Cetacean monitoring methods: using Irrawaddy dolphins to compare land-based surveys and acoustic sampling in Kep, Cambodia

3 authors, including:

Rika Chan
Liger Leadership Academy

Sarah Eleanor Tubbs
Marine Conservation Cambodia

Cetacean monitoring methods: using Irrawaddy dolphins to compare land-based surveys and acoustic sampling in Kep, Cambodia

CHAN Rika[1], TEP Thathiny[1,*] & Sarah TUBBS[2]

[1] Liger Leadership Academy, Phum Chumposka-ek, Street 112, Sangkat Prek Thmey, Khan Chbar Ampov, Phnom Penh, Cambodia.

[2] Marine Conservation Cambodia, Koh Ach Seh, Kep Archipelago, Kep Town, Cambodia.

* Corresponding author. Email tepthathiny@gmail.com

Paper submitted 7 August 2020, revised manuscript accepted 18 November 2020.

មូលន័យសង្ខេប

ការត្រួតពិនិត្យតាមដានគឺមានសារៈសំខាន់ណាស់ ដើម្បីធានាថាប៉ូពុយឡាស្យុងបាឡែននៅតែមានសុខភាពល្អ ប្រឈមទៅនឹងការគំរាមកំហែងនៃប្រព័ន្ធអេកូឡូស៊ីសមុទ្រ ជាពិសេសសម្រាប់ប្រទេសកំពុងអភិវឌ្ឍ។ វិធីអង្កេតពីដីគោកគឺជាវិធីបែបប្រពៃណីសម្រាប់ការត្រួតពិនិត្យបាឡែន វាសមស្របខ្លាំងនៅពេលដែលថវិកា ពេលវេលា និងធនធានផ្សេងៗមានកំណត់។ បច្ចុប្បន្ន ឧបករណ៍ចាប់សំឡេងគឺជាបច្ចេកទេសមួយទៀតសម្រាប់ការត្រួតពិនិត្យបាឡែន ហើយអាចត្រូវបានប្រើដើម្បីរកវត្តមានរបស់ពួកវាដោយមិនចាំបាច់មានវត្តមានមនុស្សជាប្រចាំ។ យើងបានវិភាគទិន្នន័យនៃសត្វផ្សោតអ៊ីរ៉ាវ៉ាឌី (*Orcaella brevirostris*) ដែលប្រមូលបានក្នុងអំឡុងខែសីហា ឆ្នាំ២០១៨ និងមិថុនា ឆ្នាំ២០១៩ នៅខេត្តកែប ដើម្បីប្រៀបធៀបអំពីអត្រានៃការរកឃើញដោយការអង្កេតពីដីគោក និងការប្រើឧបករណ៍ចាប់សំឡេង (C-POD)។ យើងក៏បានស៊ើបអង្កេតផងដែរពីឥទ្ធិពលនៃលក្ខណៈអាកប្បកិរិយារបស់ក្រុមផ្សោត(ព្រឹត្តិការណ៍អាកប្បកិរិយា ស្ថានភាពអាកប្បកិរិយា របៀបហែលទឹក ប្រភេទក្រុម និងទំហំក្រុម) ទៅលើអត្រានៃការរកឃើញ (detection rates)។ ទិន្នន័យផ្តល់ដោយវិធីសាស្ត្រត្រួតពិនិត្យនីមួយៗ ត្រូវបានផ្ទៀតផ្ទាត់គ្នាដើម្បីកំណត់ថាតើកំណត់ត្រាផ្សោតត្រូវបានរកឃើញដោយវិធីសាស្ត្រមួយឬវិធីសាស្ត្រទាំងពីរ និងកំណត់ពីភាពខុសគ្នាដាច់ខាតទៅលើអត្រារកឃើញនៃវិធីសាស្ត្រទាំងពីរ។ លើកលែងតែព្រឹត្តិកាណ៍អាកប្បកិរិយាលើកកន្ទុយ (fluke-up) លក្ខណៈទាំងឡាយដែលបានឃើញ មិនមានទំនាក់ទំនងជាមួយនឹងអត្រារកឃើញទេ។ ចំនួននៃការសង្កេតសម្រាប់ព្រឹត្តិកាណ៍លើកកន្ទុយគឺអាស្រ័យផងដែរទៅលើវិធីសាស្ត្រសង្កេតដែលបានប្រើ។ យើងពិចារណាពីចំណុចខ្លាំងនិងខ្សោយនៃវិធីសាស្ត្រនីមួយៗ និងផ្តល់យោបល់ថា ការប្រើវិធីអង្កេតទាំងពីរព្រមគ្នាគឺសាកសមបំផុតសម្រាប់ត្រួតពិនិត្យក្រុមបាឡែន ។

Abstract

Monitoring is crucial to ensure that cetacean populations remain healthy due to the threats facing marine ecosystems and current knowledge gaps, especially in developing countries. Land-based surveys are a traditional method for monitoring cetaceans which are practical when budget, time and other resources are limited. Passive acoustic monitoring has recently emerged as another technique for monitoring cetaceans and can be used to detect them without constant human presence. We analysed data collected on Irrawaddy dolphins *Orcaella brevirostris* between August 2018 and June 2019 in Kep Province to compare rates of detection by land-based surveys and passive acoustic sampling with a continuous porpoise detector (C-POD). We also investigated if the characteristics of dolphin groups sighted (behav-

CITATION: Chan R., Tep T. & Tubbs, S. (2020) Cetacean monitoring methods: using Irrawaddy dolphins to compare land-based surveys and acoustic sampling in Kep, Cambodia. *Cambodian Journal of Natural History*, **2020**, 51–60.

ioural events, behavioural states, swim styles, group types and group sizes) affected detection rates. Data provided by each monitoring method were crossed-referenced to determine if dolphin records were detected by one or both methods and found a significant difference in their detection rates. With the exception of fluke-up behavioural events, the characteristics of sightings were not correlated with detection rates. The number of observations for fluke-up events was also dependent on the observation method used. We consider the strengths and weaknesses of each method, and suggest that a combination of both will be most suitable for monitoring Irradwady dolphins.

Keywords Cetacean, C-POD, Irrawaddy dolphins, Kep Archipelago, land-based survey, passive acoustic monitoring, research methods.

Introduction

Population monitoring is required to develop and inform appropriate conservation strategies for cetaceans due to declines in their population sizes and lack of reliable baseline data for developing countries (Aragones *et al*., 1997; Smith *et al*., 2016). Survey goals, site geography, human resources, and available budgets, time and equipment must be considered when selecting a monitoring method (Aragones *et al*., 1997). Land-based surveys have been found to be one of the most practical methods when budgets, time and equipment are limited (Aragones *et al*., 1997; Morete *et al*., 2018). They also have disadvantages however, which include observer bias and surveys being limited to daylight hours and suitable environmental conditions (Evans & Hammond, 2004).

The use of passive acoustic monitoring (PAM) devices to study delphinids (oceanic dolphins) has increased in recent years (Verfuss *et al*., 2018). One such device, a continuous porpoise detector (C-POD; Chelonia Ltd, Cornwall, UK) is moored to seabed for the purpose of continuously recording the echolocation clicks produced by delphinids to navigate their environments and hunt prey (Au, 1993; Tyack, 1997; Chelonia Ltd, 2014a). As such, C-PODs have been used to monitor and study cetaceans for conservation purposes in variety of ecosystems from the arctic to the tropics. For example, they have been used to evaluate the status of harbour porpoises in Baltic Proper (Gallus *et al*., 2012), to study the distribution of beluga whales and killer whales in Cook Inlet, Alaska (Lammers *et al*., 2013), to track vaquita population declines in Mexico (Jaramillo-Legorreta *et al*., 2016), and explore the relationship between Burmeister's porpoise and fishing by-catch in Peru (Clay *et al*., 2018). Like other acoustic sampling devices however, they have drawbacks which include a limited detection range (no further than 1 km), with detection also confined to echolocation signals that are directed towards the device.

Irrawaddy dolphins *Orcaella brevirostris* are an Endangered cetacean species whose populations are declining (Minton *et al*., 2018), largely due to anthropogenic threats resulting from bycatch and habitat degradation (Smith & Jefferson 2002; Reeves *et al*., 2003; Smith *et al*., 2004; Perrin *et al*., 2005; Smith *et al*., 2008; Peter *et al*., 2016). The species is found in lakes, estuaries, shallow coastal waters, and large rivers in Southeast Asia (Perrin *et al*., 1995, 1996; Ponnampalam *et al*., 2013). Marine populations of Irrawaddy dolphins in Cambodia have received increased research attention in recent years (Beasley & Davidson, 2007; Smith *et al*., 2016; Tubbs *et al*., 2019, 2020). Established in 2017, the Cambodian Marine Mammal Conservation Project (CMMCP) is the first long term project dedicated to research and conservation of marine mammals in the country's southern Kep Province. Through weekly land- and boat-based surveys and PAM, the CMMCP has found that Irrawaddy dolphins are the only cetacean species present in the area and generated information on their distribution, behaviour and seasonal variation (Tubbs *et al*., 2020). Because these surveys were undertaken in the same area, this provided an opportunity to compare the efficacy of land-based surveys and acoustic sampling with C-PODs. This was of interest because although many studies have used either land-based surveys or C-PODs to monitor cetaceans, few have employed both methods simultaneously or compared their utility to our knowledge.

The present paper investigates the relative efficiency of these methods for detecting Irrawaddy dolphins (hereafter 'dolphins') using data collected in Kep Province between August 2018 and June 2019. We also investigate if the characteristics of dolphin groups sighted (behavioural events, behavioural states, swim styles, group type and group size) affected the rate of observations by either method. As such, we provide a critical analysis of the efficiency of the two methods, with the view that this may be used to facilitate selection of appropriate methods for future cetacean research in developing countries.

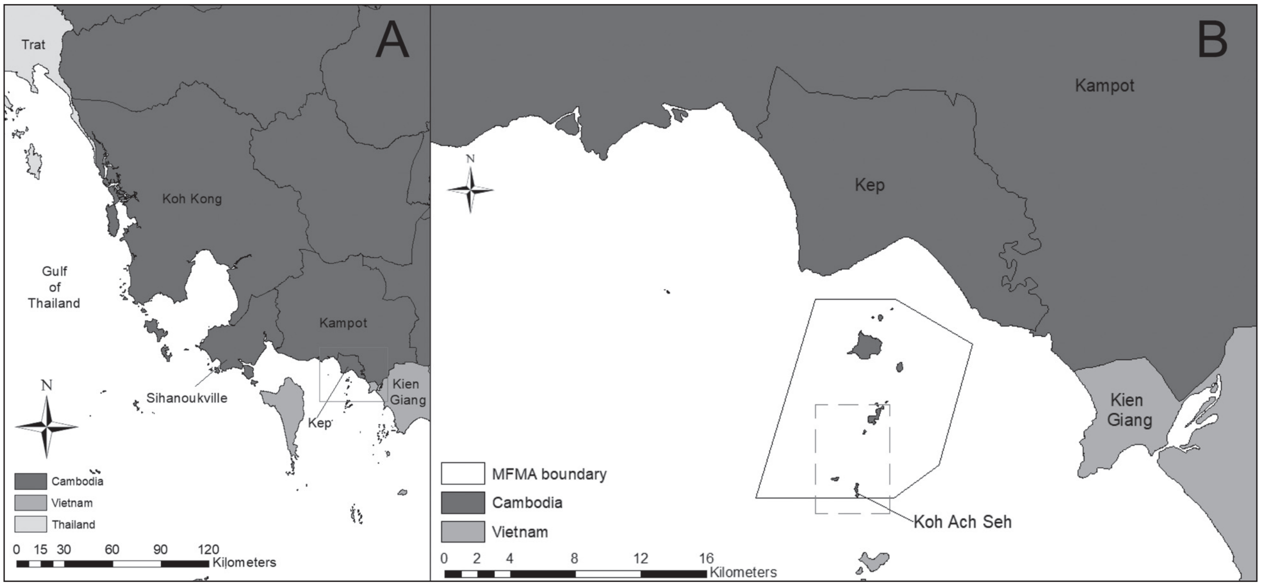

Fig. 1 Location of A) Kep Province on the coast of Cambodia and B) islands within the Kep Archipelago, including the study site (Koh Ach Seh) and Kep Marine Fisheries Management Area (MFMA). From Tubbs & Keen (2019).

Methods

Study site

Our study was undertaken in the Kep Archipelago of Kep Province, one of the four coastal provinces on Cambodia's 435 km long coastline (Fig. 1). The archipelago comprises 13 islands surrounded by marine waters <12 m in depth which include habitats such as coral reefs, seagrass beds and mangrove forests. It also includes a Marine Fisheries Management Area—Cambodia's equivalent of a marine protected area—and is considered as an important area for marine mammals (IUCN-MMPATF, 2020). Our land-based survey site and acoustic monitoring station were located on the east side of the Koh Ach Seh within the archipelago (Figs. 1–2).

Land-based surveys

Weekly land-based surveys, each lasting approximately three hours, were undertaken by the CMMCP between 1 August 2018 and 12 June 2019. These took place from an east-facing observation platform, 21 m above sea level (Fig. 2). During each survey, two surveyors used 8 x 42 Bushnell binoculars to continuously search for dolphin groups, while two additional surveyors rested. All surveys were conducted when the Beaufort Sea state was ≤ 3. For each dolphin sighting, a group number was assigned and the time was recorded. Sightings of dolphins that were seperated by >15 minutes were assumed to be

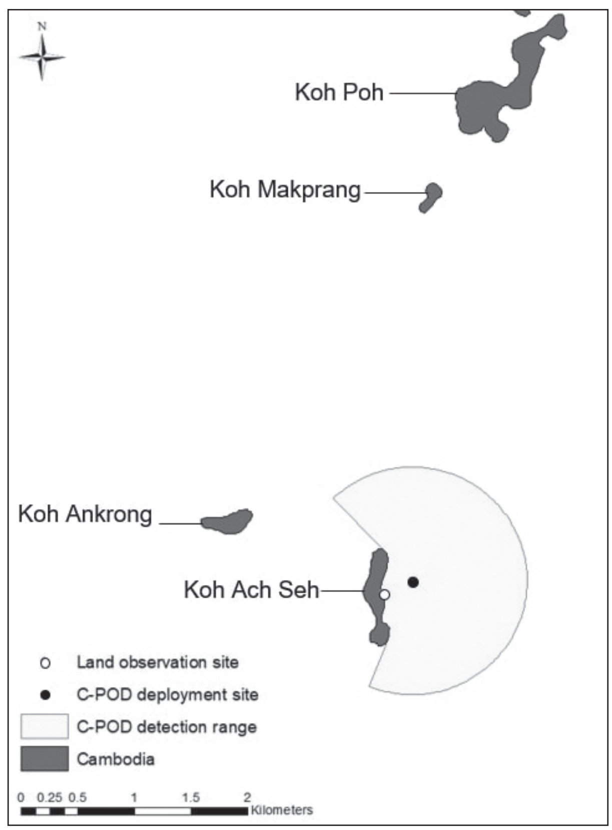

Fig. 2 Location of the land-based survey and acoustic sampling (including C-POD detection range) within the southern islands of the Kep Archipelago, Cambodia.

of different groups. Data was then collected on a variety of behavioural states, group types, swim styles and group sizes for a one-minute period (Table 1). Categories and definitions for these characteristics followed Lusseau (2003, 2006), Parra (2006), Akkaya-Bas *et al*. (2015) and Tubbs *et al*. (2020).

Acoustic sampling

We deployed a single C-POD approximately 100 m east of Koh Ach Seh (10°21’31’’N, 104°19’22’’E; Fig. 2) between 1 August 2018 and 12 June 2019 (Table 2). The device was moored 3.5 m below the sea surface and 1 m above the seabed and detected echolocation clicks between 20–160 kHz within the 1 km range of the device. Information recorded on echolocation clicks was stored on a SD card and included frequency, bandwidth, ICI (inter-click interval), NCyc (number of cycles), intensity, time and date. The sensitivity of the C-POD was adjusted to the low setting to avoid an excess of background noise in recordings, and the limit for records was set to the maximum of 4,096 per minute. The device was retrieved from the mooring site once each month to remove biofouling and replace its batteries and SD card.

Table 1 Characteristics of dolphin groups recorded during land-based surveys in the Kep Archipelago, Cambodia.

	Behavioural event
Fluke-up	Individual raises only its tail fluke above the water surface.
	Behavioural states
Diving	Individuals disappear from surface for between 30 seconds and several minutes. Individuals show no obvious progressional movement and resurface within 100 m from where they disappeared.
Travelling	Individuals move with a constant speed in a certain direction, with a diving interval of 3–5 seconds.
Travel-diving	Individuals disappear from surface for between 30 seconds and several minutes. Individuals make progressional movement, reappear at distance from their starting location.
Surface-feeding	Individuals show active, rapid directional changes just under the surface. Splashes may be present.
Resting	Individuals are drifting at the surface, disappearing and reappearing in the same location.
	Group types
Tight	Individuals are spread out less than 5 m apart from each other.
Far	Individuals are spread out more than 5 m apart from each other.
Mixed	Group is a mixture of Tight and Far.
Alone	One single individual present.
	Swim styles
Line	Individuals swim in a line, head to tail. The line can be straight or offset.
Circular-diving	Individuals create a circular formation by appearing in turns at the surface after each other.
Spread	The group is spread out, individuals do not swim close to each other.
Team	The group is split up into smaller independent teams.
Cluster	Individuals are clustered with no directional movement.
Front	Individuals swim in a line, side by side. The line can be straight or offset.
Kettled	Individuals are clustered at the surface and water appears to be boiling. Splashes may be present.
Alone	One single individual is present.
	Group sizes
Small	A group with 1–3 individuals.
Medium	A group with 4–8 individuals.
Large	A group with more than 9 individuals.

Table 2 Deployment and retrieval dates for the acoustic monitoring device (C-POD) employed in the study.

No.	Deployment date	Retrieval date
1	1 August 2018	16 August 2018
2	16 August 2018	13 September 2018
3	13 September 2018	22 October 2018
4	22 October 2018	23 November 2018
5	28 November 2018	18 December 2018
6	18 December 2018	21 January 2019
7	21 January 2019	18 February 2019
8	18 February 2019	20 March 2019
9	27 March 2019	18 April 2019
10	18 April 2019	13 May 2019
11	13 May 2019	3 June 2019
12	3 June 2019	12 June 2019

Table 3 Dates of land-based survey and acoustic sampling data employed in analyses.

No.	Date	No.	Date
1	1 August 2018	12	7 February 2019
2	3 August 2018	13	21 February 2019
3	14 August 2018	14	7 March 2019
4	15 August 2018	15	20 March 2019
5	27 August 2018	16	20 April 2019
6	4 September 2018	17	1 May 2019
7	17 October 2018	18	2 May 2019
8	6 November 2018	19	22 May 2019
9	30 November 2018	20	23 May 2019
10	5 December 2018	21	4 June 2019
11	7 December 2018	22	12 June 2019

Data processing & analysis

We used C-POD software and the associated *KERNO classifier* (Chelonia Ltd, 2014b) to sort our detections into four categories: narrow-band high frequency (NBHF), which typically represent porpoises; other cetaceans, cetacean clicks that were not NBHF; sonar, signals from boats; unclassed, distinct from the other classes. These were assigned to quality groups (doubtful, low, medium, high) and only NBHF and other cetacean clicks of high and medium quality were included in analysis.

Data from a total of 55 hours and 36 minutes of land-based surveys undertaken over 22 days were directly compared with data generated by the C-POD for the same periods (Table 3). As such, data recorded by the C-POD outside of the land-based survey periods was not included in analysis. Data provided by each method were treated as separate samples when calculating their detection rates. *Rstudio* vers. 4.0.3 (R Core Team, 2020) was used for all data analysis.

Each dolphin group sighted during a land-based survey was counted as a single observation and the timing of each land-based observation was cross-referenced against the C-POD data to determine whether the group was also recorded acoustically or not. In analysis, an observation was counted if it was recorded by at least one of the two sampling methods. Data on the characteristics of dolphin sightings (behavioural events, behavioural states, swim styles, group types and group sizes) were used to investigate differences in detection rates between the two survey methods. For this purpose, the behavioural characteristics of acoustic records were assumed to be the same as those of visual (land-based) observations that occurred simultaneously.

A Chi-square test was used to test for differences in the number of records produced by land-based surveys and C-POD sampling. The number of records produced by each method were also compared to assess differences in the frequencies of behavioural characteristics detected by either method. For this purpose, the number of observations was taken as the number of records registered by both land surveys and C-POD, whereas frequencies represented the number of times land surveys and C-POD registered a given behavioural characteristic in a single record.

Results

Over the course of the study, dolphins were detected on a total of 26 separate occasions. Twenty-two of these occasions were registered by land-based surveys and nine were registered in acoustic sampling. Five occaisons were simultaneously detected by both methods (Fig. 3).

Dolphin records were highest in August 2018 for both methods, followed by May 2019 (Fig. 3). Records from land-based surveys were higher in most months compared to acoustic sampling, aside from December 2018 (equal number of records) and January 2019 (no records). No acoustic records were made in September 2018, March 2019 and April 2019.

Detection rates

The total number of observations produced by land-based surveys was significantly greater than acoustic sampling (X^2=13.499, DF=1, P=0.0002387).

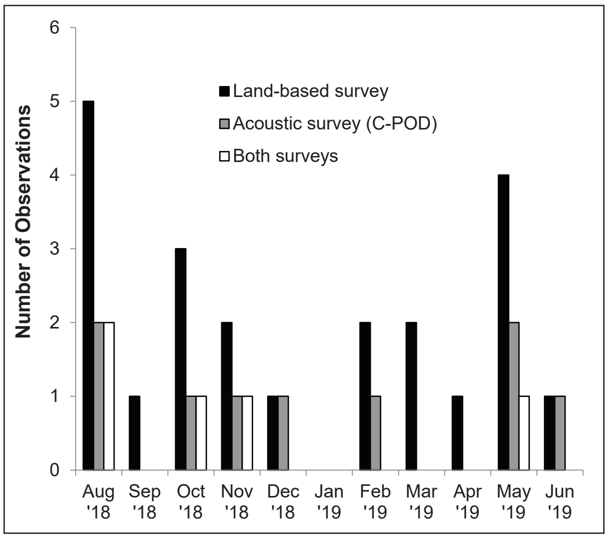

Fig. 3 Monthly dolphin observations produced by the two survey methods from August 2018 to June 2019.

Behavioural characteristics

'Fluke-up' behavioural events were registered 66 times during our land-based surveys, 15 of which occurred during observations also registered in acoustic sampling.

Similarly, our land-based surveys observed all other categories of behavioural states (Table 1) more frequently than acoustic sampling (Fig. 4). 'Diving' represented the behavioural state most frequently registered during visual and acoustic observations, with a collective total of 36 observations, followed by 'travelling' (13 observations), 'surface-feeding' (nine), and 'travel-diving' (seven).

Our land-based surveys observed all categories of group type more frequently than acoustic sampling (Fig. 5). The 'tight' category was most commonly recorded by both methods, with a collective total of 37 observations, followed by 'alone' (15 observations).

All but two categories of swim styles were observed more frequently in land-based surveys compared to acoustic sampling (Fig. 6), the exceptions being the 'team' and 'circular-diving' categories (both equal). The 'line' swim style was the most frequently observed category, with a collective total of 16 observations, followed by 'alone' (15 observations), 'cluster' (14) and 'spread' (12).

Visual (land-based) records of dolphins were more frequent than acoustic records when their groups were small or medium sized (Fig. 7), whereas large groups were observed equally frequently.

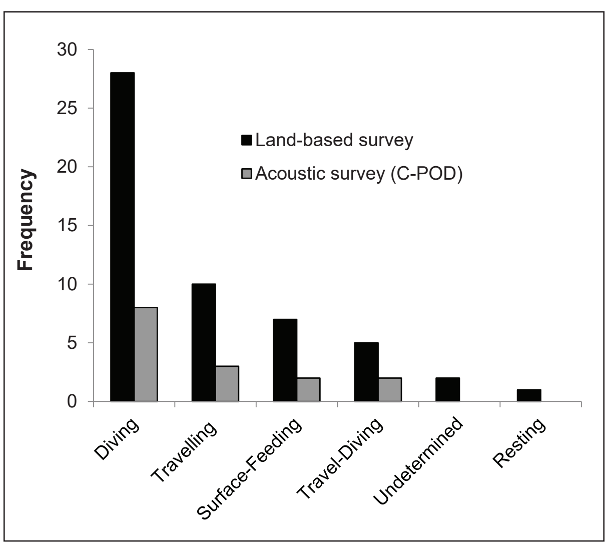

Fig. 4 Frequencies of behavioural states exhibited by dolphins recorded by the two survey methods.

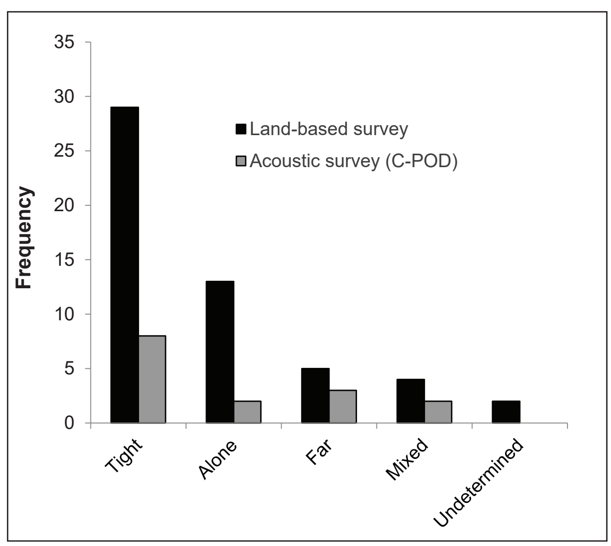

Fig. 5 Frequencies of dolphin group types recorded by the two survey methods.

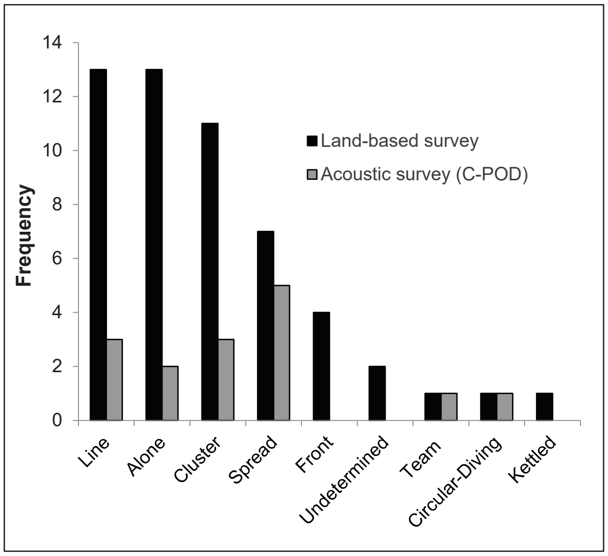

Fig. 6 Frequencies of dolphin swim styles recorded by the two survey methods.

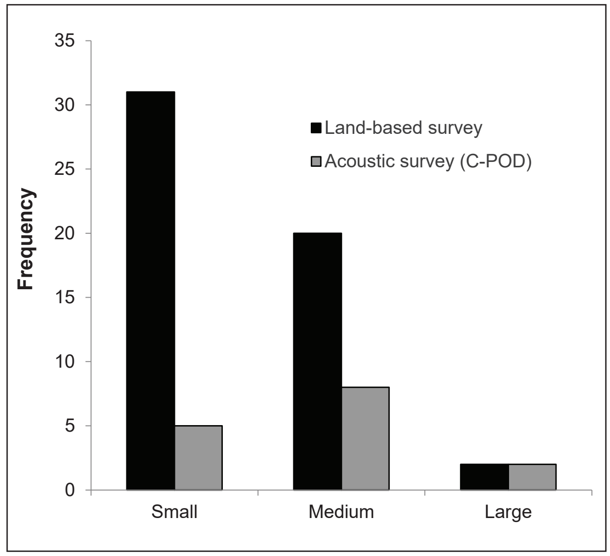

Fig. 7 Frequencies of dolphin group sizes recorded by the two survey methods.

Discussion

We found that land-based surveys generated more observations of dolphins compared to acoustic sampling. This might be due to the limited detection range of our acoustic device, since C-PODs can only detect echolocation clicks that are produced within 1 km of the device and travelling its direction, whereas greater distances could be surveyed with binoculars in our land-based surveys. Additionally, as the sensitivity of our C-POD was set to low to avoid excessive background noise in recordings and maximise battery life and digital storage, this could have contributed to under-sampling.

'Fluke-up' events and 'diving' behaviour were recorded more often in land-based surveys than acoustic sampling. Both have been associated with foraging behaviour (Smith *et al*., 1997; Casipe *et al*., 2013) and as cetaceans use echolocation during foraging to determine prey location (Johnson *et al*., 2004; Madsen *et al*., 2007), acoustic sampling should detect dolphins during this activity. That this did not always prove the case in our study might again be due to the lower detection range of the C-POD or because there were occasions when echolocation signals produced by dolphins foraging in the area were not directed towards the device.

The disparities between the frequencies of different dolphin group sizes recorded by land-based and acoustic sampling was greatest for small groups, followed by medium-sized groups. As such, these were more likely to be detected by land-based surveys, whereas large groups were equally likely to be observed by both methods. We attribute this to the likelihood that large groups of dolphins generate more echolocation signals, thereby improving their likelihood of detection in acoustic sampling. This would be consistent with our finding that the number of observations of dolphins in the 'alone' category of group types and swim styles was much greater in our land-based surveys. This collectively suggests that C-PODs are more efficient at detecting large groups compared to small groups or individual dolphins, whereas land-based surveys are more effective than C-PODs at detecting either of the latter.

While our study provides new insights on the relative efficiency of land-based survey and acoustic sampling methods for monitoring dolphins, it does have limitations. For example, we assumed that dolphin groups simultaneously registered by both methods were the same group. This could potentially have led to over-representation in the number of observations counted for both methods and under-representation in the overall number of observations. Future research to discern the acoustic characteristics associated with specific behaviours could potentially contribute to overcoming the former challenge.

Land-based surveys are a traditional and widely-used method for monitoring cetaceans worldwide.

With appropriate binoculars, they allow large areas to be surveyed from a stationary position and have been especially used to study cetacean behaviour (Giacoma *et al*., 2013; Keen *et al*., 2020). Being based on visual observation, they do have limitations however in that they can only be undertaken during daylight hours and suitable weather conditions. In contrast, acoustic sampling devices such as C-PODs have revolutionized cetacean studies in allowing researchers to remotely study the animals at any time of day or night, irrespective of weather conditions (Roberts & Read, 2014). As mentioned before however, they are limited by detection range (up to 1 km in the case of C-PODs) and can generally only detect echolocation signals directed towards the device. They can also only detect dolphins when these are actively echolocating (such that more passive activities will be under-sampled), whereas their effectiveness for behavioural studies has yet to be fully determined. Despite these drawbacks however, acoustic devices such as C-PODs have great potential for overcoming the inherent limitations of visual surveys, particularly for situations where human resources are scarce.

Our study provides new insights into the relative strengths and weaknesses of land-based surveys and acoustic sampling for studying cetaceans which will hopefully aid researchers in designing future studies. Further studies are needed to confirm and elucidate our findings however, as well as to assess their applicability to other cetacean species and geographical regions. For instance, research to determine the appropriate density of sampling stations required to ensure effective detection in studies that combine land-based survey and acoustic sampling methods would be particularly useful.

Acknowledgements

We would like to thank Ouk Vibol, Phay Somany and Chheng Touch of the Cambodian Fisheries Administration for their collaboration. We are grateful to Marine Conservation Cambodia, Heinrich Böll Foundation, Rufford Foundation, Fondation Ensemble, Mohammed Bin Zayed Species Conservation Fund, and International Conservation Fund of Canada for supporting the Cambodian Marine Mammal Conservation Project, and to Chelonia Ltd for donating a C-POD. We are also grateful to the Liger Leadership Academy for providing resources for the study and especially to Kieran O'Neil for mentoring all aspects of our research.

References

Aragones, L.V., Jefferson, T.A. & Marsh, H. (1997) Marine mammal survey techniques applicable in developing countries. *Asian Marine Biology*, **14**, 15–39.

Akkaya-Baş, A., Öztürk, A.A. & Öztürk, B. (2015) Selection of critical habitats for bottlenose dolphins (*Tursiops truncatus*) based on behavioral data, in relation to marine traffic in the Istanbul Strait, Turkey. *Marine Mammal Science*, **31**, 979–997

Au, W.W.L. (1993) *The Sonar of Dolphins*. Springer-Verlag, New York, USA.

Beasley, I.L. & Davidson, P.J. (2007) Conservation status of marine mammals in Cambodian waters, including seven new cetacean records of occurrence. *Aquatic Mammals*, **33**, 368–379.

Casipe, K.P., Espinosa, K.E, Jarabelo, C.J. & de la Paz, M. (2013) Foraging behavior association between Irrawaddy dolphins (*Orcaella brevirostris*) and tidal net fisheries in the coastal waters of Pulupandan, Negros Occidental, Philippines. *Sylvatrop*, **25**, 67–92.

Chelonia Ltd (2014a) *C-POD Specifications*. Https://www.chelonia.co.uk/cpod_specifications.htm [Accessed 29 July 2020].

Chelonia Ltd (2014b) *CPOD.exe: a Guide for Users*. Https://chelonia.co.uk/downloads/CPOD.pdf [Accessed 29 July 2020].

Clay, T.A., Mangel, J.C., Alfaro-Shigueto, J., Hodgson, D.J. & Godley, B.J. (2018) Distribution and habitat use of a cryptic small cetacean, the Burmeister's porpoise, monitored from a small-scale fishery platform. *Frontiers in Marine Science*. DOI 10.3389/fmars.2018.00220

Evans, P.G.H. & Hammond, P.S. (2004) Monitoring cetaceans in European waters. *Mammal Review*, **34**, 131–156.

Gallus, A., Dähne, M., Verfuss, U., Bräger, S., Adler, S., Siebert, U. & Benke, H. (2012) Use of static passive acoustic monitoring to assess the status of the 'Critically Endangered' Baltic harbour porpoise in German waters. *Endangered Species Research*, **18**, 265–278.

Giacoma, C., Papale, E., Azzolin, M. (2013) Are land based surveys a useful tool for managing marine species of coastal protected areas? *Diversity*, **5**, 15–25.

[IUCN-MMPATF] International Union for Conservation of Nature-Marine Mammal Protected Areas Taskforce (2020) *Kien Giang and Kep Archipelago IMMA*. Https://www.marine-mammalhabitat.org/portfolio-item/kien-giang-kep-archipelago/ [Accessed 3 June 2020].

Jaramillo-Legorreta, A., Cardenas-Hinojosa, G., Nieto-Garcia, E., Rojas-Bracho, L., Hoef, J.V., Moore, J. & Taylor, B. (2016) Passive acoustic monitoring of the decline of Mexico's critically endangered vaquita. *Conservation Biology*, **31**, 183–191.

Johnson, M., Madsen, P.T., Zimmer, W.M.X., Aguilar de Soto, N. & Tyack, P.L. (2004) Beaked whales echolocate on prey. *Proceedings of the Royal Society of London. Series B: Biological Sciences*. DOI 10.1098/rsbl.2004.0208

Keen E.M., Wray J., Hendricks B., Mahony E.O,, Picard, C.R. & Alidina, H. (2020) Determining marine mammal detection functions for a stationary land-based survey site. *Wildlife Research*. DOI 10.1071/WR19232

Lammers, M.O., Castellote, M., Small, R.J., Atkinson, S., Jenniges, J., Rosinski, A., Oswald, J.N. & Garner, C. (2013) Passive acoustic monitoring of Cook Inlet beluga whales (*Delphinapterus leucas*). *The Journal of the Acoustical Society of America*, **134**, 2497–2504.

Lusseau, D. (2003) Effects of tour boats on the behavior of bottlenose dolphins: using Markov chains to model anthropogenic impacts. *Conservation Biology*, **17**, 1785–1793.

Lusseau, D. (2006) Why do dolphins jump? Interpreting the behavioural repertoire of bottlenose dolphins (*Tursiops* sp.) in Doubtful Sound, New Zealand. *Behavioural Processes*, **73**, 257–265.

Madsen, P.T., Wilson, M., Johnson, M., Hanlon, R.T., Bocconcelli, A., Aguilar de Soto, N. & Tyack, P.L. (2007) Clicking for calamari: toothed whales can echolocate squid *Loligo pealeii*. *Aquatic Biology*, **1**, 141–150.

Minton, G., Smith, B.D., Braulik, G.T., Kreb, D., Sutaria, D. & Reeves, R. (2018) *Irrawaddy Dolphin Orcaella brevirostris. The IUCN Red List of Threatened Species 2017: e.T15419A123790805.* Https://dx.doi.org/10.2305/IUCN.UK.2017-3.RLTS.T15419A50367860.en [Accessed 5 May 2020].

Morete, M.E., Abras, D. & Martins, C.C.A. (2018) Land-based station studies of aquatic mammals in latin America: understanding behaviour for conservation. In *Advances in Marine Vertebrate Research in Latin America* (eds M. Rossi-Santos & C. Finkl), pp. 77–112. Springer, Switzerland.

Parra, G.J. (2006) Resource partitioning in sympatric delphinids: space use and habitat preferences of Australian snubfin and Indo-Pacific humpback dolphins. *Journal of Animal Ecology*, **75**, 862–874.

Perrin, W., Leatherwood, S. & Dolar, M. (1995) *The status of marine mammal research in Southeast Asia*. UNEP/SEA95/BP6, IBI Reports No. 5.

Perrin, W., Dolar, M. & Alava, M. (1996) *Report of the Workshop on the Biology and Conversion of Small Cetaceans and Dugongs of Southeast Asia*. United Nations Environment Programme, Bangkok, Thailand.

Perrin, W., Reeves, R., Dolar, M., Jefferson, T., Marsh, H., Wang, J. & Estacion, J. (2005) *Report of the Second Workshop on The Biology and Conservation of Small Cetaceans and Dugongs of South-East Asia*. CMS Technical Series Publication No. 9., Secretariat for Convention on Migratory Species of Wild Animals, Bonn, Germany.

Peter, C., Ngeian, J., Minton, G., Zulkifli, P.A., Grinang, J. & Tuen, A. (2016) *Artisanal Fisheries and Cetaceans in Kuching Bay, Sarawak, East Malaysia: Threats and Potential Mitigation*. Report presented to the Meeting of the Scientific Committee of the International Whaling Commission, SC/66b/SM09.

Ponnampalam, L., Hines, E.M., Monanunsap, S., Ilangakoon, A.D., Junchompoo, C., Adulyanukosol, K. & Morse, L.J. (2013) Short note: behavioral observations of coastal Irrawaddy dolphins (*Orcaella brevirostris*) in Trat Province, eastern Gulf of Thailand. *Aquatic Mammals*, **39**, 401–408.

R Core Team (2020) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reeves, R.R., Smith, B.D., Crespo, E.A. & di Sciara G, N. (2003) *Dolphins, Whales and Porpoises: 2002–2010. Conservation Action Plan for the World's Cetaceans*. IUCN/SSC Cetacean Specialist Group, Cambridge, UK.

Roberts, B.L. & Read A.J. (2014) Field assessment of C-POD performance in detecting echolocation click trains of bottlenose dolphins (*Tursiops truncatus*). *Society for Marine Mammalogy*, **31**, 169–190.

Smith, B.D., Ahmed, B., Mowgli, R.M. & Strindberg, S. (2008) Species occurrence and distribution ecology of nearshore cetaceans in the Bay of Bengal, Bangladesh, with abundance estimates for Irrawaddy dolphins *Orcaella brevirostris* and finless porpoise *Neophocaena phocaenoides*. *Journal of Cetacean Research and Management*, **10**, 45–58.

Smith, B.D., Beasley, I., Buccat, M., Calderon, V., Evina, R., Lemmuel de Valle, J., Cadigal, A., Tura, E. & Visitacion, Z. (2004) Status, ecology and conservation of Irrawaddy dolphins (*Orcaella brevirostris*) in Malampaya Sound, Palawan, Philippines. *Journal of Cetacean Research and Management*, **6**, 41–52.

Smith, B.D. & Jefferson, T.A. (2002) Status and conservation of facultative freshwater cetaceans in Asia. *Raffles Bulletin of Zoology*, **10**, 173–187.

Smith, B.D, Thant, U.H., Lwin, J.M. & Shaw, C.D. (1997) Investigation of cetaceans in the Ayeyarwady River and northern coastal waters of Myanmar. *Asian Marine Biology*, **14**, 173–194.

Smith, T.D., Bannister J., Hine, E., Reeves, R., Rojas-Bracho, L., Shaughnessy, P. & Rice, J. (2016) Marine Mammals. In *The First Global Integrated Marine Assessment: World Ocean Assessment* (eds A.Y. Ajawin, A.C. Alcala, P. Bernal, H.P. Calumpong, P.E. Araghi, S.O. Green, P. Harris, O.K. Kamara, K. Kohata, E. Marschoff, G. Martin, B.P. Ferreira, C. Park, R.A. Payet, J. Rice, A. Rosenburg, R. Ruwa, J.T. Tuhumwire, S. van Gaever, J. Wang & J.M. Weslawski), chapter 37. United Nations Environment Programme, Nairobi, Kenya.

Tubbs, S.E., Bas, A.A., Côté, G., Jones, A.L. & Notman, G. (2019) Sighting and stranding reports of Irrawaddy dolphins

(*Orcaella brevirostris*) and dugongs (*Dugong dugon*) in Kep and Kampot, Cambodia. *Aquatic Mammals*, **45**, 563–568.

Tubbs, S.E. & Keen, E. (2019) *Passive Acoustic Monitoring Shows Diurnal Patterns for Irrawaddy Dolphins in Kep, Cambodia*. Proceedings of the World Marine Mammal Conference, Barcelona, Spain.

Tubbs, S.E., Keen, E., Jones A.L. & Thap R. (2020). On the Distribution, Behaviour and Seasonal Variation of Irrawaddy Dolphins (*Orcaella brevirostris*) in the Kep Archipelago, Cambodia. *Conservation and Ecology*, **68**, 137–149.

Tyack, P.L. (1997) Studying how cetaceans use sound to explore their environment. In *Perspectives in Ethology, Volume 12* (eds D.H. Owings, M.D. Beecher & N.S. Thompson), pp. 251–297. Plenum Press, New York, USA.

Verfuss, U.K, Gillespie, D., Gordon, J., Marques, T., Miller, B., Sinclair, R., Theriault, J., Tollit D., Zitterbart, D., Hubert, P. & Thomas, L. (2018) Comparing methods suitable for monitoring marine mammals in low visibility conditions during seismic surveys. *Marine Pollution Bulletin*, **126**, 1–18.