Mem. Natl Inst. Polar Res., Spec. Issue, **58**, 150–156, 2004

Review

Monitoring the behavior and multi-dimensional movements of Weddell seals using an animal-borne video and data recorder

Randall W. Davis[1*], William Hagey[2] and Markus Horning[1]

[1]*Department of Marine Biology, Texas A&M University at Galveston, 5007 Avenue U, Galveston, TX 77553, USA (*davisr@tamug.tamu.edu)*
[2]*Pisces Design, Avenida Mirola, La Jolla, CA 92096, USA*

(Received April 22, 2003; Accepted August 11, 2003)

Abstract: We have developed an animal-borne video and data recorder to observe Weddell seals foraging and to reconstruct their three-dimensional movements. The video and data recorder consists of a low-light-sensitive video camera with near-infrared light-emitting diodes that is mounted on top of the seal's head to obtain close-up images of the seal's muzzle and the area in front of the animal. The main housing, which is mounted on the animal's back, contains an 8-mm video tape recorder that can record for 6 h, batteries, a microcomputer and transducers for pressure, water speed, compass bearing, and flipper stroke frequency. Sound is recorded on one audio channel of the tape recorder with a hydrophone. Using these instruments, we have recorded over 500 h of underwater video and over 1000 three-dimensional dive paths with corresponding swimming performance data from 31 adult Weddell seals. We have documented seals foraging in the water column, on the sea floor, and at the under-ice surface. Mid-water foraging included encounters with large Antarctic toothfish and smaller Antarctic silverfish. Multivariate statistical analysis of variables derived from the temporal and spatial characteristics of three-dimensional dive paths have enabled us to classify dive types and, in some cases, assign a function such as foraging.

key words: Weddell seal, diving, behavior, video

Introduction

The process by which terrestrial mammalian predators search for, locate, stalk, and subdue their prey has been the subject of considerable research effort for terrestrial mammals (reviewed by Dunstone and Gorman, 1993). Much less is known about the foraging behavior of marine mammals, primarily because they are so difficult to observe underwater. The depth and duration of dives, and the speed and maneuverability of marine mammals limits direct observation of their behavior by fixed-location cameras, remotely operated vehicles, manned submersibles or divers using SCUBA. Often these technologies provide only fleeting glimpses of highly mobile species. Time-depth recorders attached to animals and acoustic tracking provide information on diving performance and underwater movements, but do not allow direct observation of animals at depth (Kooyman, 1989; Wartzok *et al*., 1992a, b; Bjørge *et al*., 1995; Andrew, 1998; Lesage *et al*., 1999; Harcourt *et al*., 2000; Plötz *et al*., 2001; Simpkins *et al*., 2001; Hindell *et al*., 2002). As a result, our knowledge of the underwater behavior of marine mammals, especially deep diving species, is based primarily on indirect information provided by dive depth and duration statistics and estimated swimming speeds. We developed an animal-borne video and data recorder that enables us to observe Weddell seals, *Leptonychotes weddellii*, foraging, to reconstruct their movements in detail, and to record data on environmental conditions (Davis *et al*., 1999). Simultaneous measurement of physiological data provided additional information on the energetic and physiological constraints associated with hunting while submerged and the strategies used by these mammals to reduce energetic costs and maximize foraging efficiency (Williams *et al*., 2000).

Description of the video and data recorder

The video system and data recorder has been described (Davis *et al*., 1999). Briefly, the torpedo-shaped metal housing is 35 cm long, 13 cm in diameter and pressure-rated to a depth of 1000 m (Fig. 1). The low-light-sensitive, monochrome video camera (6 cm long$\times$6 cm in diameter; minimum illumination = 0.05 lux; angle of view = 80° horizontal, 60° vertical) is encircled by an array of near-infrared light-emitting diodes (LEDs). These LEDs enable the camera to record images in complete darkness to a distance of about 1 m or greater distances when additional ambient light is available. The near-infrared light source (λ_{max} = 850 nm) is believed to be invisible to Weddell seals and their prey (Lythgoe and Dartnell, 1970; Lavigne *et al*., 1977; Nelson, 1981). The camera, connected to the main housing by a cable, is mount-

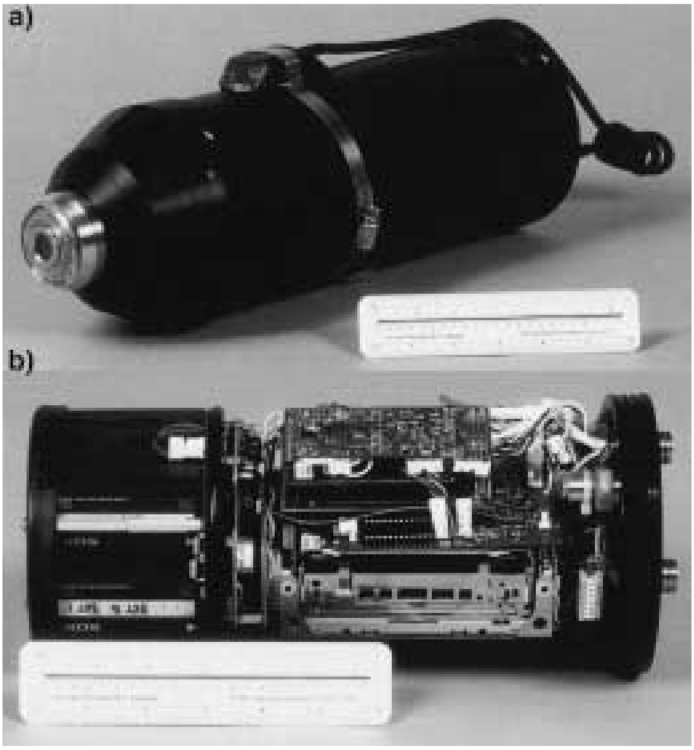

Fig. 1. a) The video and data recorder inside it's pressure-resistant housing; b) Internal structure of the video and data recorder showing the microcomputer, video tape recorder and lithium-ion rechargeable batteries.

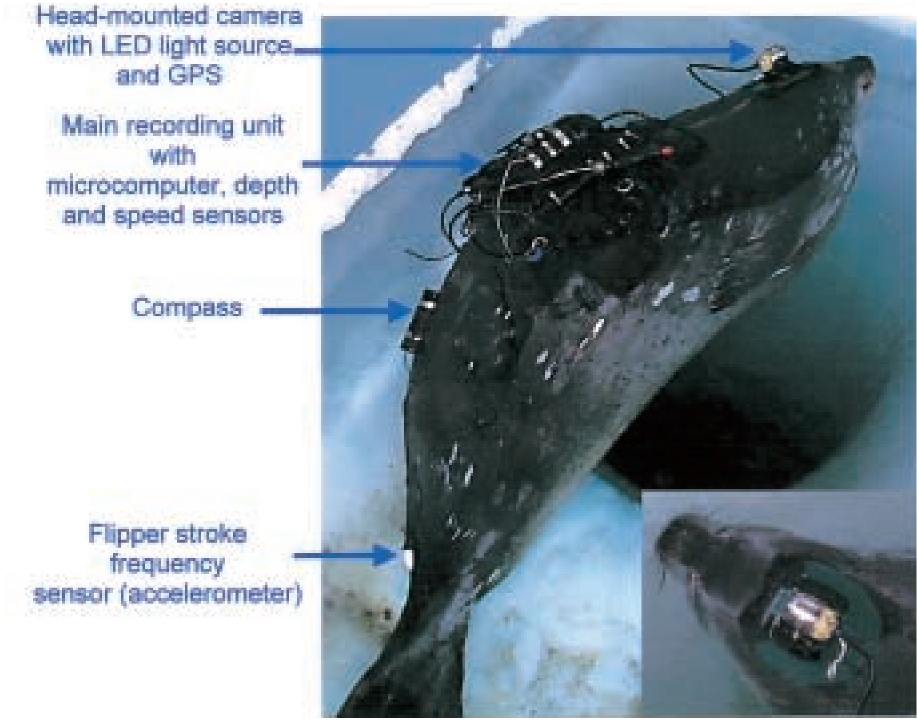

Fig. 2. Attachment of the video and data recorder to a Weddell seal.

ed on top of the seal's head to obtain close-up images of the seal's eyes and muzzle and the area in front of the animal (Fig. 2). The main housing contains an 8-mm video tape recorder (VTR), rechargeable lithium ion batteries, and an on-board microcomputer that controls the VTR and data acquisition from the transducers. The video system is activated by an external switch and records for 6 h. Transducers for pressure, water speed and compass bearing are sampled once per second, and the data stored on a Flash memory card. A separate housing (17 cm long×5.5 cm in diameter, Fig. 2) for the gimbaled flux-gate compass is positioned behind the main housing and connected to it with a cable. Sound is recorded on one audio channel of the VTR with a hydrophone with a frequency response of 50 Hz to 16 kHz. Flipper stroke frequency is determined from the lateral motion of a small accelerometer (6 cm long, 3 cm wide, 2 cm tall, Fig. 2) mounted near the base of the tail. The analog output from the accelerometer is converted into an audio signal that is recorded on the other audio channel of the videotape, or the frequency is sampled 16 times per second and stored along with the other sensor data. GPS location at the beginning and end of dives is necessary to compute the three-dimensional dive paths for free-ranging animals. The integrated GPS and antenna (3×3×1 cm) is mounted next to the camera on the seal's head and connected to the main housing by a thin cable. When the seal surfaces to breathe, the GPS determines geolocation in less than 30 s.

Using the video and data recorder to study the hunting behavior of Weddell seals

The Weddell seal has been a popular species in which to study the behavioral and physiological adaptations of deep diving pinnipeds, primarily because the isolated-ice-hole protocol in McMurdo Sound (Kooyman, 1965) enables recorders to be attached and recovered from freely diving seals. We used this experimental protocol to deploy our video and data recorder on solitary diving seals from 1997–99. This approach gave us the first observations of hunting behavior, predator-prey interactions, three-dimensional movements and estimates of metabolism during foraging and non-foraging dives (Davis *et al.*, 1999). Armed with this new knowledge of Weddell seal behavior and confidence that we could collect and interpret diverse and detailed data about dives, we abandoned the isolated-ice-hole protocol and began working with free-ranging seals in 2001.

During the past six years (1997–2002), we have recorded over 500 h of underwater video and over 1000 three-dimensional dive paths with corresponding swimming performance data from 31 adult Weddell seals. In addition, we have metabolic measurements for

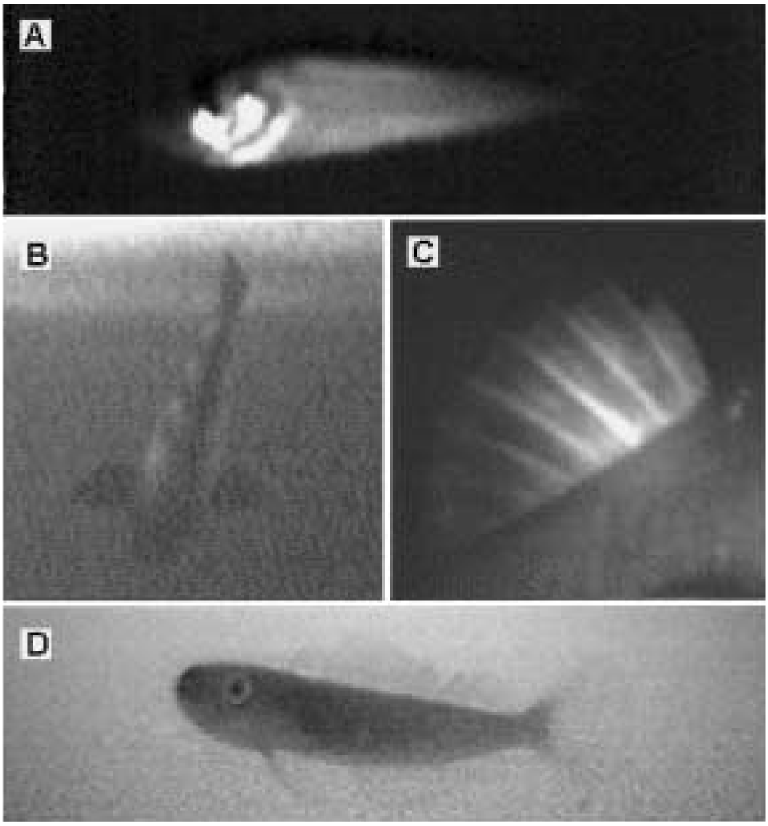

Fig. 3. Fishes observed through a video camera mounted on the head of Weddell seals: a) Antarctic silverfish (*Pleuragramma antarcticum*) at a depth of 220 m; b) Toothfish (*Dissostichus mawsoni*) at a depth of 12 m, note vertical bands on flank; c) dorsal fin of an adult toothfish at a depth of 326 m; d) *Pagothenia borchgrevinki* immediately below the sea ice (from Fuiman *et al.*, 2002).

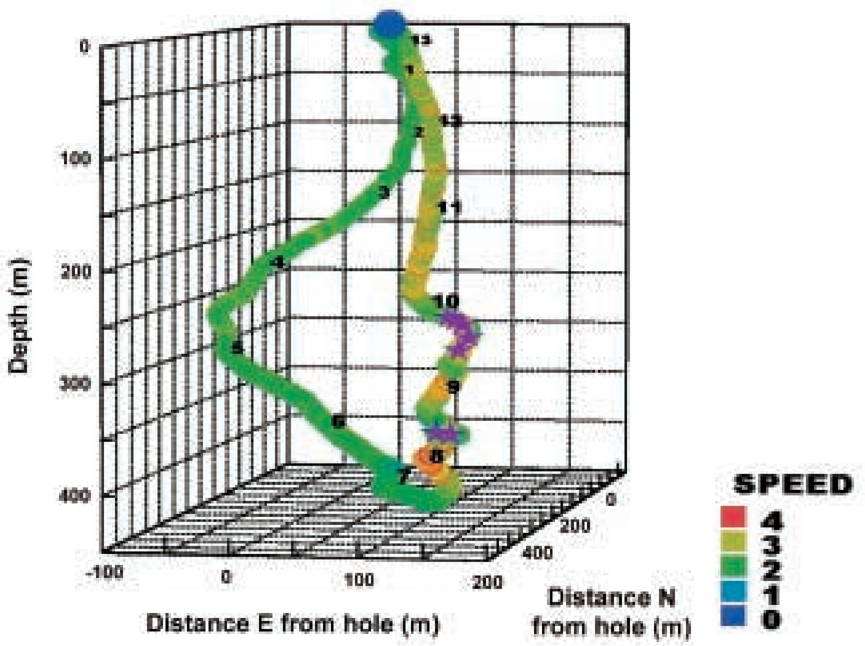

Fig. 4. Three-dimensional path of a 14.8-min dive during which the seal caught Antarctic silverfish (purple stars) while diving from an isolated ice-hole. The seal covered 1842 m and swam to a depth of 401 m. The blue dot marks the breathing hole. Colors along the path signify swim speed. Numbers indicate elapsed time (min).

172 of these dives. We recorded more than 200 vocalizations with corresponding video and position data. We documented seals foraging in the water column, on the sea floor, and at the under-ice surface. Mid-water foraging included encounters with 12 large Antarctic toothfish, *Dissostichus mawsoni*, and over 1000 encounters with smaller (*ca*. 20 cm long) Antarctic silverfish, *Pleuragramma antarcticum*, (Fig. 3). Seals attacked silverfish by ascending from beneath them, possibly using the under-ice surface for backlighting, thereby implicating vision in hunting when ambient light levels are sufficient (Fig. 4). There were many dives to the bottom of McMurdo Sound (100–585 m), where seals explored the benthic community but rarely fed. At the under-ice surface, seals blew air through their nostrils to flush small fish, *Pagothenia borchgrevinki*, from their hiding places in the platelet ice. Multivariate statistical techniques of variables derived from the temporal and spatial characteristics of three-dimensional dive paths have enabled us to classify dive types and, in some cases, assign a function such as foraging.

Our studies also provided new information about the vertical distribution, diel movements, and trends in abundance and swimming behavior of two fish species living below the sea ice (Fuiman *et al*., 2002). Silverfish occurred in loose aggregations (individuals 2–4 m apart) and migrated daily between mean depths of 252 m at night and 346 m by day. Their depth during November was correlated with surface light intensity. Most (89%) silverfish captures by Weddell seals took place between 1500 and 0000 h (local time) when light intensity was waning and silverfish were shallower. Inter-annual variations in local abundance indicated that groups of silverfish did not remain stationary. Large toothfish frequently occurred at shallow depths (12–180 m) and showed a significant change in depth with time of day but not surface light intensity. Toothfish encounters had a mean depth of 93 m, with a nighttime minimum of 17 m, and a daytime maximum of 168 m. When chased by a seal, one toothfish sustained a speed of 3.4 m/s for a period of 24 s with a maximum burst speed of 5.1 m/s. These new insights on fishes in McMurdo Sound were made possible by using their principal predator as a guided, high-speed sampling device, an approach that may be useful for other species that are difficult to study.

Future directions

We are developing a digital video and data recorder that will be smaller and record video and data longer than our current analog system. The new system will consist of a small, titanium housing for the micro-electronics, miniature hard drive, 3-axis gyros, lithium batteries and sensors for pressure, swim speed, compass bearing, ambient temperature, conductivity, ambient dissolved oxygen, light level, bio-luminance, tilt, pitch and roll (Fig. 5a). Digital video and audio are compressed on-the-fly and stored on a mini-hard drive with a recording duration up to 80 h. A second housing contains the miniature black and white video camera with near-infrared light emitting diodes (LED) as a light source (Fig. 5b). The video camera is mounted on the animal's head and connected by a thin cable to the housing containing the micro-electronics. The miniature GPS module with active antenna is mounted on the seal's head adjacent to the video camera. An accelerometer that is mounted near the tail and connected by a cable to the main housing senses flipper motion and is used to determine stroke frequency. This new generation of video and data recorder will be used to study the foraging behavior of free-ranging Weddell seals and other species of marine mammals.

Acknowledgments

This research was supported by grants from the National Science Foundation, Office of

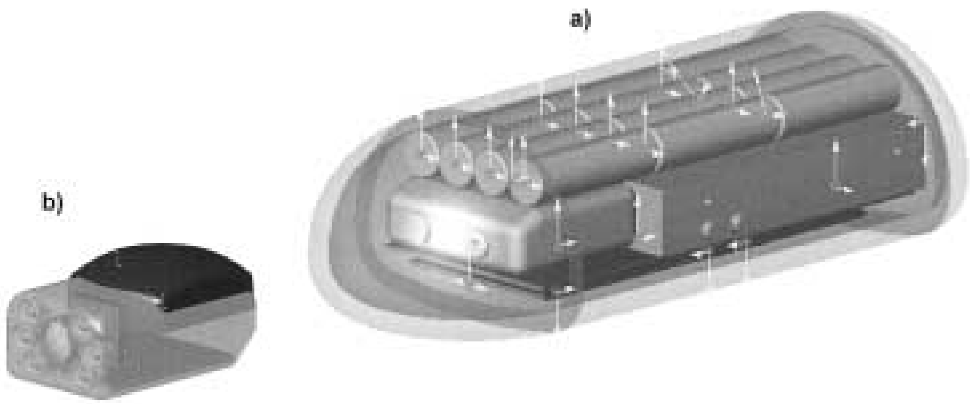

Fig. 5. Digital video and data recorder: a) CCD camera with near-infrared LED light source and GPS (4.5×7.2×4.3 cm); b) Titanium housing containing the micro-controller, miniature hard drive and lithium batteries (21×9×6 cm). The camera is mounted on the animal's head and connected to the housing by a flexible cable.

Polar Programs (OPP-9614857, OPP-9708151, OPP-9618384) and the West Coast Office of the National Undersea Research Program (UAF02-0080). We thank the U.S. Antarctic Program for their logistical support members of our field team, especially S. Kanatous, S. Kohin, R. Skrovan and L. Collier. Special thanks to S. Collier for assistance in the development of video and data recorder, and to M. Davis for analysis of the video tapes.

References

Andrew, R.D. (1998): Remotely releasable instruments for monitoring the foraging behaviour of pinnipeds. Mar. Ecol. Prog. Ser., **17**, 289–294.

Bjørge, A., Thompson, D., Hammond, P., Fedak, M., Bryant, E., Aarefjord, H., Roen, R. and Olsen, M. (1995): Habitat use and diving behaviour of harbour seals in a coastal archipelago in Norway. Whales, Seals, Fish and Man, ed. by A.S. Blix *et al*. Amsterdam, Elsevier, 211–223.

Davis, R.W., Fuiman, L., Williams, T.M., Collier, S., Hagey, W., Kanatous, S.B., Kohin, S. and Horning, M. (1999): Hunting behavior of marine mammal beneath the Antarctic fast-ice. Science, **283**, 993–996.

Dunstone, N. and Gorman, M.L. (1993): Mammals as Predators. Zoological Society of London Symposium 65, Oxford, Clarendon Press, 481 p.

Fuiman, L.A., Davis, R.W. and Williams, T.M. (2002): Behavior of midwater fishes under the Antarctic sea ice: observations by a predator. Mar. Biol., **140**, 815–822.

Harcourt, R.G., Hindell, M.A., Bell, D.G. and Waas, J.R. (2000): Three-dimensional dive profiles of free-ranging Weddell seals. Polar Biol., **23**, 479–487.

Hindell, M.A., Harcourt, R., Waas, J.R. and Thompson, D. (2002): Fine-scale three-dimensional spatial use by diving, lactating female Weddell seals *Leptonychotes weddellii*. Mar. Ecol. Prog. Ser., **242**, 275–284.

Kooyman, G.L. (1965): Techniques used in measuring diving capacities of Weddell seals. Polar Rec., **12**, 391–394.

Kooyman, G.L. (1989): Diverse Divers. Berlin, Springer, 200 p.

Lavigne, D.M., Bernholz, C.D. and Ronald, K. (1977): Functional aspects of pinniped vision. Functional Anatomy of Marine Mammals, ed. by R.J. Harrison. New York, Academic Press, 135–174.

Lesage, V., Hammill, M.O. and Kovacs, K.M. (1999): Functional classification of harbor seal (*Phoca vitulina*) dives using depth profiles, swimming velocity, and an index of foraging success. Can. J. Zool., **77**, 74–87.

Lythgoe, J.N. and Dartnell, H.J.A. (1970): A "deep sea rhodopsin" in a marine mammals. Nature, **227**, 995–996.

Nelson, K.H., ed. (1981): Bioluminescence, Current Perspectives. Minneapolis, Burgess Publ., 165 p.

Plötz, J., Bornemann, H., Knust, R., Schröder, A. and Bester, M. (2001): Foraging behavior of Weddell seals, and its ecological implications. Polar Biol., **24**, 901–909.

Simpkins, M.A., Kelly, B.P. and Wartzok, D. (2001): Three-dimensional diving behaviors of ringed seals (*Phoca hispida*). Mar. Mam. Sci., **17**, 909–925.

Wartzok, D., Elsner, R. Stone, H., Kelly, B.P. and Davis, R. (1992a): Under-ice movements and the sensory basis of hole finding by ringed and Weddell seals. Can. J. Zool., **70**, 1712–1722.

Wartzok, D., Sayegh, S., Stone, H., Barchak, J. and Barnes, W. (1992b): Acoustic tracking system for monitoring under-ice movements of polar seals. J. Acoust. Soc. Am., **92**, 682–687.

Williams, T.M., Davis, R.W., Fuiman, L.A., Francis, J., Le Boeuf, B.J., Horning, M., Calambokidis, J. and Croll, D.A. (2000). Sink or swim: strategies for cost-efficient diving by marine mammals. Science, **288**, 133–136.