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Insights into the Foraging Behavior of Magellanic Penguins (*Spheniscus magellanicus*)

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Abstract.—Between 25-30 November 2013, 2014 and 2015, miniaturized video cameras were attached to Magellanic Penguins (*Spheniscus magellanicus*; *n* = 14) in Punta Norte/San Lorenzo, Península Valdés, Chubut, Argentina. The objective was to examine prey selection, consumption of untraceable prey, and inter- and intra-specific interactions. During 56.3 hr of video footage, 1,621 dives from 14 individuals were recorded. Magellanic Penguins swam through shoals of lobster krill (*Munida gregaria* morph *subrugosa*), selectively consuming the fish, primarily anchovies (*Engraulis anchoita*), that were dispersed along the shoal, but did not consume the lobster krill. Magellanic Penguins captured fish on dives of less than 2 m in depth. The tagged individuals foraged with conspecifics in 2% (*n* = 33) of the total recorded dives. In addition, a multispecies feeding association was also documented (*n* = 1). Results were constrained to the upper 40 m of the water column; below this depth light level was too low for detections by video. The development of cameras with a light source and wider-angle lens are crucial to improve our understanding of Magellanic Penguin foraging behavior. *Received 19 January 2018, accepted 15 May 2018.*

Key words.—diving seabird, foraging behavior, Magellanic Penguin, Patagonia, *Spheniscus magellanicus*, video camera.

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During the last 30 years, the development of electronic devices that can be attached to wild marine animals has contributed to our understanding of their spatial ecology and behavior (Wilson *et al.* 2007). Tags that record multiple parameters simultaneously have been developed to provide information about movement, energy expenditure and some characteristics of the environment where animals move (Wilson *et al.* 2008). Attempts at recording food intake events have also been made by the use of devices that measure stomach and/or esophagus temperature or beak-opening angles (Ancel *et al.* 1997; Wilson *et al.* 2002). However, the use of indirect parameters has only been calibrated under captive conditions (Ancel *et al.* 1997; Kuhn and Costa 2006; Suzuki *et al.* 2009), which increases the false alarm rate (i.e., when signals detect a capture but no capture occurred) (Watanabe and Takahashi 2013).

Video cameras offer the opportunity to observe what a wild animal sees in the field (Moll *et al.* 2007; Rutz *et al.* 2007). In addition, when attached simultaneously to other electronic devices such as accelerometers and time depth recorders, cameras allow the ground truthing of electronic signal data sets (Watanabe and Takahashi 2013; Carroll *et al.* 2014).

The Magellanic Penguin (*Spheniscus magellanicus*) is an important mesopredator of the southern oceans (Brooke 2004). Using *wiggles* (otherwise known as *undulations* in the literature) to estimate prey consumption, Sala *et al.* (2012) determined that the Argentinean breeding population might consume 1.5 million metric tons of food per year of the principal Magellanic Penguin prey species, anchovy (*Engraulis anchoita*); that amount is more than 87% the mean commercial catch per year as assessed during 2000-2010 (Food and Agriculture Organization of the United Nations 2012).

The objective of this study was to document the foraging behavior of wild Magellanic Penguins through the attachment of animal-borne video cameras. Our objective focused on: 1) capture events in which the penguins did not perform an undulation; 2) prey selectivity; and 3) the interaction with inter- and intra-specifics.

METHODS

Study Site

Fieldwork was conducted at the Punta Norte/San Lorenzo (42° 04′ 59.09″ S, 63° 51′ 56.34″ W) Magellanic Penguin colony during early chick-rearing between 25-30 November 2013, 2014 and 2015. This colony is located on Península Valdés, Chubut, Argentina.

Bird Instrumentation

A total of 14 Magellanic Penguins that were brooding at least one chick less than 1 week old were instrumented. During 2013 and 2014, four Magellanic Penguins (two each year) were equipped with a POV MAC10 Mini waterproof action camera designed to be waterproof at < 10 m (65 mm in length, 15 mm in diameter, 20.5 g, 736 x 480 pixels, 25 frames per second, 1 hr battery life). As Magellanic Penguins dive deeper than 10 m, the camera was protected in an underwater custom housing (8 cm in length and 2.5 cm in diameter) (Nautilus Tail). The camera plus the housing weighed 49.8 g, which is less than 1.2% of the mean weight of an adult Magellanic Penguin (mean = 4.4 kg; Williams 1995). The cameras were programmed to record on a duty cycle of 5 min every 10 min. During 2015, nine individuals were equipped with a Digital Video Logger DVL400M065 (Little Leonardo Corporation; 61 mm in length, 21 mm in width, 15 mm in height, 29 g, 1,280 x 960 pixels, 30 frames per second, 6 hr battery life). In addition, during 2015 one Magellanic Penguin was equipped with a Digital Video Logger DVL200-I-15004 (Little Leonardo Corporation, 50 mm in length, 20 cm in width, 11 mm in height, 15 g, 1,280 x 960 pixels, 30 frames per second, 4-hr battery life). During 2015, all cameras were programmed to record in continuous mode. All cameras were programmed to start recording in the morning of the day after instrumentation (i.e., generally 12 hr after deployment) since Magellanic Penguins begin foraging at dawn (Sala 2013).

Each individual was captured from its nest and equipped with the camera on the upper back. Instruments were attached to the feathers using Tesa tape (Wilson *et al.* 1997). In all cases, the instrumentation procedure was completed in less than 5 min, and individuals were returned to their nest. Each individual foraged for a single trip before the camera was retrieved, and continued to feed chicks normally after being instrumented.

Video Data Analysis

Video footage was viewed using the open-license video analyses software (Kinovea 2006). The descent, bottom and ascent phases within each dive were visually distinguished by looking at the individual body position. The descent phase was defined as the interval from the time the camera was being observed to submerge to the time the individual was observed to stop swimming downward. The ascent phase was defined as the interval from the time the individual was observed to swim upward until the bird reached the sea surface. The bottom phase was defined as the interval from the time the individual finished swimming downward until it started swimming upward. The dive duration was used to calculate the maximum dive depth reached during a dive, following the equation: *Dive duration = -0.0163*Maximum Depth + 2.60 Maximum Depth + 28.30* (Sala *et al.* 2014).

The appearance of potential prey, conspecifics, other seabirds and/or marine mammal species was logged for each recording. When a prey item was captured, it was identified to the lowest possible taxon. As Magellanic Penguins spent a large proportion of their dives at depths where light levels were too low for video to detect prey, our observations were limited to the upper 40 m of the water column. Values are reported as mean ± SE except where noted.

RESULTS

Presence of Potential Prey and Prey Capture

A total of 55.2 hr of footage were recorded from 14 Magellanic Penguins (3.9 ± 2.3 hr per individual). During the recorded period, Magellanic Penguins performed 1,621 dives. In 11% of dives (n = 184), Magellanic Penguins captured alevin and adult fish (n = 540), ctenophores (*Mnemiopsis leidyi*) (n = 3) and jellyfish (*Chrysoara plocamia*) (n = 2) on the ascent phase. In addition, a total of 256 fish, mainly anchovy, were captured on 111 dives (7%) performed to less than 2 m depth (Fig. 1A).

In 14% of recorded dives (n = 227), Magellanic Penguins swam through shoals of lobster krill (*Munida gregaria* morph *subrugosa*). Although they swam close to the lobster krill, and on some occasions almost touched them, only one was captured. In 52 (23%) of the dives where Magellanic Penguins encountered lobster krill, they selectively pursued and captured the fish that were dispersed within the shoal (Fig. 1B).

Presence of Conspecifics or Other Species

In 2% (n = 35) of the total recorded dives, Magellanic Penguins were observed to associate with conspecifics. In 24 of these dives, between one and four individuals were observed swimming with the tagged individual. In the remaining 11 dives, the

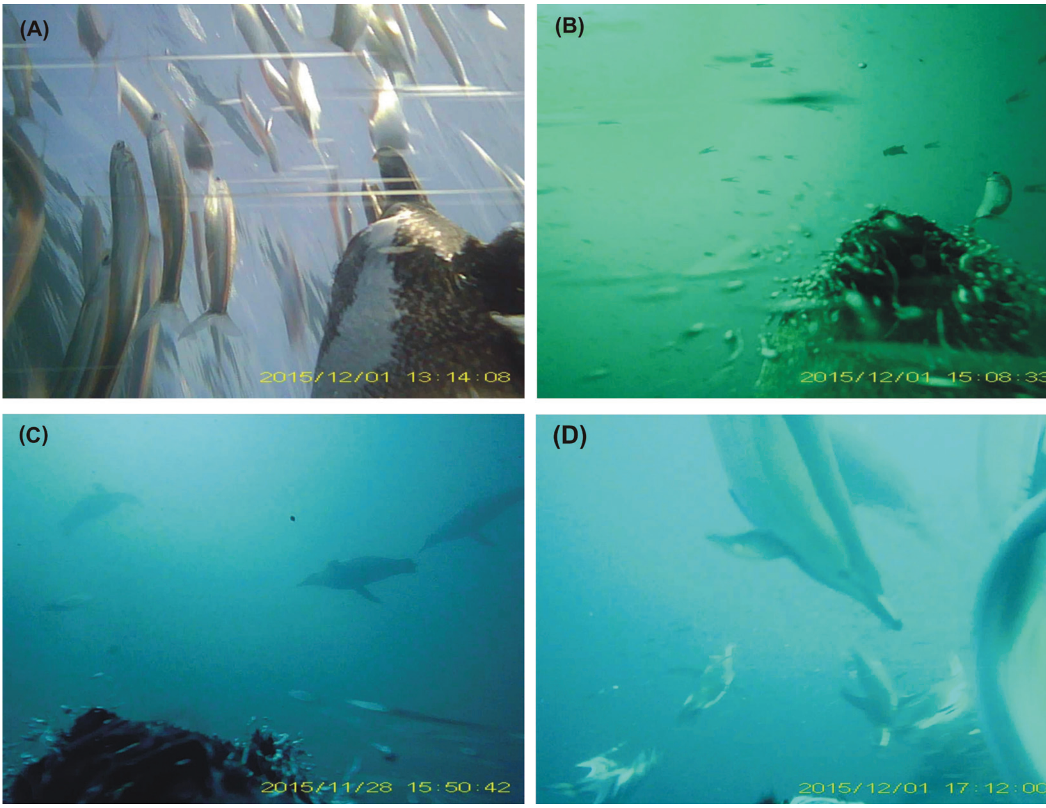

Figure 1. Still frames obtained from video loggers mounted on the backs of Magellanic Penguins (*Spheniscus magellanicus*). Image (A) shows a penguin capturing fish close to the sea surface, (B) shows a penguin pursuing a fish through a shoal of lobster krill, (C) shows three penguins swimming in front of the instrumented bird and (D) shows a feeding flock preying on a shoal of anchovy (*Engraulis anchoita*).

instrumented individual and conspecifics (between one and six individuals) preyed upon the same anchovy shoal (Fig. 1C). In all cases, the group approached the shoal from below, increasing speed as they got closer. Once in the shoal, they moved quickly to capture anchovies, making quick ascents to the surface to inhale and then diving back rapidly to the anchovy shoal. On one occasion, the tagged individual was observed to follow an anchovy shoal for approximately 10 min.

Multispecies feeding associations preying on anchovy shoals were detected on only one occasion. On this occasion, approximately six short-beaked common dolphins (*Delphinus delphis*), five Magellanic Penguins and one Great Shearwater (*Ardenna gravis*) participated in a foraging bout (Fig. 1D).

DISCUSSION

Studies on penguin diving behavior have traditionally used undulations during the bottom phase of dives that exceeded 1.5 or 2.0 m depth as an indicator of prey pursuit and consumption (Simeone and Wilson 2003; Zimmer *et al.* 2010; Sala *et al.* 2012). Here, the captures observed during the ascent phase of dives and on shallow dives (less than 2 m depth) indicated that Magellanic Penguins consumed plenty of prey without evidence of undulations in the dive profile. These prey consumption events would be difficult to detect even using indirect parameters such those obtained by the employment of beak opening, stomach or esophageal temperature sensors. These methodologies do not work well when animals consume multiple, small prey items

(Wilson *et al.* 1995; Ropert-Coudert and Kato 2006), which is exactly what Magellanic Penguins were observed to do on shallow dives. Thus, our results indicate that animal-borne video cameras are a useful technology to tackle these limitations, particularly if used in conjunction with tri-axial acceleration sensors placed on the head and body (Watanabe and Takahashi 2013; Carroll *et al.* 2014).

Even though Magellanic Penguins frequently encountered large agglomerations of potential prey (i.e., lobster krill), they almost never consumed it. As it has been suggested by Scioscia *et al.* (2014), this preference for anchovy over lobster krill may be associated with the lower energetic value (15.9 kJ g^{-1} vs 22.2 kJ g^{-1} dry weight; J. E. Ciancio, pers. commun.) and digestibility of the latter (Thompson 1993).

Video cameras had already revealed the occasional consumption of soft-bodied organisms such as jellyfish and ctenophores by the Adélie Penguin (*Pygoscelis adeliae*), Yellow-Eyed Penguin (*Megadyptes antipodes*) and Little Penguin (*Eudyptula minor*) (Thiebot *et al.* 2017). Jellyfish are important components of the southern ocean ecosystems, but the actual importance to penguins remains unknown and, given their very low food value, is likely minimal. Only video data would allow researchers to determine the frequency with which they are consumed, how they are captured and what tissues of these gelatinous animals are principally ingested (Thiebot *et al.* 2016).

Video footage showed that Magellanic Penguins associated in groups while traveling and feeding. This information complements what has been known for a long time from direct observation. Foraging in flocks may increase the probability of prey detection and especially capture (Wilson *et al.* 1987; Berlincourt and Arnould 2014). Multiple-species feeding associations, like the one recorded in our study, would also increase prey capture efficiency since the mix of underwater and aerial predators would be more efficient at disturbing fish schools (Lett *et al.* 2014; Thiebault *et al.* 2016).

Our results are limited to the upper 40 m of the water column and a narrow field of view. Future studies with cameras carrying light-emitting diodes (LEDs) near the infrared region and wider-angle lenses are crucial to have a better comprehension of the foraging behavior of the species on deeper dives and to augment the detection of interactions with other predators and with prey.

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