Aquatic Mammals 2018, *44*(6), 729-735, DOI 10.1578/AM.44.6.2018.729

Short Note

Passive Acoustic Monitoring and Concurrent Theodolite Observations of Indo-Pacific Humpback Dolphins (*Sousa chinensis*) in Hong Kong: A Case Study

Lisa Munger,[1] Sarah Piwetz,[2] Marc O. Lammers,[1] and Bernd Würsig[2]

[1]*Oceanwide Science Institute, PO Box 61692, Honolulu, HI 96768, USA*
E-mail: munger@oceanwidescience.org
[2]*Texas A&M University at Galveston, Department of Marine Biology, 200 Seawolf Parkway, Galveston, TX 77553, USA*

Multiple concurrent approaches are often useful for investigating cetacean occurrence and behavioral patterns. For example, underwater passive acoustic monitoring (PAM) can document spatial and temporal patterns and variability in cetacean vocalizations, while visual observations at the surface can provide information on group size and composition, behavior, and surface movement patterns. Together, both types of data collection can elucidate the behavioral context of sound production, which is important to understand when using acoustic data to characterize habitat use, to inform abundance estimates, and to achieve other monitoring objectives. We compare the results of two observation modalities—(1) PAM using autonomous moored recorders and (2) shore-based theodolite tracking—both of which were conducted concurrently as part of a study of Indo-Pacific humpback dolphins (*Sousa chinensis*) north of Lantau Island, Hong Kong.

In 2013 and 2016, PAM, theodolite tracking, and vessel-based surveys were conducted to study Indo-Pacific humpback dolphins (hereafter "dolphins") as part of a broader Environmental Impact Assessment (EIA) for large coastal development projects off Hong Kong (Hung, 2014, 2017; Jefferson, 2018, this issue). The goals of these efforts were to characterize dolphin occurrence and habitat use; to observe fine-scale movements, behavior, and potential response to vessels and other human activities; and to document potential changes over time in local abundance and distribution. Data were collected north of Lantau Island at two locations selected as potential land reclamation and development sites, and results from one of the locations, Lung Kwu Tan (LKT) (Figure 1), are presented herein as a case study to compare the findings of PAM and shore-based theodolite tracking.

Three Ecological Acoustic Recorders (EARs), a type of autonomous PAM instrument (Lammers et al., 2008), were deployed in the LKT study area on seafloor moorings at depths of < 10 m. The EARs were spaced approximately 1 km apart and deployed within 1.5 km of the shore-based theodolite station. The EARs were programmed to record for 1 min every 5 min (20% duty cycle) and sample at 64 kHz for an effective recording bandwidth of 20 Hz to 32 kHz. This frequency band encompasses most of the energy from Indo-Pacific humpback dolphin whistles and the low end of clicks (Sims et al., 2012; Wang et al., 2013). Acoustic data were analyzed by researchers who searched all recordings for the presence of dolphin signals upon retrieval of EAR disk drives (Munger et al., 2016). No other small cetacean species are known to occur in the study area. The only other regularly occurring cetacean species in Hong Kong waters is the finless porpoise

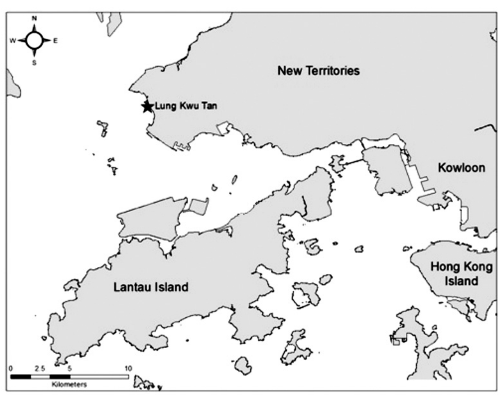

Figure 1. Map of waters to the west and south of Hong Kong. Lung Kwu Tan, the monitoring site discussed herein, is represented by a black star.

(*Neophocaena phocaenoides*), which occurs south of Lantau Island and produces acoustic signals above the recording frequency of the EARs (Goold & Jefferson, 2002; Jefferson et al., 2002).

Shore-based tracking effort was conducted during daylight hours on approximately 6 d/mo. Observers searched for dolphins using unaided eyes and handheld 7×50 binoculars. Theodolite tracking sessions were initiated when an individual dolphin or group of dolphins was located. When possible, an identifiable individual was selected within the group. The focal individual's position and behavioral state were recorded when the dolphin surfaced (Table 1). If an individual could not be reliably distinguished from other group members, the group was tracked by recording positions based on a central point within the group (Bejder, 2005). Tracking sessions continued until animals were lost from view, either because they moved beyond visible range or due to environmental conditions such as haze, sunset, or Beaufort sea state. Visibility was estimated using categorical descriptions: 1 (excellent), 2 (good), 3 (fair), 4 (poor), and 5 (no useful visibility).

In 2013, theodolite effort was conducted from LKT on 20 d that coincided with EAR monitoring. During this period, dolphins were detected by at least one method on 15 d, and they were detected both visually and acoustically on 5 d (Figure 2). Concurrent detections, defined as

Table 1. Indo-Pacific humpback dolphin (*Sousa chinensis*) behavioral activity state descriptions, modified from Karczmarski & Cockcroft (1999)

Behavioral state	Description
Foraging	Asynchronous diving in varying directions in one location; may observe dolphins visibly pursuing or capturing fish.
Milling	Individuals simultaneously moving in different directions; no overall clear direction of travel.
Resting	Low level of activity; dolphins close to surface of water and each other. At times apparently floating stationary and motionless at surface, with occasional slow forward movement.
Socializing	Vigorous activities; includes chasing, leaping out of water, high speed movement with frequent direction changes, and prolonged body contact with other dolphins.
Traveling	All animals oriented and moving in the same direction with group members diving and surfacing synchronously; includes higher speed forward movement.

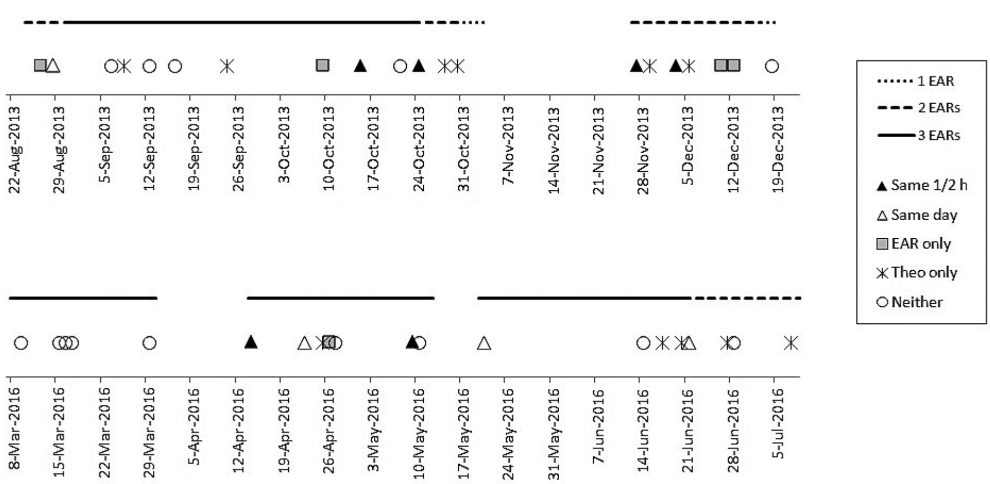

Figure 2. Timeline showing EAR recording effort (lines) and days with shore-based theodolite effort (symbols) in 2013 (*top*) and 2016 (*bottom*) at LKT. Symbols represent method(s) of detection: filled triangles indicate concurrent detections by EAR and theodolite within same ½ h, open triangles indicate detections by both methods within the same day, gray squares indicate an acoustic EAR detection only (excluding those outside of theodolite monitoring hours), asterisks indicate a visual theodolite detection only, and open circles indicate no detections by either means on that day of effort.

visual and acoustic detections within 30 min, took place on 4 of the 5 d and comprised 13 dolphin groups that were observed from shore and co-occurred with acoustic detections on one or more EARs (Table 2; Figure 3). Most of these dolphin groups (10 of 13) were initially observed within 1 km of EARs, although acoustic detection was not always on the nearest EAR (Figure 3). On 6 d, dolphins were observed from shore with no corresponding acoustic detection during theodolite effort hours. Conversely, dolphins were detected in EAR recordings on 4 d with no corresponding visual observation. No dolphins were detected using either method on 5 d.

The most frequently observed behaviors at LKT during theodolite tracking in 2013 were milling and traveling, which were observed on 9 of 11 d with visual detections (Table 2). During concurrent acoustic and visual detections, milling was the most commonly recorded behavior (5 h on 2 d), followed by traveling (4 h on 2 d) and foraging (2 h on 2 d) (Table 2). More than one behavior may have been recorded during visual observation of dolphin groups. Beaufort sea state ranged from 1 to 3, and visibility ranged from 1.5 to 4 (Table 2). Clicks were the only type of dolphin acoustic signal detected during concurrent PAM and theodolite effort in 2013.

In 2016, theodolite tracking effort was conducted from LKT on 20 d that coincided with EAR monitoring. During this period, dolphins were detected by at least one method on 11 d, and they were detected both visually and acoustically on 5 d (Figure 2). Concurrent detections were recorded on 2 of the 5 d and comprised one dolphin group on each day that was visually

Table 2. Detections by hour (local time) on days with both EAR and theodolite effort (Theo) at LKT in 2013. Numbers in parentheses after Theo indicate Beaufort sea state and visibility, respectively (or range in values if they changed during the day). For EAR detections, C = clicks, W = whistles, and subscripts indicate the EAR(s) that detected the signal (e.g., EAR 1, 2, and/or 3; see Figure 3). For theodolite detections, letters denote behavioral state: U = unknown, T = traveling, M = milling, and F = foraging.

Y 2013	Hour:	08	09	10	11	12	13	14	15
26 Aug	EAR		C_3						
	Theo (2, 2)								
28 Aug	EAR			C_3			C_3		
	Theo (2, 1.5)	M	T						
8 Sept	EAR								
	Theo (1, 2)				MT	M			
24 Sept	EAR								
	Theo (3, 1.5)							U	
9 Oct	EAR	C_3						C_2	
	Theo (2, 2-3)								
15 Oct	EAR	C_3	C_3						
	Theo (2, 2)		FT	FM	T				
24 Oct	EAR		C_3				$C_{2,3}$	$C_{1,2,3}$	$C_{1,3}$
	Theo (2, 2)		T			M	M	M	
28 Oct	EAR								
	Theo (1-2, 2)		T	U	MU		T		
30 Oct	EAR								
	Theo (1, 1.5)		TU	MT	MU				
27 Nov	EAR			C_1					
	Theo (2, 2.5)		F	F					
29 Nov	EAR								
	Theo (2-3, 1.5)				F	FM	FT	FM	
3 Dec	EAR		C_1	C_1	C_1				
	Theo (2, 1.5-2.5)	MT	MT	M	MT	M			
5 Dec	EAR								
	Theo (2, 2)		FM	MT	MT				
10 Dec	EAR	C_1	C_1						
	Theo (2, 4)								
12 Dec	EAR		C_1	C_1	$C_{1,2}$		C_1	$C_{1,2}$	
	Theo (2, 3.5-4)								

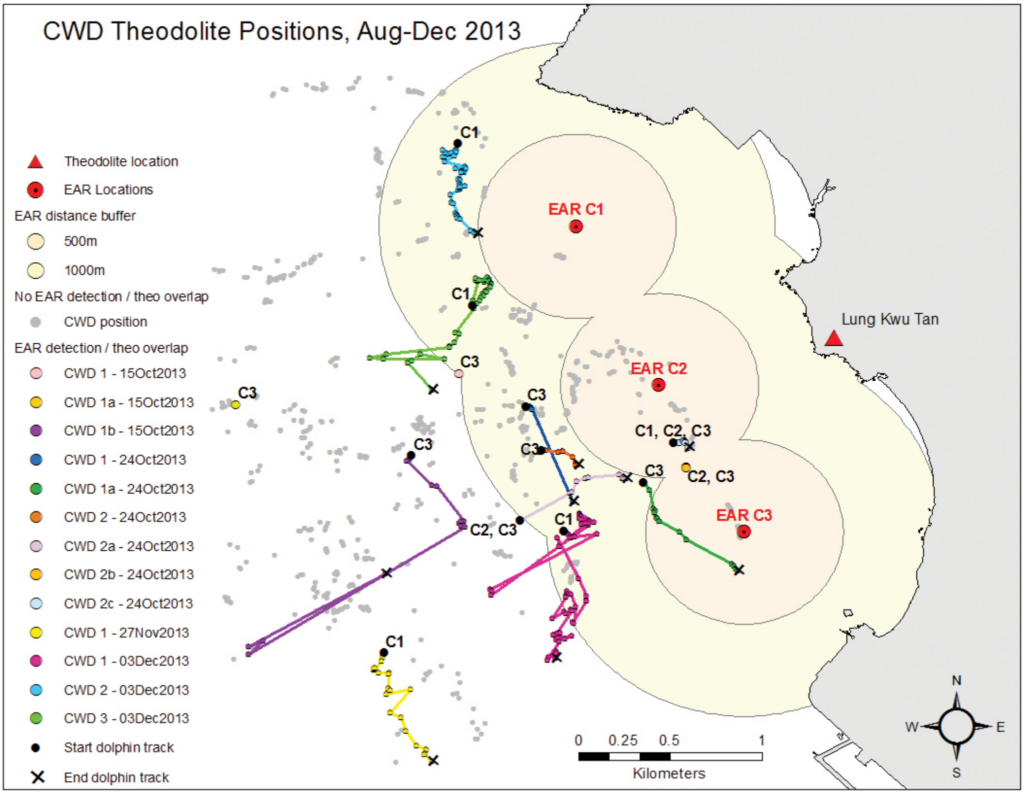

Figure 3. Dolphin positions recorded via theodolite on days with EAR recording effort in 2013. Colored tracks indicate dolphin positions recorded within 30 min of acoustic detection on EAR(s). Label at start of position track indicates the EAR unit(s) that recorded dolphin detections. Gray circles indicate dolphin positions (tracks omitted) with no concurrent acoustic detection. Peach and light yellow filled areas around EARs indicate respective 500 and 1,000 m distance buffers for reference. CWD = Chinese white dolphin, a locally used common name for *S. chinensis*.

observed within 30 min of acoustic detection on one or more EARs (Table 3; Figure 4). Each dolphin group was initially observed within 100 to 200 m of an EAR (Figure 4). On 5 d, dolphins were observed from shore with no acoustic detections during theodolite effort hours; and on 1 d, dolphins were detected acoustically but not visually. On a total of 9 d, no dolphins were observed via either method.

Traveling was the most frequently observed behavior in 2016 and was noted on 8 of the 10 d with visual detections; foraging was observed on 3 d, and socializing was observed on 2 d. Traveling was visually observed during the two concurrent dolphin acoustic detections on EARs (Table 3). On 1 d, dolphin clicks were recorded in the hour following a visual observation of socializing, but these detections were not considered concurrent because more than 30 min had elapsed. Clicks comprised most of the acoustic signals that were detected in EAR recordings, although a dolphin whistle was detected on 1 d with no concurrent visual detections. Beaufort sea state ranged from 2 to 3, and visibility ranged from 1 to 4 during visual observations in 2016 (Table 3).

In total, dolphins were detected by at least one method on 26 of 40 d (65%) with concurrent monitoring (Figure 2). Detections were solely visual on 11 d (42% of days with detections) and solely acoustic on 5 d (19%). Several factors could have influenced the probability of detection by either method—for example, dolphin sound production varies depending on factors such as group size and behavior (Van Parijs & Corkeron, 2001). When visual sightings were not accompanied by acoustic detections, dolphins may have been vocalizing very little or not at all. The frequent observations of traveling at LKT and relatively low number of concurrent or same-day acoustic detections suggests that these dolphins may vocalize less while traveling compared to other behaviors (Tables 2 & 3).

Table 3. Detections by hour (local time) on days with both EAR and theodolite effort (Theo) at LKT in 2016. Numbers in parentheses after Theo indicate Beaufort sea state and visibility, respectively (or range in values if they changed during the day). For EAR detections, C = clicks, W = whistles, and subscripts indicate the EAR(s) that detected the signal (e.g., EAR 1, 2, and/or 3; see Figure 4). For theodolite detections, letters denote behavioral state: U = unknown, S = socializing, T = traveling, M = milling, and F = foraging.

Y 2016	Hour:	08	09	10	11	12	13	14	15
14 April	EAR		C_3	$C_{2,3}$	$C_{2,3}$	C_2	C_2		
	Theo (2-3, 3-4)			T					
22 April	EAR								C_3
	Theo (2, 2)			U					
25 April	EAR								
	Theo (2, 2)				ST	T			
26 April	EAR							W_2	
	Theo (3, 2)								
9 May	EAR					C_1	C_2		
	Theo (3, 1)		FT	FT		T	T		
20 May	EAR				C_1				
	Theo (3, 3)							T	
17 June	EAR								
	Theo (2-3, 2-3)	F	F	F					
20 June	EAR								
	Theo (2, 1)	U	T	T					
21 June	EAR					C_1			
	Theo (2, 1)			T	ST				
27 June	EAR								
	Theo (2, 1)		T						
7 July	EAR								
	Theo (2, 2)			FT	T	T			

Distance of animals to the receiver also contributed to their detectability. Most of the theodolite-tracked groups with concurrent acoustic detections were observed within 1 km of the EARs, with a few exceptions (Figures 3 & 4), suggesting that the acoustic detection range on EARs did not usually exceed 1 km. This is consistent with results from the detailed analyses of year-round PAM at LKT and other nearby sites by Munger et al. (2016), who suggested that the variation in dolphin detection rates among EARs may indicate that the acoustic detection range was usually less than the distance between EARs. However, acoustic signals detected on EARs may have been produced by dolphin(s) other than the groups being tracked from shore. Acoustic detection range varies depending on environmental conditions and ambient noise levels and is affected by vessel traffic, industrial activities, weather, and ocean conditions. When dolphins were detected acoustically but not visually, the acoustic detection range may have exceeded the visual line of sight. Factors that could have reduced the visual detectability of animals include sea surface conditions, the number of dolphins in a group, and/or their behavioral state.

This case study of visually and acoustically detecting and tracking Indo-Pacific humpback dolphins in Hong Kong highlights the complementary nature of multiple sampling methods. For the purposes of the EIA, theodolite tracking was used to observe fine-scale movement patterns and collect behavioral data on individual dolphins and groups, and to provide simultaneous data on potential sources of disturbance such as boats and construction activity (e.g., Bejder & Samuels, 2003; Piwetz et al., 2012, 2018 [this issue]). Passive acoustic monitoring was useful for characterizing dolphin occurrence when visual surveys could not operate and over longer, near-continuous time scales. For example, detection rates of dolphin clicks were significantly greater at night than during the day, which may indicate that dolphins typically forage and echolocate more actively in these areas at night (Munger et al., 2016). Year-round PAM also allowed for documentation of seasonal patterns, with greater acoustic detection rates in summer through autumn than in the spring (Munger et al., 2016).

When conducted concurrently, PAM and shore-based theodolite tracking have the potential to provide detailed information about dolphin vocalizations in association with behavior,

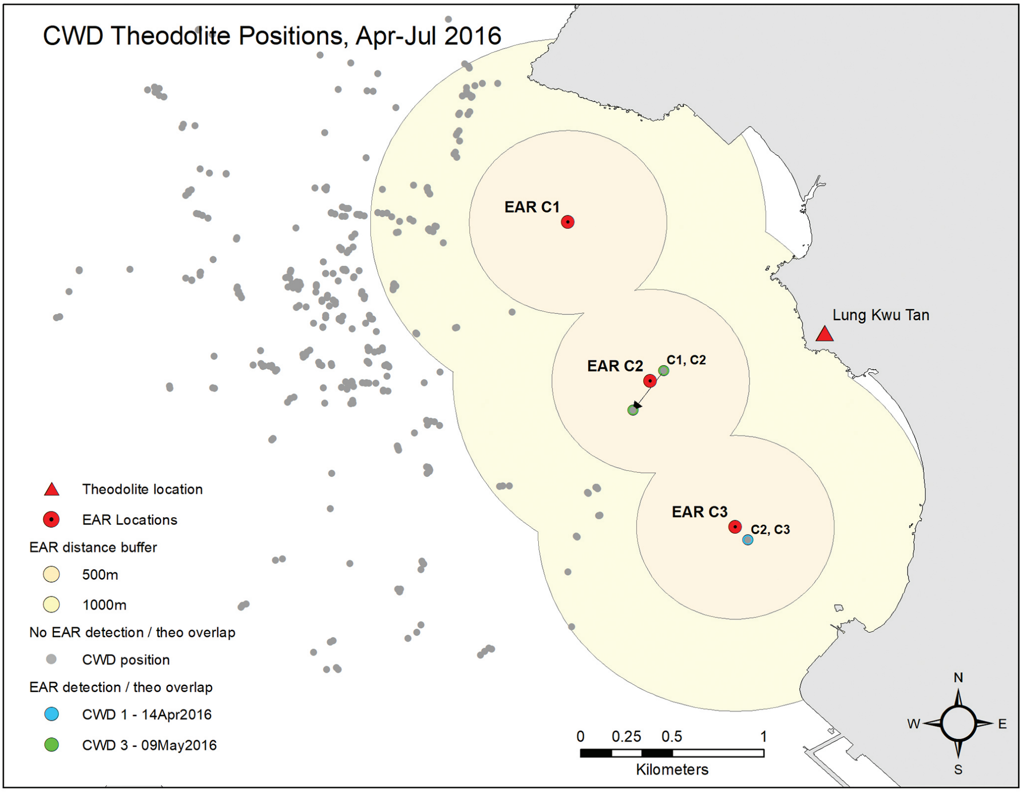

Figure 4. Dolphin positions recorded via theodolite on days with EAR recording effort in 2016. Colored symbols indicate dolphin positions recorded within 30 min of acoustic detection on EAR(s). Label at start of position track indicates the EAR unit(s) that recorded dolphin detections. Gray circles indicate dolphin positions (tracks omitted) with no concurrent acoustic detection. Peach and light yellow filled areas around EARs indicate respective 500 and 1,000 m distance buffers for reference. CWD = Chinese white dolphin, a locally used common name for *S. chinensis*.

group sizes, movement, response to disturbance, and other observable variables. However, associating acoustic data with theodolite-tracked dolphin groups was not an explicit goal of the initial study design. As such, the amount of concurrent PAM and theodolite data collection was limited by sampling schedules (e.g., duty cycle of EARs and shore-based effort days), and localization of dolphin sound sources was not within the scope of this project. Nonetheless, 15 groups of dolphins were tracked visually within 30 min of acoustic recordings, and the comparison of these data suggests links between behavior, sound production, and habitat use that warrant further investigation. In addition, detections made by one method but not the other are a reminder that the absence of detections by a particular method does not necessarily indicate the absence of animals.

With additional data and analyses, acoustic signals could be definitively associated with theodolite-tracked dolphin groups, thereby enhancing our understanding of the behavioral context and acoustic characteristics of these dolphins' calls. Such information would improve our ability to characterize dolphin habitat use and, with suitable spatial sampling, estimate abundance from autonomous PAM recorders, which can be a cost-effective and non-invasive means for long-term monitoring of dolphin population trends in a given area. Visual observation techniques, however, are irreplaceable for identifying and observing animals, ground-truthing acoustic data, and providing detailed information on other surface events and conditions. One of the main advantages to both of these methods is their lack of disturbance to animals, in contrast to vessel-based methods, which can cause animals to alter their behavior. Together, the two approaches described in this case study provide a more holistic understanding of the behavior, movement, habitat use, and potential response to disturbance, at the surface and below, for these Indo-Pacific humpback dolphins.

Acknowledgments

We thank Ove Arup & Partners Hong Kong Limited and the Hong Kong Civil Engineering and Development Department for access to data collected under contract. We also thank Mott McDonald, Inc. and Oceanway Corporation, Ltd. of Hong Kong for assistance with data collection, staff members at Oceanwide Science Institute for their assistance with the analysis of EAR data, and Thomas A. Jefferson for valuable project input.

Literature Cited

Bejder, L. (2005). *Linking short and long-term effects of nature-based tourism on cetaceans* (Doctoral dissertation). Dalhousie University, Halifax, Nova Scotia.

Bejder, L., & Samuels, A. (2003). Evaluating the effects of nature-based tourism on cetaceans. In N. Gales, M. Hindell, & R. Kirkwood (Eds.), *Marine mammals: Fisheries, tourism and management issues* (pp. 229-256). Collingwood, UK: CSIRO Publishing.

Goold, J. C., & Jefferson, T. A. (2002). Acoustic signals from free-ranging finless porpoises (*Neophocaena phocaenoides*) in the waters around Hong Kong. *Raffles Bulletin of Zoology*, *Supplement 10*, 131-139.

Hung, S. (2014). *Monitoring of marine mammals in Hong Kong waters (2013-14)* (AFCD/SQ/183/12). Retrieved from https://www.afcd.gov.hk/english/conservation/con_mar/con_mar_chi/con_mar_chi_chi/files/FinalReport2013_14pp1_98.pdf

Hung, S. (2017). *Monitoring of marine mammals in Hong Kong waters (2016-17)* (AFCD/SQ/156/15). Retrieved from https://www.afcd.gov.hk/english/conservation/con_mar/con_mar_chi/con_mar_chi_chi/files/Final_Report_2016_17.pdf

Jefferson, T. A. (2018). Hong Kong's Indo-Pacific humpback dolphins (*Sousa chinensis*): Assessing past and future anthropogenic impacts and working toward sustainability. *Aquatic Mammals*, *44*(6), 711-728. https://doi.org/10.1578/AM.44.6.2018.711

Jefferson, T. A., Hung, S. K., Law, L., Torey, M., & Tregenza, N. (2002). Distribution and abundance of finless porpoises in Hong Kong and adjacent waters of China. *Raffles Bulletin of Zoology*, *Supplement 10*, 43-55.

Karczmarski, L., & Cockcroft, V. G. (1999). Daylight behaviour of humpback dolphins *Sousa chinensis* in Algoa Bay, South Africa. *Zeitschrift für Säugetierkunde*, *64*, 19-29.

Lammers, M. O., Brainard, R. E., Au, W. W. L., Mooney, T., & Wong, K. B. (2008). An ecological acoustic recorder (EAR) for long-term monitoring of biological and anthropogenic sounds on coral reefs and other marine habitats. *The Journal of the Acoustical Society of America*, *123*(3), 1720-1728. https://doi.org/10.1121/1.2836780

Munger, L., Lammers, M. O., Cifuentes, M., Würsig, B., Jefferson, T. A., & Hung, S. K. (2016). Indo-Pacific humpback dolphin occurrence north of Lantau Island, Hong Kong, based on year-round passive acoustic monitoring. *The Journal of the Acoustical Society of America*, *140*(4), 2754-2765. https://doi.org/10.1121/1.4963874

Piwetz, S., Hung, S., Wang, J., Lundquist, D., & Würsig, B. (2012). Influence of vessel traffic on movements of Indo-Pacific humpback dolphins (*Sousa chinensis*) off Lantau Island, Hong Kong. *Aquatic Mammals*, *38*(3), 325-331. https://doi.org/10.1578/AM.38.3.2012.325

Piwetz, S., Gailey, G., Munger, L., Lammers, M. O., Jefferson, T. A., & Würsig, B. (2018). Theodolite tracking in marine mammal research: From Roger Payne to the present. *Aquatic Mammals*, *44*(6), 683-693. https://doi.org/10.1578/AM.44.6.2018.683

Sims, P., Vaughn, R., Hung, S., & Würsig, B. (2012). Sounds of Indo-Pacific humpback dolphins (*Sousa chinensis*) in West Hong Kong: A preliminary description. *The Journal of the Acoustical Society of America*, *131*(1), 48-53. https://doi.org/10.1121/1.3663281

Van Parijs, S. M., & Corkeron, P. J. (2001). Vocalizations and behaviour of Pacific humpback dolphins *Sousa chinensis*. *Ethology*, *107*, 701-716. https://doi.org/10.1046/j.1439-0310.2001.00714.x

Wang, Z., Fang, L., Shi, W., Wang, K., & Wang, D. (2013). Whistle characteristics of free-ranging Indo-Pacific humpback dolphins (*Sousa chinensis*) in Sanniang Bay, China. *The Journal of the Acoustical Society of America*, *133*(4), 2479-2489. https://doi.org/10.1121/1.4794390