Ecological and Environmental Management During the Hail 3D Transition-Zone Survey: Safe Working Practices Within a UNESCO World-Biosphere Reserve

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Summary

The Hail 3D transition-zone seismic survey, carried out by Abu Dhabi National Oil Company (ADNOC) in 2013–14, was located within an area considered to be of significant national and international environmental importance. Falling within a designated marine protected area (MPA) that was ratified by Abu Dhabi ministerial decree, as well as in a United Nations Educational, Scientific, and Cultural Organization (UNESCO) world-biosphere reserve, high standards of environmental and ecological management throughout the acquisition program were of paramount importance.

Effective environmental and ecological management throughout the project was attained through the design and implementation of numerous working procedures and monitoring programs. These included the development of specific sets of mitigation guidelines for use during transition-zone surveys for minimizing disturbance and injury to marine mammals and turtles and for operating within mangrove areas, and the use of environmental profiling, auditing, and post-operational monitoring in both the terrestrial and marine environment for collecting new data on the biodiversity and ecology of the area.

For the first time, we present ecological and environmental data collected over a period of 12 months within the Hail shoal area. In addition to data on species numbers and distributions, we present a method for effectively managing complex seismic surveys being carried out simultaneously in both the marine and terrestrial environment.

For marine-mammal and turtle species, visual observations were compared over time and analyzed against seismic activity by use of a regression analysis. Our results demonstrate seasonal variation in total numbers throughout the year, with no significant reduction in observed numbers occurring as a result of seismic-exploration activities.

We further demonstrate how a complex seismic survey can be managed and supervised to mitigate and minimize the environmental footprint or negative impacts on biodiversity as a result of the exploration and resource development considered crucial to the socioeconomic development of Abu Dhabi.

Introduction

Marine seismic operations that use air guns have the potential to negatively impact marine wildlife, including cetaceans, sirenians, sea turtles, and other marine taxa.

Many papers have been penned to numerous journals and magazines of diverse areas of erudition and learning pertaining to the effects of subsurface audio disturbance from seismic-source acoustic energy (Southall et al. 2007; Madsen and Møhl 2000; OSPAR Commission 2009). Several studies have noted a range of adverse reactions of marine fauna to seismic operations. Documented effects of seismic surveys on marine fauna include spatial-avoidance behavior by Atlantic spotted dolphins (*Stenella frontalis*) (Weir 2008), bowhead whales (*Balaena mysticetus*) (Ljungblad et al. 1988), and several species of delphinids and mysticetes in UK waters (Stone and Tasker 2006); startle-and-dive response in loggerhead sea turtles (*Caretta caretta*) (DeRuiter and Doukara 2012); altered vocalization patterns in blue whales (*Balaenoptera musculus*) (Di Iorio and Clark 2010); and complete cessation of vocalizations in fin whales (*Balaenoptera physalis*) (Clark and Gagnon 2006). For a review of seismic-survey effects on marine mammals and other environmental implications, see Gordon et al. (2003) and McCauley et al. (2000).

It is worth noting, however, that several similar studies were either inconclusive or found little to no evidence of negative impacts on marine fauna from seismic-survey activities (Gosselin and Lawson 2005; Parente et al. 2006; Richardson et al. 1986; Weir 2007; Yazvenko et al. 2007).

The Hail 3D transition-zone seismic survey constitutes the first of its kind in the UAE with mitigation measures dedicated to transition-zone surveys. Further, transition-zone seismic surveys as a whole represent only a small percentage of seismic operations worldwide. This, coupled with the lack of any survey-specific on-site regulatory management within the UAE for marine mammals and other marine fauna during seismic operations, highlights the need to develop a set of guidelines for industrial best practice within the region.

Current national environmental legislation for marine mammals and turtles in the UAE is limited and not specific to mitigation during seismic operations. Dugong (*Dugong dugon*) are protected under UAE Federal Laws No. 23 and 24 (1999); however, these mostly refer to the protection of dugong from direct hunting and fishing activities. Regional environmental legislation includes Appendix II of the Convention on the Conservation of Wildlife and Their Natural Habitats in the Countries of the Gulf Cooperation Council (Cooperation Council for the Arab States of the Gulf 2009), which provides general protection for one species of marine mammal, *D. dugon*, but does not cover any other species or cover specific operations such as marine seismic surveys. International legislation agreed by the UAE includes the signing of three memorandums of understanding: the Memorandum of Understanding on the Conservation and Management of Marine Turtles and Their Habitats of the Indian Ocean and South-East Asia (CMS 2009), the Memorandum of Understanding on the Conservation and Management of Dugongs (*Dugong dugon*) and Their Habitats Throughout Their Range (CMS 2007), and, most recently, the Memorandum of Understanding on the Conservation of Migratory Sharks (CMS 2014).

In areas where there is no specific regulatory management for marine fauna during seismic operations, it is considered environ-

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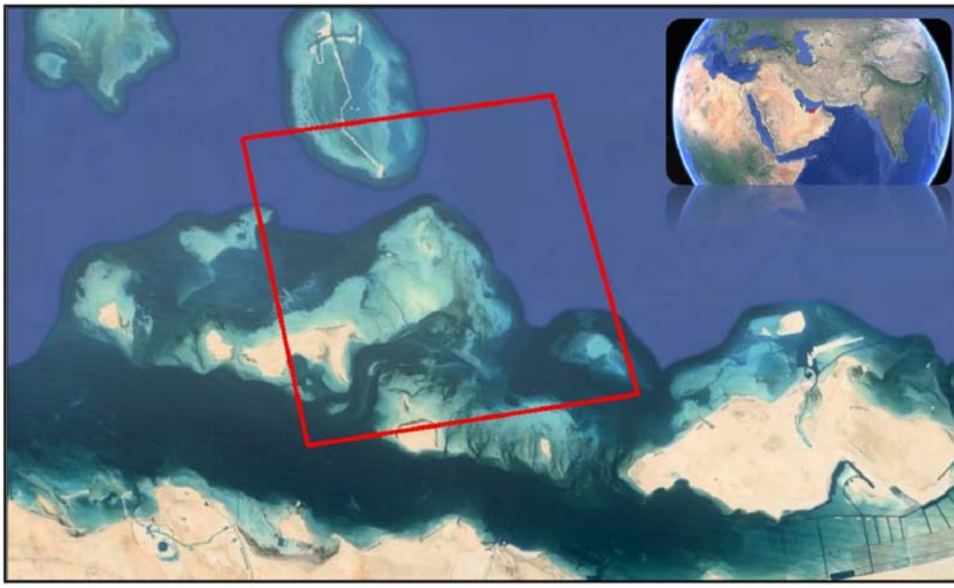


Fig. 1—Map of prospect/study area. (Google Earth; Image: Landset; Data: SIO, NOAA, US Navy, NGA, GEBCO.)

mental best practice to adopt and follow the guidelines of other countries, which in most cases have been the Joint Nature Conservation Committee (JNCC) guidelines of the UK. These guidelines, while well-established and offering a good framework for marine-mammal mitigation, were originally designed as part of the Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS 2015) convention for use in the deep waters of the North Sea (Weir and Dolman 2007), and do not in all cases provide a comprehensive and fully workable set of guidelines for different types of seismic survey such as transition-zone surveys. For use during the Hail 3D transition-zone seismic survey, a set of guidelines were created that, while modeled originally on the JNCC guidelines, could be used during transition-zone surveys, taking into consideration the complexity of such operations and yet providing the best-possible mitigation measures to prevent disturbance/injury to marine mammals and turtles.

Prospect Location. The prospect zone is located in the Hail field, approximately 95 km west of Abu Dhabi. Covering an area of 636 km^2, the acquisition area falls over a transition zone that includes land, tidal flats, and shallow water (**Fig. 1**). The majority of the prospect area falls within one of the five designated MPAs within the UAE (**Fig. 2**), which is the only one that has currently been ratified by Abu Dhabi ministerial decree (Emiri Decree No. 18 of 2001 Declaring Marawah as a Protected Marine Area). Further to this protection, the area was also designated a world-biosphere reserve

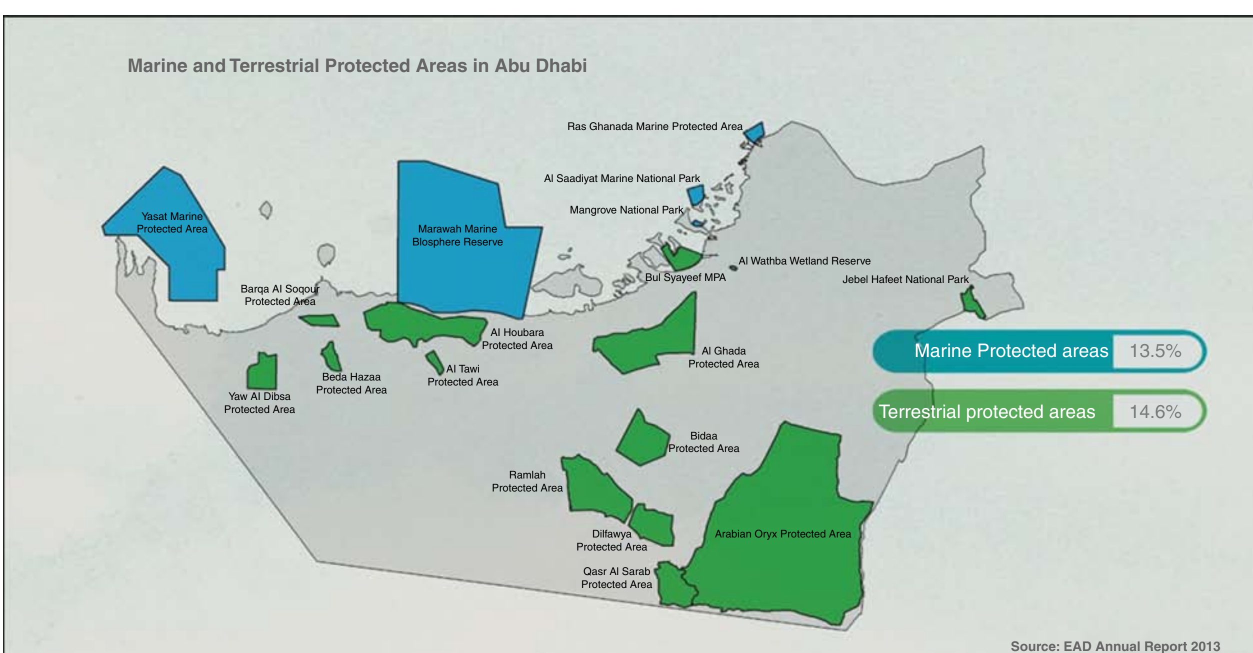


Fig. 2—Map displaying protected areas established across the emirate of Abu Dhabi (EAD 2013).

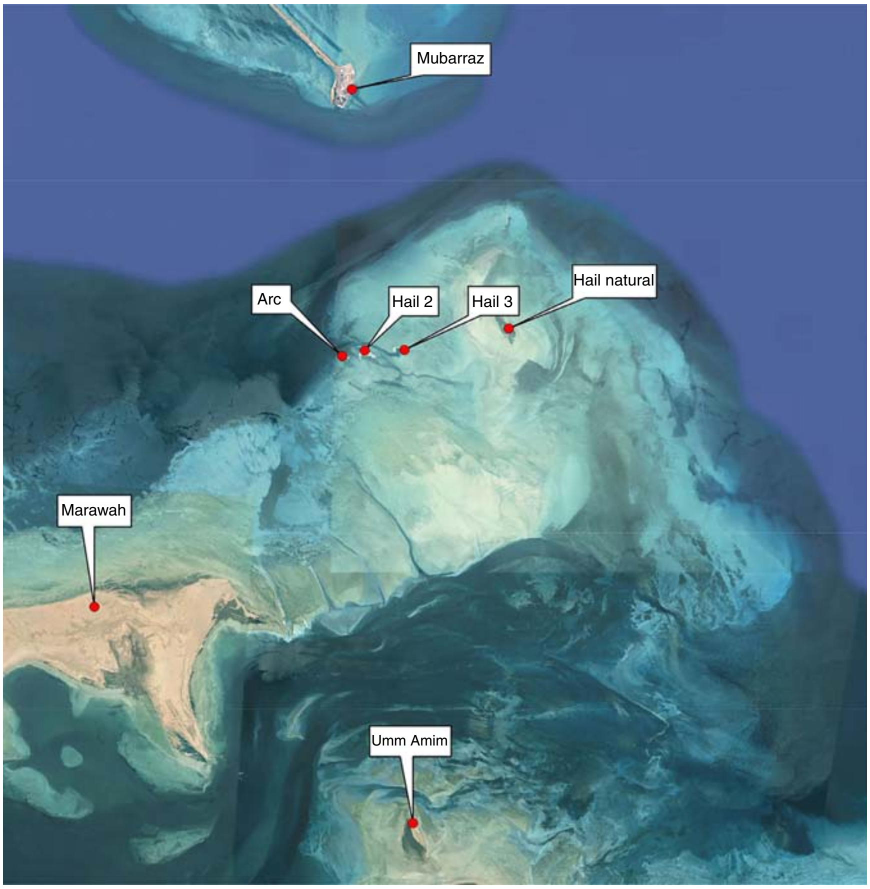


Fig. 3—Satellite image of islands within the prospect area: Hail 2, Hail 3, Arc, Hail Natural, Mubarraz, Marawah, and Umm Amim. (Google Earth; Image: DigitalGlobe; Data: SIO, NOAA, US Navy, NGA, GEBCO.)

in 2007 as part of UNESCO's "man and biosphere program," covering a total area of 4255 km^2 (**Fig. 3**), making any management and environmental mitigation particularly important.

Biosphere reserves are intended to support sociocultural and environmentally sensitive economic and human development alongside biodiversity conservation. This remit is usually achieved through zonation, with a central "core" and surrounding buffer zone, each with specific activities controlled for each. The Hail shoal falls on the outer edge of the designated core zone and within the buffer zones of the MPA.

Because of the international importance of this designation, the Abu Dhabi government has a responsibility to ensure the area is conserved and managed sensitively. Designation of areas and awards by UNESCO are reviewed periodically (every 10 years) and can be removed (or undesignated) should the strict criteria not continue to be met (Nautica Environmental Associates LLC 2012).

Methods

Before any survey activities within the area, an extensive project-specific health, safety, and environmental impact assessment (HSEIA) was produced on behalf of ADNOC. The purpose of this document was to identify potential environmental hazards that could occur as a result of project activities and to detail methods either to remove these hazards or to reduce them to lower levels as far as reasonably practicable.

Environmental supervision on the project was carried out by two ADNOC representatives. One representative was on crew at all times providing constant environmental supervision throughout the course of the survey. In addition, the seismic contractor was requested to provide a team of protected-species observers (PSOs) and passive-acoustic-monitoring (PAM) operators. This took the form of two PSOs and one PAM operator on crew at any one time. The purpose of these personnel was to carry out protected-species mitigation during seismic activities.

Mitigation Protocol During Marine Seismic Surveys. One PSO was placed onboard each of the larger source vessels (800 and 1,120 $in.^3$, respectively) during seismic-survey activity. These observers monitored seismic operations to ensure compliance with the specific mitigation measures created for the survey by ADNOC (Appendix A).

The seismic survey took place from north to south. This arrangement, while allowing for optimal survey activity, also allowed activities to be restricted as much as possible to occur outside of periods of high sensitivity for key species in specific areas, as identified in the project HSEIA. This was particularly important for work being carried out near Hail Natural and Umm Amim Islands, both recognized as being highly important areas for birds, including a number of UAE priority species (Nautica Environmental Associates LLC 2012).

Visual assessments of the surrounding area were made before any use of the seismic air guns by means of a combination of scanning the surrounding water with the naked eye and using binoculars (10×40) to further examine areas of interest, a method commonly used in marine-mammal monitoring (JNCC 2015).

Monitoring effort continued throughout all seismic operations, with all observations recorded to analyze trends and distributions. Information gathered during a sighting included date, start and end times of encounter, species (or higher taxonomic grouping if unable to determine species), number, location [latitude and longitude, World Geodetic System 1984 (International Terrestrial Reference Frame 2008)], water depth to mean sea level, a description

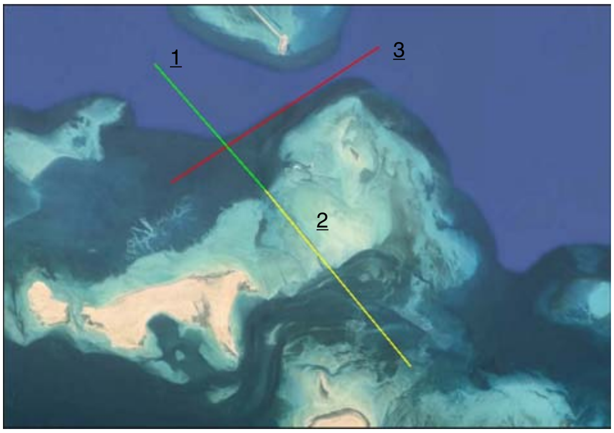


Fig. 4—Satellite image of prospect area highlighting cross-sectional survey transects (1 = Hail NW, 2 = Hail SE, 3 = Mubarraz Channel). (Google Earth; Image: DigitalGlobe; Data: SIO, NOAA, US Navy, NGA, GEBCO).

of characteristics, behavior, bearing and range from vessel, direction of travel (relative to vessel and compass points), air-gun activity during sighting, and any mitigation actions if required.

Additional Monitoring and Surveys. In addition to monitoring during marine seismic operations, the following surveys were designed to provide a more-extensive environmental and ecological monitoring program in the Hail 3D prospect area. These surveys were carried out by the ADNOC environmental representative. During all additional monitoring surveys, position data were collected by use of a Garmin® eTrex 20 handheld global-positioning-system (GPS) unit, and images were recorded by use of a Nikon® D60 camera with 18- to 55-mm, 55- to 200-mm Nikor lens or a Canon® Rebel T2 with a 55- to 300-mm Canon lens. Because all oil fields in the UAE are protected by security protocols, especially for film and picture taking, all cameras had Critical National Infrastructure Authority authorization before being taken to the survey sites.

The aims of these surveys were

1. To identify hazards to the environment as a result of survey activities, removing or reducing these hazards where possible
2. To monitor survey activities in real time, reviewing existing hazard-mitigation measures and implementing further measures where required
3. To assess and document existing environmental damage in the area not attributable to survey activities
4. To make environmental assessments after survey activities to identify any damage to the environment as a result of operations and restoration work needed, if any
5. To collect data on the abundance and distribution of marine mammals, birds (terrestrial and marine), sea turtles, and other marine fauna located within the Hail prospect area
6. To allow analysis over time, highlighting trends and/or changes throughout the duration of the project
7. To allow analysis across the prospect area, identifying and highlighting key areas of ecological importance
8. To collect any other relevant information relating to the environment in the prospect area

The following surveys were designed to achieve these aims and, combined with the standard marine-fauna surveys being conducted alongside marine seismic operations, provided a more-detailed view of ecological and environmental conditions within the Hail prospect area during the project.

- Island environmental surveys, carried out before, during, and after survey operations
- Prospect cross-sectional surveys
- Opportunistic vessel surveys

Island Environmental Surveys. A number of islands are located within the seismic-survey area (Fig. 3). These islands differ widely in their characteristics, ranging from natural uninhabited islands with vegetation cover and sand flats to man-made islands consisting mainly of sand and coral rubble.

By conducting environmental surveys on these islands, a better understanding of species abundance and diversity within the prospect area could be achieved along with the identification of potential environmental impacts on specific species of interest.

The aims of island environmental surveys were

1. To assess potential impacts deriving from the seismic acquisition program using Vibroseis® trucks and upholes
2. To identify and select areas of environmental sensitivity to be designated as exclusions with a safety buffer zone during seismic operations
3. To conduct bird surveys by means of total counts and bird-nest surveys to allow survey planning around peak times for breeding birds
4. To investigate the presence of sea turtles and sea turtle nest sites
5. To conduct marine-mammal/turtle carcass surveys
6. To collect any other relevant environmental data, as necessary

Island environmental surveys were carried out on foot, recording observations and species numbers. Areas of specific interest, such as uphole drill locations and areas with mangrove growth, were surveyed before, during, and after survey operations. A further set of mitigation measures was developed for use during operations within mangrove areas and were used during all land-based seismic operations (Appendix B).

Cross-Sectional Surveys. The prospect zone covers an area of approximately 636 km^2. While large amounts of ecological data were collected during marine seismic operations, these data were limited to areas in which the two large seismic-source vessels had been operating. The purpose of the prospect cross-sectional surveys was to conduct dedicated marine-mammal, seabird, and other marine-fauna surveys along predetermined transect lines, which would cover as much of the prospect area as possible independent from operational activities. To achieve this, three survey transect lines were created, crossing the prospect area **(Fig. 4).** Visual monitoring for marine fauna followed the same procedure as monitoring during seismic activities.

The aims of these surveys were

1. To record marine fauna in the survey area
2. To collect data from a much wider area and independantly of marine seismic operations, allowing the identification of key areas of high marine-fauna density
3. To be repeatable and allow comparisons over time, highlighting trends and seasonal changes in species diversity and abundance throughout the duration of the project

Cross-sectional transects were surveyed by use of a variety of vessels, depending on water depths and the tide cycle. During all surveys, the vessels traveled at speeds of approximately 11 knots, with the observer positioned on deck in a position that provided the best field of view around the vessel. Observations were recorded whenever made, at any distance or location.

Opportunistic Vessel Surveys. Whenever onboard a vessel, but not engaged in a cross-sectional survey, observations of marine mammals, turtles, other marine vertebrates, and birds were made and recorded as opportunistic sightings. This allowed the recording of data that would otherwise go unrecorded as vessels moved around the prospect for transect surveys or transiting to and from different islands. Surveys were completed as described previously, except for survey lines (see cross-sectional-survey method).

Standardization of Data. To standardize observation data, the unit observation rate (O_r) was created. The observation rate was calculated by dividing the number of observations (O_n) by the total observation time (O_t) and multiplying by 100, thus creating a unit

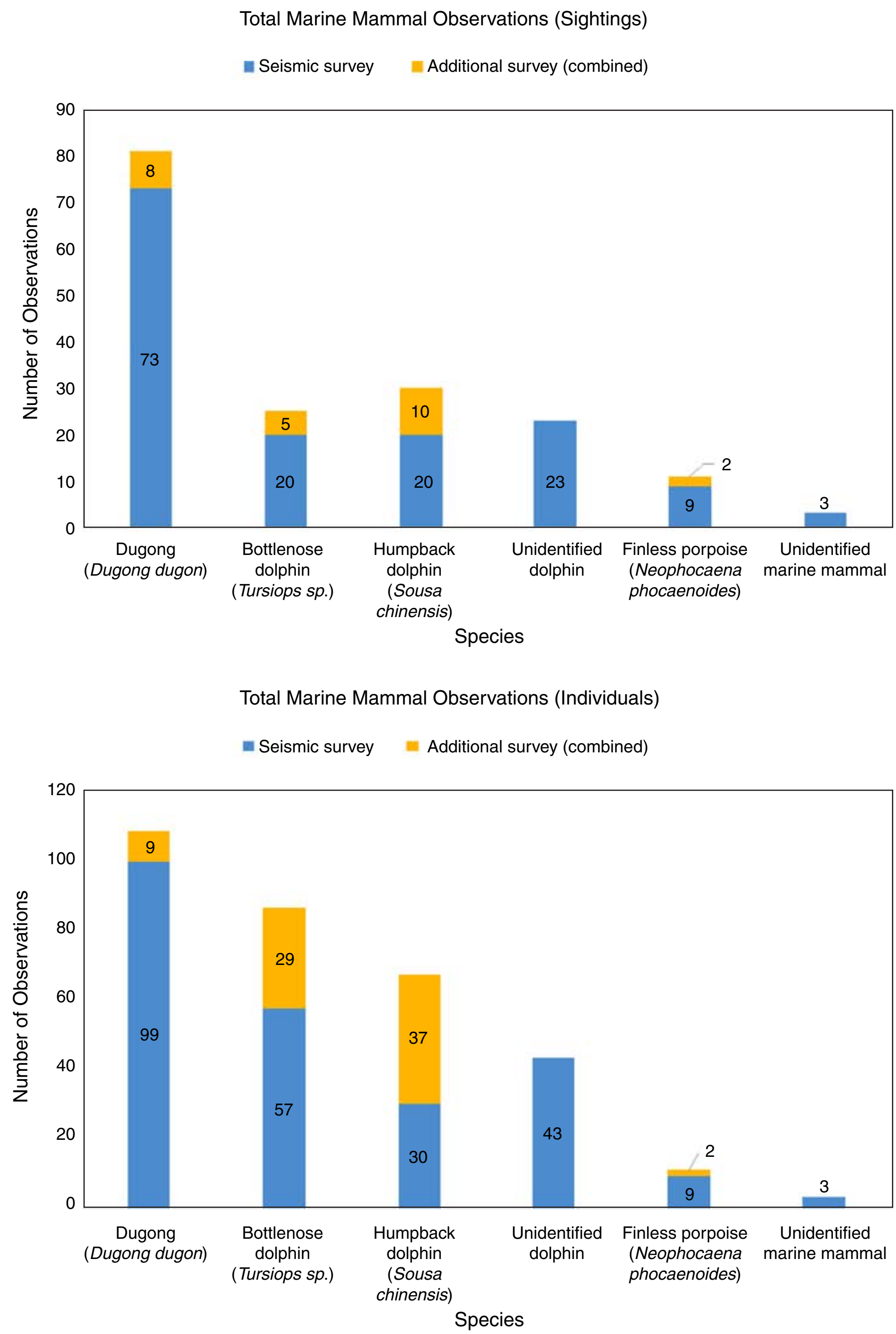


Fig. 5—Total marine-mammal observations by species and survey type.

of measure that allowed comparisons to be made between surveys that differed in duration:

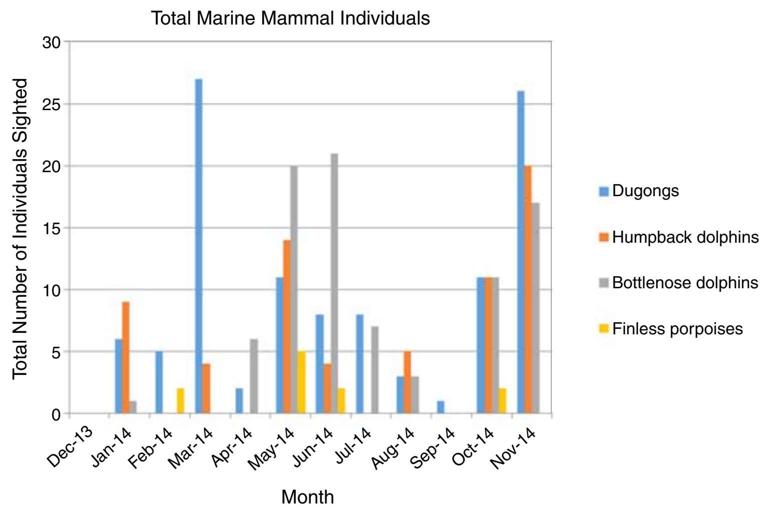
$$O_r = \frac{O_n}{O_t} \times 100 \quad \text{......(1)}$$

Plotting Distribution Data and Statistical Analysis. Observation data were plotted with QGIS (2015) software. Statistical analysis was carried out using Microsoft® Excel.

Additional Mitigation Measures. Throughout the course of the project, activities were monitored actively and, where necessary, additional mitigation measures were implemented. These include the designation of specific vehicle-crossing routes while moving vibrators and other vehicles between islands over shallow-water areas. These routes were scouted ahead of any large-vehicle movements by use of a small all-terrain vehicle and mapped to avoid areas of seagrass growth and other sensitive areas. Designated routes were marked with white flags and entered into GPS devices for use by other vehicles. The use of designated routes allowed any

Species	Seismic Survey	Other Survey (Transect)	Other Survey (Opportunistic)	Other Survey (Combined)
Sightings				
Dugong (*Dugong dugon*)	73	1	7	8
Bottlenose dolphin (*Tursiops* sp.)	20	5	0	5
Humpback dolphin (*Sousa chinensis*)	20	1	9	10
Unidentified dolphin	23	0	0	0
Finless porpoise (*Neophocaena phocaenoides*)	9	0	2	2
Unidentified marine mammal	3	0	0	0
Total Marine Mammals	148	7	18	25
Individuals				
Dugong (*Dugong dugon*)	99	1	8	9
Bottlenose dolphin (*Tursiops* sp.)	57	29	0	29
Humpback dolphin (*Sousa chinensis*)	30	2	35	37
Unidentified dolphin	43	0	0	0
Finless porpoise (*Neophocaena phocaenoides*)	9	0	2	2
Unidentified marine mammal	3	0	0	0
Total Marine Mammals	241	32	45	77

Table 1—Total marine-mammal observations by species and survey type.



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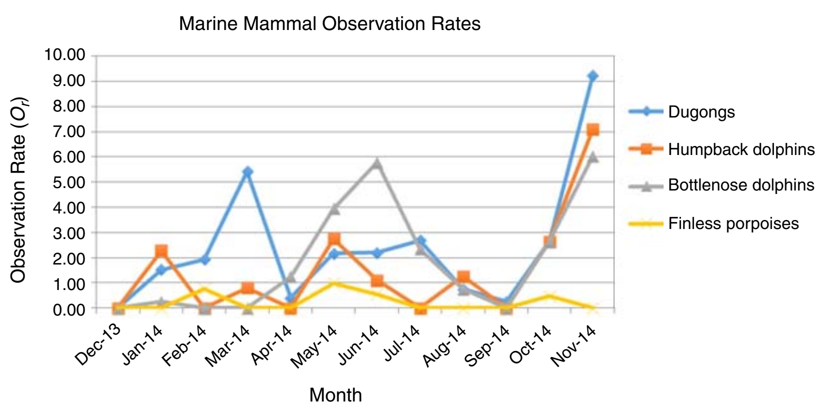


(b)

Fig. 6—(a) Total numbers of dugongs, dolphins, and finless porpoises observed by all observers on all surveys from December 2013 to November 2014. (b) Observation rates (number of individuals/on-effort observational hours × 100) of dugongs, dolphins, and finless porpoises from December 2013 to November 2014.

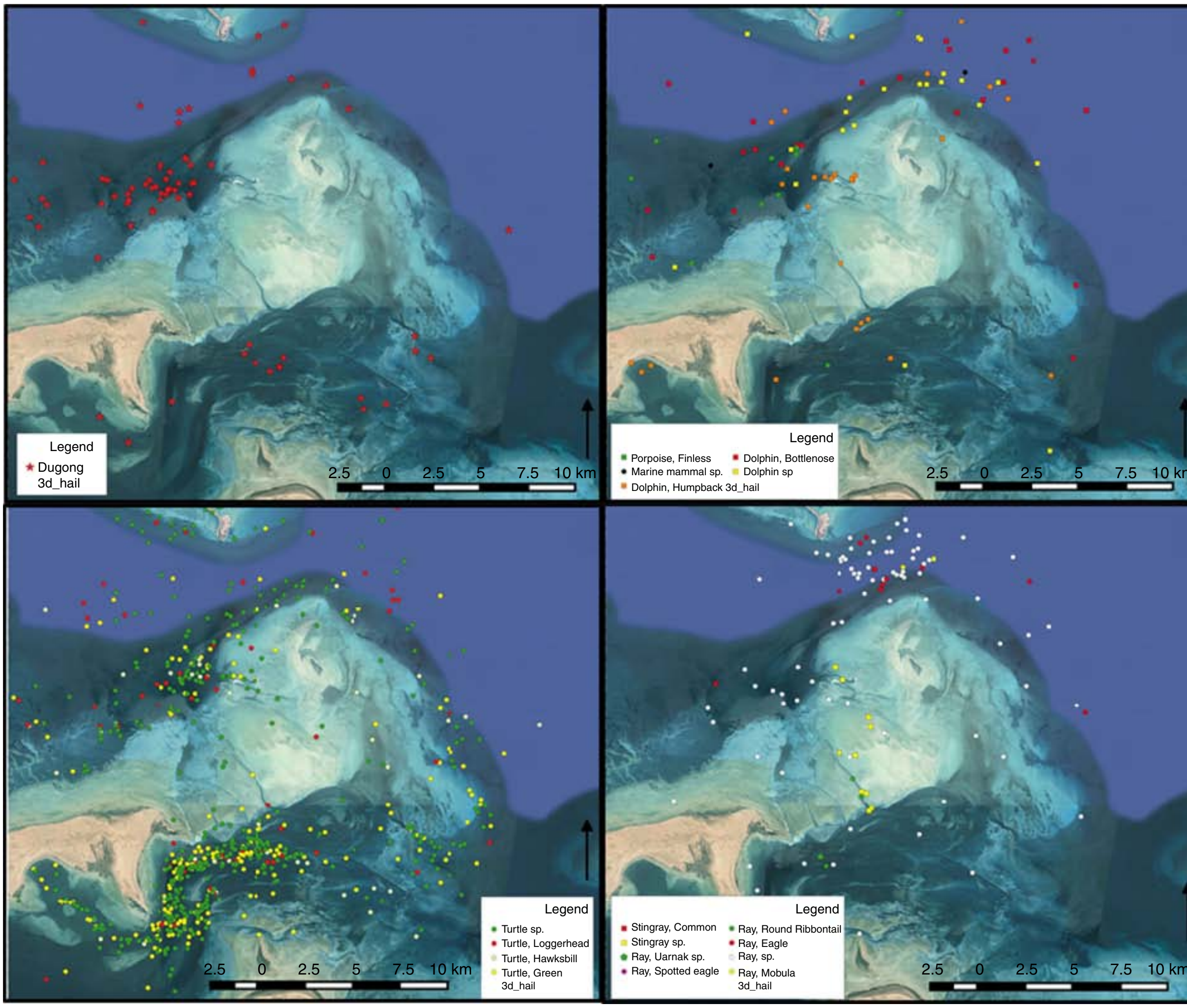


Fig. 7—Observations within the Hail 3D prospect areas. Dugong (top left), dolphin species (top right), turtle species (bottom left), and ray species (bottom right).

potential disturbance to substrate to be limited to areas of reduced environmental sensitivity.

Species abundance and distribution were monitored continuously throughout the project. This allowed the mapping and identification of high-density areas for certain species. Once identified, additional mitigation measures were used within these areas to further reduce potential environmental risk. These included vessel speed limits within two areas identified as being of high density for dugongs and sea turtles.

Further additional mitigation measures specific to location were used within the UNESCO core zone. A small area on the eastern part of the survey area fell within the core-zone designation. While operating in this location, vessel movements were highly restricted, with only vessels involved in active survey being permitted and no vessels on standby allowed within this zone. No bunkering or maintenance involving hydraulic fluid, fuel, water coolant, or bilge pump was allowed. Anchor points were restricted to three predesignated locations that had been surveyed and confirmed to be clear of seagrass and coral before deployment. In addition, the anchoring system used within these areas involved a low-impact weight system that further reduced impact on the sea floor.

All vessels and Vibroseis vehicles were fitted with fuel-spill-containment equipment. Both vessels and Vibroseis vehicles operating within the shallow water followed the vessel-spill emergency contingency plan prepared before the start of the survey. Further spill-mitigation measures included specialized spill-free fueling fittings fixed to vessels and biodegradable hydraulic oil used in Vibroseis vehicles.

All vessels used during the seismic survey were either jet propelled or fitted with prop guards, with speeds reduced to prevent injury to marine species and disturbance to sea grass by propeller damage.

Results

Marine-Fauna Observations. Sighting data for marine mammals, sea turtles, and other marine vertebrates (e.g., rays) from all observers and types of surveys (e.g., observations from seismic vessel, dedicated survey transects, and opportunistic surveys) were combined to increase sample size and enable enhanced investigation of ecological parameters (e.g., seasonality, group size). The results are presented by taxonomic grouping in the following subsections.

Marine Mammals. A total of 318 marine mammals distributed over 173 sightings were recorded during the project (**Fig. 5; Table 1**). Of these, 81 sightings (47%) were of dugongs (*D. dugon*), 89 sightings (51%) were of cetaceans, and three sightings (2%) were of unidentified marine mammals. Cetaceans accounted for 63% (O_n = 207) of the 318 individual marine mammals observed, with dugong sightings making up 34% (O_n = 108). Of the 207 cetaceans observed, 196 were dolphins and 11 were finless porpoises. Of the 196 dolphins sighted, 43 (22%) could not be identified to species level as a result of several factors that made identification difficult (e.g., distance and brevity of sighting).

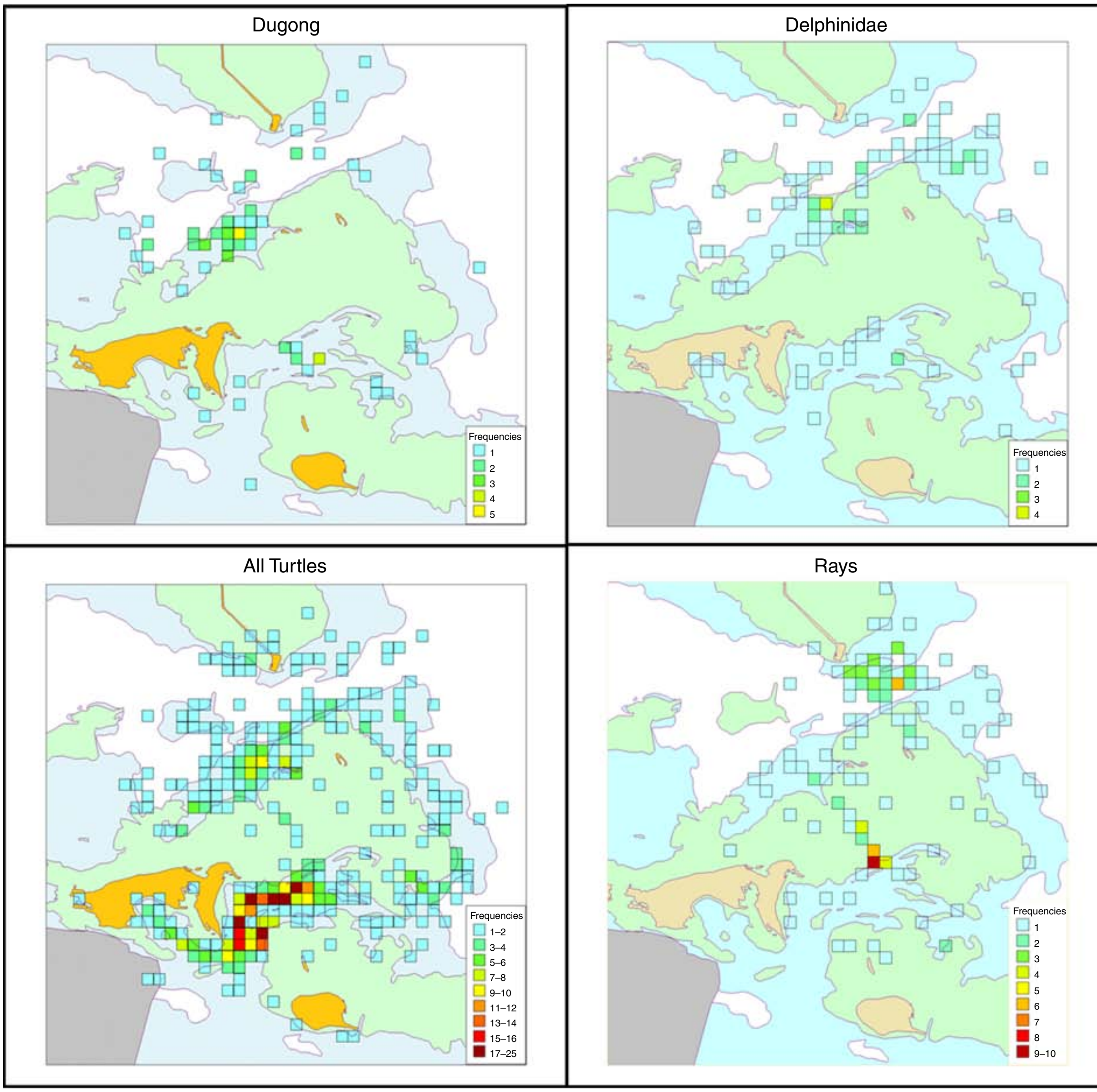
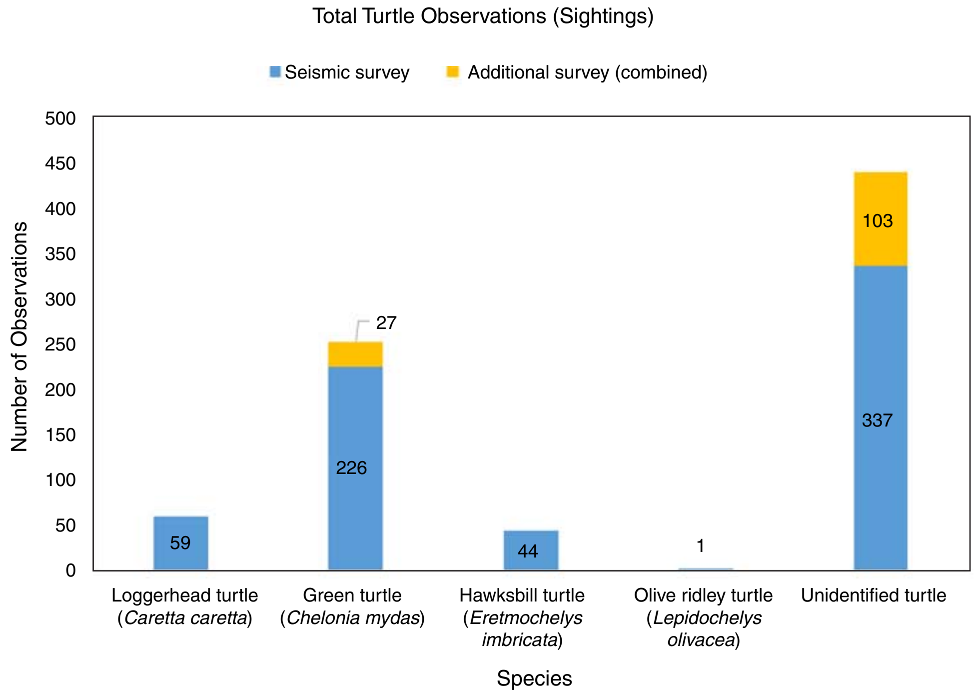


Fig. 8—Frequency distribution plots within the Hail 3D prospect area. Dugong (top left), dolphin species (top right), turtle species (bottom left), and ray species (bottom right).

Dugongs. The dugong was the most-commonly-sighted and most-numerous marine-mammal species encountered throughout the project period (81 sightings of 108 individuals). Group size ranged from one to six (average = 1.33). Most sightings were of single dugongs (O_n = 67), with eight pairs, two trios, two groups of four, and one group each of five and six observed. Dugongs were sighted in water depths between 2.2 and 16.3 m, with an average sighting depth of 7.3 m. Most dugongs were sighted during March and November (O_n = 27 and 26, respectively), with no dugongs observed during December 2013 and a single animal sighted in September 2014. The highest dugong-observation rates occurred in November (O_r = 9.24), followed by March (O_r = 5.42) **(Fig. 6).** Few dugongs were observed in April (O_n = 2; O_r = 0.41), with a moderate increase to a lower peak in July (O_n = 8; O_r = 1.46). An area of high dugong density located a few kilometers west/southwest of Hail 3 was identified **(Figs. 7 and 8).**

Humpback Dolphins. Humpback dolphins, the second-most-commonly-sighted marine mammal, were observed during 35 sightings, comprising 67 individuals. Group sizes ranged from one to eight individuals (average = 2.23), with a single animal being the most commonly encountered (O_n = 13). Average sighting water depth was 6.1 m, with sightings occurring in water depths ranging from 1.2 to 12.5 m. The highest total numbers and observation rates were recorded during November (O_n = 20; O_r = 7.10), followed by May (O_n = 14; O_r = 2.76). None were sighted during December, February, April, and July, resulting in no clear seasonal trend observed (Fig. 6).

Bottlenose Dolphins. Eighty-six bottlenose dolphins (25 sightings) were recorded, making them the second-most-numerous marine-mammal species encountered during the project. Observed group sizes ranged from 1 to 20, with an average of three individuals per group. Single bottlenose dolphins were most commonly encountered (O_n = 11). Absolute numbers increased gradually from winter and peaked in summer (July: O_n = 21; June: O_n = 20), with a secondary peak in November (O_n = 17). When adjusted for observer effort, the highest observation rates were recorded in November (O_r = 6.04), followed by July (O_r = 5.78) (Fig. 6). The observed trend suggests an influx of bottlenose dolphins to the region during the summer months and late autumn. Sightings occurred in water depths ranging from 4.0 to 19.2 m, with an average sighting depth of 10.2 m.



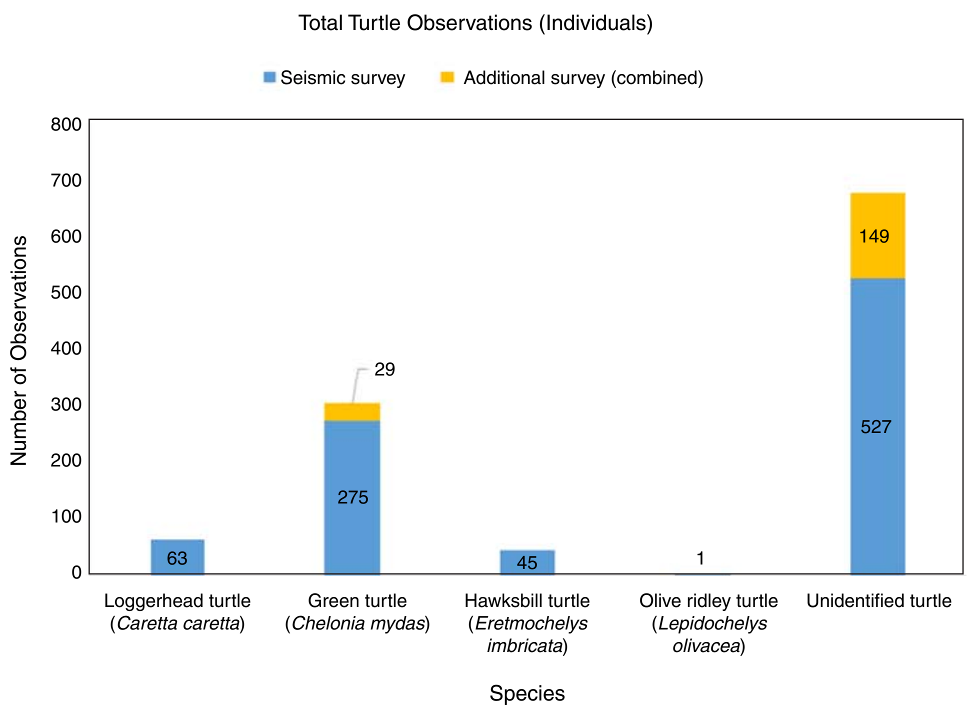


Fig. 9—Total turtle observations by species and survey type.

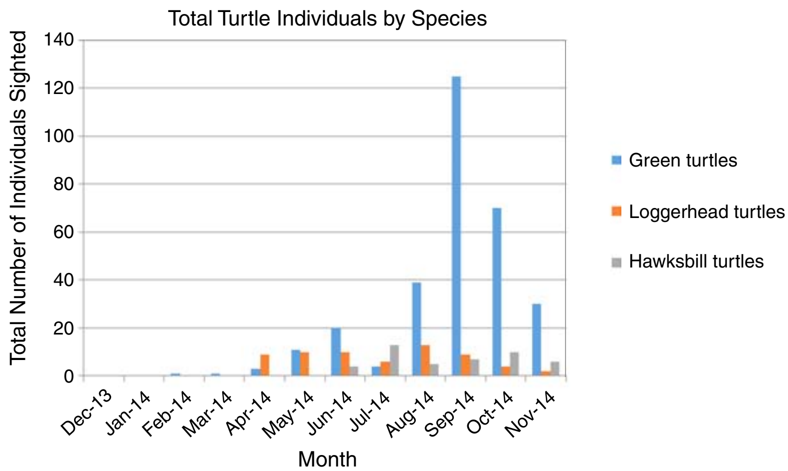
Finless Porpoises. Eleven finless porpoises were observed during the survey, all of which were of single animals (Fig. 6). During the month of May, five finless porpoises were recorded. Sighting water depths ranged from 1.9 to 13.3 m, with an average sighting depth of 7.6 m.

Sea Turtles. A total of 1,089 sea turtles were recorded by all observers on seismic, transect, and opportunistic surveys during the project **(Fig. 9; Table 2).** Of these, 676 turtles (62%) could not be identified to species, owing to several factors such as brevity of sighting and distance and similarity in appearance between species. A cautionary approach to sea turtle identification was adopted during the project, with observers only assigning a specific species designation to a sighting if it could be determined with great certainty. Total turtle numbers and observation rates increased gradually throughout the year, with peak numbers and sighting rates—299 and 312 and O_r = 74.40 and 74.90, respectively—recorded during September and October **(Fig. 10).** An area of high sea turtle density was identified off the east of Marawah Island (Figs. 7 and 8). Sighting depth did not vary significantly among species, and ranged from 0.3 to 16.8 m (average = 6.2 m) when all turtle sightings were combined.

Green Turtles. The green turtle was the most-commonly-encountered sea turtle identified to species (O_n = 304), accounting for

Species	Seismic Survey	Other Survey (Transect)	Other Survey (Opportunistic)	Other Survey (Combined)
Sightings				
Loggerhead turtle (*Caretta caretta*)	59	0	0	0
Green turtle *(Chelonia mydas)*	226	5	22	27
Hawksbill turtle (*Eretmochelys imbricata*)	44	0	0	0
Olive ridley turtle (*Lepidochelys olivacea)*	1	0	0	0
Unidentified turtle	337	6	97	103
Total Turtles	667	11	119	130
Individuals				
Loggerhead turtle (*Caretta caretta*)	63	0	0	0
Green turtle *(Chelonia mydas)*	275	5	24	29
Hawksbill turtle (*Eretmochelys imbricata*)	45	0	0	0
Olive ridley turtle (*Lepidochelys olivacea)*	1	0	0	0
Unidentified turtle	527	7	142	149
Total Turtles	911	12	166	178

Table 2—Total turtle observations by species and survey type.



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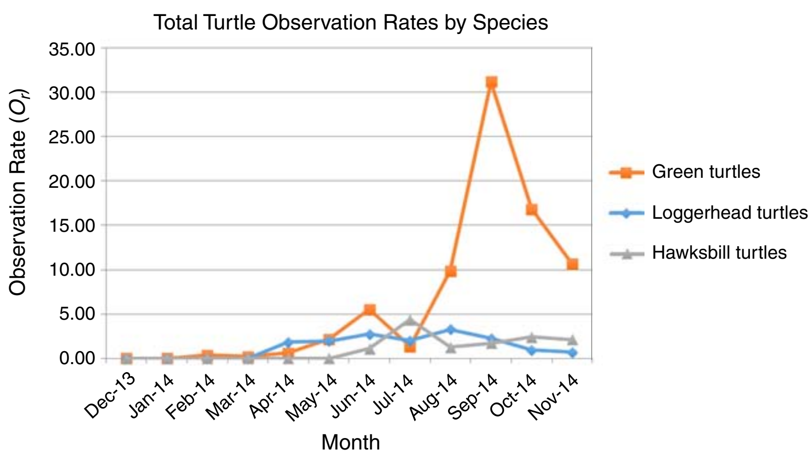

(b)

Fig. 10—(a) Total number of sea turtles by species sighted by all observers on all surveys from December 2013 to November 2014. (b) Observation rates (number of individuals/on-effort observational hours × 100) of sea turtles by species from December 2013 to November 2014.

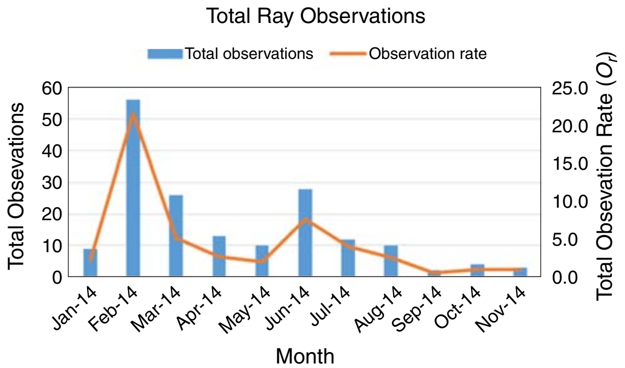

Fig.11—Total ray observations and observation rates by month from January to November 2014.

28% of all turtle sightings. An area of high green turtle density coincided with the area of high overall turtle density off the east coast of Marawah Island (Figs. 7 and 8). Low total numbers and observation rates were recorded in January, but climbed steadily to a peak in September (O_n = 125; O_r = 31.10). However, green turtle numbers and observation rates decreased in October to approximately one-half of those observed during the previous month (O_n = 70; O_r = 16.80) (Fig. 10).

Loggerhead Turtles. Loggerhead turtles, the second-most-commonly-observed sea turtle identified to species, were observed every month between April and November, with monthly totals ranging from two (November) to a high of 13 in August, with a resultant observation rate of 3.23 for that month (Fig. 10).

Hawksbill Turtles. This species was observed every month between June and November, with monthly totals ranging from four in June to a high of 13 in July (O_r = 4.36) (Fig. 10).

Olive Ridley Turtle. A single olive ridley turtle was recorded in June.

Rays. A total of 184 rays were observed throughout the program. Of those that could be identified to species level, 52 were eagle rays of the genus *Mylobatidae*. These were most often observed jumping 0.5 to 1.5 m out of the water in the deeper waters between Mubarraz and the shallower shoals to the south, with sighting depths ranging between 10.1 and 16.4 m (average = 13.4 m) (Figs. 7 and 8). These rays are common in the area and known to often jump out of the water to avoid predators and remove parasites. In addition, stingrays were frequently encountered over the shallow sandy areas throughout much of the southern portion of the prospect. A total of 41 stingrays were sighted, seven of which were identified as the round ribbon-tail ray (*Taeniura meyeri*) and one as belonging to the *Uarnak* complex of stingrays. Sighting depths for stingrays ranged between 1 and 3 m, with an average of 1.7 m. Rays were recorded during every month between January and November 2014, with a peak in February (O_n = 56) **(Fig. 11).**

Comparison of Observations With Seismic Activity and Survey Type. No significant association was observed between marine-mammal observation rates recorded alongside seismic surveys (individuals and observations) and total seismic activity (R^2 = 0.01 and 0.02, respectively). This result remains the same when comparing marine-mammal observation rates recorded during additional surveys (individuals and observations) and total seismic activity (R^2 = –0.1 and –0.20, respectively) **(Fig. 12; Table 3).** In contrast, highly significant positive associations were observed between turtle observation rates recorded alongside seismic surveys (individuals and observations) and total seismic activity (R^2 = 0.39 and 0.32, respectively; $P \leq 0.001$). No significant association was observed between turtle observation rates and total seismic surveys during additional surveys (R^2 = 0.03 and 0.03, respectively) **(Fig. 13; Table 4).**

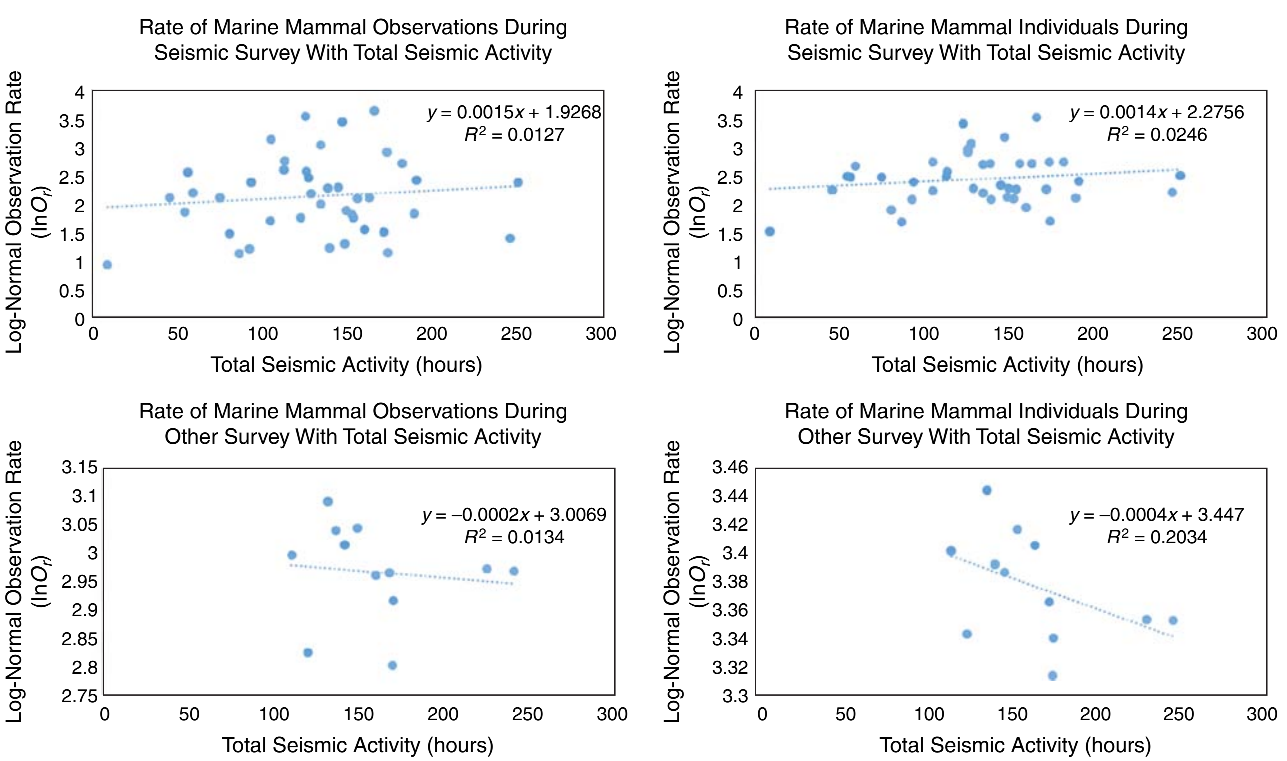

Fig.12—Scatter plots of log-normal observation rates with total seismic hours. Marine-mammal total observations during seismic survey (top left) is O_n = 40, and total individuals during seismic survey (top right) is O_n = 40. Total marine-mammal observations during other survey (bottom left) is O_n = 12, and total individuals during other survey (bottom right) is O_n = 12. Marine-mammal observations during seismic survey (lnMMObsSeis), marine-mammal individuals during seismic survey (lnMMIndSeis), marine-mammal observations during other survey (lnMMindsOther), and marine-mammal individuals during other survey (lnMMIndsOther).

Log-Normal Observation Rates: Total Marine-Mammal Observations During Seismic Survey (lnMMObsSeis)

Regression Statistics	
Multiple *R*	0.112786131
R^2	0.012720711
Adjusted R^2	–0.012594142
Standard error	0.686173727
Observations	41

ANOVA

	df	SS	MS	F	SignificanceF
Regression	1	0.236594231	0.236594231	0.5024999	0.482619914
Residual	39	18.36254098	0.470834384		
Total	40	18.59913521			

	Coefficients	Standard Error	*t* Stat	*P*-Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	1.926812833	0.304596867	6.325780198	1.82784E–07	1.310707515	2.542918151	1.310707515	2.542918151
X Variable 1	0.001533124	0.002162765	0.708872273	0.482619914	–0.002841481	0.005907729	–0.002841481	0.005907729

Log-Normal Observation Rates: Total Marine-Mammal Individuals During Seismic Survey (lnMMIndSeis)

Regression Statistics	
Multiple *R*	0.156700343
R^2	0.024554998
Adjusted R^2	–0.000456413
Standard error	0.43770672
Observations	41

ANOVA

	df	SS	MS	F	SignificanceF
Regression	1	0.188091055	0.188091055	0.981751818	0.327874608
Residual	39	7.471899734	0.191587173		
Total	40	7.659990789			

	Coefficients	Standard Error	*t* Stat	*P*-Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2.275627	0.194300788	11.71187738	2.4276E–14	1.882616561	2.668637439	1.882616561	2.668637439
X Variable 1	0.001366971	0.001379617	0.9908339	0.327874608	–0.001423567	0.004157509	–0.001423567	0.004157509

Table 3—Regression analysis log-normal observations with total seismic activity. Marine-mammal observations during seismic survey (lnMMObsSeis), marine-mammal individuals during seismic survey (lnMMIndSeis), marine-mammal observations during other survey (lnMMObsOther), and marine-mammal individuals during other survey (lnMMIndsOther).

Observation rates of marine-mammal and turtle observations and individuals were compared between survey types (seismic and additional monitoring) and are presented in **Tables 5 and 6.** Both marine mammals and turtles showed greater observation rates for both total individuals (*Z*-score = –3.94 and –4.24, respectively) and observations during the additional survey methods compared with surveys carried out alongside seismic activity ($P \leq 0.001$).

Species Distribution. Observation data were plotted to allow comparison of distribution within the study area. After plotting observation data, three areas of high observation concrentration were observed. The majority of dugong observations took place west/northwest of Hail 3 Island, high numbers of ray species were observed in the channel north of Hail 3 Island, and high concentrations of turtle observations were made along the east coast of Marawah Island (Figs. 7 and 8). No area of concentrated observations was observed for cetacean species.

Analysis of Observation Depth by Species. Mean water depths recorded during observations were compared between species for marine mammals and turtles by means of one-way Anova analysis. Mean depth during observations of bottlenose dolphins (*Tursiops* sp.) was significantly greater than for other marine-mammal species, with an average observation depth of 10.2 m ($P \leq 0.05$) **(Fig. 14; Table 7).**

No significant difference was observed between mean water depths during observations of different turtle species **(Fig. 15).**

Damage to Substrate and the Terrestrial Environment. After completion of operations on Marawah Island, post-operation surveys were carried out alongside operator decommission surveys, during which the only impact noted was that of vehicle tracks and compressed ground vegetation outside of the designated environmental exclusion zones. The total area of impacted ground vegetation was estimated to be approximately 14 000 m^2.

No damage to bird nests was observed on any island. This was mostly because of Vibroseis activities being limited to areas below the high-tide mark on all islands except Marawah, where no bird

Log-Normal Observation Rates: Total Marine-Mammal Observations During Other Survey (lnMMObsOther)

Regression Statistics	
Multiple *R*	0.115830861
R^2	0.013416788
Adjusted R^2	–0.085241533
Standard error	0.088730761
Observations	12

ANOVA

	df	SS	MS	F	SignificanceF
Regression	1	0.001070689	0.001070689	0.135992467	0.719985626
Residual	10	0.07873148	0.007873148		
Total	11	0.079802169			

	Coefficients	Standard Error	*t* Stat	*P*-Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	3.006885213	0.112651202	26.69199404	1.2576E–10	2.755882693	3.257887733	2.755882693	3.257887733
X Variable 1	–0.000246096	0.000667339	–0.368771565	0.719985626	–0.001733019	0.001240828	–0.001733019	0.001240828

Log-Normal Observation Rates: Total Marine-Mammal Individuals During Other Survey (lnMMIndsOther)

Regression Statistics	
Multiple *R*	0.450971707
R^2	0.203375481
Adjusted R^2	0.123713029
Standard error	0.035369241
Observations	12

ANOVA

	df	SS	MS	F	SignificanceF
Regression	1	0.003193717	0.003193717	2.552965366	0.141171217
Residual	10	0.012509832	0.001250983		
Total	11	0.015703549			

	Coefficients	Standard Error	*t* Stat	*P*-Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	3.447022157	0.044904242	76.76384292	3.43683E-15	3.346969272	3.547075043	3.346969272	3.547075043
X Variable 1	–0.000425031	0.00026601	–1.597800165	0.141171217	–0.001017738	0.000167676	–0.001017738	0.000167676

Table 3 (continued)—Regression analysis log-normal observations with total seismic activity. Marine-mammal observations during seismic survey (lnMMObsSeis), marine-mammal individuals during seismic survey (lnMMIndSeis), marine-mammal observations during other survey (lnMMObsOther), and marine-mammal individuals during other survey (lnMMIndsOther).

nests or other environmentally sensitive areas were observed along source lines.

Vehicle tracks below the high-tide mark were monitored regularly and noted to be of short-term impact, remaining visible for only a number of days.

Species Mortality. During the course of the current project, five dead dugongs, one dead dolphin, one dead juvenile baleen whale, and 10 dead sea turtles were recorded **(Fig. 16).** The dead whale was estimated at approximately 5 m in length and may have been a Bryde's whale (*Balaenoptera edeni*), although this could not be established conclusively from the images obtained. Of the 10 dead sea turtles encountered, three were identified as green turtles, two as loggerhead turtles, and one as an olive ridley turtle, with the remaining four not identified to species. The finding of a dead olive ridley sea turtle further confirms the presence of this species in this area, with one at-sea sighting reported during the project. Out of the five dead dugongs reported, four were found at sea in various stages of decay, with one dugong in an advanced stage of decomposition found on Mubarraz in March. It was noted that this individual had numerous abrasions consistent with being caught in fishing gear. The dead dolphin was a juvenile humpback dolphin found in a desiccated state on Arc Island in September.

Discussion

Throughout the course of the 3D seismic survey, no significant environmental impact was observed. This includes any impacts to both the marine and the terrestrial environment.

Species-Observation Rates. Observation rates of individuals fluctuated throughout the course of the seismic survey; however, no significant reduction in observation rates for marine mammals and turtles was observed. Dugong, humpback dolphin, and bottlenose dolphin individual-observation rates all showed sharp increases toward the end of the seismic survey, peaking to highest levels during October and November. A similar pattern was observed with turtle species, with fluctuation throughout the seismic survey, but with loggerhead

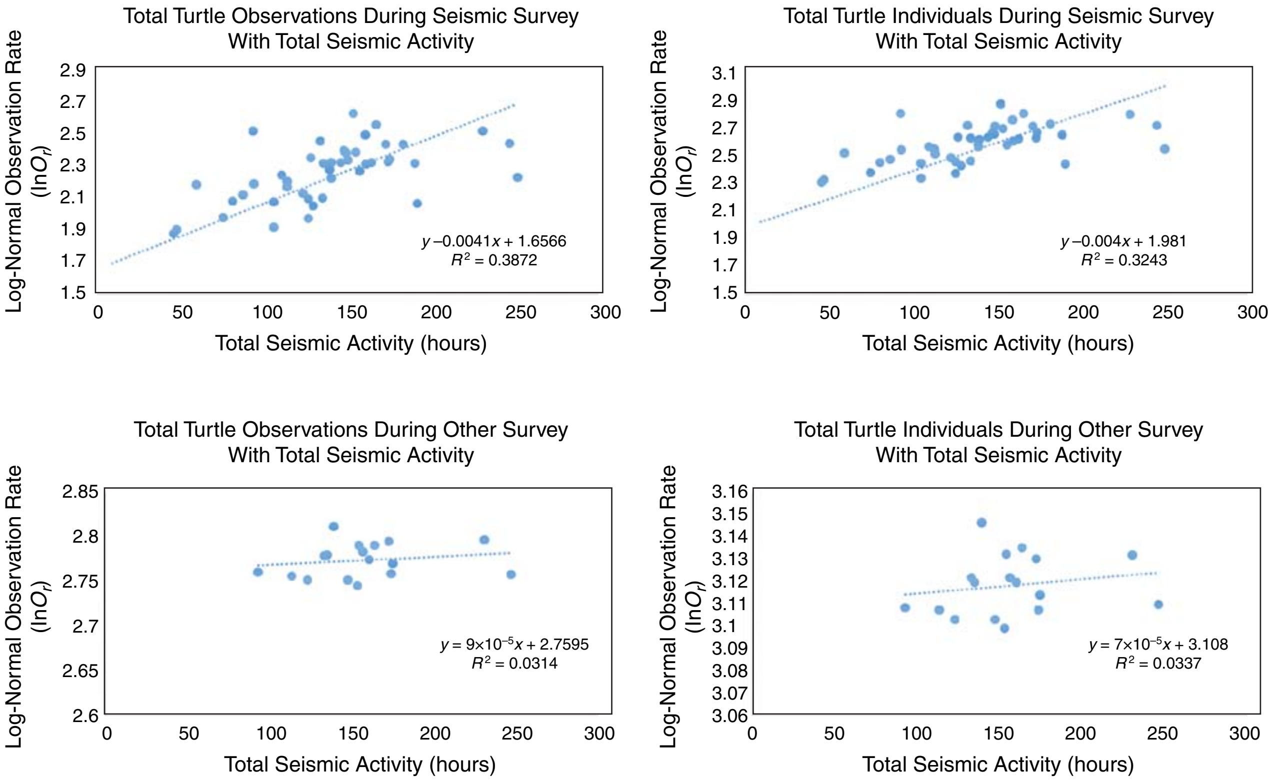

Fig.13—Scatter plots of log-normal observation rates with total seismic hours. Turtle total observations during seismic survey (top left) is O_n = 44, and total individuals during seismic survey (top right) is O_n = 44. Total turtle observations during other survey (bottom left) and total individuals during other survey (bottom right) are O_n = 17. Turtle observations during seismic survey (lnTObsSeis), turtle individuals during seismic survey (lnTIndSeis), turtle observations during other survey (lnTindsOther), and turtle individuals during other survey (lnTIndsOther).

and hawksbill turtles remaining at similar levels. Green turtle observation rate, however, showed a sharp peak during September.

While the current study represents the first of its kind in the area providing unique data on the distribution and frequency of marine species, data collection was limited to the duration of the seismic survey. To accurately assess species patterns, a longer-term study is recommended, ideally over the course of a full year to assess annual changes. Longer studies covering a period of 10 years have been suggested by some authors, with at least two surveys carried out 10 years apart, allowing for a 95% confidence rate in observed trends (Marsh 1989; Marsh et al. 1995).

To assess clearly any impact on species numbers within the area, observation rates should be analyzed across the short, medium, and long term. Our data collection was limited to a period of 12 months and displays fluctuations across the short and medium term, over which observation rates showed marked increases for most species; however, long-term trends could not be assessed.

Observation Rates With Seismic Activity. No significant relationship was found between marine-mammal observation rates (both observations and individuals) and total seismic activity, either during observations made alongside the seismic survey or during other surveys. This result suggests that the amount of seismic activity (in this case, the total number of seismic hours) cannot be considered a reliable indicator of marine-mammal numbers and that, during the current study, increasing the amount of seismic activity did not directly reduce marine-mammal numbers within the area.

In contrast, a significant positive relationship between the amount of seismic activity and total turtle observation rates (observations and individuals) was recorded during observations made alongside seismic activity ($P \leq 0.001$). A positive relationship between total turtle observations and total seismic activity was also found during observations made by other surveys; however, this result was not significant.

The observed results suggest that while total seismic activity can be considered a reliable indicator of total turtle numbers, the relationship is positive, with turtle numbers increasing with increased seismic activity. It is not clear why a positive relationship should occur for these species, but it is possible that the noise created by seismic activity may cause turtles to spend more time at the surface, where they are more easily observed by vessel-based observers. Observations of turtles fleeing at the water's surface have been reported to be inversely correlated with vessel speed (Hazel et al. 2007). This is most likely a result of turtles having time to react to oncoming vessels and moving accordingly. All of the seismic-source vessels used in the current project were slow moving, particularly during active seismic survey. Therefore, the increased turtle observations reported during increased seismic activity may be more related to the vessel speed than the seismic noise itself.

Observation Rates by Survey Type. Observation rates of both marine mammals and turtles were significantly higher during additional surveys than when recorded alongside seismic activity ($P \leq 0.01$). This included observation rates of both total observations and total individuals.

The general purpose of protected-species mitigation measures, including those developed for use during this survey, is to allow seismic activity to occur while reducing the risk of injury and disturbance to those species (JNCC 2010). The primary tools used to achieve this aim include the use of prewatch and soft-start procedures—first, to ensure that no animals are within a critical distance of the sound source before any seismic activity, and, second, to introduce the sound source gradually at increasing levels to allow

Log-Normal Observation Rates: Total Turtle Observations During Seismic Survey (lnTObsSeis)

Regression Statistics	
Multiple R	0.62224537
R^2	0.387189301
Adjusted R^2	0.372937889
Standard error	0.257888632
Observations	45

ANOVA

	df	SS	MS	F	SignificanceF
Regression	1	1.806882287	1.806882287	27.16848771	5.03581E–06
Residual	43	2.859781492	0.066506546		
Total	44	4.666663779			

	Coefficients	Standard Error	t Stat	P Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	1.656582263	0.114038791	14.52648041	3.43534E–18	1.426601123	1.886563403	1.426601123	1.886563403
X Variable 1	0.004117825	0.000790015	5.212339946	5.03581E–06	0.002524608	0.005711041	0.002524608	0.005711041

Log-Normal Observation Rates: Total Turtle Individuals During Seismic Survey (lnTIndSeis)

Regression Statistics	
Multiple R	0.569470456
R^2	0.3242966
Adjusted R^2	0.308582567
Standard error	0.286907177
Observations	45

ANOVA

	df	SS	MS	F	SignificanceF
Regression	1	1.698781691	1.698781691	20.63738882	4.45355E–05
Residual	43	3.539576315	0.082315728		
Total	44	5.238358006			

	Coefficients	Standard Error	t Stat	P Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	1.980953079	0.126870841	15.61393511	2.50064E–19	1.725093644	2.236812514	1.725093644	2.236812514
X Variable 1	0.003992746	0.00087891	4.542839291	4.45355E–05	0.002220255	0.005765237	0.002220255	0.005765237

Table 4—Regression analysis log-normal observation rates with total seismic activity. Turtle observations during seismic survey (lnTObs Seis), turtle individuals during seismic survey (lnTIndSeis), turtle observations during other survey (lnTObsOther), and turtle individuals during other survey (lnTIndsOther).

any animals within close proximity that were not observed to move away to a safer distance before full power is achieved.

The higher observation rates recorded during surveys carried out independently and away from any seismic activity compared with those recorded alongside seismic activity suggest that both marine mammals and turtles may be moving away from the sound source, but are not displaced significantly from the wider surrounding area.

Patterns of Observation Rates. Observation rates of all species fluctuated over time; however, no overall reduction was observed to occur over the study period as a result of the seismic activity being carried out. For a number of species, observation rates increased sharply toward the later stages of the survey (October–November 2014). Further, after comparisons between survey types, our data show higher observation rates for all species groups during the additional surveys compared with those carried out alongside seismic operations.

After analysis comparing observation rates with total seismic activity, no significant result was observed for marine mammals, but a significant positive association was observed for turtles.

Our data suggest that while animals may have moved away from seismic activity, this effect was temporary, with no large-scale net movement out of the surrounding area during the study period. This indicates that the mitigation measures put in place for the project may have been successful in their aims to ensure that animals were temporarily moved away from activity so that seismic testing could be carried out safely without permanently displacing individuals.

Species Distribution and Density. Throughout the course of the study, the location of species observations were recorded and plotted using QGIS (2015) software. In doing so, near-real-time monitoring of species distribution and relative densities within the prospect area was achieved. Areas of high relative density were recorded for dugong, turtle, and ray species within the prospect area west/southwest of Hail 3 Island, along the east coast of Marawah

Log-Normal Observation Rates: Total Turtle Observations During Other Survey (lnTObsOther)

Regression Statistics	
Multiple R	0.177232167
R^2	0.031411241
Adjusted R^2	–0.033161343
Standard error	0.019506667
Observations	17

ANOVA

	df	SS	MS	F	SignificanceF
Regression	1	0.000185099	0.000185099	0.486448569	0.49618502
Residual	15	0.005707651	0.00038051		
Total	16	0.00589275			

	Coefficients	Standard Error	*t* Stat	*P*-Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	2.759525085	0.02076569	132.8886802	1.87251E–24	2.715264065	2.803786104	2.715264065	2.803786104
X Variable 1	8.97319E–05	0.000128655	0.69745865	0.49618502	–0.000184491	0.000363954	–0.000184491	0.000363954

Log-Normal Observation Rates: Total Turtle Individuals During Other Survey (lnTIndsOther)

Regression Statistics	
Multiple R	0.187078222
R^2	0.034998261
Adjusted R^2	–0.045418551
Standard error	0.01449426
Observations	14

ANOVA

	df	SS	MS	F	SignificanceF
Regression	1	9.14306E–05	9.14306E–05	0.435210751	0.521903464
Residual	12	0.002521003	0.000210084		
Total	13	0.002612434			

	Coefficients	Standard Error	*t* Stat	*P*-Value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	3.109414278	0.015593989	199.3982571	1.70221E–22	3.075437894	3.143390662	3.075437894	3.143390662
X Variable 1	6.36257E–05	9.64457E–05	0.659705049	0.521903464	–0.000146511	0.000273763	–0.000146511	0.000273763

Table 4 (continued)—Regression analysis log-normal observation rates with total seismic activity. Turtle observations during seismic survey (lnTObsSeis), turtle individuals during seismic survey (lnTIndSeis), turtle observations during other survey (lnTObsOther), and turtle individuals during other survey (lnTIndsOther).

Island, and north of Hail Island within the deepwater channel between Hail 3 Island and Mubarraz Island, respectively.

Upon discovery of these high-density areas for dugong and sea turtles, additional mitigation measures were created and used for vessels operating within these areas. This included vessel speed limits being reduced to a maximum of 10 knots and increased awareness and observation by vessel crew while moving throughout the areas.

No increase to species mortality was observed while operating within these areas.

The reason for the higher concentration of dugong observations in one particular area is not clear. Further investigation of the area revealed the substrate to consist mainly of algae-covered coral rubble and not significant seagrass beds, as would be expected if the area was used for feeding. Instead, the area may represent a site used more as a nursery or other social purpose.

For ray species, the areas of concentrated observations were expected when considering the biology of these species. For example, the majority of rays observed in the channel north of Hail 3 Island belonged to the *Myliobatidae* family, a group of species that prefer deeper, faster-moving waters. Most of the species observed at the southern end of the channel in the center of the study area belonged to the *Dasyatidae* family, which prefer shallower sandy areas.

Average water depth during observation was recorded and compared between species for marine mammals and turtles. Of the marine-mammal species observed, most observations took place in waters 6 to 7 m deep. The mean water depth during observations of bottlenose dolphins (*Tursiops* sp.), however, was significantly greater than that for other species at 10.2 m. This pattern is also visible in Fig. 7, with bottlenose dolphins predominantly being observed in the deeper waters in the north of the study area. No significant difference was observed between mean water depths during turtle observations.

Damage to Substrate and the Terrestrial Environment. The mitigation measures created for use while operating within mangrove

Species	Seismic Survey Obs. (O_n)	Obs. Rate (O_r)	lnO_r	Individuals (O_n)	Obs. Rate (O_r)	lnO_r	Other Survey Obs. (O_n)	Obs. Rate (O_r)	lnO_r	Individuals (O_n)	Obs. Rate (O_r)	lnO_r
Dugong (*Dugong dugon*)	73	1.74	0.30	99	2.35	0.30	8	6.69	0.31	9	7.52	0.27
Bottlenose dolphin (*Tursiops* sp.)	20	0.48	0.21	57	1.36	0.27	5	4.18	0.30	29	24.25	0.28
Humpback dolphin (*Sousa chinensis*)	20	0.48	0.21	30	0.71	0.24	10	8.36	0.31	37	30.93	0.28
Unidentified dolphin	23	0.55	0.22	43	1.02	0.25	0	0.00	0.00	0	0.00	0.00
Finless porpoise (*Neophocaena phocaenoides*)	9	0.21	0.16	9	0.21	0.18	2	1.67	0.29	2	1.67	0.26
Unidentified marine mammal	3	0.07	0.11	3	0.07	0.14	0	0.00	0.00	0	0.00	0.00
Total Marine Mammals	148	3.52	0.35	241	5.73	0.35	25	20.90	0.32	77	64.38	0.28
Loggerhead turtle (*Caretta caretta*)	59	1.40	0.28	63	1.50	0.27	0	0.00	0.00	0	0.00	0.00
Green turtle *(Chelonia mydas)*	226	5.37	0.39	275	6.54	0.36	27	22.57	0.32	29	24.25	0.28
Hawksbill turtle (*Eretmochelys imbricata*)	44	1.05	0.26	45	1.07	0.26	0	0.00	0.00	0	0.00	0.00
Olive ridley turtle (*Lepidochelys olivacea)*	1	0.02	0.07	1	0.02	0.11	0	0.00	0.00	0	0.00	0.00
Unidentified turtle	337	8.01	0.42	527	12.53	0.40	103	86.11	0.33	149	124.5	0.29
Total Turtles	667	15.86	0.48	911	21.66	0.43	130	108.69	0.33	178	148.8	0.29

Table 5—Total observation numbers and rates by species and survey type (lnOr = log-normal observation rate).

Species Group	Seismic Survey O_n	Mean (O_r)	SD (O_r)	Median	Other Survey N	Mean (O_r)	SD (O_r)	Median	Z-score	P-value
Sightings										
Marine mammals	11	2.96	1.84	2.42	11	40.00	20.22	35.59	–3.94	<0.001
Turtles	17	28.06	22.35	22.57	17	179.37	184.20	125.79	–4.24	<0.001
Individuals										
Marine Mammals	11	5.82	6.35	3.37	11	129.95	146.13	96.62	–3.87	<0.001
Turtles	17	39.08	39.14	24.35	17	261.96	351.28	157.23	–3.82	<0.001

Table 6—Mann-Whitney U test comparing mean observation rates during weeks of sightings during both survey types between seismic and additional survey methods for marine mammals and turtles. (SD = standard deviation.)

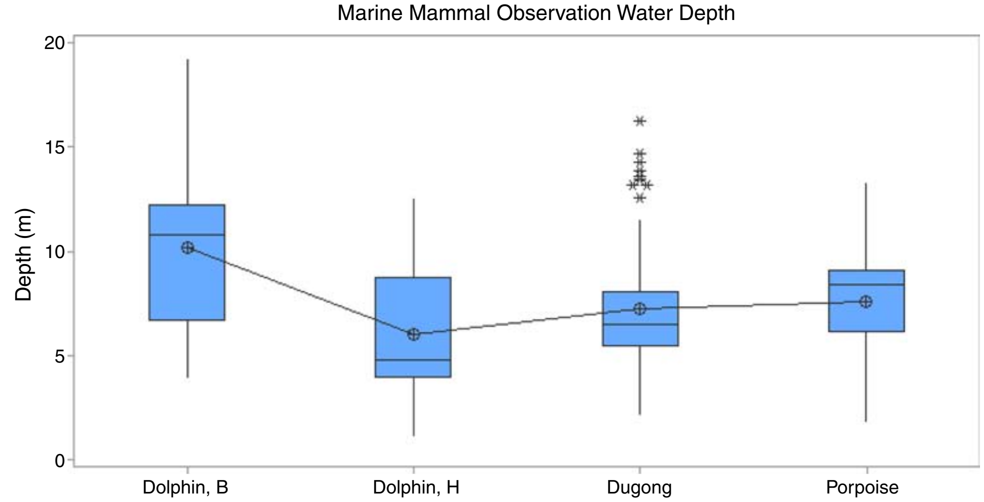

Fig.14—Box plot of marine-mammal observation depths by species ($P \leq 0.05$).

Species/Species Group	Average Depth (m)	Depth Range (m) Minimum	Maximum	Project Total Sightings
Dugong	7.3	2.2	16.3	81
Indo-Pacific humpback dolphin	6.1	1.2	12.5	30
Bottlenose dolphin	10.2	4.1	19.2	25
Finless porpoise	7.6	1.9	13.3	11
Green turtle	6.3	1.0	16.1	253
Loggerhead turtle	6.7	0.5	15.7	59
Hawksbill turtle	5.6	1.0	14.6	44
Olive ridley turtle	*n/a*	*6.0*	*6.0*	*1*
Turtle sp.	6.2	0.3	16.8	440
All turtles combined	6.2	0.3	16.8	797

Table 7—Water depths during observations of marine-mammal and turtle species.

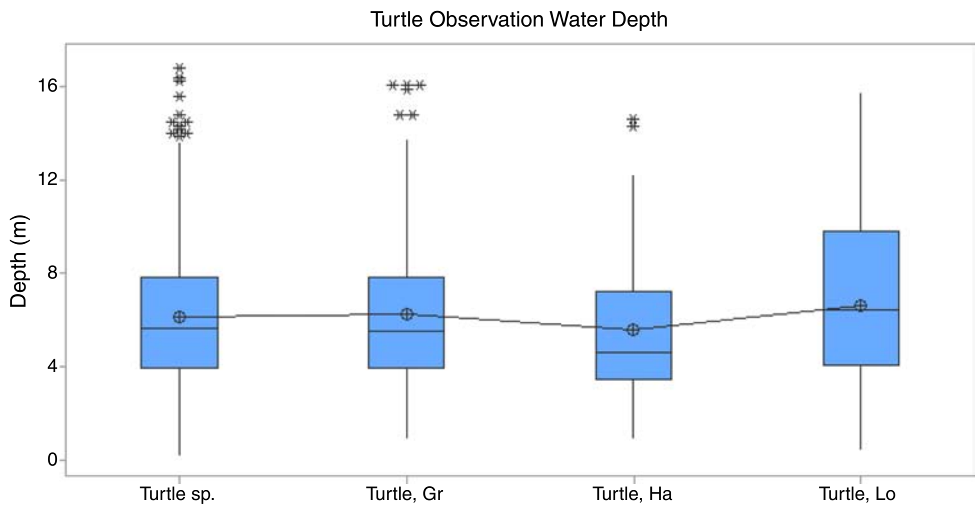

Fig.15—Box plot of turtle observation depths by species (nonsignificant).

areas were used during operations within the terrestrial environment. As a result, no significant damage to substrate and the terrestrial environment was observed.

On Hail 2, Arc, Umm Amim, and Hail Natural Island, Vibroseis activities were limited to the sand flats below the high-water mark. Any other equipment that needed to be laid across the islands and in areas of vegetation was done so by hand by crew who had been strictly instructed and trained to minimize environment disturbance in these areas.

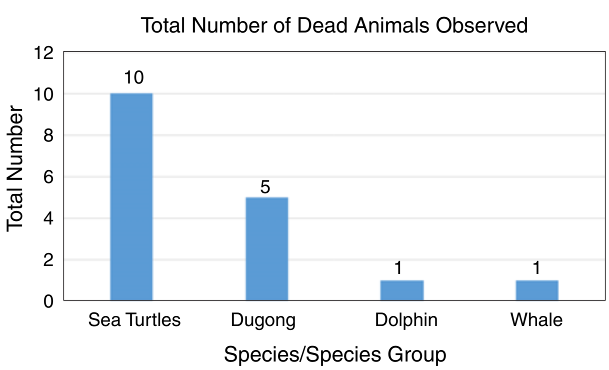

Fig.16—Total number of dead animals observed throughout the study by species.

Seismic operations on Marawah Island included the use of Vibroseis vehicles across a large portion of the island. Three areas of high environmental sensitivity were recorded on the island, consisting of three areas of mangrove growth along the eastern shoreline. As a result, no vehicles were permitted to enter these areas and all equipment was laid by hand by trained and experienced crew.

During environmental-profile surveys before seismic operations, existing environmental damage within these areas was recorded, including the presence of garbage and evidence of tree harvesting. No additional significant damage was recorded during post-operation assessments of these areas. Damage to other areas not classified as environmentally sensitive was limited to vehicle tracks within the substrate and patches of crushed or compressed vegetation. Affected vegetation in these areas were dominated by halophytic, salt-resistant plants and semi-woody dwarf shrubs, none of which are listed as being a conservation concern.

Species Mortality. Our data represents total numbers observed. At present, few population assessments of marine species specific to the area have been carried out, with the current study representing the first of its kind to describe marine-mammal- and turtle-species numbers.

A study carried out by Al-Ghais and Das (2001) estimated dugong numbers in the wider area to be 1,861 in the summer, increasing to 2,185 in the winter. These sightings indicated key areas (80% of recorded sightings during study) to occur around the islands of Abu Al Abyad, Salalah, Marawah, Janannah, Al-Fayl, Al

Bazm, and Bu Tinha (Al-Ghais and Das 2001). Without a clear understanding of total population sizes and dynamics in the area, it is unclear whether the numbers of dead individuals observed during the current study represent a significant percentage of the total population or normal mortality rates, or at least those in areas with similar third-party risks, such as vessel collision and fishing gear, without any seismic activity.

Studies carried out for the Queensland Parks and Wildlife Service indicate that, since 1996, up to 30% of the 80 dugong reported dead to the service had died as a result of disease and parasites (Haines and Limpus 2000, as cited in Marsh et al. 2002). Detailed information on the natural mortality rate within dugong populations is lacking; however, because they are long-lived and late to mature with low fecundity, natural mortality rates within dugong populations are assumed to be low (Marsh et al. 1984).

The low numbers of dead marine mammals, turtles, and birds observed over the course of the seismic survey were not considered attributable to seismic activity. Although the exact cause of death for different species could not be determined, the presence of cracked shells and the high numbers of fast-moving third-party watercraft frequently observed in the area suggest that the primary cause of mortality to turtles in the area was vessel strike. Vessel strike causing increased mortality to both Sirenia and turtle species has been reported by a number of authors (Hazel et al. 2007; Hazel and Gyuris 2006; Ackerman et al. 1995; Greenland and Limpus 2005), and is considered a major factor contributing to mortality and population decline of both turtles and marine mammals. Further, marine mammals and turtles are also at high risk of entanglement and subsequent drowning in fishing gear. Of the total of five dead dugong observed, one was observed with numerous abrasions consistent with being caught in fishing gear.

Dead birds observed in the area primarily consisted of Socotra cormorants (*Phalacrocorax nigrogularis*). The majority of these were found on the shore above the high-water line and in close proximity to discarded fishing nets and other fishing debris. Cormorants feed under the water, where they dive for small fish and invertebrates. For this reason, it is highly likely that these birds were caught in fishing gear and later discarded by local fisherman.

For future studies, it is recommended that necropsies be carried out on dead marine mammals and turtles when found, a strategy commonly used in the UK Cetacean Strandings Investigation Programme (CSIP 2015); however, it is not known if such facilities currently exist within the UAE.

Limitations of Study and Future Research. The current study represents the first of its kind in respect to a major oil company taking further steps to proactively manage its environmental and ecological footprint during operations. While every effort was made to ensure scientific robustness of sampling methods and survey design, it is important to note that this work was carried out alongside an active seismic-testing program and was not originally planned to be part of a more-detailed scientific analysis. For example, no hypothesis was made before the start of the study, with the aim of our research and data collection being of an exploratory nature to investigate patterns in species abundance and distribution and how this interacted with seismic operations during a survey of this type. This ultimately allowed the correct implementation of mitigation actions as identified in the project HSEIA. It is hoped that this knowledge can be used as a foundation on which to apply more-detailed and -specific research in the area and provide a better understanding of environmental management during future seismic surveys of this type.

For any study investigating patterns in species abundance, a large sample (ideally spanning over a significant time period) is necessary to accurately assess patterns and account for short-term changes as a result of influencing factors such as environmental conditions (temperature, salinity, pH, plankton levels), changes in food abundance, observer bias, and sampling error. The current study allowed analysis over a period of 12 months; however, it is recommended that future research be carried out to assess these patterns over a longer period, ideally 5 to 10 years, to confidently assess abundance and distribution (Marsh 1989; Marsh et al. 1995).

Because of the relatively high observation frequency, it is likely that a number of the marine mammals observed in the current study represent a local population. To assess this and allow further exploration of the marine-mammal population present in the area, studies identifying the recapture rate involving the photo identification of individuals and subsequent network analysis are recommended. This type of research has been carried out on a number of marine-mammal populations worldwide (Whitehead 1994, 1997, 1999, 2008a, 2008b; Whitehead et al. 1982, 2005; Whitehead and Dufault 1999), as well as being applied to other species, including elasmobranchs and terrestrial mammals (MacGlennon 2008; Wittemyer et al. 2005).

Environmental Supervision During Oil and Gas Activities. Before the project startup, an extensive HSEIA was produced to identify and reduce where possible any potential impacts on the environment from operations. In providing continuous in-field environmental supervision throughout the entirety of the project, potential environmental impacts from operations during the Hail 3D seismic survey were monitored in real time and actively managed, either removing or reducing these risks to lower levels.

A further benefit of this work includes the collection of detailed data across a long period of time in an area in which, to date, little data currently exist. It is hoped that these data may be beneficial to the production of environmental policy and environmental management of the area, as well as provide a better understanding of the marine species present within UAE waters as a whole.

Nomenclature

O_n = number of observations
O_r = unit observation rate
O_t = total observation time

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Appendix A—Marine Mammal and Sea Turtle Mitigation Guidelines for Transition-Zone Seismic Operations: ADNOC Hail and Shuweihat 3D Campaign

The following guidelines are based on the JNCC (2010) *Guidelines for Minimizing the Risk of Injury and Disturbance to Marine Mammals From Seismic Surveys* and adapted for use during the Hail and Shuweihat 3D seismic project.

Preshooting Search (Prewatch). During daylight hours, a preshooting search (prewatch) will comprise a 30-minute watch before the use of any air guns. A visual assessment will be made to determine if any marine mammals or turtles are within 500 m of the center of the air-gun array (mitigation zone).

If a single boat is to be used with a line change between survey lines, to facilitate effective timing for operations, the prewatch may commence before the end of line (while the air guns are still firing). This is useful for surveys with a relatively short line change.

The PSO will conduct the prewatch from the highest possible vantage point that can be used safely.

Prewatches and other operations must be monitored by a dedicated PSO on all large-source vessels. A dedicated PSO is one whose only responsibility on the vessel is to monitor operations and apply protected-species mitigation. For mini-source vessels, a member of the crew may conduct prewatch and monitor operations so long as they have received training in marine-mammal/turtle-mitigation monitoring.

Marine-Mammal and Turtle Sightings/PAM Detections Within Mitigation Zone. If marine mammals/turtles are observed/detected within 500 m of the center of the air-gun array during a prewatch, the soft start for the seismic source must be delayed until their passage, or the transit of the vessel, results in the marine mammals/turtles being more than 500 m away from the source. In both cases, there must be a 30-minute delay from the time of the last sighting/detection within 500 m of the source to the commencement of the soft start to determine whether the animals have left the area.

Marine-Mammals/Turtle Sightings/Detections After Soft Start. Once a soft start has commenced and while operating at full power, there is no requirement to shut down if marine mammals/turtles are observed within the mitigation zone unless any obvious signs of distress are observed. If signs of distress are observed, operators must shutdown the source and follow the guidance in the preceding as per observations made during a prewatch. It shall be the decision of the PSO to decide if animals are distressed and a shutdown is required. Operators must facilitate the PSO in this regard.

Guidelines if Marine Mammals/Turtles Remain Stationary in Location. If during a prewatch marine mammals/turtles are observed remaining stationary in a particular location and enter the mitigation zone, then a delay to operations must follow, as in the preceding, and run until there has been at least a minimum of 30 minutes of marine-mammal/turtle clear time since the last observation within the 500-m mitigation zone.

Once an observation of marine mammal/turtle has been made, a vessel may not conduct a soft start away from the location and immediately return to continue shooting the seismic source toward the animals.

It may be advisable in the preceding situation to relocate operations away from the area to prevent long delays.

Soft-Start Procedure. The soft start is defined as the time that air guns commence shooting until the time that full operational power is obtained. Power should be built up slowly from a low-energy startup (e.g., starting with the smallest air-gun in the array and gradually adding in others) over at least 20 minutes to give adequate time for marine mammals/turtles to leave the area. This buildup of power should occur in uniform stages to provide a constant increase in output. There must be a soft start every time the air guns are used (exemption for testing at low power, as detailed subsequently). The duration of the preshooting search (at least 30 minutes) and the soft-start procedure (at least 10 or 20 minutes, depending on source size) should be factored into the survey design.

General Advice To Follow for Soft Starts. To minimize additional noise in the marine environment, a soft start (from commencement of soft start to commencement of the line) must not be significantly longer than 20 minutes and not exceed 40 minutes (for example, soft starts greater than 40 minutes are considered to be excessive, and an explanation must be provided within the PSO report).

Once the soft start has been performed and the air guns are at full power, the survey line should start immediately. Operators must avoid unnecessary firing at full power before commencement of the line.

During simultaneous operations, each source vessel must complete its own soft start in accordance with the preceding guidance.

Soft Starts for Mini-Source Vessels (Source ≤ 320 in.^{3}). Because of the lower volume source, a reduced soft-start time of 10 minutes will be acceptable for mini-sources up to 320 in.^{3}. Soft starts for mini-sources must follow the same criteria (with the exception of duration) stated previously for soft-start procedures.

Soft-Starts and Air-gun Testing. Air-gun tests may be required before a survey commences, or to test damaged or misfiring guns following repair, or to trial new arrays. Individual air guns, or the entire array, may need testing, and the air guns may be tested at varying power levels. The following guidance is provided to clarify when a soft start is required:

- If the intention is to test all air guns at full power, then a 20-minute soft start is required (10 minutes for mini-source up to 320 in.^{3}).
- If the intention is to test a single air gun on low power, then a soft start is not required.
- If the intention is to test a single air gun or a number of guns on high power, then the air gun or air guns should be fired at lower power first, and the power then increased to the level of the required test; this should be carried out over a time period proportional to the number of guns being tested and ideally not exceed 20 minutes in duration.

Break in Firing >10 Minutes. If, for any reason, firing of the air guns has stopped and not restarted for at least 10 minutes, then a prewatch (30 minutes) and soft start must be carried out before

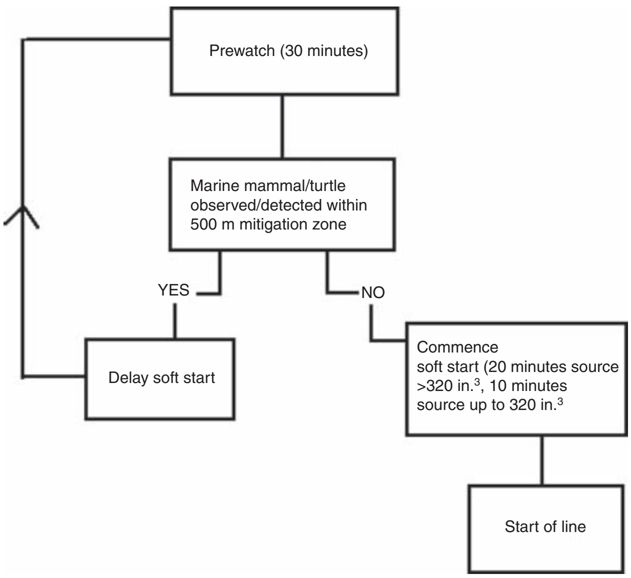

Fig. A-1—Flow diagram for start of any air-gun operation.

recommencing shooting at full power. The requirement for a preshooting search only applies if there was no PSO on duty and observing at this time. If a constant watch has been maintained and no marine mammals/turtles have been observed within the exclusion zone for at least 30 minutes, then an immediate soft-start procedure may begin. For operations at night, a constant watch cannot be maintained by PAM if the source vessels are operating more than 500 m away from the PAM vessel. In this scenario, source vessels must return to the mitigation zone maintained by PAM to restart a soft start.

Break in Firing <10 Minutes. Any break in firing for less than 10 minutes will require the PSO/crew member to conduct a visual assessment (not a prewatch) to assess if any marine mammals/turtles are present in the mitigation zone. If none are present, then firing may recommence immediately; if present, then a 30-minute delay will be made in accordance with the preshooting watch guidelines detailed previously. For operations at night, no assessment can be made.

Guidance During Line Change. Because of the unique nature of shallow-water and transition-zone surveys, it is often a requirement to start and stop lines at short notice, shifting between lines in response to shallow water and other obstacles. To prevent the need for additional soft starts, and thus excessive noise in the environment, source vessels may use a minimum source to conduct a shot at least once every 10 minutes between survey lines. This must be the lowest possible source output from the array with a shot greater than 160 dB (dB *re 1* μPa).

Note that this procedure may be used to avoid additional soft starts and delays in response to short line changes and unforeseen circumstances. It may not be used to keep a source vessel "on standby" (soft start completed and at full power but not on a survey line) for significant lengths of time. Any occurrence where the mitigation gun is used for more than 30 minutes (i.e., soft start has been completed but no line has been started) will require an explanation in the PSO report.

Passive-Acoustic Monitoring. During hours of darkness, PAM effort is the only available method of mitigation for marine mammals. It should be noted that turtles do not communicate acoustically, and thus, it is assumed these will not be detected by PAM, even if present.

During hours of darkness, the prewatch will be at least 30 minutes in duration.

Because of the nature of transition-zone surveys, during which multiple source vessels (often small in size) are to be used, it may not be practical to have a PAM system with towed array on each source vessel. In this scenario, a PAM station may be used, where a dedicated PAM vessel/platform is used to deploy hydrophones and monitor a mitigation zone of at least 500 m.

If the mitigation zone surrounding the PAM-hydrophone array has been clear of any marine-mammal detections for a period of at least 30 minutes, then each source vessel may approach the PAM station to initiate a soft start. Soft starts by each source vessel should be initiated as close to the PAM station as is safe to do so and must not be more than 500 m away.

Once soft start has commenced, there is no requirement to remain with the PAM station, and source vessels may head toward the line.

If a break in firing lasting longer than 10 minutes occurs, then, as in the preceding stated guidance, the source vessel must return to the PAM station to restart the soft start. This can be done immediately and without delay so long as a constant watch has taken place by means of PAM in the area and no marine-mammal detections have been made in the preceding 30 minutes. If no constant watch has been maintained by means of PAM, then a 30-minute prewatch must precede any soft-start operation.

Simultaneous Operations. At least one PSO will be placed on each source vessel. This will allow constant monitoring and prevent delays from the need to conduct a new prewatch should a break in firing that is longer than 10 minutes occur. If multiple vessels are to be used in the same area, soft starts must be completed as close as possible to the start of line time. A soft start followed by lengthy periods shooting with minimum source before the start of a line will be considered excessive and an explanation must be provided in the PSO report (see preceding guidance during a line change).

Summary of Mitigation Measures (Fig. A-1).

- 30-minute prewatch before any use of guns (30-minute PAM search in hours of darkness)
- 20–40-minute soft start (source > 320 in.^{3})
- 10–40-minute soft start (mini-source ≤ 320 in.^{3})
- Minimum of one dedicated PSO on each source vessel (source > 320 in.^{3})
- Vessel crew may conduct prewatch and monitor operations on mini-source vessels (source up to 320 in.^{3})
- 500-m mitigation zone for marine mammals/turtles
- No shutdown if observation/detection after soft start or at full power (unless obvious signs of distress are observed)
- Break in activity of less than 10 minutes, no action required if mitigation zone is clear; 30-minute delay if marine mammals/turtles are present
- Break in activity of more than 10 minutes, soft start required (additional prewatch required only if constant monitoring has not taken place)
- Soft start required for full gun test
- No soft start required for single gun test at low power

Glossary of Terms.

- Prewatch: The period of time in which an observer must watch/listen for marine mammals/turtles within the mitigation zone.
- Mitigation zone: Defined as a 500-m area around the air-gun source.
- Soft start: The gradual increase in power and output of seismic air-gun arrays.
- PSO: Protected species observer.
- PAM: Passive acoustic monitoring.
- Mini-source: Source with output ≤ 320 in.^{3}.
- Large source: Source with output > 320 in.^{3}.
- Marine mammal: Dolphin, whale, or dugong.
- Dedicated PSO: A suitably qualified and trained individual whose only role on the vessel is to monitor for marine mammals, turtles, and other protected species.

Appendix B—Environmental Mitigation Measures for Seismic-Exploration Activities Within Mangrove Areas

The following highlights the environmental mitigation measures used during seismic-exploration activities within mangrove areas on the Hail and Shuweihat 3D seismic surveys, and incorporates information from the ADNOC environmental-management plan and the oil and gas exploration and production in mangrove areas guidelines produced in collaboration between the International Union for Conservation of Nature (IUCN) and the Exploration and Production (E&P) forum.

Reason for the Development of Site-Specific Mitigation Measures. Mangrove forests represent a valuable resource both ecologically and socio-economically. By providing an important nursery habitat for numerous fish (many of which support commercial offshore fisheries) and marine invertebrates and feeding/roosting areas for large numbers of birds, these areas are characterized by their importance to wider ecosystem function.

Mangroves are essentially wetland forests and, as such, are represented within the 1971 Convention on Wetlands of International Importance (Ramsar Convention), an international convention for the conservation of wetland habitats. The UAE became a member of the 1971 Ramsar Convention in 2007 and, as such, has a responsibility to ensure wetland conservation and the management of activities with potential negative effects on such areas.

The IUCN, in collaboration with the E&P forum, have set out general guidelines for oil and gas activities in mangrove areas, which include the following:

"Operations should be planned and operated in a manner that avoids or, where unavoidable, minimizes direct or indirect adverse impacts on the mangrove environment."

This can be achieved by:

- The minimal use of mangrove forest areas
- Minimal interruption to freshwater flow within the mangroves
- Minimal alteration to tidal flows within the mangroves
- Minimal disruption to vegetation
- Minimal disruption to soils and sediments
- Maintenance of buffer zones along coastlines
- The control of environmental pollution
- Careful planning of activities
- The selection of techniques and equipment to minimize infrastructure within the mangrove area
- Careful monitoring of activities to identify unexpected impacts

Full details of these general guidelines can be found in the oil and gas exploration and production in mangrove areas guidelines produced in collaboration between the IUCN and the E&P forum. While this document outlines general guidelines, it identifies the need for site/project-specific guidelines and mitigation measures to be developed.

In accordance with the general guidance of the IUCN and E&P forum, the following site/project-specific guidelines and mitigation measures were used during the Hail and Shuweihat 3D seismic surveys.

Survey Planning. Survey planning will at an early stage consult with relevant experts in the production of a project-specific environmental-impact assessment (EIA) to identify areas of concern and the potential impacts of the seismic-survey operations. The EIA should identify all potential impacts and cover all activities. Where impacts are unavoidable, mitigation measures to reduce the impact as much as reasonably practicable within the requirements of the 1971 Ramsar Convention should be highlighted.

Operator's environmental-management plans should be reviewed to ensure they meet ADNOC standards.

Operators should be made aware of environmental considerations and mitigation measures highlighted in the project EIA to ensure they are met and factored into the survey design.

Use of Vibroseis Trucks and Other Vehicles. To prevent the need for clearing vegetation and other environmental impacts, the use of Vibroseis trucks and other vehicles shall not take place within mangrove areas. Vibration-point offsets will be made where required. Despite the environmental impacts accessing these areas with vehicles would have, they are generally not suitable for vehicles and pose additional risks to personnel and machinery.

Receiver Lines. Where receiver lines cross areas of mangrove, they should be laid with minimal disturbance to wildlife and vegetation.

As stated previously, the use of vehicles for cable layout should be avoided, with cables and other equipment being taken into the mangrove area by hand.

The clearing of vegetation must be avoided as much as possible; instead, the cable should be run around dense vegetation.

Geophones or other receivers should be planted in such a manner as to avoid damage to vegetation and, in particular, the root systems of mangrove trees.

If using geophones, these should be bunched to minimize the area of potential impact and planted in such a way as to avoid damaging root systems or other vegetation.

Crew Training. Crew operating in mangrove areas must be informed regarding the environmental considerations of such areas and trained to minimize environmental disturbance. Environmental-safety flash cards should be produced, and measures to minimize disturbance should be incorporated into preactivity toolbox talks.

Crew should be instructed that any hunting/fishing or collection of flora/fauna is strictly prohibited.

Removal of Equipment and Rubbish. After operations have been completed, all equipment used in the area must be removed and no rubbish left behind. It is also recommended that any rubbish found already in the area from third parties be removed and disposed of correctly.

Environmental Profile. An environmental profile of each area with planned activity must be made by means of a pre-operations survey with the collection of baseline data. These surveys allow the establishment of baseline information to assess the current condition and presence of existing environmental damage. This information can be compared to the presurvey EIA to assess its applicability and note any differences if they occur. Any changes noted at this point can be factored into project design. It is also important for comparisons to be made between pre- and post-operation data to assess any impacts that may have occurred as a result of operations.

Environmental profiles should include the following:

- Detailed description of the area concerned
- Images of areas where operations are to occur
- Details of any existing environmental damage
- Details of potential impacts from planned operations
- Relevance of impacts and mitigation measures identified by project EIA
- Additional mitigation considerations if required

Environmental Monitoring. Throughout and after operations within mangrove areas, environmental monitoring should be carried out. This may take the form of environmental audits and post-operation/decommission surveys.

Environmental Audit. Environmental audits should be carried out during operations and cover all types of work to be conducted in the mangrove area. The purpose of such audits is to assess the impact of ongoing operations, identify if existing mitigation measures are successful in preventing/reducing as far as possible environmental damage, and introduce further measures if required.

Detailed reports should include the following:

- Details of the operations being carried out

- Images of these operations, particularly in reference to their interaction with the environment
- Details of any environmental damage caused
- An assessment of existing mitigation measures and their effectiveness in preventing/reducing environmental damage
- Details of further mitigation measures if required

Post-Operation/Decommission Surveys. Post-operation/decommission surveys must be completed after operations have finished within the mangrove area. The purpose of such surveys is to assess the impact of operations and identify any environmental restoration needed.

Comparisons should be made with data collected during environmental profiles to assist in this process.

Detailed reports should include the following:

- Detailed description of the area concerned
- Images of areas where operations have occurred
- Details of any damage caused during operations or during demobilization from the working area

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