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Irrawaddy dolphin *Orcaella brevirostris* strandings between 2017 and 2020 in Kep Province, Cambodia

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មូលន័យសង្ខេប

ប្រជុំកោះកែបនៃប្រទេសកម្ពុជា ទ្រទ្រង់ដល់ប្រភេទសត្វប្លែកៗមួយចំនួន ដែលដើរតួយ៉ាងសំខាន់ក្នុងប្រព័ន្ធអេកូឡូស៊ី ដោយរួមមានសត្វផ្សោតក្បាលត្រឡោក (*Orcaella brevirostris*) ផងដែរ។ ប៉ុំពុយឡាស្បុងផ្សោតក្បាលត្រឡោកនេះ កំពុងមានការចាប់អារម្មណ៍សិក្សាស្រាវជ្រាវកាន់តែច្រើនឡើង ខណៈពេលដែលពួកវាកំពុងទទួលរងនូវការគំរាមកំហែងកាន់តែច្រើនឡើងពីសកម្មភាព មនុស្សដូចជា៖ ការបំពុល និងការនេសាទខុសច្បាប់ គ្មានការរាយការណ៍ និងការគ្រប់គ្រង។ ការសិក្សានេះ រាយការណ៍ពីការងាប់របស់សត្វផ្សោតក្បាលត្រឡោកចំនួន១០ក្បាលក្នុងខេត្តកែប ក្នុងអំឡុងឆ្នាំ២០១៧ ដល់ ២០២០ និងកំណត់ត្រាអំពីរបួសទាំងខាងក្រៅ និងខាងក្នុងខ្លួន ដោយការវះកាត់សាកសពផ្សោតនីមួយៗ ក៏ដូចជារបាយរដូវ និងប្រជាសាស្ត្រនៃព្រឹត្តិការណ៍កឿងងាប់នីមួយៗ។ ការកឿងងាប់កើតឡើងនៅទូទាំងប្រជុំកោះ និងគ្រប់រដូវ ប៉ុន្តែប្រទះឃើញច្រើននៅចុងរដូវវស្សា (ពីខែតុលា ដល់ វិច្ឆិកា)។ ផ្សោតមិនទាន់ពេញវ័យងាយនឹងកឿងងាប់ជាង ប៉ុន្តែគេមិនបានប្រទះឃើញមានកូនផ្សោតងាប់ទេ។ គេមិនទាន់អាចកំណត់ពីមូលហេតុជាក់លាក់នៃការងាប់របស់ពួកវានៅឡើយទេ ដោយសារកង្វះខាតធនធាន និងបុគ្គលិកជំនាញ។ ទោះជាយ៉ាងណា គេយល់ថា ការងាប់គឺបណ្តាលមកពីជំងឺ សារធាតុគីមីពុល និងការនេសាទបានដោយចៃដន្យ។ ការសង្កេតពីអាហារក្នុងក្រពះ បានបញ្ជាក់ថា ត្រីឆ្អឹងតូចៗ សប្បិសត្វ និងពពួកមឹកគឺជាចំណីរបស់ពួកវា។ ជាអនុសាសន៍ យើងសុំស្នើឲ្យបន្តការតាមដានពីការកឿងងាប់របស់សត្វផ្សោតក្បាលត្រឡោកនៅតាមតំបន់ឆ្នេរនៃប្រទេសកម្ពុជា រួមជាមួយនឹងគំនិតផ្តើមបង្កើតបណ្តាញត្រួតពិនិត្យការងាប់ផ្សោតតាមតំបន់ឆ្នេរ ដែលមានការគាំទ្រគ្រប់គ្រាន់ខាងផ្នែកថវិកា ធនធាន សម្ភារៈ និងការបណ្តុះបណ្តាលអ្នកជំនាញ ដូចជាផ្នែកពេទ្យថនិកសត្វសមុទ្រជាដើម។ ព័ត៌មានដែលប្រមូលបានពីបណ្តាញខាងលើ អាចនឹងជួយបង្កើនការយល់ដឹងផ្នែកកាយវិភាគវិទ្យា សរីរៈវិទ្យា និងរោគវិទ្យានៃផ្សោតក្បាលត្រឡោក ហើយវាក៏ជាព័ត៌មានសម្រាប់ការរៀបចំយុទ្ធសាស្ត្រអភិរក្ស និងគ្រប់គ្រងប្រភេទនេះ។

Abstract

The Kep Archipelago in Cambodia supports a variety of ecologically important species, including the Endangered coastal Irrawaddy dolphin *Orcaella brevirostris*. This dolphin population has recently been subject to increased research, but faces growing threats from a variety of anthropogenic pressures, including pollution and illegal, unreported and unregulated fishing activity. This study reports on the fatal strandings of ten Irrawaddy dolphins in Kep Province between 2017 and 2020 and documents the internal and external injuries recorded during rudimentary necropsies as well as the distribution, seasonality and demography of the stranding events. The strandings occurred throughout the archipelago in all seasons, although they were most prevalent during the post-monsoon season (October to November). Juveniles were most susceptible to stranding and no strandings of calves were recorded. The causes of death could not be accurately determined due to a lack of resources and trained personnel, although disease, chemical pollution and

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bycatch would appear to be the most likely causes of stranding. Observations of stomach contents confirmed small bony fish, crustaceans and cephalopods as prey species. We recommend continual monitoring of Irrawaddy dolphin strandings along the Cambodian coastline, with a view to establishing a coastal-wide stranding network supported by adequate funding, resources, facilities and trained personnel such as marine mammal veterinarians. The information gathered from such a network would enhance understanding of the anatomy, physiology and pathology of Irrawaddy dolphins and inform conservation and management strategies for the species.

Keywords Cambodia, diet, distribution, Indo-Pacific, Irrawaddy dolphins, IUU fishing, necropsy, seasonality, strandings, stranding networks.

Introduction

Irrawaddy dolphins *Orcaella brevirostris* are an endangered, euryhaline species with a declining population and a discontinuous distribution across the Indo-Pacific coastline (Stacey & Arnold, 1999; Minton *et al*., 2017; Smith, 2018; Kumar *et al*., 2019). Irrawaddy dolphins are uniformly dark grey on the dorsal and lateral fields, with a lighter ventral field (Smith, 2018). Body lengths of sexually mature individuals are 2.1–2.2 m for females and as large as 2.8 m for males (Smith, 2018). The diet of the species consists of small bony fish, cephalopods and crustaceans (Baird & Mounsouphom, 1997; Ponnampalam *et al*., 2013; Jackson-Ricketts *et al*., 2018). Irrawaddy dolphins are currently categorised as Endangered by the IUCN Red List (Minton *et al*., 2017). However, five subpopulations have been reported as 'Critically Endangered' (Malampaya Sound, Philippines; Chilika Lagoon, India; Ayeyarwady River, Myanmar; Mahakam River, Indonesia; Songkla Lake, Thailand; Mekong River, Cambodia, Laos and Vietnam; Smith, 2007; Minton *et al*., 2017). The main natural predators of Irrawaddy dolphins are believed to be sharks (Khan *et al*., 2011). However, key threats to the species are of anthropogenic origin and include entanglement in fishing gears, habitat loss and fragmentation, pollution (industrial and noise), and live capture for aquaria (Nelson, 1999; Smith, 2007; Smith *et al*., 2008; Smith, 2009; Minton *et al*., 2017). The first major documented decline of Irrawaddy dolphins in Cambodia occurred during the Pol Pot regime (1975 to 1979) when dolphins were shot by Vietnamese soldiers for target practice. Dolphin oil was used by the Khmer Rouge for lamps, motorbikes and boat engines, and their meat was consumed as food (Tana, 1995; Perrin *et al*., 1996; Baird & Beasley, 2005; Beasley 2007; Beasley *et al*., 2013). Since the early 2000's Irrawaddy dolphins have become a flagship species for the conservation of marine and freshwater ecosystems in Cambodia (Beasley, 2007; Deutsch, 2020), and they are now protected from targeted hunting by national and international regulations (Minton *et al*., 2017; Ministry of Agriculture, Forestry and Fisheries [MAFF], 2018). Despite these measures, Irrawaddy dolphin strandings and bycatch events occur regularly in Cambodia and across their range (Smith, 2007; Dove, 2009; Kumar *et al*., 2019; Tubbs *et al*., 2019; Kreb *et al*., 2020).

Nine cetacean species have been observed in Cambodian waters: false killer whale *Pseudorca crassidens*, Indo-Pacific bottlenose dolphin *Tursiops aduncus*, Indo-Pacific common dolphin *Delphinus tropicalis*, Indo-Pacific finless porpoise *Neophocaena phocaanoides*, Indo-Pacific humpback dolphin *Sousa chinensis*, Irrawaddy dolphin, pantropical spotted dolphin *Stenella attenuata*, short-finned pilot whale *Globicephala macrohynchus* and spinner dolphin *S. longirostris* (Beasley & Davidson, 2007). Whilst sightings and strandings of these species have been recorded along the Cambodian coastline, only two marine mammal species have been observed within the Kep Archipelago, Irrawaddy dolphins and dugongs *Dugong dugon*. Two peer-reviewed papers have described strandings of Cambodia's coastal Irrawaddy dolphins to date (Tubbs *et al*., 2019; Jones *et al*., 2021). This paper aims to build on this knowledge base and contribute to conservation and management through improved implementation of Cambodia's marine mammal stranding network.

Beasley & Davidson (2007), Bohm (2019), Tubbs *et al*. (2019) and Hines *et al*. (2020) highlighted threats posed by illegal, unregulated and unreported (IUU) fishing activity to marine mammals (notably Irrawaddy dolphins and dugongs), including bycatch, habitat degradation, and prey depletion. Cambodian fisheries law prohibits the use of electrified gears, gillnets and seine nets with a mesh size smaller than 1.5 cm, pair trawling nets, and bottom trawling at a depth less than 20 m (MAFF, 2007). Despite these laws and attempted enforcement, IUU fishing, including the use of electrified nets, small-mesh gill and seine nets, and shallow water bottom-trawling, continues to be observed across the Cambodian coastline (Nelson, 1999; Beasley & Davidson, 2007). For instance, non-compliance to fisheries law frequently occurs within the Kep Archipelago including daily observations of both Cambodian and transnational vessels bottom-trawling,

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electric trawling and pair-trawling (Bohm, 2019; Tubbs *et al*., 2019). This illegal activity results in marine mammal entanglement, bycatch and habitat degradation (Nelson, 1999; Beasley & Davidson, 2007; Minton *et al*., 2017; Tubbs *et al*., 2019, 2020).

The frequent non-compliance with fisheries law is due to the complex socio-political and economic challenges facing a developing country such as Cambodia. Lack of funding and other resources make it difficult to enforce and issue appropriate sanctions for IUU fishing at the local and transnational level (Bohm, 2019) and limits capacity for compensating compliant actors and conservation efforts within constituent fishing communities. Similar parallels can be drawn between the Critically Endangered vaquita *Phocoena sinus* in the Sea of Cortez and the ongoing threat from IUU fishing targeting *Totoaba macdonaldi* (Jaramillo-Legorreto *et al*., 2016; Cisneros-Mata *et al*., 2021). Current conservation actions in Cambodia include in-situ research and monitoring of identified Irrawaddy dolphin populations, establishment of protected areas, and inclusion of the species in international legislation including the Convention on International Trade in Endangered Species (Appendix I) and the Convention of Migratory Species (Smith, 2007; Minton *et al*., 2017). Although studies have highlighted the need for further research and habitat and species-specific conservation strategies (Tubbs *et al*., 2019; Jones *et al*., 2021), coordination of an effective and well-resourced stranding network is integral to improving understanding of Irrawaddy dolphins, reliably identifying the causes of strandings and reducing the likelihood of these where possible.

The Cambodian Marine Mammal Conservation Project (CMMCP) was established by the non-government organisation Marine Conservation Cambodia in 2017 and combines scientific research and monitoring with protected area management and national government collaboration. These efforts are focussed in the Kep Archipelago which supports a small resident population of coastal Irrawaddy dolphins (Tubbs *et al*., 2019, 2020). The archipelago was recognised as a Marine Fisheries Management Area (MFMA; equivalent to a marine protected area: Reid *et al*., 2019) in 2018 and later, as an Important Marine Mammal Area (MMPATF, 2019). This study presents data collected by the CMMCP on fatal strandings of Irrawaddy dolphins in the Kep Archipelago between November 2017 and November 2020 (including those reported by Tubbs *et al*., 2019 and Jones *et al*., 2021). Sex and age class were investigated independently, while the distribution of stranding sites and seasonality of stranding events were compared with the population distribution and seasonality data reported by Tubbs *et al*. (2020). The aim of this research is to instigate and inform a coastal-wide marine mammal stranding programme for Cambodia, with the potential for collecting valuable data regarding Irrawaddy dolphin biotoxins, contaminants, cytology, genetics, histology, life history, microbiology, parasitology and virology, as well as identifying and confirming threats facing the species along the country's coastline. This knowledge, along with lessons learnt from other strandings programs within the Indo-Pacific region, can be used to inform and guide a national marine mammal strandings response, to ensure effective species conservation and habitat management at local, national and transnational scales.

Methods

Study area

Cambodia's coastline extends 17,791 km^2 (Rizvi & Singer, 2001) and includes four coastal provinces: Koh Kong (10,090 km^2), Sihanoukville (2,536 km^2), Kampot (4,873 km^2) and Kep (335 km^2). Cambodia's neritic zone features a number of closely interrelated ecosystems, beaches, forests, mangroves, estuaries, seagrass beds and coral reefs with a gently sloping, relatively shallow seabed (Rizvi & Singer, 2011). Kep, Cambodia's smallest coastal province, is home to an archipelago of 13 islands extending approximately 15 km offshore. The Kep Archipelago (Fig. 1B) is a shallow (≤ 12 m depth), coastal region with two riverine inputs, the Giang river to the east and the Kampot river to the northwest. The archipelago includes important marine ecosystems including seagrass meadows, coral reefs and mangrove forests, which provide habitats for endangered fauna including Irrawaddy dolphins, green sea turtles *Chelonia mydas* and hawksbill sea turtles *Eretmochelys imbricata*, dugongs and seahorses *Hippocampus* spp. (Beasley & Davidson, 2007; Reid *et al*., 2019; Tubbs *et al*., 2019; Strong *et al*., 2021). Formally designated in 2018 as an MFMA, the region protects 113 km^2 of archipelagic waters which provide a potential refuge for Kep's resident population of Irrawaddy dolphins (Tubbs *et al*., 2019, 2020). The archipelago is bordered on three sides by Vietnam (Fig. 1A) and as a result attracts transnational IUU fishing activity in the form of bottom trawling and electric trawling from both Cambodian and Vietnamese vessels (Bohm, 2019; Strong *et al*., 2021). Only small-scale sustainable subsistence fishing activities such as pot fishing and hook-and-line fishing are permitted within the fisheries protected areas (which represent 100 km^2 of Kep MFMA), while all fishing activity is prohibited within the conservation, and research and recreation areas (5.2 km^2). For the duration of this study, the research team inhabited Koh Ach Seh,

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an island located within a conservation zone approximately 13 km from mainland Kep (Fig. 1B).

Recovery and necropsy of carcasses

Irrawaddy dolphin carcasses were recovered by the CMMCP between November 2017 and November 2020. Strandings within the archipelago and along the Kep coastline were reported to the CMMCP by local fishers and community leaders or discovered by the CMMCP research team during routine surveys and patrols of Koh Ach Seh and the Kep Archipelago. Once the locations of individual strandings were confirmed, GPS coordinates were recorded using a Garmin 64s GPS unit and a carcass recovery procedure was initiated.

Carcasses found on land were photographed and transported on foot using a tarpaulin sheet to a safe location away from the shoreline. Where appropriate, a basic on-site necropsy was conducted. Body measurements and photographs were taken along with teeth, bone and tissue samples for future laboratory analysis. Sex was determined by external and internal examination of sex organs, and the age class of each individual was categorized as adult (> 2.2 m length), juvenile (1.30–2.19 m length) or calf (< 1.3 m length) based on body measurements and confirmed by other indicative factors such as odontogeneses. A rudimentary investigation of internal organs and tissues was undertaken to assess the internal body condition of each individual and helped to determine factors which may have contributed to death, such as plastic ingestion. Internal and external assessments, environmental factors and confirmed regional threats were used to ascertain the suspected cause of stranding. Carcasses were buried 1–1.2 m deep on Koh Ach Seh and the coordinates of each burial site were recorded. Some carcasses were later exhumed to collect additional samples such as bone after the initial phase of tissue decomposition.

On discovering a carcass in water, photographs were taken and the site coordinates were collected using a Garmin 64s GPS. Recovery of these carcasses was dependent on the distance of the site from the research island of Koh Ach Seh. For instance, as one of the carcasses was sighted < 300 m from the island, two individuals waded out to retrieve the carcass using a tarpaulin sheet. The second carcass in water was discovered ca. 3 km east of Koh Tbal during a routine boat-based survey (Fig. 2A; Jones *et al.*, 2021). In this case, the research vessel was used to approach and tow the carcass back to Koh Ach Seh. The carcass was secured to the stern of the vessel by the tail fluke using a 5 m length of rope and the vessel maintained a speed of 7.4 km/hr to avoid damaging or deforming the carcass prior to examination. Once recovered to a safe location, the same measurements, assessments and burial procedures were conducted as above.

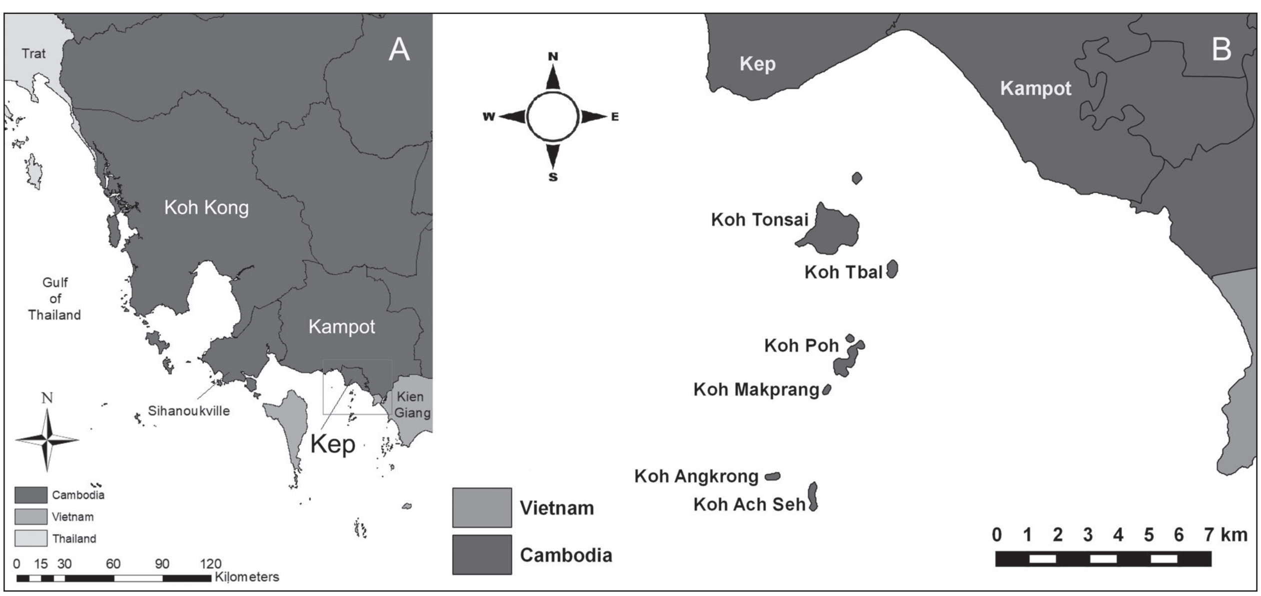

Fig. 1 A) Eastern Gulf of Thailand highlighting the Kep Archipelago (outlined area), B) The Kep Archipelago, including Koh Ach Seh where the research team resided during the study.

Distribution of strandings

The distribution of strandings was mapped using QGIS (ver. 2.8.5). The GPS locations for each Irrawaddy dolphin carcass were uploaded as point data and used to create a raster heatmap highlighting stranding hotspots. Each point was given a heat radius of 1 km and was proportioned as the number of strandings (count data) with a mean standard deviation of 2.0. Colour interpolation was set as linear with a single-band pseudo-colour render type.

Seasonality of stranding events

We report the seasonality of Irrawaddy dolphin stranding events as the mean number of stranding events per month and per season over the three-year study period. Seasons were categorised as pre-monsoon (March to April), summer monsoon (May to September), post-monsoon (October to November) and dry (December to February), as defined by Tsujimoto *et al*. (2018). Due to our small sample size (n = 10), we employed a one-tailed Fisher's exact test of independence (FET) rather than a Chi-squared (X^2) test (Winters *et al*., 2010) to investigate differences in stranding events across seasons. The influence of sex and seasonality on strandings was also assessed, although not statistically due to the small sample size.

Results

Distribution of strandings

Irrawaddy dolphin carcasses were recovered throughout the Kep Archipelago and within the Kep MFMA (Figs. 2A–2B). Eight carcasses were encountered on land (comprising four reported to CMMCP and four discovered by the research team) and two in water (Fig. 2A). The waters around Koh Ach Seh were the primary hotspot for strandings, accounting for 40% of all strandings recorded (Fig. 2B). A secondary hotspot was located in the northern archipelago along the southern tip of the Kep mainland, which accounted for 30% of the recorded strandings. The remaining 30% occurred in a trilateral formation between Koh Tonsai, Koh Poh and the waters to the east of Koh Tbal.

Seasonality of stranding events

Stranding events occurred in all seasons with a mean of 2.5 strandings per season during the study period (Fig. 3). The number of stranding events observed per season differed significantly (FET, p = 0.0215), indicating that these were not seasonally uniform. Stranding events were most prevalent during the post-monsoon season with four occurring in October and November during the study period (Fig. 3). In contrast, stranding events were least prevalent during the summer monsoon season (May to September), with just one stranding event. The post-monsoon season consequently accounted for 40% of all stranding events, whereas the remaining three seasons accounted for 60%.

Although stranding events occurred in all seasons, male and female strandings only co-occurred during the post-monsoon and dry seasons (Fig. 4). Male strandings were most prevalent during the pre-monsoon season (n = 2) when no female strandings were recorded. In contrast, no male strandings were recorded during the summer monsoon season, when one female stranding occurred. Female strandings were most prevalent during the post-monsoon season (n = 2) and an equal proportion of male and female strandings occurred during the dry season.

Our measurements of body length identified four adults and four juveniles. Strandings of calves were not observed during the study. Adult strandings occurred during three of the four seasons, pre-monsoon, post-monsoon and dry, whereas juvenile strandings occurred in all seasons (Fig. 5). Adult strandings were most prevalent during the post-monsoon season (n = 2), whereas juvenile strandings were equally prevalent in all seasons (n = 1 /season).

Necropsy findings: Sex, age, body measurements and suspected cause of strandings

Sex and age class was confirmed through necropsy of eight of the ten stranded individuals included in our study. The remaining two individuals were not examined due to the difficulty of carcass recovery and transport. For the eight individuals necropsied, four were identified as male and four as female. According to the Decomposition Condition Code (DCC) outlined by Pugliares *et al*. (2007), one female carcass was considered fresh with a DCC of 2. Six carcasses, comprising four males and two females, were in a state of moderate decomposition with a DCC of 3, and the remaining female carcass was found in a state of advanced decomposition with a DCC of 4. Tissue, teeth and bone samples were taken from all necropsied individuals. Examinations of body size and odontology identified four of the carcasses as adults and four as juveniles. The adults consisted of three males and one female, whereas the juveniles consisted of three females and one male.

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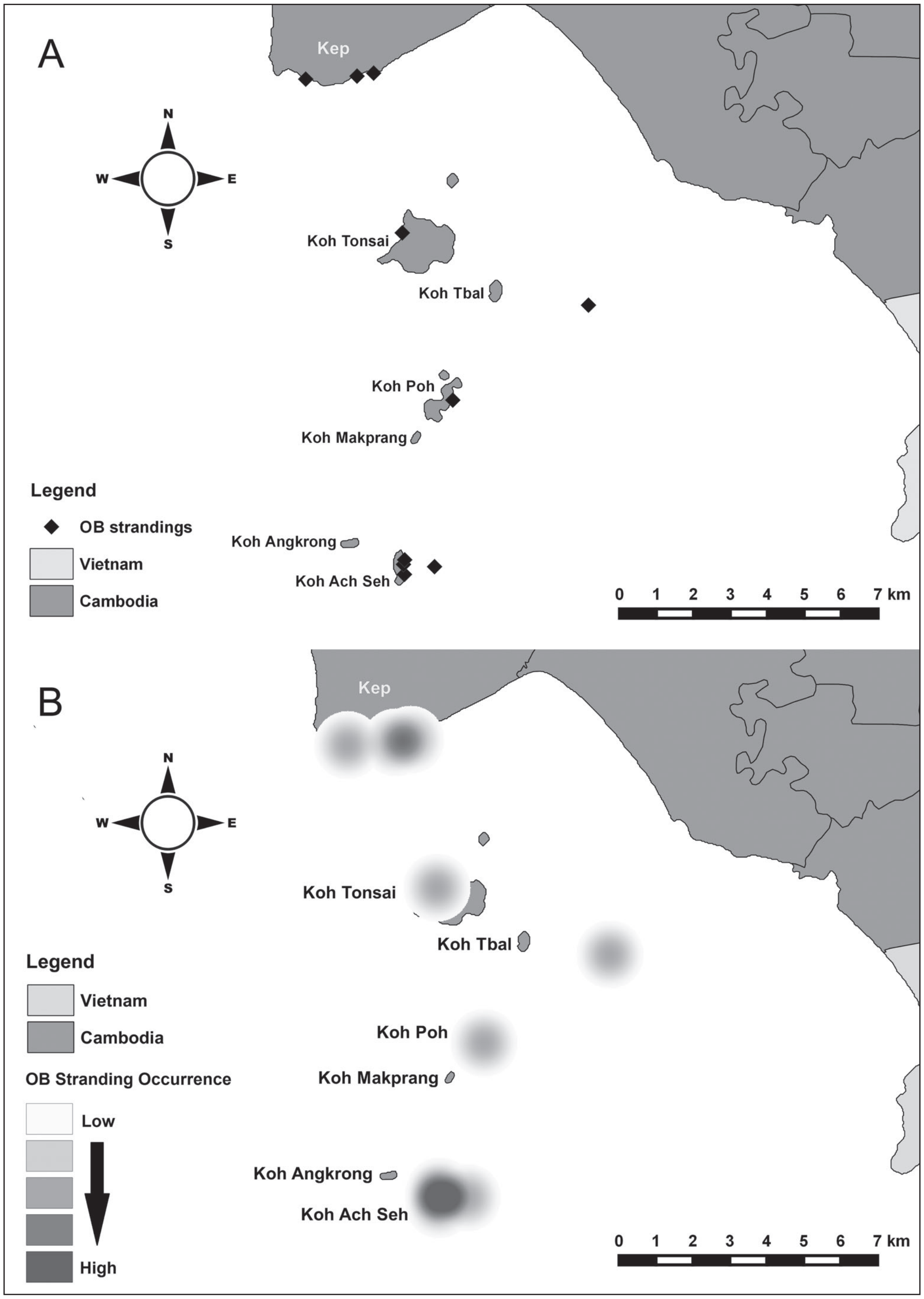

Fig. 2 Distribution of A) Irrawaddy dolphin stranding events (OB) in the Kep Archipelago and on the Kep mainland between 2017–2020, B) Hotspots of Irrawaddy dolphin stranding events during the same period.

Future analysis of samples from carcasses with DCC values of 2 and 3 may provide information about histology, virology, parasitology, contaminants, biotoxins, life history and genetics, whereas analysis of DCC 4 samples may only provide information about histology, virology, life history and genetics (Pugliares *et al*., 2007). The cause of deaths of all individuals remains uncertain due to the lack of trained personnel, levels of decomposition observed and ambiguities regarding whether external injuries occurred before or after death.

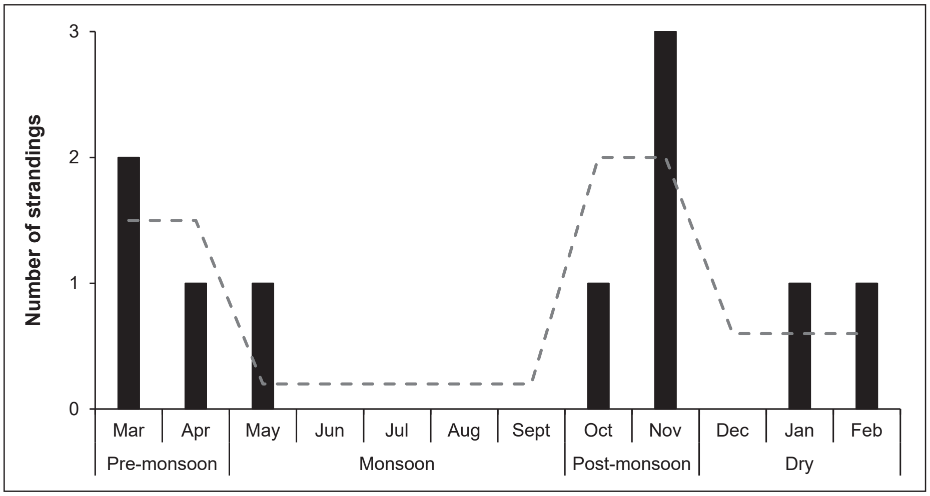

Fig. 3 Seasonality of Irrawaddy dolphin stranding events in the Kep Archipelago between 2017–2020. The dashed line indicates the mean number of strandings per season over the three-year study period.

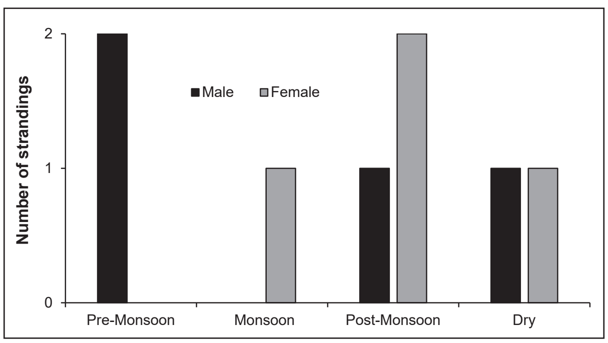

Fig. 4 Seasonality of male and female Irrawaddy dolphin strandings within the Kep Archipelago between 2017–2020.

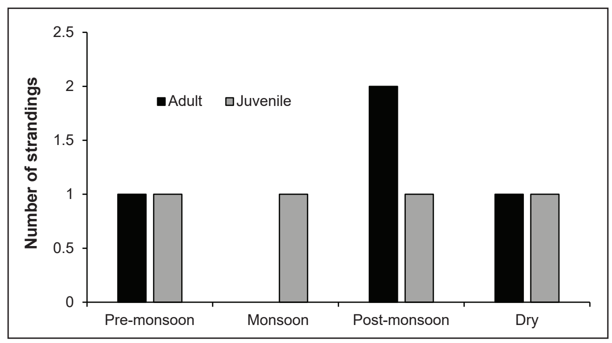

Fig. 5 Seasonality of adult and juvenile Irrawaddy dolphin strandings within the Kep Archipelago between 2017–2020.

However, our study does identify regional threats including IUU fishing activity, habitat degradation, prey depletion, chemical pollutants and historical hunting as contributing stressors likely to impact Irrawaddy dolphin health (individual and population).

Despite external examinations of the stranded individuals, we could not accurately determine cause of death due to carcass decomposition and uncertainties regarding primary and secondary injuries and diseases. Five carcasses showed evidence of interactions with fishing gear, such as the tail fluke enmeshed in netting and rope. In one case, the tail fluke of a stranded individual had been completely severed (Figs. 7A–7B) and possible causes include primary and secondary predation by sharks, or interaction with boats (e.g., propellers) and fisheries. There was no evidence of starvation or emaciation based on external examination.

Basic internal examinations indicated that all individuals had healthy stomach contents, with no evidence of plastic ingestion. Stomach contents included small fish bones including otoliths, squid beaks and shrimp tails (Figs. 6A–6B), confirming these as prey species for Kep's population of Irrawaddy dolphins. Fish bones were thought to be those of *Cirrihinus siamensis* and *Paralaubuca typus* (Baird *et al*., 1994). Stable isotope analyses were not conducted on stomach contents.

While the exact cause of death could not be confirmed, our findings suggest the following as possible causes of death: bycatch, chemical pollution, disease and other natural causes including predation. Disease and bioaccumulation of toxins within systems is highly likely to impact survival, leaving the afflicted individual more susceptible to bycatch or stranding.

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Fig. 6 Stomach contents of Irrawaddy dolphins stranded in the Kep Archipelago between 2017–2020. A) Small bony fish, undigested fish bones and squid beaks, B) Small bony fish and shrimp tail.

Fig. 7 Irrawaddy dolphins stranded in the Kep Archipelago. A) Adult male with a severed tail fluke on Koh Poh, B) Stranded individual with severed tail fluke, C) Juvenile female with burns and protruding organs on Koh Ach Seh, D) Adult male with severe blistering and flesh wounds, E) Collection of tissue, bone and teeth samples from a juvenile female on Koh Ach Seh, F) Stomach contents of an adult female found at sea west of Koh Tbal.

Discussion

Most of the strandings in this study occurred close to land, with a primary hotspot around Koh Ach Seh where four of the ten strandings were discovered. A secondary hotspot (three strandings) was located in the north of the archipelago along the southern tip of the Kep mainland. Stranding events occurred in all seasons but were most prevalent during the post-monsoon season (October to November) and least prevalent during the summer monsoon season (May to September). Necropsy findings showed evidence of external injuries typical of intra and/or interspecific interactions, including but not limited to humans, sharks and other Irrawaddy dolphins. Sex was not a determining factor in stranding likelihood, although with 50% of the identified individuals being juveniles (an unrepresentative proportion of the population), juveniles would appear to be substantially more vulnerable to stranding. Finally, while yearly trends showed a small decline in strandings events over time, from four in Year 1 to three apiece in Years 2 and 3, this plateaued with recorded strandings remaining at three per year.

Distribution, seasonality, sex and age

Our data on Irrawaddy dolphin stranding events in the Kep archipelago directly overlaps with the sightings and strandings data reported by Tubbs & Croxford (2019) and Tubbs *et al*. (2020), where dolphin sightings were clustered around Koh Ach Seh and the central archipelagic islands. This overlap highlights the Kep Archipelago as a critical yet threatened habitat for Irrawaddy dolphins. Our data also notably overlaps with reported IUU fishing activity within the region (Bohm, 2019), with strandings distributed in areas with regular and concentrated IUU fishing activity, specifically bottom trawling and electric trawling (Bohm, 2019), further emphasising the likelihood of bycatch as cause of death.

Observer bias almost certainly accounts for the higher number of strandings recorded around Koh Ach Seh, as their discovery was more likely due to the continuous presence of the research team. Similarly, observer bias may have led to a greater number of stranding reports around the Kep mainland as it is more densely populated than the archipelagic islands. To reduce this bias, a small-scale marine mammal stranding network was established in collaboration with local communities in November 2017 to facilitate reporting from the less densely populated islands of Koh Poh and Koh Tonsai.

The spatial distribution of strandings reported may also be explained by seasonal shifts in the prevailing winds. For example, the northeast prevailing winds occurring during the dry (December to February) and pre-monsoon seasons (March to April) may explain the seasonal increase in strandings on mainland (north) and western shorelines such as at Koh Tonsai. Conversely, southwest prevailing winds during the summer monsoon and post-monsoon seasons (May to November) may explain the prevalence of strandings in the east of the archipelago during the post-monsoon season such as those discovered at Koh Ach Seh and Koh Poh.

Stranding events were most prevalent during the post-monsoon season (40%), despite this only accounting for two months of the year. Tubbs *et al*. (2020) reported highest encounter rates for Irrawaddy dolphins in the archipelago during this season and attributed this to freshwater inputs and variations in prey distribution. As greater numbers of dolphins congregate in this area at this time, they are more vulnerable to threats including overfishing, bycatch and pollution. In addition, the post-monsoon season is characterised by high winds and storm events which make it difficult for law enforcement and fisheries officers to patrol the region, and this in turn results in more IUU fishing activity (Bohm, 2019; Thap R., unpublished data), increasing the threat and likelihood of dolphin strandings.

Cultural celebrations may also explain the seasonal increase in IUU activity. The water festival (*Bon Om Thook* in Khmer), a traditional Southeast Asian celebration, typically occurs in late October to early November and is celebrated with a fluvial parade and seafood banquets. This seasonal increase in seafood demand leads to a localised surge in IUU fishing activity within the Kep Archipelago, particularly bottom trawling, by both Cambodian and Vietnamese vessels (Thap R., unpublished data), resulting in increased habitat degradation and likelihood of dolphin strandings.

Our analysis of age and seasonality did not reveal any calf strandings during the study period. Conversely, juvenile strandings occurred during all seasons, whereas adult strandings did not, suggesting that juveniles are more vulnerable to stranding throughout the year. Despite accounting for 24% of sightings on average (calculated from land and boat-based sightings between 2017 and 2020: Tubbs *et al*., 2020), juveniles also accounted for 50% of strandings in the Kep Archipelago during our study, indicating that they are disproportionately susceptible to stranding and premature death. Other studies found similar results in wild Irrawaddy dolphin populations, attributing premature death in juveniles to disease (*Aeromonas hydrophila* and other opportunistic bacterial diseases: Dove, 2009), environmental contaminants (DDT, PCBs and mercury: Dove, 2009), inbreeding depression (Dove, 2009; Krutzen *et al*., 2018) and interactions with fisheries (Reeves *et al*., 2009). Juve-

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nile stranding events pose a significant concern for the long-term survival of Irrawaddy dolphin populations. Low genetic diversity, fragmented populations and slow reproduction rates, coupled with increasing population extirpations and mounting anthropogenic pressures, highlight the urgent need for improved species and habitat protection. Interactions with fisheries have been emphasized as the primary threat to Irrawaddy dolphins in both the Mekong (Reeves *et al*., 2009) and the Kep Archipelago (Bohm, 2019; Tubbs *et al*., 2019, 2020), with IUU fishing considered the most pertinent threat in Kep's coastal waters. Effective management of fisheries and enforcement of fisheries law is essential to the survival of Irrawaddy dolphins across their range. Despite the Kep Archipelago being highlighted as a critical breeding habitat for Irrawaddy dolphins (Tubbs *et al*., 2019), no calf strandings were reported within the archipelago. This may indicate a small population of sexually mature adults and/or low birth rates within the population. Sightings of calves were notably rare, accounting for less than 1% of Irrawaddy dolphin sightings in the archipelago (Tubbs *et al*., 2020).

When assessing sex and age, female juveniles were found to be the most vulnerable to fatal strandings whereas male adults were least vulnerable. This could have significant consequences for the future reproductive success of Irrawaddy dolphins in Kep as population dynamics are shifted by mounting anthropogenic pressures.

Necropsy findings and cause of death

Illegal, unregulated and unreported fishing has been regularly recorded by surveyors within the archipelago during land and boat-based cetacean observation surveys. Together with recorded cases of Irrawaddy dolphin bycatch, these suggest that IUU activity continues to pose a major threat to dolphin populations along the Kep coastline (Bohm, 2019; Tubbs *et al*., 2019).

Some of the individuals we examined showed evidence of harmful intra and/or interspecific interactions including body scars, nicks, notches and a severed caudal fin. These external injuries may have been caused by other Irrawaddy dolphins, sharks or interactions with fishing gear. It is unclear whether they occurred prior to or following death. Injuries prior to death may not have been immediately fatal, although they are likely to have hindered the survival of the afflicted individual, resulting in increased risk of disease, stranding and premature death.

Chemical pollutants such as polychlorinated biphenyls (PCBs) and agricultural fertilisers can build up to toxic levels in the marine environment (Chia, 2000; Todd *et al*., 2010). Bioaccumulation and biomagnification of PCBs, fertilisers and other chemical pollutants in dolphin blubber can severely impact reproductive success and immune responses and increase the likelihood of premature death from disease and infection (Aktar *et al*., 2009; Jepson *et al*., 2016). With riverine inputs from the Giang and the Kampot rivers and a ubiquity of such chemical pollutants in Cambodia, the Kep Archipelago is vulnerable to threats posed by wastewater and agricultural runoff. Although we could not test for such contaminants due to a lack of precision equipment, in-situ veterinary assistance and laboratory support, toxic bioaccumulation may have contributed to dolphin strandings and death and blubber and other soft tissue samples were retained for future analysis. Given the appropriate resources, stable isotope analysis of stomach contents and tissue toxicity levels could also be assessed in future. However, consistent with stable isotope analysis of other Irrawaddy dolphin populations in the Gulf of Thailand and the Andaman Sea (Jackson-Ricketts *et al*., 2018), direct observation of stomach contents confirmed small bony fish, crustaceans and cephalopods as prey species. Noise and plastic pollution were dismissed as possible causes of stranding due to modest vessel traffic within the region and lack of plastic entanglement and ingestion in examined individuals.

Despite current regional threats to the species, the strandings documented here could have been due to natural causes such as illness, infection, internal malfunction, and disease, including age-related diseases. Long-term monitoring of strandings, improvement of a national stranding network (including access to marine mammal veterinarians and adequate sampling equipment and storage) and collaboration among marine mammal research organisations across the Indo-Pacific region is essential to understanding the causes of Irrawaddy dolphin strandings and to ensuring appropriate implementation of conservation legislation and management strategies.

Marine mammal stranding programmes in SE Asia

The report of the third Southeast Asian marine mammal symposium (Hines *et al*., 2015) outlined the activities and findings of marine mammal conservation and research programmes across the Indo-Pacific region. At the time of its publication, China, Japan, Taiwan and Thailand reported well-established national stranding programmes created by fisheries administrations or independent research initiatives. These initiatives attributed their success to awareness, international collaboration, trained personnel, infrastructure, funding and

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expertise. Most recently, in 2015, the IUCN and Swedish postcode lottery provided funding, training and technical support to Thailand's Department of Marine and Coastal Resources. This support improved data collection and strengthened the capacity of the dolphin stranding network (Smith *et al*., 2016). Programs such as this provide a replicable framework for neighbouring countries such as Cambodia, Myanmar and Vietnam to follow.

Conversely, Brunei, Cambodia, China, Indonesia, Malaysia, Myanmar, the Philippines, and Vietnam reported scarce or unsubstantiated bycatch and strandings data. They also highlighted a need for formal monitoring through a coastal-wide, nationally coordinated stranding response, supported by adequate funding, facilities, researchers and trained personnel. The Department of Fisheries Malaysia identified capacity-building, education and international collaboration as priorities for long-term research and conservation initiatives, extending to the establishment of national strandings networks (Hines *et al*., 2015).

Short-term solutions in the form of online collaboration and communication through forums such as the Global Stranding Network (www.globalstrandingnetwork.com) have been highlighted as useful tools for raising awareness, sharing training materials and protocols and identifying areas of global concern (Gulland & Stockin, 2020). These, combined with funding, expertise and facilities on longer timescales would enable developing nations such as Cambodia to implement an enhanced coastal-wide marine mammal stranding programme, with potential for transnational collaboration. Such a programme could provide valuable information about the histology, virology, parasitology, contaminants, biotoxins, life history and genetics of Irrawaddy dolphins, in addition to informing management strategies for the species and its habitats.

A nationally coordinated response is urgently needed to address threats to coastal Irrawaddy dolphins in Cambodia. This could be led by a statutory body such as the Fisheries Administration or by non-government organisations such as Marine Conservation Cambodia or the World Wildlife Fund for Nature. This effort should focus on responding to and transporting fresh carcasses to qualified veterinarians at fully equipped laboratories as quickly as possible so that the causes of death can be accurately determined. With funding, training and technical support, Cambodia can provide important data on Irrawaddy dolphin strandings, and put effective measures in place to prevent the continued decline of this globally Endangered species.

Conclusions

Between 2017 and 2020, ten fatal Irrawaddy dolphin strandings were recorded within the Kep Archipelago. This study found that stranding events occurred in all seasons throughout the archipelago, with juveniles most vulnerable to fatality. The causes of death could not be confirmed due to lack of trained personnel, facilities and resources, although disease, chemical pollution and bycatch as a result of IUU fishing represent the most likely causes. Establishment of a coastal-wide marine mammal stranding network is urgently needed to record, analyse and mitigate Irrawaddy dolphin strandings. Lessons from stranding programmes in neighbouring countries highlight the importance of adequate funding, facilities, resources and trained personnel in creating and maintaining large-scale stranding networks. We strongly recommend the initiation of a collaborative, coastal-wide strandings network to improve understanding of the anatomy, physiology, pathology and genetics of Irrawaddy dolphins and inform related conservation efforts in Cambodia and across their range.

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