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PRIMARY RESEARCH PAPER

Does bait type and bait container configuration influence the performance of remote underwater video systems in temperate freshwater lakes for assessing fish community structure?

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Abstract Methods for the use of baited remote underwater video stations (BRUVS) have been tested and refined such that they are now widely used in marine research for assessing fish community structure. There is comparatively less known about the effectiveness of different bait types or bait containers for use with BRUVS in freshwater temperate environments. We conducted a field-based experiment in Lake Opinicon, located in southeastern Ontario, Canada to compare the effectiveness of three baits and two styles of bait container to unbaited systems. Species richness per deployment and the probability of detecting each species were used as measures of effectiveness. BRUVS were deployed in weedy habitats in the littoral zone of the lake (1–3 m depth) with corn, cat food, sardines, or no bait, in an accessible mesh bag, or an inaccessible perforated PVC container. The mean species richness detected was uniform across bait type and container. For *Micropterus salmoides*, *Cyprinidae* spp., and *Esox lucius*, there were associations between bait type and proportion of detections. BRUVS appear to be effective in observing species richness in a shallow, low-visibility freshwater environment; however, there is little evidence that use of bait improves effectiveness relative to unbaited RUVS.

Keywords BRUVS · Baited remote underwater video · Freshwater fish · Bait type · Species richness · Effectiveness

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Introduction

Remote underwater video systems (RUVS) and baited remote underwater video systems (BRUVS) are video cameras deployed in aquatic habitats which can observe and record the species present, their abundance, and body size (reviewed in Whitmarsh et al., 2017). BRUVS surveys are a non-extractive method which can complement or replace extractive and potentially harmful methods of population and community survey such as netting, angling, and electrofishing for aquatic ecosystem monitoring and research (Willis et al., 2000; Ellender et al., 2012; Hannweg et al., 2020). As a non-extractive method they are similar to underwater visual census (UVC) techniques such as diver or snorkel surveys, but with the advantages of creating permanent records, which can be verified or reviewed by multiple observers, and avoiding issues of bias due to the behavior of fish in response to human presence (Harvey et al., 2013). Additionally, BRUVS can be used in situations where it would be dangerous or impractical to have a human perform UVC, such as in strong currents, cold water temperatures, habitats where swimmers could come into conflict with dangerous wildlife such as large predatory or territorial animals, or where boat traffic could pose a hazard to human safety (Mallet & Pelletier, 2014). BRUVS have become increasingly popular with the development of inexpensive compact action cameras since the early 2000s and have been deployed in a variety of environments ranging from the tropics to the poles and from shallow to abyssal depths (Mallet & Pelletier, 2014; Whitmarsh et al., 2017). Although there are many studies making use of BRUVS, there is great disparity in their geographic and environmental distribution; in a review of 161 studies which used BRUVS, a majority (61%) were performed in Australia, and all but three were performed in marine or estuarine environments (Whitmarsh et al., 2017). Due to the scope and keywords included in the Whitmarsh et al. (2017) review unbaited (i.e., RUVS) studies were excluded, some freshwater BRUV studies were not captured (e.g., Fulton et al., 2013), and there are examples of freshwater BRUV research occurring since then (Bajaba et al., 2021). Despite the apparent lag in BRUVS adoption in freshwater environments, their increasing use speaks to their potential utility provided we understand their limitations and validate their suitability for use in freshwater.

Underwater video is used with some frequency in freshwater (reviewed in Ebner et al., 2014; Struthers et al., 2015) though more often than not the cameras are unbaited. While there are situations where using bait may interfere with the observations by changing the behavior of the taxa studied, this is curious in that baits could help to bring fish closer to the camera and thus improve camera performance as has been demonstrated by Donaldson et al. (2019). Visibility in many freshwater bodies is often low, caused by eutrophication, suspended sediments, and dissolved organic carbon, which can vary temporally and spatially (Davies-Colley et al., 1994; Kirk, 1994; Erlandsson et al., 2008). The turbidity of freshwater poses a challenge for video identification of individuals which are far from the camera or are particularly small, and for species which have similar body shapes and size (Schmid et al., 2017; Donaldson et al., 2019). Furthermore, in littoral habitats macrophytes provide cover for fish and limit the visual field of cameras. One way to address these issues is to select baits that attract fish to the immediate vicinity of the camera, thus making this approach potentially more effective even in lower visibility environments (Wilson et al., 2014; Donaldson et al., 2019). Moreover, it has been documented in marine systems that bait can increase the diversity of organisms observed (Harvey et al., 2007; Wraith et al., 2013), which is useful when assessing community composition.

The type of bait and how it is deployed can also influence system performance. For example, studies have shown that meat-based baits increase the likelihood of observing and the abundance of mobile predator and scavenger species that rely heavily on their olfactory senses to find food (Harvey et al., 2007; Ghazilou et al., 2016). The most common meat-based bait used is whole or crushed sardines, or an alternate soft-fleshed oily baitfish (Whitmarsh et al., 2017), although as noted before, rarely has bait been used or assessed in freshwater systems. The method of attaching the bait to the camera system varies but is typically a mesh bag or wire cage that allows fish to directly feed on the bait, or a perforated rigid container that allows oils to disperse from the bait but prevents direct feeding. Researchers have mentioned rationales behind their choice of bait delivery method (for example Ebner & Morgan, 2013), but no published freshwater studies have compared their effectiveness. Bait plume size is dependent on many factors and is still little understood (Harvey et al., 2013), but all else being equal, having a larger surface area exposed to currents should allow the bait plume to diffuse more rapidly, so accessible baits should attract fish over a larger area than inaccessible baits.

If BRUVS are to become widely used in freshwater research and comparisons are to be made across studies, it would be prudent to understand how methodological choices affect results before proposing any standard to be followed. We tested the hypothesis that bait type and bait container configuration would influence the performance of BRUVS in a temperate freshwater lake for the assessment of the fish community. Endpoints of particular interest included fish community composition and latency to detect new species. Specifically, we compared vegetable, meat, and mixed vegetable/meat baits in accessible and inaccessible bait containers. We predicted that baited cameras would perform better than the unbaited cameras and that the mixed bait would perform better than the other baits due to it containing ingredients that would attract species with a range of different diets. For the effect of container type, we predicted that an accessible bait container would yield better performance than the inaccessible bait containers due to greater bait plume dispersion.

Methods

Study site

Lake Opinicon is a 785 ha shallow mesotrophic lake in southeastern Ontario, Canada. The lake is part of the Rideau Canal waterway, and home to the Queen's University Biological Station (Fig. 1). The fish community of Lake Opinicon has been well studied with UVC methods (Keast & Harker, 1977; Keast et al., 1978) which found it to have highest species richness and abundance in the nearshore areas with water depths less than 3 m. The lake has approximately 61 km of shoreline and the habitat of the nearshore area is mostly made up of organic sediment, or sand

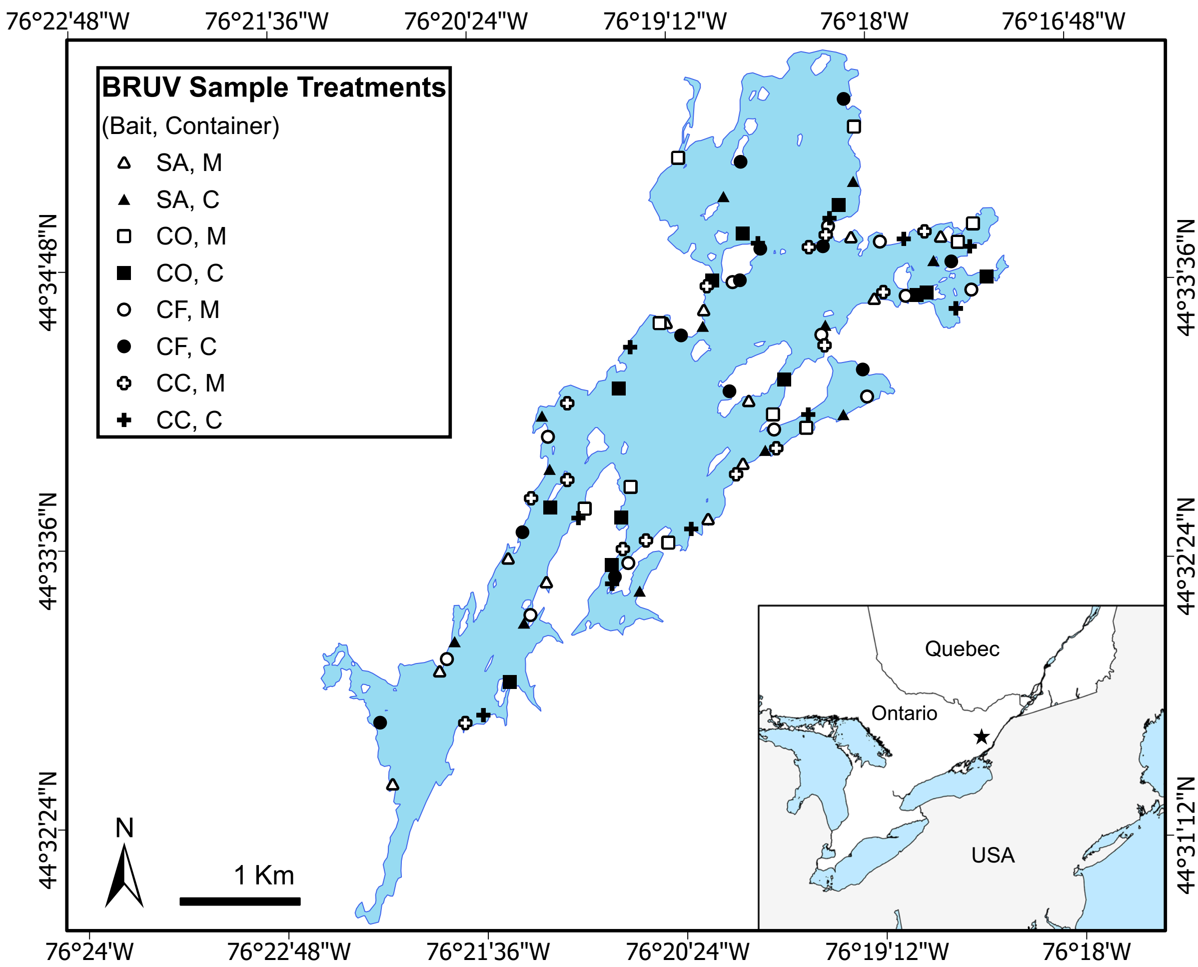

Fig. 1 Map of southwestern Ontario showing: the location of Opinicon Lake (inset), and the location of replicates. *CCC* creamed corn can, *CCM* creamed corn mesh, *CFC* cat food can, *CFM* cat food mesh, *COC* control can, *COM* control mesh, *SAC* sardine can, and *SAM* sardine mesh

substrate with extensive submergent and emergent macrophyte patches. Water clarity in Lake Opinicon is high with the average Secchi depth exceeding 4 m (Cataraqui Region Conservation Authority, 2017).

Experimental design

Sampling occurred from July 16 to August 22, 2018 after spring spawning had finished and water temperature stabilized, to avoid the influence of spawning and nesting behavior of *Lepomis* spp. and *Micropterus* spp. and changing water temperature during the experiment. The sampling design consisted of two factors: Bait (four categories: unbaited control, canned corn, cat food, and sardines), and container (two categories: accessible and inaccessible). Thirteen samples for each treatment combination were collected for a total of 104 recordings at locations in the littoral zone (water depths of ~ 1 to 3 m) randomly selected across the lake with a minimum distance of 200 m between deployed cameras to reduce the chance of individual fish being observed at more than one station. A shorter separation distance was used than in many marine and riverine studies because the lack of current or significant wave action in Lake Opinicon means that bait plume dispersal would be minimal so the likelihood of interference between concurrent recordings would be low. Minimum separation between samples on different days was 50 m but no recordings were made within 200 m of a previous sample for 48 h to avoid the possibility of conditioning fish to the presence of food in an area. Sampling occurred only when there was less than 50% cloud cover, beginning at least 3 h after sunrise and ending at least 3 h before sunset to avoid crepuscular variation in fish activity, or large differences in light availability between samples.

Equipment

The video systems used for this study consisted of an Apeman 4 K action camera mounted to a stainless steel frame with base dimensions of 50 × 50 cm tapering to 40 × 40 cm at the top with an overall height of 50 cm (Fig. 2). The cameras were set to record in 720p at 60 frames per second in ultra-wide angle (170°) mode. This balanced video quality with battery life, allowing the cameras to record for around 75 min. A single camera was mounted facing horizontally outwards from the frame at a height of 50 cm with a bait arm extending 50 cm into the field of view (Fig. 3). A 25-mm-diameter PVC pipe extended another 50 cm beyond the bait arm which was used to ensure that the camera had a 1 m unobstructed field of view. Nylon mesh bags with expandable holes (1 cm when stretched) (Fig. 3a), and custom-built containers made from 100-mm-diameter PVC pipe with thirty-eight 5-mm-diameter holes drilled in the top and bottom caps (Fig. 3b) were used to hold the bait for the accessible and inaccessible treatments, respectively. For the controls (no bait), an empty container which had never held bait or an unused mesh bag with a section of sponge approximately the size of the bait portions was used. The baits used were Green Giant® canned sweet creamed corn, Whiskas® Seafood Selections dry cat food, and Brunswick® canned sardines with soy oil. Approximately 100 g of bait was used in each case. Corn is a common bait used for freshwater cyprinids, and creamed corn was chosen because its mostly liquid consistency would allow it to disperse more readily. Whiskas Seafood Selections cat food was chosen because its main protein component is fishmeal which would presumably be more attractive to piscivorous fish than protein from terrestrial animal sources. Sardines in soy oil were chosen because oil from the can would help disperse the scent of the sardines better

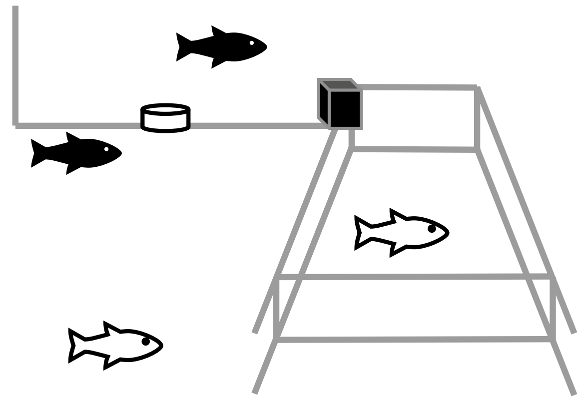

Fig. 2 Schematic drawing of the BRUVS stand with camera position and bait arm. The camera stand and bait arm are represented by the gray lines, the camera (black cube) faces left towards the bait container, represented by the white cylinder. The solid black fish show how fish attracted close to the bait container will be recorded while the black outlined fish show how species which relate strongly to the substrate or structure would be less likely to be seen

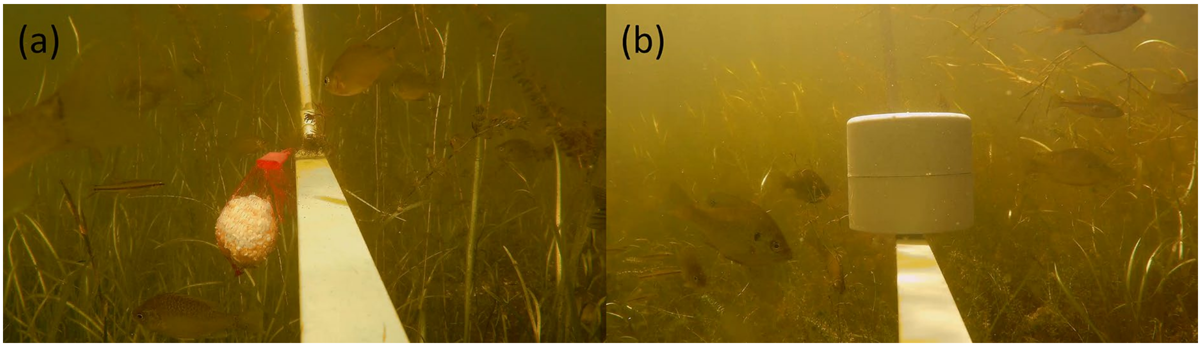

Fig. 3 Screenshot of BRUVS field of view with an accessible mesh bait holder (**a**) and an inaccessible can bait holder (**b**)

than water-packed sardines, and soy-based baits have been shown to increase CPUE of catfish and carp in trap nets (Pierce et al., 1981; Flammang & Schultz, 2007). A length of rope with a buoy that floated on the surface was attached to the frame to allow the system to be retrieved.

Procedures

Deployments were standardized by habitat in 1–3 m water depth. This depth range was selected as it was easily accessible for a snorkeler, represented a large portion of the lakebed, and was found to have the highest concentration of species in a previous study on Lake Opinicon (Keast & Harker, 1977). Due to the predominance of macrophyte beds in the lake, macrophyte beds were chosen as the standard habitat. Sample locations with the desired habitat within the 1–3 m contours of the lake were selected by a researcher familiar with the lake, and treatments were randomly assigned to each location (Fig. 1). We had three BRUVS stands to use so locations were chosen in groups of 3 in a stratified random order to visit, such that there were always 3 different bait treatments and at least one of each container treatment deployed at the same time. After navigating to the location by boat, a snorkeler verified that the habitat was appropriate while the camera and bait were prepared and attached to the stand. The BRUVS stand was passed to the snorkeler in the water and placed in an appropriate spot with the camera faced towards shore and an unobstructed field of view. While the stand was being positioned, the surface water temperature was taken. After 70 min the boat returned to collect and reset the BRUVS in a different location.

Statistical analysis

Videos were saved from the cameras to an external hard drive and reviewed on a 33 cm 1366:768 resolution laptop screen in a room with low lighting to avoid glare using VLC media player. The first 2–7 min of the video were disregarded to give time for sediment to settle after being disturbed by the stand then the following 60 min of video were analyzed. If visibility was so poor that detection or identification of fish closer than the bait canister was still difficult, or if vegetation drifted into the field of view which blocked more than 25% of the field of view for more than five minutes the recording was discarded. Videos were quickly reviewed for visibility after recording so that replacements could be taken to maintain a similar number of replicates in each treatment. In total 8 out of 104 videos taken were discarded due to visibility issues for a final total of $n = 11$ inaccessible control, $n = 12$ accessible control, $n = 12$ inaccessible corn, $n = 13$ accessible corn, and $n = 12$ inaccessible cat food, accessible cat food, inaccessible sardine, and accessible sardine replicates. Videos were watched at regular or 1.5 × speed. Regular speed was used for the first 10 min of the recording, which was when most new species were observed, and whenever the field of view was crowded with fish, to avoid missing new species.

The time of the first individual of each species on the screen was recorded (T1st). Most cyprinid species present in Opinicon Lake are small bodied with similar body shape (~ 5 cm, elongate) and coloration (largely silver), making them extremely difficult to tell apart visually without close inspection. In cases where identification to species level was impossible, a higher taxonomic level was used. If another fish of the same taxonomic group was seen but could not be definitively identified as another species, it was not counted. This was common with cyprinids but also necessary in some cases with juvenile centrarchids, such as pumpkinseed [*Lepomis gibbosus* (Linnaeus, 1758)] and bluegill [*Lepomis macrochirus* (Rafinesque, 1819)], or largemouth bass [*Micropterus salmoides* (Lacepède, 1802)] and smallmouth bass (*Micropterus dolomieu* Lacepède, 1802), which differ only subtly in coloration early in life.

We compared the number of species observed per replicate using a two-way ANOVA with bait type, and container as grouping variables in the statistical software package R v3.5.3 (R Core Development Team, 2020). The assumption of homogeneity of variance was satisfied using Levene's test, but the assumption of normality was not. Absolute skewness and kurtosis of the groups were <2 so a parametric two-way ANOVA test was used with significance level $\alpha = 0.05$ (Kim, 2013).

The effectiveness of each bait and holder type at attracting each species was evaluated by comparing the frequency of observations of each species by each treatment. For each species, we assessed which treatment variables influenced the probability of detection in a replicate by fitting a logistic regression model. The regression equation included bait, container, and their interaction as predictor variables, and species presence/absence as a binomial response variable. We compared the Akaike Information Criterion (AIC) value of models with both explanatory variables with and without interaction, and for each predictor individually to determine which should be included in the final model. The model with only bait type as a predictor had the lowest AIC across all but one species, so we restricted further analysis to only the effect of bait type. We used Fisher's exact test to determine if the proportion of positive to negative observations was dependent on the type of bait used. Fisher's exact test was chosen over a chi-square test because many cells of the comparison matrices had values less than 5, and the sample size for all of the matrices were smaller than 1000 (McDonald, 2014). For cases where the overall Fisher's exact test was significant ($\alpha = 0.05$), pairwise comparisons of bait types were conducted with Holm's sequentially rejective Bonferroni-adjusted p-values to reduce the probability of type I error due to multiple comparisons (Holm, 1978). Species accumulation curves for each bait type were made by plotting the average species richness for each treatment against time to determine what an optimum time for deployment would be in future studies.

Results

Overall, 11 fish species (and 5 non-fish vertebrate species) were observed during the study. In order from most to least frequently observed were *L. macrochirus, L. gibbosus*, *M. salmoides*, yellow perch [*Perca flavescens* (Mitchill, 1814)]; golden shiner [*Notemigonus crysoleucas* (Mitchill, 1814)]; unidentified cyprinid species, rock bass [*Ambloplites rupestris* (Mitchill, 1814)]; black crappie [*Pomoxis nigromaculatus* (Lesueur, 1829)]; brown bullhead [*Ameiurus nebulosus* (Lesueur, 1819)]; *M. dolomieu*, and northern pike (*Esox lucius* Linnaeus, 1758). Excluding species that were detected only in one replicate, the bait treatments where the most species overall were observed were the control, and sardines with nine species each. Cat food and canned corn detected 8 and 7 total species in more than one replicate, respectively. Non-fish vertebrate species observed were the muskrat [*Ondatra zibethicus* (Linnaeus, 1766)] common loon [*Gavia immer* (Brünnich, 1764)], northern map turtle [*Graptemys geographica* (Lesueur, 1817)], northern painted turtle [*Chrysemys picta* (Schneider, 1783)], and snapping turtle [*Chelydra serpentina* (Linnaeus 1758)].

The most species observed in a single recording was eight on an accessible control deployment. The fewest species observed in a recording was two, which occurred in one inaccessible control, two inaccessible sardine, and two accessible sardine deployments. The ANOVA revealed that there was no interaction between bait type or container ($df = 3$, $F = 0.246$, $P = 0.864$) and no significant effect of bait type ($df = 3$, $F = 2.472$, $P = 0.067$), or container ($df = 1$, $F = 0.0749$, $P = 0.864$) on the number of species observed (Fig. 4).

Most species did not have a significant association between bait type and the presence/absence ratio, however, *M. salmoides* ($P = 0.008$), Cyprinidae spp. ($P = 0.006$), and *E. lucius* ($P = 0.041$) did (Table 1). In the pairwise comparison of bait types, for Cyprinidae spp. only the cat food and sardine baits showed

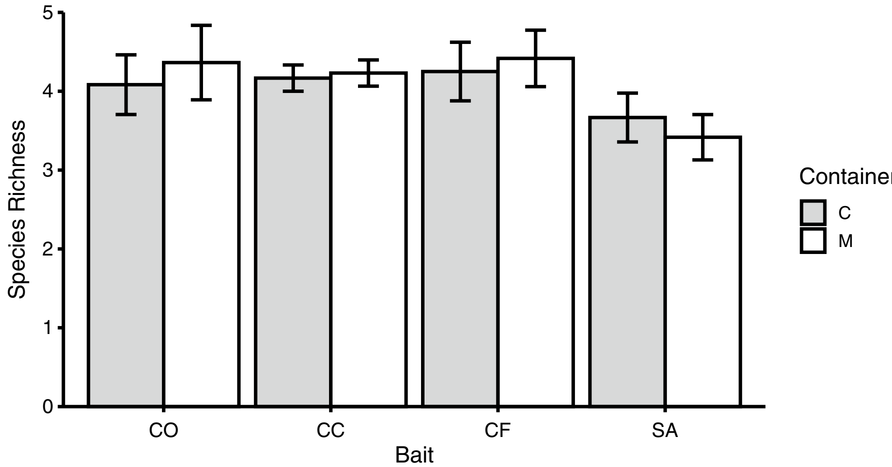

Fig. 4 Bar plot of mean ± se of the number of species observed per video deployment with canned corn (CC), cat food (CF), no bait (CO), and sardines (SA), in the inaccessible can (C), and accessible mesh (M)

a significant difference in odds, with cyprinids 19.5 times more likely to be detected by a cat food than a sardine-baited recording ($P = 0.011$). The pairwise comparisons of bait types for *M. salmoides* and *E. lucius* were not significant. Sardines were the most dissimilar to the other baits in terms of detection probability, with fewer detections of most species than the other baits, but a higher probability of detecting *Ameiurus nebulosus*, and was the only bait to detect *E. lucius* (Fig. 5).

At least one species of fish was seen in frame at the beginning of most of the videos analyzed (90.6%). *L. macrochirus* was the first species observed in all but two recordings, in which *L. gibbosus* was the first in one and *M. salmoides* was first in the other. The number of species observed showed a saturating relationship with time which was similar across all bait types. By 30 min more than 80%, and by 40 min more than 88% of species had been observed by all bait types (see Fig. 6). Bait was depleted before the end of recording in three (25%) accessible sardine deployments and lasted only eight minutes after the BRUV was deployed in one, but more than 46 min in the other two. Bait was depleted in two (15%) accessible corn deployments, lasting 24 and 32 min, respectively. In the accessible cat food deployments one (8%) deployment had the bait depleted, at 51 min after deployment. In one of the accessible sardine deployments where the bait was depleted, an *A. nebulosus* bit onto the bait bag at 29 min and shook it violently, releasing clouds of food particles and attracting many *L. macrochirus*, which finished the contents of the bag within 20 min. In all the other cases where the bait was depleted, large *Lepomis* spp. individuals were responsible for consuming almost all the bait, shaking the bag and releasing clouds of food particles which provoked feeding frenzy-like behavior. *Lepomis* spp. individuals were observed using aggressive behavior to try to prevent conspecifics and heterospecifics from feeding from the bag. In most of the cases where bait was depleted, *L. macrochirus*, *L. gibbosus* and only one other species were observed, and in the two videos where more than three species were observed, the other species were only seen after the bait had been depleted.

Discussion

All the large-bodied species known to inhabit Opinicon Lake except for the common carp (*Cyprinus carpio* Linnaeus, 1758) were recorded using BRUVS in this study, however, no bait was successful in recording every species. Although we do not have a comparison to efforts with other survey methods to compare to here, King et al. (2018), found that unbaited cameras observed more species than netting methods in small water bodies. Although fish appeared to be enticed closer to the camera using bait, water clarity during this study as well as limitations of the video quality prevented identification of individuals of the family Cyprinidae to lower taxonomic levels. This is an issue common to underwater visual census techniques for species small in size with similar visual characteristics (Lyle et al., 2007; Pelletier et al., 2011; Mallet & Pelletier, 2014). It is often difficult and

Table 1 Results of Fisher's exact test of independence for the presence/absence ratio of each species for all bait types overall, and results of pairwise comparisons of bait types

Species	Fisher exact *P* value	Pairwise fisher exact test Holm-adjusted *P* value					
	Overall	CO–CC	CO–CF	CO–SA	CC–CF	CC–SA	CF–SA
Lepomis macrochirus	1	–	–	–	–	–	–
Lepomis gibbosus	0.056	–	–	–	–	–	–
Micropterus salmoides	0.008*	1	1	0.289	1	0.0635	0.113
Perca flavescens	0.087	–	–	–	–	–	-
Notemigonus crysoleucas	0.437	–	–	–	–	–	–
Cyprinidae spp.	0.006*	0.774	0.389	0.774	0.389	0.116	0.011*
Ambloplites rupestris	0.701	–	–	–	–	–	–
Pomoxis nigromaculatus	0.557	–	–	–	–	–	–
Ameiurus nebulosus	0.240	–	–	–	–	–	–
Micropterus dolomieu	0.592	–	–	–	–	–	–
Esox Lucius	0.041*	1	1	1	1	0.659	1

Pairwise comparisons were only conducted if the result of the overall Fisher's exact test was significant. Bait types were *CO* control, *CC* canned corn, *CF* cat food, *SA* sardines. Asterisks (*) indicate significant results at the significance level $\alpha = 0.05$

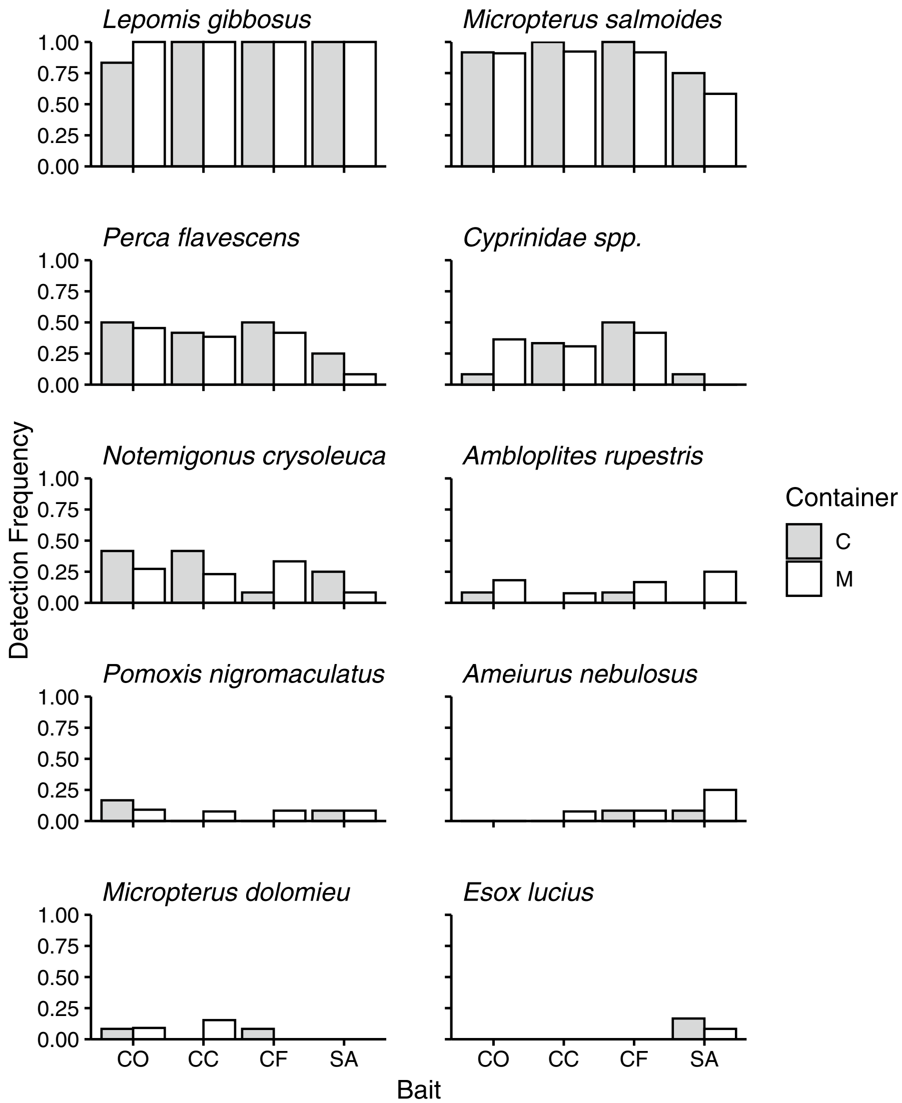

Fig. 5 Proportion of replicates with a detection for each species according to bait type (CO, control; CC, canned corn; CF, cat food; SA, sardines) and presentations (C, container, M, mesh). The detection frequency graph for *Lepomis macrochirus* was excluded as the probability was 1 for all bait types and presentations

time-consuming to identify small cyprinid species even while holding them in person. The banded killifish [*Fundulus diaphanus* (Lesueur, 1817)] is known to be present in the lake (Keast et al., 1978) but was not observed. Although the killifish is a small-bodied species, it has a square tail rather than a forked one, so it is unlikely it was present but mistaken for a cyprinid. Ultimately, BRUVS were able to detect the presence of small-bodied taxa and small individuals that would not be caught by angling, or depending on mesh size, by netting, but which could be captured and positively identified using specialized gear such as minnow traps. Other researchers have gone further to use image-restoration software to improve their ability to identify indistinct images of fish and found that more fish were able to be identified this way and with greater agreement between observers (Donaldson et al., 2019).

Some species of the family *Percidae,* such as logperch [*Percina caprodes* (Rafinesque, 1818)], and darters were not observed, although they have been reported in a study of the fish community of Opinicon Lake (Keast et al., 1978). This could be explained by the fact that these fish associate close to the substrate in gravel habitats in the lake, while the bait and camera were elevated 0.5 m from the substrate in silty, vegetated areas. Deploying cameras with a downward orientation may increase the probability

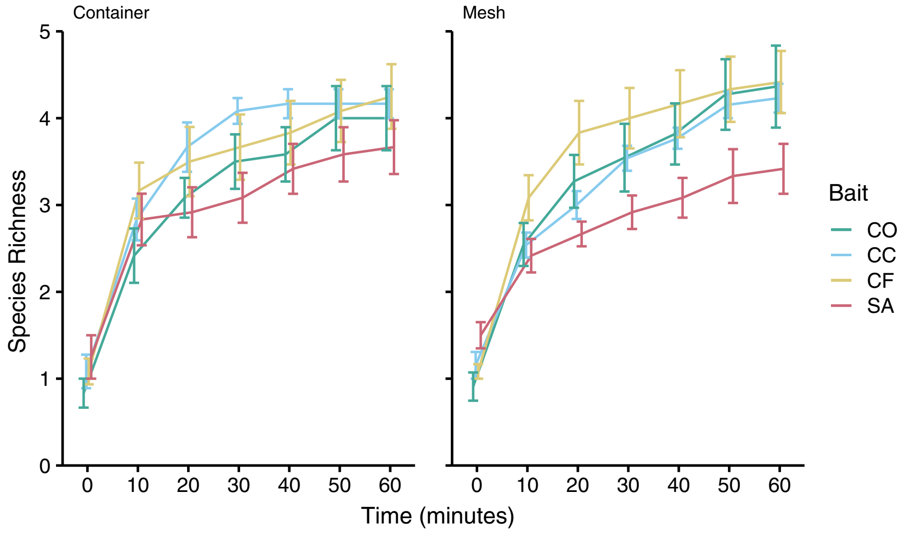

Fig. 6 Mean species richness of all replicates at 10-min intervals for each bait and container type. Error bars show one standard error. *CO* control, *CC* creamed corn, *CF* cat food, and *SA* sardine bait

of detecting species which associate closely with the substrate, however, a study of deep-sea fish by Jamieson et al. (2006) found that more species were willing to approach bait in front of horizontally oriented cameras than perceived confined spaces below vertically oriented cameras. However, many lake-dwelling fish do associate with overhanging structure and may be attracted to, rather than cautious of, the refuge inside the camera stand frame (Helfman, 1981; Maine et al., 1994; Ahrenstorff et al., 2009; Sass et al., 2012). Due to the differences in fish behavior and habitat use between the deep-sea and lakes, it would still be useful to compare vertical and horizontal camera configurations, or horizontally facing cameras and bait closer to the substrate as suggested in Harvey et al. (2013).

The results of the two-way ANOVA suggest that neither bait type, nor container type influenced the number of species observed by BRUVS. Our study found that only a small number of taxa could be reliably identified from video (i.e., ten species could be identified to the species level and one only to the family level) which was a small pool of species and therefore there was only a small scale upon which to measure differences that bait or container type may have on attracting species. Previous studies about the efficacy of baited vs unbaited RUVS and different bait types have had mixed results. Marine studies which found significant effects of fish-based bait had very low numbers of herbivorous and omnivorous species, suggesting differences were driven by carnivorous species (Ghazilou et al., 2016), or had large numbers (> 50) of overall species (Watson et al., 2005), or both (Harvey et al., 2007). In temperate coastal waters, Jones et al. (2020) found animal-based bait increased species richness estimates over unbaited videos in Swansea Bay, United Kingdom but found no differences between baits. Ebner and Morgan (2013), and Cousins et al. (2017) found that sardine-baited and unbaited cameras in Australian river pools observed similar total species richness and average species richness per sample and found lower overall species richness (25 or fewer) in the areas sampled than marine studies. In contrast, a study comparing two fish-based bait types, cat food, and corn in an Amazonian river where high overall species richness was observed (56 species) found that sardines, and a local alternative baitfish observed greater species richness than cat food, which outperformed corn, and unbaited cameras (Schmid et al., 2017).

We believe our study to be the first to experimentally compare how bait container types affect sampling with BRUVS, however, other authors have commented that they believe reducing access to bait to extend the bait persistence could improve the performance of the technique (Dorman et al., 2012; Ebner & Morgan, 2013). Container type was predicted to affect bait plume dispersion, as mesh bait bags would allow fragments of bait to be released by feeding behavior and the larger surface area exposed would increase diffusion of oils from the bait into the surroundings compared to PVC containers. Since baits were not depleted before the end of the recording in most cases, we would not expect to see any benefit from an inaccessible container for deployments up to one hour. Because no effect of bait on species richness observed was found, it is unsurprising that a change in bait dispersion would also fail to have an impact.

Only a few species (i.e., *L. macrochirus*, *L. gibbosus*, *N. crysoleucas*, and *A. nebulosus*) were observed feeding directly from bait containers. Of these, *L. macrochirus* and *L. gibbosus* were seen in almost all replicates, and only bullhead had an increased detection rate by the baited cameras. *L. macrochirus* and *L. gibbosus* behaved territorially over the bait and may have deterred other species from approaching, or the number of individuals and the amount of activity may have obscured individuals of other species from the camera's view. Territorial behavior and feeding activity by *L. macrochirus* and *L. gibbosus* were greatest in sardine-baited replicates, which correspondingly had the lowest average species richness. This could have been due to interspecific aggression, or due to the amount of the field of view which was taken up by *Lepomis* spp. at any given time, potentially obscuring other taxa present. Additionally, when *E. lucius* were present at the camera—which only occurred in sardine treatments—other fish fled, so sardines as a bait may have indirectly deterred other species by attracting a predator species.

The proportion of detections of Cyprinidae spp. was dependent on bait type overall, and upon pairwise comparison the proportion of detections by sardines was significantly lower than cat food, while all other comparisons were not significant. As this is a collection of species present in the lake with potentially varying dietary preferences, explaining why this pattern is observed is difficult. The most common genus of cyprinids in the lake are *Notropis* spp. [e.g., *N. atherinoides* Rafinesque, 1818; *N. hudsonius* (Clinton, 1824); *N. heterolepis* Eigenmann & Eigenmann, 1893], which largely feed on zooplankton (Hartman et al., 1992; Roberts et al., 2006) as do many other species of cyprinids, so it could be generalized that the label of Cyprinidae spp. refers to invertivore fish. The lower detection rate of cyprinids when using sardines may have been due to the aggressive behavior of sunfish or the attraction of *E. lucius* to this bait.

Esox Lucius and A. nebulosus were not detected on any unbaited videos. *E. Lucius* were only detected in sardine deployments and are piscivorous, but have poor olfactory sensing ability (Hara, 1975). Several studies comparing unbaited and baited video techniques found that sardine-baited cameras recorded higher piscivorous fish species richness than unbaited cameras without changing herbivorous species richness (Harvey et al., 2007; Stobart et al., 2007; Ebner & Morgan, 2013), however, Ebner and Morgan noted that some species were observed less frequently when fish-based baits were used, and care should be taken when making general statements. *Ameiurus nebulosus* was not found to have a significant association with bait type; however, the pattern of its occurrences is interesting. The absence of *A. nebulosus* from unbaited deployments was likely because sampling occurred outside their usual active period and habitat, as Keast and Harker (1977) observed *A. nebulosus* in Opinicon Lake most often nocturnally and below 3 m depth. *A. nebulosus* are omnivorous, olfactory-driven feeders (Olmsted, 1918) and observing them only in baited deployments, outside their usual spatiotemporal distribution is evidence that they were attracted by the bait. This is corroborated by evidence from the previous BRUV studies (Bassett & Montgomery, 2011; Ebner et al., 2015).

All bait types and the unbaited RUVS showed similar trends in species observed over time. Depending on the purpose of the recordings, to optimize sampling and processing time to increase the number of replicates which can be analyzed, reducing recording times by one-half or one-third to 30 or 40 min would still capture 80% or 88% of the species richness observed with the full hour recording. Whether this is an acceptable trade-off will depend on the purpose of the sampling and the relative value of detecting uncommon species versus increased replicates. The amount of bait used appears to have been appropriate as there was still bait left in the accessible replicates most of the time for all bait types, however, with sardines as bait, the bait was depleted in one-quarter of the deployments. Using more bait would increase the cost of deployments but it could also increase the attraction of species that do respond to baiting. As noted, however, bait appears to bias the observations of some species so care should be taken to decide whether bait is necessary and to choose the correct bait for the objectives to be addressed.

Conclusion

We conclude that remote underwater video systems can be effectively used in temperate freshwater lakes to survey species richness. The current study found baited and unbaited RUVS were able to detect almost the whole complement of large-bodied species in a mesotrophic lake with a short visual field due to submergent macrophytes. Although bait type and container did not affect overall species richness observed by BRUVS, detection frequency of some species was affected. Using a variety of baits is likely the best way to maximize the number of species detected. Understanding which species are attracted by and which are deterred by these baits will help inform future research using BRUVS. This study also provides early evidence that mesh bags are better than inaccessible PVC containers for attracting an olfactory-driven species, *Ameiurus nebulosus*. In future studies in temperate freshwater lakes, recording times for deployed cameras can be reduced to between 30 and 40 min while detecting more than 80% of the species richness of an hour-long set.

For BRUVS to be used more in freshwater research and monitoring, testing baits in other lakes with greater species richness, especially of large-bodied species will help to determine in what conditions using bait is helpful to achieve sampling goals. To improve detection of small, cryptic, and benthic fish, we recommend research experimenting with substrate-level and downward-facing cameras. Additionally, future research should consider if bait and container type affect community structure estimates if BRUVS are to be used to investigate the ecology of temperate freshwater environments beyond the question of species presence/absence.

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Data availability The datasets generated during the current study are available from the corresponding author on reasonable request.

Code availability n/a.

Declarations

Conflict of interest The authors have no conflicts of interest to disclose.

References

Ahrenstorff, T. D., G. G. Sass & M. R. Helmus, 2009. The influence of littoral zone coarse woody habitat on home range size, spatial distribution, and feeding ecology of largemouth bass (*Micropterus salmoides*). Hydrobiologia 623: 223–233.

Bajaba, S. Z., S. Hugo, A. J. van Wyk, S. M. Marr, N. G. Vine & O. L. F. Weyl, 2021. Can bait improve the efficiency of underwater video monitoring of fish in headwater streams? A case study from the Rondegat River, South Africa. African Journal of Aquatic Science 46: 246–249.

Bassett, D. K. & J. C. Montgomery, 2011. Investigating nocturnal fish populations in situ using baited underwater video: with special reference to their olfactory capabilities. Journal of Experimental Marine Biology and Ecology 409: 194–199.

Cataraqui Region Conservation Authority, 2017. Opinicon Lake Fact Sheets. Glenburnie, ON. [available on internet at https://www.crca.ca/wp-content/uploads/PDFs/LakeReports/2017-FactSheet-OpiniconLake.pdf].

Cousins, S., M. J. Kennard & B. C. Ebner, 2017. Depth-related composition and structuring of tropical riverine fish assemblages revealed by baited video. Marine and Freshwater Research 68: 1965–1975.

Davies-Colley, R. J., W. N. Vant & D. G. Smith, 1994. Colour and Clarity of Natural Waters. Science and Management of Optical Water Quality, Prentice Hall Inc, Englewood Cliffs:

Donaldson, J., P. Drews-Jr, M. Bradley, D. Morgan, R. Baker & B. Ebner, 2019. Countering low visibility in video survey of an estuarine fish assemblage. Pacific Conservation Biology 26: 190.

Dorman, S. R., E. S. Harvey & S. J. Newman, 2012. Bait effects in sampling coral reef fish assemblages with stereo-BRUVs. PLoS ONE 7: e41538.

Ebner, B. C. & D. L. Morgan, 2013. Using remote underwater video to estimate freshwater fish species richness. Journal of Fish Biology 82: 1592–1612.

Ebner, B. C., D. Starrs, D. L. Morgan, C. J. Fulton, J. A. Donaldson, D. J. Sean, S. Cousins, M. Kennard, G. Butler, Z. Tonkin, S. Beatty, B. Broadhurst, R. Clear, M. Lintermans & C. S. Fletcher, 2014. Emergence of field-based underwater video for understanding the ecology of freshwater fishes and crustaceans in Australia. Journal of the Royal Society of Western Australia 97: 287–296.

Ebner, B. C., C. J. Fulton, S. Cousins, J. A. Donaldson, M. J. Kennard, J. O. Meynecke & J. Schaffer, 2015. Filming and snorkelling as visual techniques to survey fauna in difficult to access tropical rainforest streams. Marine and Freshwater Research 66: 120–126.

Ellender B. R., A. Becker & O. L. F. Weyl, 2012. Underwater video analysis as a non-destructive alternative to electrofishing for sampling imperilled headwater stream fishes. Aquatic Conservation: Marine and Freshwater Ecosystems 65: 58–65

Erlandsson, M., I. Buffam, J. Fölster, H. Laudon, J. Temnerud, G. A. Weyhenmeyer & K. Bishop, 2008. Thirty-five years of synchrony in the organic matter concentrations of Swedish rivers explained by variation in flow and sulphate. Global Change Biology 14: 1191–1198.

Flammang, M. K. & R. D. Schultz, 2007. Evaluation of hoopnet size and bait selection for sampling Channel Catfish in Iowa impoundments. North American Journal of Fisheries Management 27: 512–518.

Fulton, C. J., D. Starrs, M. P. Ruibal & B. C. Ebner, 2013. Counting crayfish: active searching and baited cameras trump conventional hoop netting in detecting *Euastacus armatus*. Endangered Species Research 19: 39–45.

Ghazilou, A., M. R. Shokri & W. Gladstone, 2016. Animal v. plant-based bait: does the bait type affect census of fish assemblages and trophic groups by baited remote underwater video (BRUV) systems? Journal of Fish Biology 88: 1731–1745.

Hannweg, B., S. M. Marr, L. E. Bloy & O. L. F. Weyl, 2020. Using action cameras to estimate the abundance and habitat use of threatened fish in clear headwater streams. African Journal of Aquatic Science 45: 372–377.

Hara, T. J., 1975. Olfaction in fish. Progress in Neurobiology 5: 271–335.

Hartman, K. J., B. Vondracek, D. L. Parrish & K. M. Muth, 1992. Diets of Emerald and Spottail Shiners and potential interactions with other Western Lake Erie planktivorous fishes. Journal of Great Lakes Research Elsevier 18: 43–50.

Harvey, E. S., M. Cappo, J. J. Butler, N. Hall & G. A. Kendrick, 2007. Bait attraction affects the performance of remote underwater video stations in assessment of demersal fish community structure. Marine Ecology Progress Series 350: 245–254.

Harvey, E. S., D. L. McLean, S. Frusher, M. D. E. Haywood, S. J. Newman & A. Williams, 2013. The use of Bruvs as a tool for assessing marine fisheries and ecosystems: A review of the hurdles and potential. Fisheries Research and Development Corporation, and the University of Western Australia, Crawley, Australia.

Helfman, G. S., 1981. The advantage to fishes of hovering in shade. American Society of Ichthyologists and Herpetologists 1981: 392–400.

Holm, S., 1978. A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics 6: 65–70.

Jamieson, A. J., D. M. Bailey, H. Wagner, P. M. Bagley & I. G. Priede, 2006. Behavioural responses to structures on the seafloor by the deep-sea fish *Coryphaenoides armatus*: implications for the use of baited landers. Deep Sea Research Part i: Oceanographic Research Papers 53: 1157–1166.

Jones, R. E., R. A. Griffin, S. R. Januchowski-Hartley & R. K. F. Unsworth, 2020. The influence of bait on remote underwater video observations in shallow-water coastal environments associated with the North-Eastern Atlantic. PeerJ 8: 1–21.

Keast, A. & J. Harker, 1977. Fish distribution and benthic invertebrate biomass relative to depth in an Ontario lake. Environmental Biology of Fishes 2: 235–240.

Keast, A., J. Harker & D. Turnbull, 1978. Nearshore fish habitat utilization and species associations in Lake Opinicon (Ontario, Canada). Environmental Biology of Fishes 3: 173–184.

Kim, H. Y., 2013. Statistical notes for clinical researchers: assessing normal distribution (2) using skewness and kurtosis. Restorative Dentistry & Endodontics Korean Academy of Conservative Dentistry 38: 52–54.

King, A. J., A. George, D. J. Buckle, P. A. Novak & C. J. Fulton, 2018. Efficacy of remote underwater video cameras for monitoring tropical wetland fishes. Hydrobiologia 807: 145–164.

Kirk, J. T. O., 1994. Light and Photosynthesis in Aquatic Ecosystems, Cambridge University Press, Cambridge:

Lyle, J. M., D. M. Furlani & C. D. Buxton, 2007. Cutting-edge technologies in fish and fisheries science. Australian Society for Fish Biology Workshop Proceedings. Hobart, Tasmania 2007: 101–114.

Maine, P. I. N., J. R. Moring & P. H. Nicholson, 1994. Evaluation of three types of artificial habitats for fishes in a freshwater pond in Maine, USA. Bulletin of Marine Science 55: 1149–1159.

Mallet, D. & D. Pelletier, 2014. Underwater video techniques for observing coastal marine biodiversity: a review of sixty years of publications (1952–2012). Fisheries Research 154: 44–62.

McDonald, J. H., 2014. Handbook of Biological Statistics, Sparky House Publishing, Baltimore:

Olmsted, J. M. D., 1918. Experiments on the nature of the sense of smell in the common catfish, *Amiurus Nebulosus* (Leseur). American Journal of Physiology 46: 443–455.

Pelletier, D., K. Leleu, G. Mou-Tham, N. Guillemot & P. Chabanet, 2011. Comparison of visual census and high definition video transects for monitoring coral reef fish assemblages. Fisheries Research 107: 84–93.

Pierce, R. B., D. W. Coble & S. Corley, 1981. Fish catches in baited and unbaited hoop nets in the Upper Mississippi River. North American Journal of Fisheries Management 1: 204–206.

R Core Team 2020. R: A language and environment for statistical computing. R Foundationfor Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Roberts, M. E., B. M. Burr, M. R. Whiles & V. J. Santucci, 2006. Reproductive ecology and food habits of the blacknose shiner, *Notropis heterolepis*, in Northern Illinois. American Midland Naturalist 155: 70–83.

Sass, G. G., S. R. Carpenter, J. W. Gaeta, J. F. Kitchell & T. D. Ahrenstorff, 2012. Whole-lake addition of coarse woody habitat: response of fish populations. Aquatic Sciences 74: 255–266.

Schmid, K., J. A. Reis-Filho, E. Harvey & T. Giarrizzo, 2017. Baited remote underwater video as a promising nondestructive tool to assess fish assemblages in clearwater Amazonian rivers: testing the effect of bait and habitat type. Hydrobiologia 784: 93–109.

Stobart, B., J. A. García-Charton, C. Espejo, E. Rochel, R. Goñi, O. Reñones, A. Herrero, R. Crech'riou, S. Polti, C. Marcos, S. Planes & A. Pérez-Ruzafa, 2007. A baited underwater video technique to assess shallow-water Mediterranean fish assemblages: methodological evaluation. Journal of Experimental Marine Biology and Ecology 345: 158–174.

Struthers, D. P., A. J. Danylchuk, A. D. M. Wilson & S. J. Cooke, 2015. Action cameras: bringing aquatic and fisheries research into view. Fisheries 40: 502–512.

Watson, D. L., E. S. Harvey, M. J. Anderson & G. A. Kendrick, 2005. A comparison of temperate reef fish assemblages recorded by three underwater stereo-video techniques. Marine Biology 148: 415–425.

Whitmarsh, S. K., P. G. Fairweather & C. Huveneers, 2017. What is big BRUVver up to? Methods and uses of baited underwater video. Reviews in Fish Biology and Fisheries 27: 53–73.

Willis T. J., R. B. Millar & R. C. Babcock, 2000 Detection of spatial variability in relative density of fishes:comparison of visual census, angling, and baited underwater video. Marine Ecology Progress Series 198: 249–260

Wilson, K. L., M. S. Allen, R. N. M. Ahrens & M. D. Netherland, 2014. Use of underwater video to assess freshwater fish populations in dense submersed aquatic vegetation. Marine and Freshwater Research 66: 10–22.

Wraith, J., T. Lynch, T. E. Minchinton, A. Broad & A. R. Davis, 2013. Bait type affects fish assemblages and feeding guilds observed at baited remote underwater video stations. Marine Ecology Progress Series 477: 189–199.