visual pigments of freshwater fish have optimal spectral response within the range of 510 to 545 nm; coastal marine fish are in the 490 to 510-nm range, whereas deep sea marine fish are even more blue-shifted (470-490 nm) (Lythgoe 1988; Jobling 1994). However, most freshwater fish have trichromatic vision, with the visual pigments having absorption peaks around 455 nm (blue), 530 nm (green), and 625 nm (red). The use of red LEDs has some advantages as it has reduced luminous intensity output compared to white light. The red wavelength may be less impactful especially for deep water applications as many fish species lack red sensing cones in their eyes (Lythgoe 1988) and studies have shown less of an impact on fish species using red lights as compared to white (Boldt et al. 2018). A typical white light used for deep sea imaging has a color temperature of 5700-6500 CCT, or degree Kelvin, and has peak wavelengths of 440 and 550 nm.

Power Supplies

If batteries are to be used, it is important to determine the total power requirement of the underwater components in amp-hours. Power consumption by video survey components can be estimated by constructing a power consumption list (Table S10.5). A key factor in battery selection is the consumption rated in ampere-hours for a given component. The ampere-hour (amp hr.) rating is the total amount of energy that a battery can deliver for 20 hours at 26°C before the battery drops to 10.5 V (i.e., a 100-amp hr. battery can run a 10-amp load for 10 hr. before reaching its discharge limit). Deep-cycle marine batteries are the preferred type because they are designed to withstand frequent cycles of deep discharge and recharge.

Table S10.5. Sample power consumption rate chart for video components for a 24-hour period (Amp hour = W/12 (volt) x 24 = 2 x W).

Component	Watt	Ampere	Amp hour
Camera	1.3	0.11	2.6
Lighting	200	16.7	400
DVD Recorder	25	2.11	50
Lasers	1.4	0.12	2.8

If associated light sources are used, they usually require a great deal of power. It is important to know power consumption for each component. The amperage draw can be determined by the wattage divided by volts (A = W/V) for a certain duration (i.e., ampere-hours). Setting the light to the highest output can increase the current draw by a factor of 3 to 4. The light duration can be extended by decreasing the intensity (W) of the light bulbs, adding battery ampere-hours (e.g., keeping a larger battery at a higher temperature), changing battery type (using lithium batteries instead of lead or nickel-cadmium types), or adding a generator-powered battery charger. The power requirements for underwater video cameras are 12 to 24 V DC at approximately 110 mA for non-lighted models.

Conclusion

Optical cameras have many uses for documenting fish interactions with tidal power generation devices. Best results will be obtained when camera capabilities are well matched to the conditions, the subject of observation, and the data needs. There are many commercial options for hardening systems against ocean conditions and depths, as well as for transmitting or retrieving images and video. Other types of monitoring technology, such as ADCP and acoustic imaging, can be incorporated with optical imaging to provide additional context for behavior and interactions.

S10.2. TECHNICAL GLOSSARY

Acoustic Doppler velocimeter (ADV)	Instrument used to measure the speed of moving water in three dimensions at a single point. Sound pulses are reflected off moving particles in the water and are shifted (have a different frequency) in proportion to the water speed when they return to the instrument. This change is used to calculate water velocity.
Acoustic Doppler current profiler (ADCP)	Instrument used to measure the speed of moving water over a range of depths. Sound pulses are reflected off moving particles in the water and are shifted (have a different frequency) in proportion to the water speed when they return to the instrument. This change is used to calculate water velocity.
Galvanic circuits	Electrical circuit induced between dissimilar metals (cathode and anode) connected by conductive media.
Hydrophone	Underwater microphone to record underwater sounds from all directions.
Multibeam sonar	System to measure the depth of the water column and map the seafloor by emitting sound waves and measuring the time the sound takes to return to the system.
Transducer	Device used to convert one form of energy or signal to another. Typically, the resulting signal is easier to store or interpret.

S10.3. REFERENCES

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