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METHOD

# Testing and deployment of C-VISS (cetacean-borne video camera and integrated sensor system) on wild dolphins

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**Abstract** Multi-sensor biologgers are a powerful method for studying individual behaviors of free-ranging species, yet the challenges of attaching non-invasive biologgers to agile, fast-moving marine species have prohibited application of this technique to small (<5 m) cetaceans. Integration of video cameras into such biologgers is critical to understanding behavior from the animal's perspective; however, this technique has not been applied to small cetaceans. We examined the feasibility of remotely deploying a cetacean-borne video camera and integrated sensor system ("C-VISS") on small cetaceans. We deployed C-VISS on eight free-swimming dusky dolphins (*Lagenorhynchus obscurus*) off New Zealand (42°25′15″S 173°40′23″E) from December 2015 to January 2016, collecting a total of 535 min of video footage (average = 66.8 ± 91.10 SD, range 9–284). Dolphins were observed to show limited reactions to biologger attachment attempts and deployments. Social and environmental parameters derived from video footage include conspecific body condition, mother-calf spatial positioning, affiliative behavior, sexual behavior, sociability, prey, and habitat type. The ability to record behavioral states and fine-scale events from the individual's perspective will yield new insights into the behavior, socioecology, conservation, rehabilitation, and welfare of small cetaceans.

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## Introduction

In spite of recent advances in biologger technology, fine-scale aspects of behavior, physiology, and ecology "from the animal's perspective" remain mostly unknown for many species (Moll et al. 2007; Hays et al. 2016). For apex marine predators, such as cetaceans, such data are critical for creating conservation and management strategies and understanding the adaptive significance of social behavior (Dudzinski 1998), individuals' roles in structuring ecological communities, vertical oceanographic profiles, and impacts from anthropogenic pressures. Direct observations independent of visual confirmation may be conducted via deployment of biologgers combining multiple sensors (Machovsky-Capuska et al. 2016a). However, studies involving direct observations of free-ranging individual behavior in highly gregarious species, such as small (<5 m) cetaceans, are rare. To advance our knowledge of these species, several challenges must be overcome including: undertaking the continuous observations necessary to interpret the behavior of individuals within highly gregarious but cryptic social groups (Challenge 1; e.g., Rutz and Hayes 2009); studying species that spend the majority of their lives underwater (Challenge 2; Marshall 1998; Davis et al. 1999); working with species characterized by typically small, curved body sizes and fast and evasive movements, which provide a narrow window of opportunity for biologger deployment (Challenge 3); concerns over the use of invasive pronged satellite biologgers (Challenge 4; e.g., Andrews et al. 2008); and retrieval of data for analysis (Challenge 5).

Over the past 20 years, animal-borne video cameras have provided glimpses of fine-scale behaviors that enabled insights into understanding individual actions within groups (Moll et al. 2007). Short-term, non-invasive biologgers incorporating animal-borne video cameras have successfully obtained footage from diverse marine taxa, including: invertebrates (e.g., Passaglia et al. 1997), sharks (e.g., Heithaus et al. 2001), sea turtles (e.g., Heithaus et al. 2002), seabirds (e.g., Grémillet et al. 2006), pinnipeds (e.g., Davis et al. 1999), manatees (e.g., Adimey et al. 2007), and baleen whales (e.g., Williams et al. 2000). However, biologger deployments in the aforementioned species were facilitated via use of: (1) animals with large body sizes and broad, relatively flat surfaces that facilitated biologger attachment or (2) the ability to capture and restrain the animals. While some previous studies (Stone et al. 1994; Hanson and Baird 1998; Baird et al. 2001; Kaplan et al. 2014; Silva et al. 2016) succeeded in remotely deploying suction-cup biologgers on small Cetacea to record diving and movement patterns, none to our knowledge have utilized animal-borne video cameras.

Here, we examine the feasibility of remote deployment of an animal-borne, multi-sensor, suction-cup biologger (Cetacean-borne Video camera and Integrated Sensor System or “C-VISS”) on small cetaceans. As previous impact studies of remote deployment of suction-cup biologgers in small cetaceans have shown diverse effects ranging from mild (Stone et al. 1994; Hanson and Baird 1998; Sakai et al. 2011; Silva et al. 2016) to strong reactions that led to the abandonment of the method (Schneider et al. 1998), we will additionally provide evidence of: (1) the components of our biologger and field techniques that enabled our success; (2) the different individual reactions encountered during attachment and deployment attempts; (3) the maximum biologger attachment duration; and (4) the social and environmental parameters that can be obtained from our biologger.

## Materials and methods

### Study species and site

Our focal species was the dusky dolphin (*Lagenorhynchus obscurus*). This small-bodied (maximum length 1.8 m, maximum weight 85 kg; Cipriano 1992) gregarious species has been the focus of long-term study off the coast of Kaikoura, New Zealand since the mid-1980s (Würsig and Würsig 2010). Both species and study site were optimal for developing and testing our biologging method, because: (1) approximately 2000 dusky dolphins may be found off Kaikoura at any given time (Markowitz 2004); (2) individuals form large groups (up to 1000) of mixed age-sex classes near shore during the day (Markowitz 2004); and (3) dolphin tourism (Buurman 2010) and regular research presence (Würsig and Würsig 2010) have habituated the dolphins to vessel presence.

### C-VISS components

C-VISS consists of a syntactic foam float (modified and customized from a Wildlife Computers base model) to which a miniaturized video camera, time-depth recorder (TDR), miniature very high frequency (VHF) and satellite (platform transmitter terminal, PTT) transmitters, and four silicon suction cups are attached using a combination of cable ties and screws (Table 1; Fig. 1a). C-VISS is positively buoyant and weighted on one end. Thus, C-VISS rises to the surface upon release from the individual, so that the antennae sit upright when floating at the surface to allow tracking for recovery.

The video camera (modeled after Machovsky-Capuska et al. 2016b) is based around a U10 Mini USB Flash Drive DVR Camera (Taiwan) with an OV7670 optical sensor having 36° field-of-view and with a resolution of 720 × 480 pixels captured at 30 frames/s (Fig. 1b). The video camera is powered by a Turnigy nano-tech 600 mAh 1 S lithium polymer battery which provides a maximum recording time of *c.a.* 4 h. The deployed video camera generates an AVI file containing video (MJPG codec) and audio every 30 min each of which has a size of approximately 1.2 GB and is written to a 32 GB microSD card. We used a UP Plus extruded-filament 3D printer (also sold under the Afinia brand) with ABS plastic filament to produce a close-fitting case to minimize size and weight while retaining sufficient structural protection. Waterproofing is provided by inserting the video camera into a Qualatex 646 balloon and attaching a clear Perspex disk secured with an o-ring to the lens end. The video camera on/off and recording functions are operated using a small handheld magnet.

C-VISS is deployed using a 1–2.5 m extendable pole with a custom-made solid foam core or cradle hollowed out

**Table 1** C-VISS components, specifications, and approximate costs

| Component | Dimensions (L × W × H (mm)), weight (g) | Model and manufacturer | Approximate unit cost (USD) |
|---|---|---|---|
| Syntactic foam float with lead weight | 175 × 110 × 20, 152 | Modified from AZ-FLOAT-010, wildlife computers (Redmond, WA) | $650 |
| Time-depth recorder | 33 × 7 × 7, 3 | LAT 1500, Sirtrack (Havelock North, New Zealand) | $1125 |
| PTT/VHF transmitter | 20 × 20 × 62 (without antennae), 41 | Custom KiwiSat 202, Sirtrack (Havelock North, New Zealand) | $2000 |
| Video camera | 108 × 27 × 27, 68 | Custom-made, University of Sydney | $1750 |
| Silicon suction cups: 1 large and 3 small | Large: 80 × 80 × 40, 69<br>Small: 20 × 20 × 12, 3 (each) | Large "saddle cup" and 3 small "Acousonde" cups, Cetacean Research Technology (Seattle, WA) | $90 (large), $45 (small) |

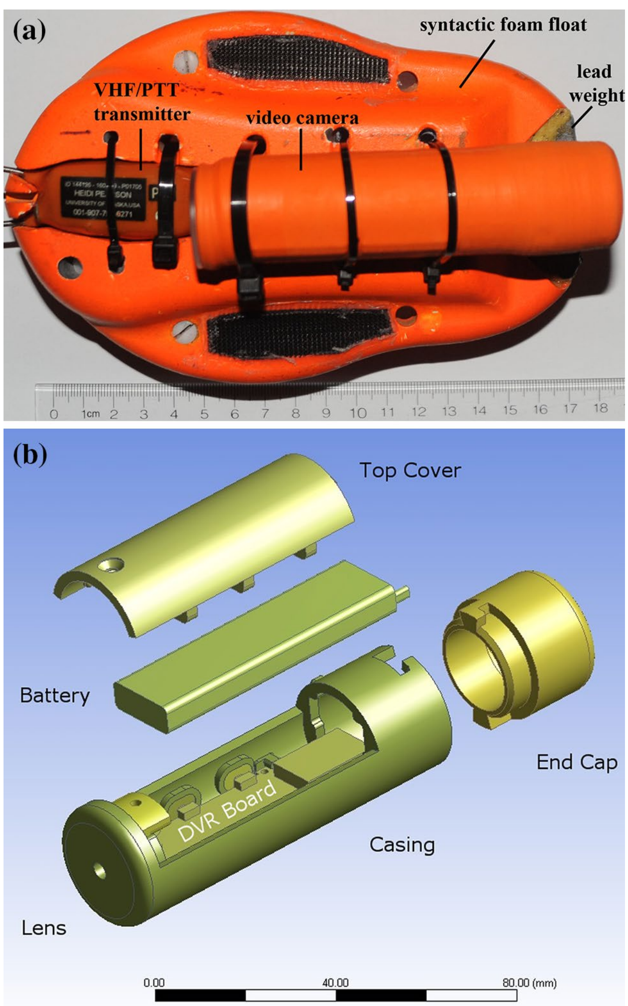


**Fig. 1** C-VISS components. **a** Dorsal view of C-VISS. The time-depth recorder is embedded in the float under the video camera. **b** Video camera assembly

specifically to fit the biologger (Fig. 2). Velcro is used to attach C-VISS to the cradle on the end of the deployment pole. Once the suction cups on the underside of the biologger adhere to the animal, the simultaneous momentum of the deployment pole being pulled back and the dolphin swimming away from the pole causes the Velcro between C-VISS and the cradle to detach. The target area for attachment was the lateral flank cranial to the dorsal fin (Fig. 2).

## Development and field validation

C-VISS was developed and validated via a field technique conducted during five trials (Fig. 2). All trials except Trial 3 were conducted in the wild. During the wild dolphin trials, two different 5 m rigid hull inflatable boats were used; one with a 60 hp four-stroke engine and one with a 100 hp four-stroke engine. Dolphin groups were located with the naked eye and approached at low speed (≤3 knots), moving in a direction parallel to the group. Biologger attachment attempts were made from the bow of the boat on adults as they swam alongside and near the bow. Trial 3 was conducted at the Vancouver Aquarium (Vancouver, BC), where one Pacific white-sided dolphin (*L. obliquidens*) was housed in an outdoor pool measuring $2.4 \times 10^4$ m$^3$ with a volume of $2.5 \times 10^6$ L, temperature of 16.1 °C, pH of 7.51, and salinity of 28.1 ppt. As dusky dolphins do not occur in captivity, we conducted captive trials on the Pacific white-sided dolphin, a species of comparable size to dusky dolphins.

During Trials 1–4, C-VISS was created and we developed an observational protocol to determine reactions and potential effects of C-VISS on dolphins. As described below, we used a stepwise approach to adding components to the biologger. The aims of Trials 1–4 were to test: (1) dusky dolphin reactions to attachment attempts of a lower profile suction-cup biologgger without a video camera (Trial 1; see Fig. 2); (2) dusky dolphin reactions to

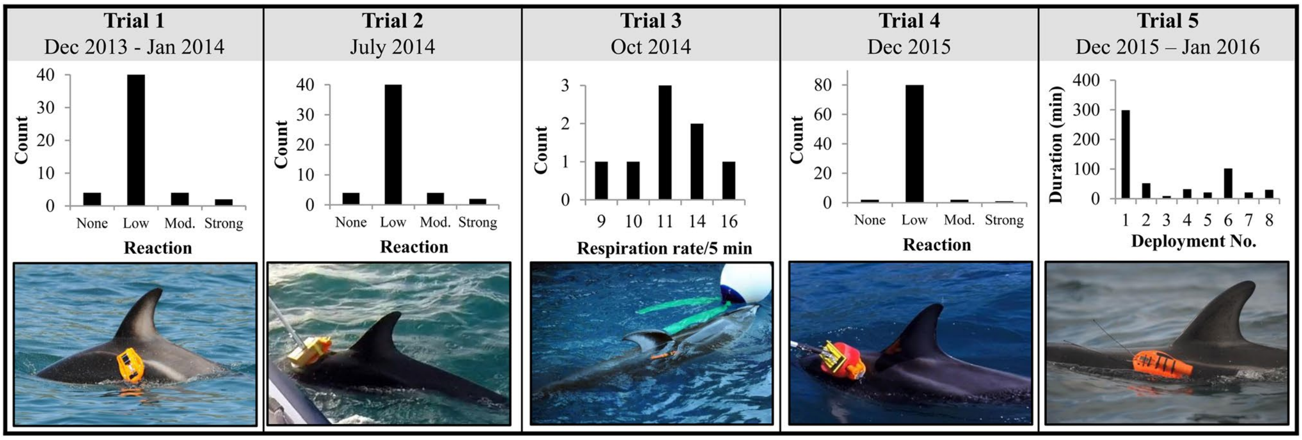


**Fig. 2** Summary of the trials conducted for validation and deployment of C-VISS. The graphs depict the primary outcome evaluated during each trial (Trial 1 $N=61$, Trial 2 $N=19$, Trial 3 $N=10$, Trial 4 $N=85$, Trial 5 $N=8$). For Trials 1, 2, and 4, dolphin reactions to biologger attachment attempts are as defined in the text [none, low, moderate (mod.), and strong]. For Trial 3, respiration rate was used to assess individual reaction to biologger attachment

attachment attempts of a "dummy" biologger (a model of similar size to C-VISS but with non-working video camera components) (Trial 2); (3) reactions of a captive Pacific white-sided dolphin to C-VISS deployments (Trial 3); and (4) dusky dolphin reactions to attachment attempts of C-VISS (Trial 4). During Trial 1, the optimal configuration (i.e., number, placement, and combination) of large vs. small suction cups was also determined; this configuration (see Table 1) was then used during all future trials.

Following Sakai et al. (2011), dusky dolphin reactions to tagging attempts (measured according to change in an individual's behavior pre- vs. post- tagging attempt) during Trials 1, 2, and 4 were classified as: (a) "none" when behavior did not change; (b) "low" when behavior changed slightly, but there was no apparent vigorous response (e.g., dive/swim away); (c) "moderate" when behavior was modified in a forceful manner (e.g., tail slap); and (d) "strong" when behavior changed in a succession of forceful movements (e.g., dive away and leap). Reactions were recorded and classified in the field and verified post-hoc by analyzing video footage (taken via GoPro Hero 3 + Black) of tagging attempts.

When working with the captive Pacific white-sided dolphin (Trial 3), remote deployment was not used. Thus, reactions to C-VISS deployments were measured via respiration rate recorded during randomly selected 5-min sampling periods during low-intensity behavior during three long-term (>30 min) deployments. This is the standard method used by the Vancouver Aquarium to measure respiration rate for this animal (Vancouver Aquarium Marine Mammal Trainer C. Nagata, pers. comm.).

During Trial 5, C-VISS was successfully deployed (i.e., remained attached on the animal for >5 min). Continuous VHF tracking was used to maintain the research vessel within 500 m of the group in which the instrumented individual occurred. We assessed dusky dolphin reactions to successful C-VISS deployments by determining if the instrumented individual's behavior matched overall group behaviors. For each sighting of the instrumented individual at the surface, we recorded individual and group behavioral state (foraging, resting, socializing, traveling; Pearson 2009) and distance of the instrumented individual from the research vessel. To further assess potential impacts of the biologger, we used C-VISS video footage to measure respiration rate (no. surfacings/min, after Cipriano 1992) for each instrumented animal. To assess proof of concept for C-VISS, we measured biologger attachment duration across successful deployments, identified social and environmental parameters that can be derived from video footage, and analyzed depth data from the TDR.

## Results

### Reactions to the biologger

A total of 165 biologger attachment attempts were conducted during the trials designed to assess wild dolphin reactions to attachment attempts (Trials 1, 2, and 4). No negative effects from biologger attachment attempts were observed during these trials. Most (90%, $n=148$) dusky dolphin reactions to biologger attachment attempts were classified as "low" (Fig. 2). The most commonly observed behavioral response to biologger attachment attempts was for the individual to quickly swim or dive away from the deployment pole. During the captive trial (Trial 3), average respiration rate for the instrumented animal was $2.1 \pm 0.54$ SD breaths/min ($N=10$ 5-min sampling periods, range

1.8–3.2 breaths/min). This was near to the expected range of 2.2–3.4 breaths/min for this animal when engaged in low-intensity behavior (Vancouver Aquarium Marine Mammal Trainer C. Nagata, pers. comm.) and comparable to values reported for wild Pacific white-sided dolphins (2.5 ± 0.32 SD breaths/min; Black 1994). In addition, the instrumented dolphin was observed to perform typical activities (e.g., playing with an enrichment ball; Fig. 2). During all surface sightings of instrumented dusky dolphins throughout successful deployments during Trial 5, individuals were engaged in the same behavioral state as the group and exhibited no avoidance relative to the research vessel. Average respiration rate was 2.6 ± 0.72/min ($N=8$, range 1.61–4.23).

### Attachment duration

During Trial 1, 4% ($n=3$) of attempts were successful. No successful attachments were achieved during Trials 2 and 4. Maximum biologger attachment durations during Trials 1 and 3 were 360 and 255 min, respectively, providing initial proof of concept that suction-cup biologgers can successfully be applied to small Cetacea, such as *Lagenorhynchus* spp. Total attachment durations during Trials 1 and 3 were 476 min ($N=3$, mean = 158.7 ± 174.4 SD, min. = 29) and 615 min ($N=9$, mean = 68.3 ± 85.92 SD, min. = 14), respectively.

During Trial 5, 12% ($n=8$) of attempts were successful. Total C-VISS attachment duration across eight successful deployments was 566 min (mean = 71.9 ± 96.03 SD, range 9–299; Fig. 2), with a total of 535 min of video footage obtained (mean = 66.8 ± 91.10 SD, range 9-284). Total C-VISS attachment duration exceeded the total duration of video footage, because the video camera was turned on at the commencement of biologger attachment attempts, with some battery power consumed in the period prior to successful attachment on the animal.

### Social and environmental parameters

We identified seven social and environmental parameters that can be obtained from C-VISS footage: conspecific body condition (Fig. 3a), mother-calf spatial positioning according to infant (calf swims underneath its mother) or echelon (calf swims alongside its mother) position (Mann and Smuts 1999; Fig. 3b, Video S1), affiliative behavior

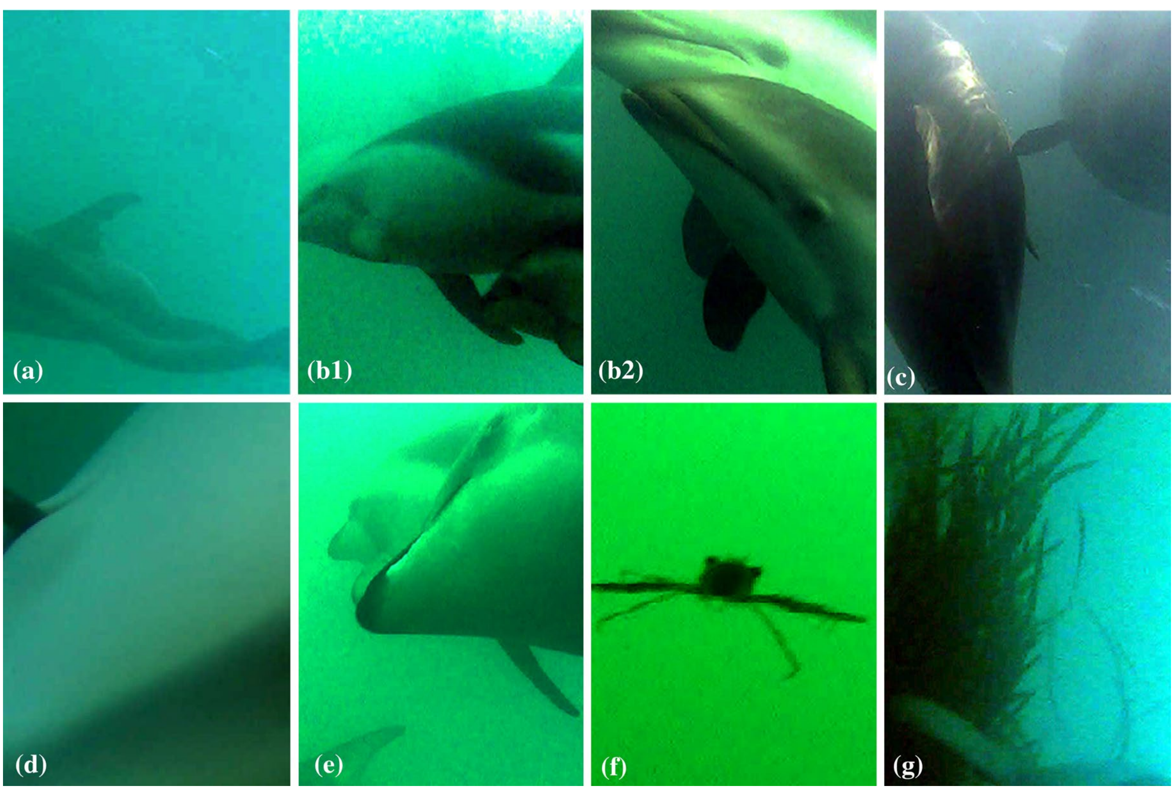


**Fig. 3** Video stills of social and environmental parameters recorded by C-VISS. **a** Conspecific body condition assessed via presence/absence of wounds/disfigurements. **b** Mother-calf spatial positioning categorized as: (1) infant position or (2) echelon position. **c** Conspecific affiliative behavior identified by flipper rubbing. **d** Conspecific sexual behavior identified by an erect penis. **e** Minimum social index. Three conspecifics are shown here. **f** Prey availability determined by presence and type. **g** Habitat type assessed by substrate type

(Fig. 3c), sexual behavior (Fig. 3d), minimum social index (no. conspecifics in view/min; Fig. 3e, Video S1), prey (Fig. 3f), and habitat type (Fig. 3g). The average depth of instrumented individuals recorded by the TDR was 5.6 ± 5.33 m ($N$ = 8, max = 46.5).

## Discussion

Here, we describe the first study to successfully deploy an animal-borne video camera on small Cetacea. As previously described, there are several inherent challenges to studying fine-scale aspects of cetacean behavior. With C-VISS, we have overcome these challenges by: (1) integrating a novel combination of sensors that allowed us to observe the social and environmental interactions of individuals in large groups while eliminating the potentially negative effects of a research vessel in close and constant proximity (Challenges 1–2); (2) creating a custom-made deployment mechanism and developing a remote-deployment technique which facilitated success in attaching the biologger to fast-swimming, free-ranging individuals (Challenge 3); (3) using suction cups for non-invasive attachment (Challenge 4); and (4) integrating coarse-range (VHF) and fine-range (PTT) transmitters for biologger retrieval and subsequent data download (Challenge 5). Importantly, mainly mild reactions to biologging attachment attempts and deployment were observed at the surface, indicating that C-VISS is a safe method for cetaceans >5 m for short duration deployments. Furthermore, while respiration rates for non-instrumented individual dusky dolphins are not available (per Challenge 1), the average respiration rate of instrumented individuals during Trial 5 was similar to that reported for radio-tagged dusky dolphins (Cipriano 1992) and Pacific white-sided dolphins (Black 1994).

Our deployment success rate and mean and maximum biologger attachment durations during Trial 5 were lower than that reported in deployments of animal-borne cameras on large cetaceans, such as blue (*Balaenoptera musculus*; Calambokidis et al. 2007), humpback (*Megaptera novaeangliae;* Cade et al. 2016), and sperm (*Physeter macrocephalus*; Marshall 1998) whales. However, the aforementioned species are >5 times longer and >300 times heavier than dusky dolphins (Jefferson et al. 2008) and typically travel at one-half the speed of dusky dolphins (Würsig and Würsig 1980 for dusky dolphins; Watkins et al. 2002 for sperm whales; Bailey et al. 2009 for blue whales; Horton et al. 2016 for humpback whales), all of which facilitates biologger deployment and attachment success. Furthermore, animal-borne technology for large cetaceans has been in development for more than 20 years (Marshall 1998). As we continue to refine the hydrodynamic design of the biologger and enhance our deployment technique, we expect that deployment success and attachment durations in small cetaceans will approach those in larger cetaceans.

Over the past 30 years, traditional surface-based observations have been a primary method for advancing understanding of cetacean behavior (Samuels and Tyack 2000). However, there is limited capacity for tracking fine-scale individual behaviors for durations >5 min in agile, free-ranging, and gregarious species, such as small cetaceans (Mann 1999; Whitehead 2004). Our multi-sensor biologger overcomes this obstacle by allowing researchers to conduct prolonged focal animal observations (Altmann 1974) to track and record the behavior of the same individual amidst a group of hundreds of other individuals. This information, combined with vertical movements obtained from diving data and various abiotic (substrate type, Fig. 3f) and biotic (prey availability, Fig. 3e; conspecifics, Fig. 3a–d) factors, represents a crucial methodological advancement in studying the social and foraging strategies of small cetaceans.

Findings presented here suggest that C-VISS has the potential to complement traditional data collection methods and advance the state of knowledge on dolphin behavior, particularly with respect to cryptic social and maternal strategies and their interaction with environmental parameters. We also foresee practical applications for future cetacean research using animal-borne video cameras, including: (1) conservation strategies that utilize fine-scale information on interactions between biotic and abiotic factors and (2) assessment of release success in rehabilitated cetaceans. Future enhancement of this biologger should focus on continued evaluation of its physical and behavioral effects on dolphins, maximizing attachment duration through continued miniaturization, improving hydrodynamic design using 3D printing, the incorporation of a 360° lens in the camera, and integration of advanced sensors (inertial measurement unit, temperature, light, and accelerometer) to further monitor dolphin movements in the context of their physical environment.

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**Compliance with ethical standards**

**Conflict of interest** All authors declare that they have no conflicts of interest.

**Ethical approval** All applicable international, national, and/or institutional guidelines for the care and use of animals were followed. All procedures performed in studies involving animals were in accordance with the ethical standards of the institution or practice at which the studies were conducted. This study was conducted under University of Alaska Fairbanks IACUC 490961-8, Massey University Animal Ethics Committee approval MU13/90, and DOC permit 37696-MAR. The authors have no conflicts of interest to declare. This article does not contain any studies with human participants performed by any of the authors.

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