The distribution and relative abundance of marine mega-fauna, with a focus on humpback whales (*Megaptera novaeangliae*), in Exmouth Gulf, Western Australia, 2018

LYN IRVINE[1] AND CHANDRA SALGADO KENT[2]

[1] Irvine Images, PO Box 454, Exmouth, Western Australia 6707
[2] Oceans Blueprint, Coogee, Western Australia 6166

Image 1: Humpback whale cow and calf pair in Exmouth Gulf, Western Australia (photo taken by Lyn Irvine).

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Author Contributions: The work in this report, including the experimental design, was conceived by LI and CSK. LI, Katie Anderson, Gemma Francis and Andrea Lopez performed the surveys; LI and CSK analysed the data and provided the report.

1. EXECUTIVE SUMMARY

Subsea 7 propose to construct a pipeline bundle fabrication facility on the western shore of Exmouth Gulf, Western Australia, and tow 10 km sections of pipeline bundle through Exmouth Gulf to the offshore oil and gas fields of the northwest shelf. Exmouth gulf is a recognised resting area for the Breeding Stock D (BSD) humpback whales, the largest population on the globe. Resting areas are considered to be critical habitat for humpback whale survival, as they provide a suitable environment for lactating mothers to feed and raise their young calves, in preparation for the long migration to their polar feeding grounds. In addition to humpback whales, Exmouth Gulf also supports a range other marine mega-fauna species including dugongs, dolphins, turtles, manta rays, sharks and sea snakes.

An aerial survey program was conducted between August and November 2018, to determine the relative abundance and spatiotemporal distribution of humpback whales (*Megaptera novaeangliae*), and other mega-fauna, in Exmouth Gulf during the documented humpback whale resting season. Nine aerial surveys, with full coverage of Exmouth Gulf, were conducted between 08 August 2018 and 02 November 2018.

- Humpback whales were sighted on all surveys, with a total of 2772 humpback whales in 1661 groups being recorded in Exmouth Gulf between 08 August and 02 November 2018.
- At the time of peak whale occurrence, September 20, 754 humpback whales were recorded in Exmouth Gulf.
- Humpback whale calves were sighted on all surveys in Exmouth Gulf with a total of 688 calves being recorded.
- At the time of peak calf occurrence, October 02, 196 calves were recorded in Exmouth Gulf.
- 23 neonate calves were recorded during the aerial surveys - this is the first time neonate calves have been documented in Exmouth Gulf.
- The majority (82.6%) of the neonate calves in Exmouth Gulf were observed during August and September.
- Calves were present in an average of 41.1% of all groups sighted. It is to be noted that the percentage of calves is under-estimated in aerial surveys as their small size renders them difficult to see at distance and they're often masked by their mothers.
- The highest numbers of calves were present in Exmouth Gulf between mid-September and mid-October.
- The majority (81.3%) of all humpback whale groups observed were milling or resting; 83.3% of groups containing calves were milling or resting.
- Humpback whales had a broad distribution throughout the waters of Exmouth Gulf, except for the shallow waters along the southern and eastern shores.
- This study supports previous findings (Jenner et al., 2001) that Exmouth Gulf is an important resting area for the Breeding Stock D humpback whales.
- A total of 605 dugongs, including 75 calves, in 342 herds were observed in Exmouth Gulf. These were distributed in shallow waters mainly along the southern and eastern areas of the gulf.
- A total of 556 dolphins, including 10 calves, in 179 pods were observed in Exmouth Gulf. They had a broad distribution throughout the gulf with the highest density in the north-west portion of the gulf.
- A total of 1472 turtles were observed in Exmouth Gulf. They had a wide distribution throughout Exmouth Gulf with the highest numbers in the shallow waters along the southern and eastern areas of the gulf.
- A total of 329 manta rays were observed in Exmouth Gulf, distributed mainly in the north-western sector and also the shallow waters of the bottom third of the gulf.
- A total of 153 sharks were observed in Exmouth Gulf, distributed mainly along the shallow waters of the southern and eastern shores of the gulf.
- A total of 41 sea snakes were observed in Exmouth Gulf, distributed mainly in the north-western sector of the gulf.

High numbers of humpback whales, and other mega-fauna species including dugongs, dolphins, turtles, manta rays, sharks and sea snakes, were present in Exmouth Gulf between early August and early November 2018. These mega-fauna species can be subject to injury and disturbance from vessel strike and vessel noise. In particular, the majority of humpback whales observed in Exmouth Gulf were resting or milling at the surface, rendering them vulnerable to vessel strike. Many were lactating mothers with young, dependent calves, including neonate calves. Calves are particularly vulnerable to vessel strike as they are small and weak and have limited swimming and diving abilities. The highest probability of vessel strike occurs in areas where vessel activity and high animal density overlap. To minimise adverse impacts of vessel activity on mega-fauna in Exmouth Gulf, vessel activities can be planned spatiotemporally to avoid areas, or times, of high animal density, particularly those of vulnerable components of the population such as calves.

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2. INTRODUCTION

Subsea 7 Australia Contracting Pty Ltd (Subsea 7) propose to construct a pipeline bundle fabrication facility at Heron Point, on the western side of Exmouth Gulf, approximately 35 km south of the Exmouth township, Western Australia.

Pipeline bundles are used in the development of offshore gasfields. The Subsea 7 pipeline bundle project involves the compilation of short 2m sections of pipeline bundles into 10km lengths. These 10km lengths of pipeline will be launched from a purpose-built launchway into Exmouth Gulf, and then towed through Exmouth Gulf out to the offshore gasfields. The tow will be conducted by two tug boats; the tow configuration of the tug boats and the pipeline bundle may need reconfiguring in Exmouth Gulf before exiting the gulf.

Numerous species of marine fauna found in Exmouth Gulf are specially protected under state and federal laws. Humpback whales (*Megaptera novaeangliae*), are listed as Conservation Dependent under the *Biodiversity Conservation Act 2016 (BC Act)* and Vulnerable under the *Environment Protection and Biodiversity Act 1999* (*EPBC Act*); Dugong (*Dugong dugon*) are listed as Species in need of Special Protection under the *BC Act*; green (*Chelonia mydas*) and hawksbill turtles (*Eretmochelys imbricata*), are both listed as Vulnerable under the *BC Act* and the *EPBC Act*.

The largest humpback whale population on the globe, the Breeding Stock D (BSD) population, breeds along the coast of Western Australia (Branch, 2011, Salgado Kent et al., 2012, IWC, 2014). Along this coast, there are a number of locations that have been identified as critical habitat, essential for the survival of humpack whales. These habitats are areas known to seasonally support significant aggregations of humpback whales undertaking vital life-processes such as migrating, calving, and resting. Exmouth Gulf, on the eastern side of North West Cape, has been identified as one of three important resting areas along the Western Australian coast (Department of the Environment and Heritage, 2005), as it provides a sheltered environment for mother-calf pairs and mature males to rest and mate during their southern migration.

Humpback whales migrate past North West Cape between June and November each year (Salgado Kent et al., 2012). This migration is segregated according to age and reproductive class, typically in the following order: immature individuals and females with yearling calves travel in the vanguard of the migratory stream; mature males travel between the middle and the end of the migratory stream, and pregnant females travel at the rear. Non-pregnant females travel throughout the entire migratory stream (Chittleborough, 1965). The time that a humpback whale population passes a particular location along the coast varies each year (Dawbin, 1966). For the BSD population that migrates along the Western Austalian coast, the peak of the northbound migratory stream typically passes North West Cape around late July (Dawbin, 1997), however this has been documented to vary by up to three weeks annually (Chittleborough, 1965), most likely in response to variability in the environmental conditions in the Antarctic feeding grounds.

Exmouth Gulf is used as a resting area between July and November, with the majority of humpback whales documented as occupying the gulf between late August and late October, during their southwards migration from the breeding grounds to the Antarctic feeding grounds (Chittleborough, 1953, Jenner et al., 2001, Jenner and Jenner, 2005). Similar to the northern migration, the timing of occurrence in Exmouth Gulf has been documented to vary by up to four weeks annually, with peak numbers occurring between mid-September and mid-October (Jenner and Jenner, 2005). Peak occurrence in Exmouth Gulf is thought to coincide with the arrival of southbound mother-calf groups from the Kimberley region (Jenner and Jenner, 2005).

Mothers and their calves utlise the sheltered waters of Exmouth Gulf for resting and nursing; the calves growing and building up sufficient energy reserves for the long southwards migration to their Antarctic feeding grounds. Whilst in the gulf, humpback whale calves spend approximately 20% of their time suckling (Videsen et al., 2017), growing at a rate of 2.4 - 3.3 cm per day (Irvine et al., In Prep, Christiansen et al., 2016). This is one of the fastest growth rates of all mammals (Frazer and Huggett, 1974). In order to maximise the energy reserves available for transfer to their calves, humpback whale mothers restrict their energy use to about half of that they use on the foraging grounds (Bejder et al., 2019). This energy conservation in the breeding grounds is important for the lactating mothers who have extreme energy demands from feeding calves during long periods of fasting (Oftedal, 1993). Calves, and their lactating mothers, rest in Exmouth Gulf for periods of up to two weeks, before migrating southwards towards their feeding grounds (Jenner and Jenner, 2005). Mature males can reside in Exmouth Gulf for up to four weeks while searching for receptive females to breed with (Jenner and Jenner, 2005).

Recent research illustrated that North West Cape is an important area for neonate calves from the BSD population and suggested that neonate calves may reside in Exmouth Gulf during the northern migration (Irvine et al., 2017). Neonate calves are a vulnerable component of the population as they are essentially defenceless, have limited immune function, and limited swimming and diving abilities (Thomas and Taber, 1984). At this early time in their lifecycle, they are particularly prone to predation by killer whales (*Orcinus orca*) (Pitman et al., 2015). Estimates of natural calf mortality rates for humpback whales during this early life stage have been approximated at 15-24%

(Gabriele et al., 2001). Females are also more vulnerable when pregnant and accompanied by calves because of the increased energetic demands of gestation and lactation (Lockyer, 1981). Humpback whales either entirely or mostly fast over the many months of migration between the foraging and breeding / calving grounds (Chittleborough, 1965, Dawbin, 1966). Thus, migrating mothers and their calves are more susceptible to declining condition and health if energetic demands are pushed to their limit by disturbance, stress, predation attacks, injury, and other impacts. The successful rearing of calves, which relies to a large extent on adequate maternal energy reserves (Arnbom et al., 1993, McMahon et al., 2000, Christiansen et al., 2014), ensures survival of the next generation that is essential for population stability.

To mitigate impacts of vessel activity on humpback whales, and their calves, in Exmouth Gulf, Subsea 7 has proposed to exclude towing pipeline bundles during the period of main humpback whale usage in Exmouth Gulf. This time period has nominally been defined as mid-September to mid-November. However, knowledge of humpback whale usage of Exmouth Gulf is currently not well known, as the most recent humpback whale survey in Exmouth Gulf was conducted over 10 years ago, in 2005 (Jenner and Jenner, 2005). The BSD population has been increasing at over 10% per year since the cessation of commercial whaling, and at the most recent population survey in 2008, was estimated to have reached approximately 30,000 animals (Salgado Kent et al., 2012). It is not known how this population increase has effected the distribution and abundance of humpback whales in Exmouth Gulf resting area.

To inform and improve the management of potential impacts associated with the pipeline bundle project, a research program was undertaken to determine the spatial and temporal distribution of humpback whales within Exmouth Gulf. Opportunistic sightings of other species of marine mega-fauna inhabiting Exmouth Gulf were also recorded. The study was conducted between August and November, the period when humpback whales are known to rest in Exmouth Gulf. The work presented here specifically aimed to: (1) estimate the relative abundance and distribution of humpback whales and their calves in Exmouth Gulf during their annual migration; (2) estimate the relative abundance and distribution of other marine mega-fauna species; namely dugongs, dolphins, turtles, manta rays, sharks and sea snakes in Exmouth Gulf between August and early November. The knowledge gained will inform management decisions on the timing and location of tow activities that will minimise potential disturbance to humpback whales, and their calves, in the Exmouth Gulf resting area. It will also provide information about the distribution of other marine mega-fauna in Exmouth between August and early November.

3. MATERIALS AND METHODS

3.1. Study Site

Exmouth Gulf is a northward facing embayment situated on the eastern side of North West Cape between the latitudes of 21°45' and 22°33' (Figure 1). It is a relative turbid and shallow environment with a mean depth of <20 m. It covers an area of approximately 4000 km^2 and is a recognised resting area (Department of the Environment and Heritage, 2005) for the Breeding Stock D (BSD) humpback whales, the largest humpback whale population on the globe (Branch, 2011, Salgado Kent et al., 2012, IWC, 2014). Although humpback whales have been opportunistically sighted in Exmouth Gulf in June (pers. comm. Eric Roulston, Norwest Airwork), they are typically found in the gulf between July and November each year.

3.2. Survey Design

The aerial surveys were designed to optimise sampling for humpback whales and to record other marine mega-fauna species on an opportunistic basis. They covered the entire study area within the waters of Exmouth Gulf and complied with the assumptions of distance sampling. The survey design consisted of 9 box-end line transects, spaced 10 km apart. The survey transects ran in an east-west direction, between the eastern and western edges of the gulf. Surveys were planned to be undertaken between the beginning of August and early November; however logistical constraints delayed the commencement of the survey program until the second week of August. All aerial surveys were conducted between 08 August and 02 November 2018, approximately every 10-12 days when weather conditions were favourable.

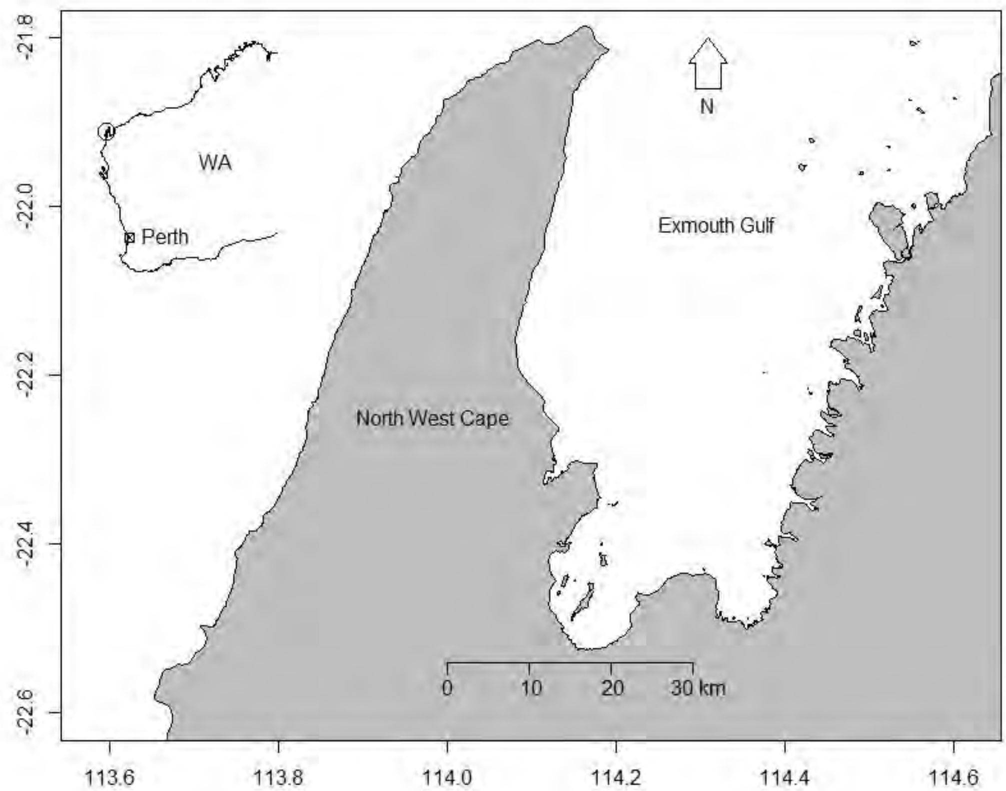

Figure 1. Location of the study area of Exmouth Gulf, along the north-west coast of Western Australia.

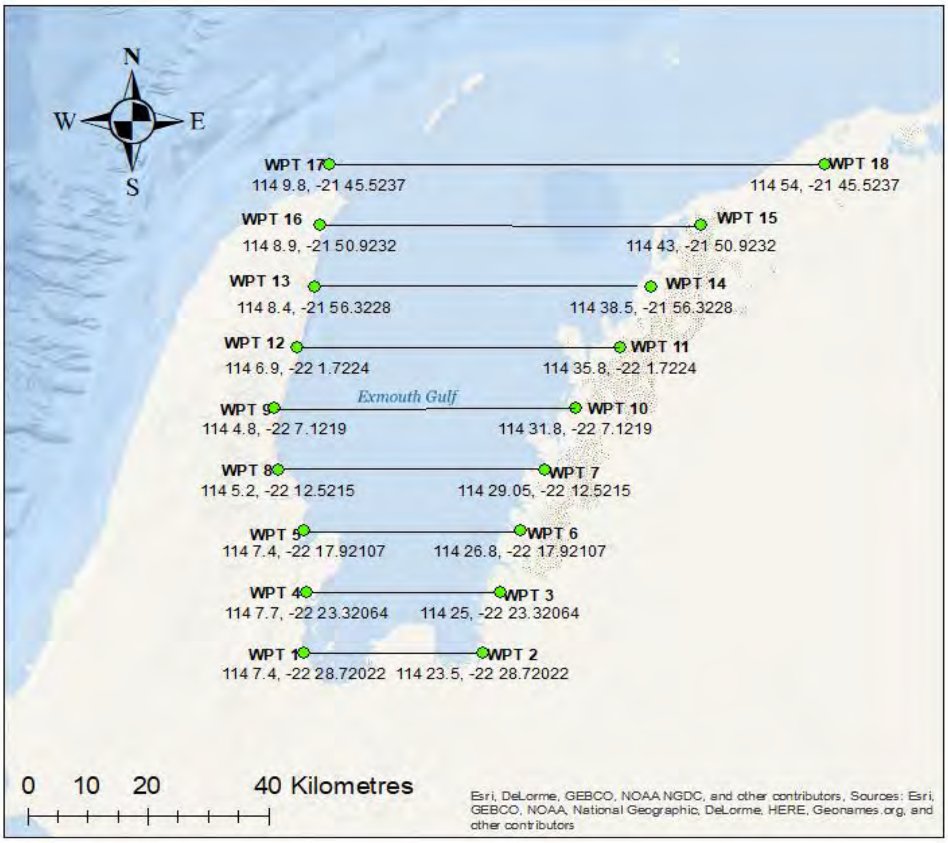

Figure 2. Map of the aerial survey design for humpback whales in Exmouth Gulf.

3.3. Data Collection

The surveys were conducted using a twin engine, high wing aircraft (Cessna 337), flying at an altitude of 305m (1000 ft) at a speed of 204 km hr^{-1} (110 knots). Survey personnel consisted of a pilot and four observers linked via an intercom system that could be isolated from the pilot when necessary. The two primary observers were seated in the middle seats of the aircraft and visually screened from the secondary observers in the rear seats. The primary and secondary observers were acoustically isolated from each other by being connected to two separte intercoms. Observations were recorded on a time-coded digital sound recorder synchronised to a hand-held GPS that provided coordinates every second during the flight. All devices (including a digital camera) were calibrated to ±1 sec accuracy prior to each flight. Angle of drift of the aircraft from the flight path (Lerczak and Hobbs, 1998) was recorded by the pilot.

Two modes were used during the surveys: i) passing mode where observations were recorded without deviating from the transect line; and ii) closing mode where the aircraft broke from transect to collect more detailed information about an observation. Once the information was collected in closing mode, passing mode was resumed by returning to the location where the aircraft broke from transect. Passing mode was used on all transects in the aerial surveys. The aircraft transitioned to closing mode when a humpback whale group was sighted within 600 m either side of the transect, in order to confirm group composition. If the whale group sighted within 600 m of the transect was sighted clearly, the group was not circled.

3.3.1 Passing mode

Observers recorded the location of each pod sighted, in relation to the aircraft by recording the vertical angle down from the horizon (using *Suunto* PM-5/360PB clinometers), and the horizontal angle (using a compass board) from the aircraft's travel direction to the whale. The position of each group of whales was calculated post survey following Salgado-Kent *et al.* (2012). In addition to location, observers recorded group size, group composition, behaviour, direction of travel, and calf colour (light grey, mid-grey, dark grey or adult colour). Group composition was described in terms of the number of adults and calves present. Here, a calf was defined as a whale within close proximity to another whale, and visually estimated to be less than 2/3rds of the length of the accompanying animal (Clapham, 1999). Behaviour was categorised as travelling, milling, resting or undetermined.

At the beginning of each transect, the following environmental conditions were recorded: sea state (Beaufort scale) (Appendix A: Table 7), wind speed (knots), wind direction, cloud cover (oktas), visibility, turbidity (Appendix A: Table 8) and glare intensity and coverage on each side of the aircraft. These conditions were updated during the transect whenever they changed. Surveys were conducted in weather conditions of Beaufort sea state ≤3 as the the high windspeed and extensive white caps in higher Beaufort conditions (sea state ≥4) typically restrict sightings to surface active individuals (e.g. breaching or tail slapping).

3.3.2 Closing mode

The aircraft was directed to fly directly overhead the group in order to i) obtain an accurate assessment of the number of individuals in each group, and ii) identify calf colour (as an indication of developmental stage). Calf colour was described relative to that of the closest accompanying adult (i.e. the mother). All light grey and mid-grey calves were classified as neonates (<1 month of age) while those the same colour as their mother (dark grey - black) were classified as post-neonate (>1 month of age) (Kaufman and Forestell, 2006). Aerial images of neonate calves were taken when possible (i.e. when the calves remained at the surface as the plane circled overhead) by the starboard observer with a Canon EOS 5D Mark III fitted with a Canon 85mm fixed lens.

3.3.3. Analyses

The position (latitude and longitude) of each group of whales was calculated post survey using the R function 'destPoint' in the package *geosphere* in R v3.3.2 (R Development Core Team, 2017). 'destPoint' requires radial distances from the position at the track line in which the observation was made. Distances were calculated by: $RD = h * tan(\theta)$, where RD is the radial distance, h is the height of the observer from the surface of the ocean, and θ is the vertical angle up to the group from directly below the aircraft (calculated by subtracting the declination angle from the horizon from 90°) (Lerczak and Hobbs, 1998). All whale observations greater than 5 km from the transect line were deleted from the analyses to prevent double-counting. The measured angles from the aircraft to the group were corrected for the course and drift of the aircraft by: $AW = AC + MHA \pm DA$, where *AW* is the true angle to the whale, *AC* is the aircraft's course, *MHA* the measured horizontal angle and *DA* the angle of the aircraft's drift that was subtracted or added depending upon the side of the aircraft the sighting was on (as defined and described in Lerczak and Hobbs, 1998 and applied in Salgado Kent et al. 2012).

The positions of all sightings were plotted in ArcGIS version 10.6.1. Kernel density plots were produced, using the spatial analyst tool, to visually show the magnitude of relative abundance per unit area surveyed, using the kernel function to fit a smooth surface to observation points. A Geodesic method was used with an output cell size of 300 m. The analyses here do not include absolute estimates that adjust for imperfect detection.

Relative abundance was plotted in R using the package *ggplot*. This was plotted over time to show peak periods of humpback whales and proportions of calves. Loess smoothing curves with 95% CIs were computed for relative abundance points and plotted to visualise temporal patterns using R's 'ggplot' function.

4. Results

A total of 9 surveys were conducted between 08 August and 02 November 2018 (Table 1). The majority of surveys were completed as planned i.e. Beaufort Sea State ≤3, however the western end of transect 9 was completed in high Beaufort Sea States (Beaufort Sea State ≥4) in surveys 7, 8 and 9 as the wind speed increased in the western, unsheltered sections of the survey north of North West Cape. The number of observations from these sections will likely be under-estimates as whales are difficult to see amongst the white caps generated in beaufort force 4 and 5 seas.

Table 1. Aerial surveys completed in Exmouth Gulf between August and November 2018.

Date	Survey Number	Transects completed	Beaufort sea state
08/08/18	1	1 - 9	1 - 2
18/08/18	2	1 - 9	1 - 2
27/08/18	3	1 - 9	1 - 3
08/09/18	4	1 - 9	1 - 2
20/09/18	5	1 - 9	2 - 3
02/10/18	6	1 - 9	2 - 3
12/10/18	7	1 - 8	1 - 3
12/10/18	7	9	3 - 4
23/10/18	8	1 - 8	2 - 3
23/10/18	8	9	3 - 5
02/11/18	9	1 - 8	2 - 3
02/11/18	9	9	3 - 5

4.1. Humpback whales

4.1.1. Relative abundance and distribution

A total of 2772 individuals in 1661 groups were sighted in Exmouth Gulf during the nine surveys conducted between 08 August and 02 November 2018 (Table 2). This consisted of between 55 and 754 humpback whales in 37 and 446 groups, respectively, sighted each survey. Humpback whale numbers were low in early August and increased steadily throughout August and early September until peak numbers were observed in late-September to early October (20 Sep - 02 Oct). Following the peak, numbers gradually decreased throughout October and into early November when numbers reached their lowest of all surveys (Figure 3).

Humpback whale calves were sighted during all surveys, with a total of 688 calves being observed in the nine surveys (Table 2). Significantly, 23 of the calves observed during the surveys were small neonate calves. While neonate calves were sighted in Exmouth gulf between early August and late October, just under half (47.8%) of the neonate calves were observed during August. The majority (77.8%) of the calves sighted in the first survey, 08 August, were neonate calves (Table 2). To the authors' knowledge, this is the first time that neonate calves (<1 month of age) have been formally documented in Exmouth Gulf.

Table 2. Numbers of humpback whales sighted each survey.

Date	Survey Number	Humpback groups	No. whales	No. calves	No. neonates
8/08/2018	1	60	93	9	7
18/08/2018	2	79	120	6	0
27/08/2018	3	165	257	30	4
8/09/2018	4	167	263	44	2
20/09/2018	5	446	754	166	6
2/10/2018	6	340	607	196	2
12/10/2018	7	249	424	154	1
23/10/2018	8	118	199	68	1
2/11/2018	9	37	55	15	0
Total	9	1661	2772	688	23

The total number of calves was low in August, and gradually increased during September, to reach peak numbers in mid-September to early October (Figure 3). Calf numbers decreased during late October and into November (Figure 3). Calves were present in an average of 41.1% of all groups sighted. The percentage of humpback whale groups containing a calf was low during August (7.6% - 18.2%) and increased during September before reaching a peak of peak of 61.4% in mid-October (Figure 4). This percentage remained high throughout the majority of October and began to decrease in late October and early November (Figure 4).

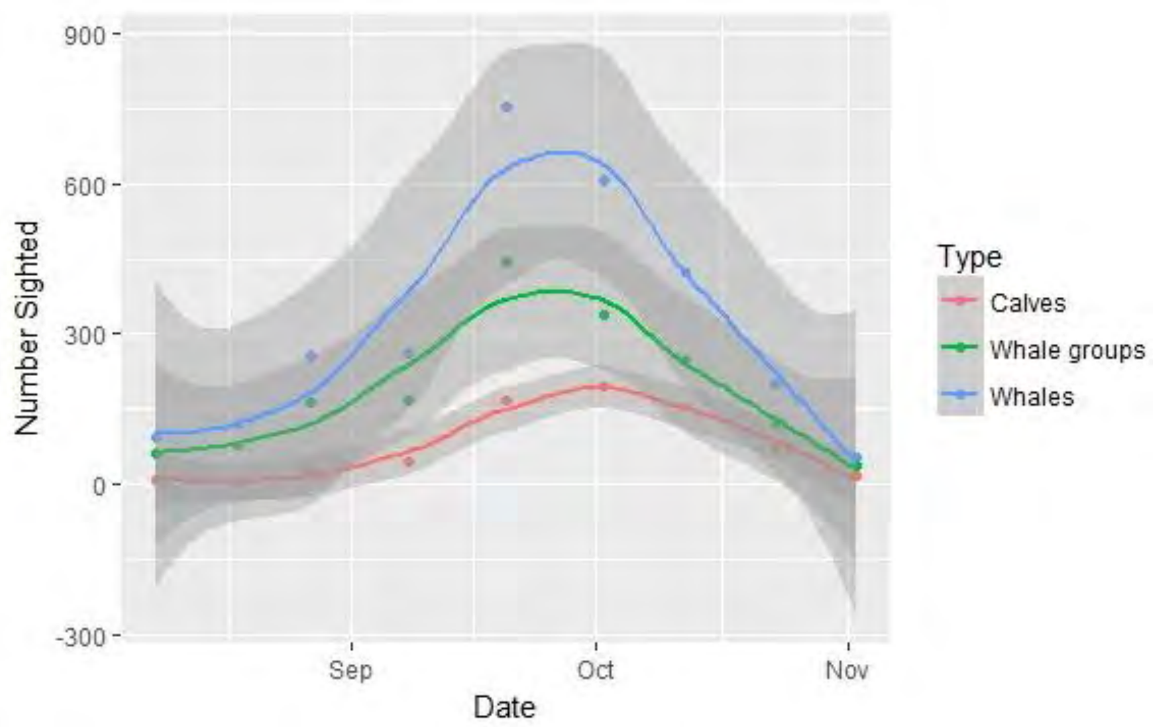

Figure 3. Relative numbers and loess smoothing curves (with 95% CIs) for total number of humpback whales, number of calves, total number of whale groups, and number of groups with calves sighted per flight in Exmouth Gulf.

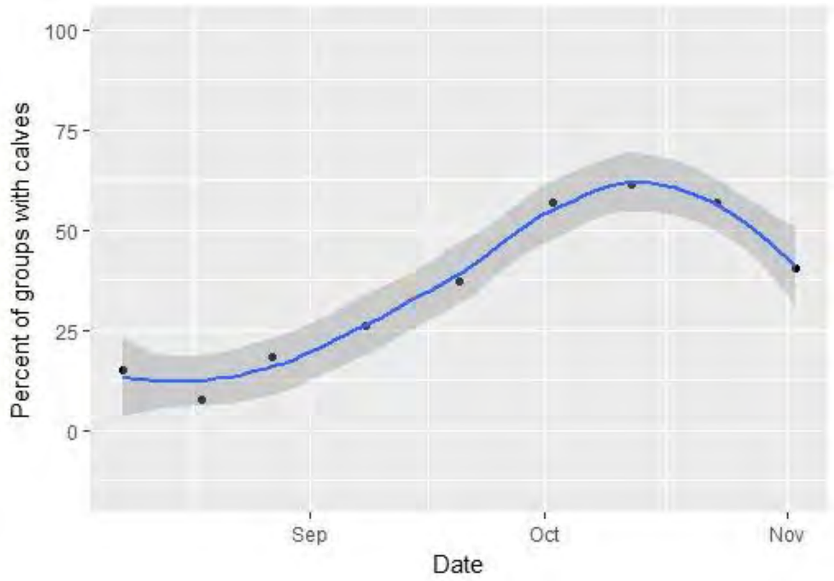

Figure 4. Percentages fitted with a loess smoothing curve (with 95% CIs) of humpback whale groups containing one or more calves during aerial surveys in Exmouth Gulf.

The majority of humpback whale groups (81.3%) were milling or resting; 13.1% were travelling; and 5.8% had an undefined behaviour (Table 3). For the groups that contained calves, 83.3% were milling or resting; 12.3% were travelling and the behaviour of 4.4% was undefined (Table 3).

Table 3. Behaviour of humpback whale groups and calf groups in Exmouth Gulf.

Date	Survey Number	Humpback groups	Groups milling	Groups resting	Groups travelling	Groups undefined	Calf groups	Calf groups milling	Calf groups resting	Calf groups travelling	Calf groups undefined
8/08/2018	1	60	21	9	30	0	9	1	2	6	0
18/08/2018	2	79	54	17	7	1	6	3	1	1	1
27/08/2018	3	165	108	26	26	7	30	18	8	3	1
8/09/2018	4	167	86	48	28	5	44	17	22	4	1
20/09/2018	5	446	238	122	34	52	166	60	78	13	15
2/10/2018	6	340	187	90	41	22	193	100	57	28	8
12/10/2018	7	249	57	165	23	4	153	33	105	14	1
23/10/2018	8	118	51	41	22	4	67	27	24	13	3
2/11/2018	9	37	23	7	6	1	15	11	2	2	0
Total	9	1661	825	525	217	96	683	270	299	84	30

Humpback whales had a broad distribution throughout the waters of Exmouth Gulf, other than the shallow waters along the southern and eastern shores. Although distributed widely throughout the majority of Exmouth Gulf, calf groups tended to be concentrated in the southern two-thirds of the gulf, mostly in the central and western portions (Figure 5). The majority of groups not containing calves were sighted in the northern-most areas of the gulf (Figure 5).

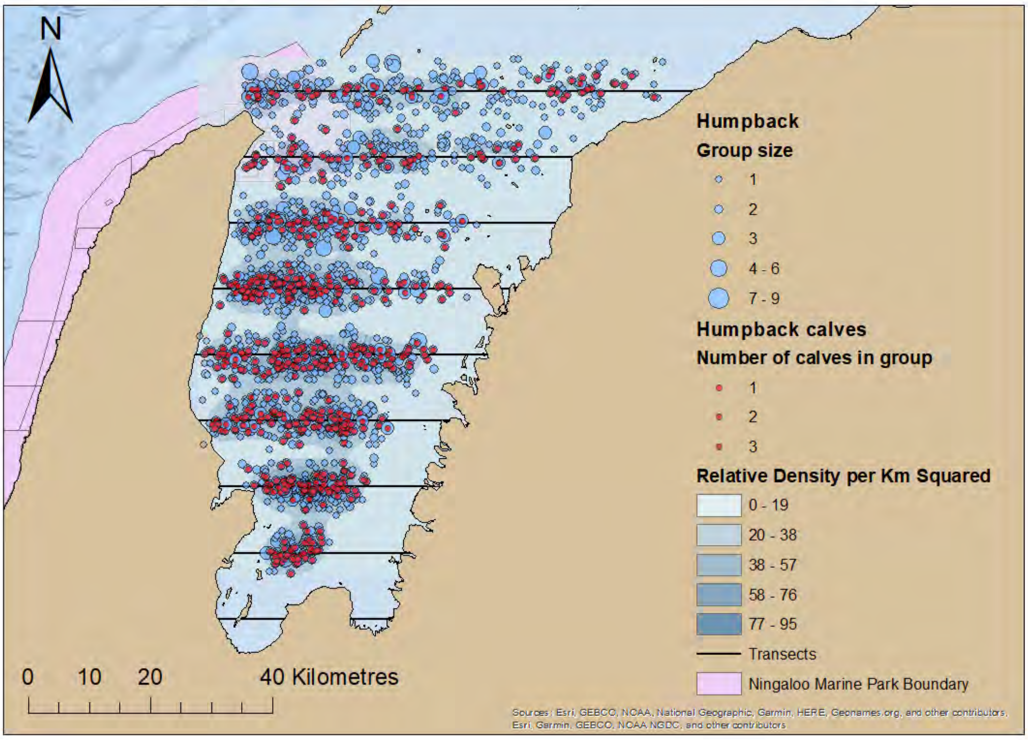

Figure 5. Distribution of humpback whales in Exmouth Gulf during aerial surveys. Transects are marked in black lines.

Humpback whale distribution, composition and density all varied temporally, as the breeding season progressed (Figures 12-20). During early August, humpback whales were concentrated in the northern and western areas of Exmouth Gulf. By late August, humpback whale distribution had expanded in high densities from the northern to southern areas of the Gulf, mainly in the central to western regions of the gulf. The majority of groups in Exmouth Gulf during August contained adults only. Importantly however, the groups that contained calves during August consisted mainly of neonate calves, with the highest proportion of neonate calves being observed in the northern areas of Exmouth Gulf.

Humpback whale density increased during September, with the distribution encompassing the entire Exmouth Gulf, other than the shallow waters along the eastern and southern shores. The number of groups containing calves increased throughout September and into October, when the percentage of groups containing calves reached its maximum. During September and October calf groups were widely distributed across the gulf, with a tendency of being concentrated in the central and southern regions of Exmouth Gulf. In late October, the density started to decrease, and the distribution began retreating from the north-east to mainly the south-western three-quarters of the Gulf. In November, the distribution retreated further, mainly into the western areas of Exmouth Gulf.

The peak density of humpback whales in Exmouth Gulf (9.1 - 13 whales / km^2) occurred on 20 September (Figure 16); high densities of whales (>4 whales / km^2) occurred between 18 August and 23 October (Figures 13 - 19).

4.2. Dugongs

4.2.1. Relative abundance and distribution

A total of 605 dugongs in 342 herds were sighted in Exmouth Gulf during the nine surveys conducted between 08 August and 02 November 2018 (Table 4). This consisted of between 30 and 121 dugongs in 23 and 59 herds, respectively, observed each survey (Table 4). Dugong numbers oscillated between August and November with high numbers in mid-August, low numbers in late-August to early September, high numbers in late-September to early-October and numbers decreasing in late October and early November (Table 4).

A total of 75 dugong calves were observed during the surveys, with between 2 and 18 calves sighted each flight. Dugong calves were sighted on all flights and constituted 5.1% to 20.9% (mean = 12.4%) of individuals sighted during each survey (Table 4).

Dugongs were distributed in shallow waters mainly along the eastern and southern areas of Exmouth Gulf (Figure 6).

Table 4. Numbers of dugongs sighted each survey.

Date	Survey Number	Dugong herds	No. dugongs	No. calves
8/08/2018	1	35	79	6
18/08/2018	2	59	121	8
27/08/2018	3	23	39	2
8/09/2018	4	31	54	4
20/09/2018	5	40	75	13
2/10/2018	6	56	101	18
12/10/2018	7	47	63	11
23/10/2018	8	23	30	4
2/11/2018	9	28	43	9
Total	9	342	605	75

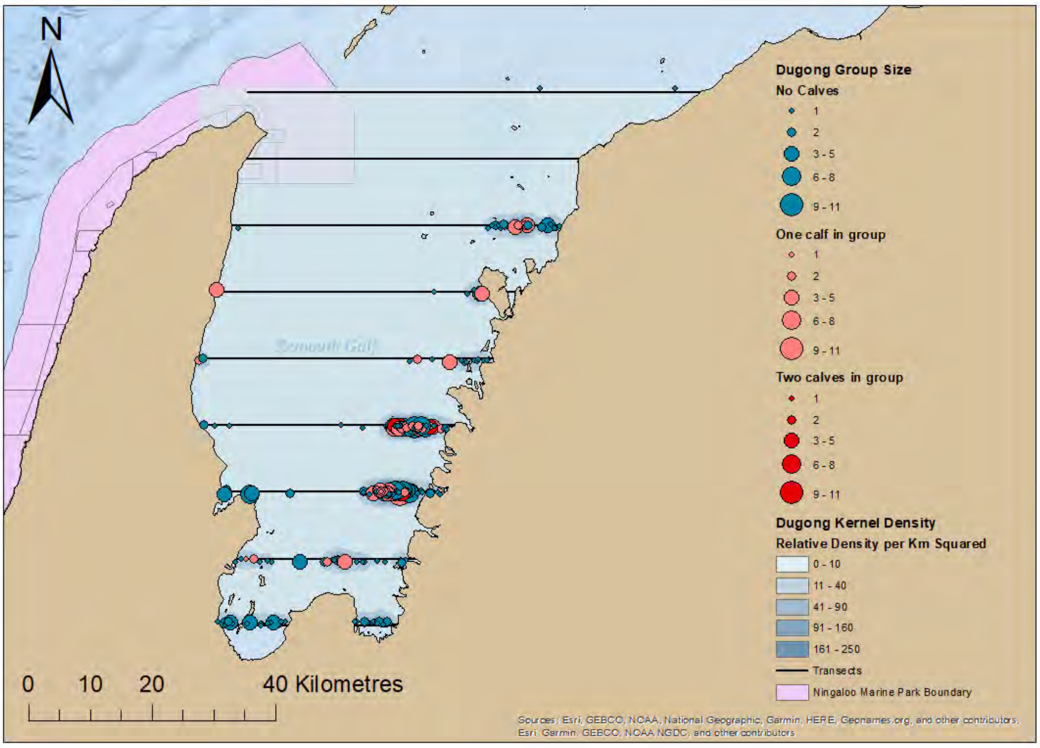

Figure 6. Distribution of dugongs within Exmouth Gulf during aerial surveys. Transects are marked in black lines.

4.3. Dolphins

4.3.1. Relative abundance and distribution

A total of 556 dolphins (including 10 calves) in 179 pods were sighted in Exmouth Gulf during the nine surveys conducted between 08 August and 02 November 2018 (Table 5). This consisted of between 21 and 114 dolphins in 8 and 30 pods, respectively, observed each survey (Table 5). Both Indo-Pacific bottlenose (*Tursiops aduncus*) and Australian humpback dolphins (*Sousa sahulensis*) were observed during the surveys, however not reported in detail here as dolphin species are difficult to identify reliably from an altitude of 1000 ft.

Dolphin numbers ranged between August and November with higher numbers during August and generally lower numbers between September and early November (Table 5). Dolphin calves were sighted on six out of the nine surveys and constituted between 0% and 9.5% (mean = 1.8%) of the dolphins sighted during each survey (Table 5). Dolphin calves were difficult to sight due to their small size and the high altitude of the survey aircraft.

Dolphins had a broad distribution throughout Exmouth Gulf with the highest density in the northern portion of the gulf (Figure 7).

Table 5. Numbers of dolphins sighted each survey.

Date	Survey Number	Dolphin pods	No. dolphins	No. calves
8/08/2018	1	31	109	0
18/08/2018	2	24	54	1
27/08/2018	3	30	114	1
8/09/2018	4	23	38	0
20/09/2018	5	13	49	0
2/10/2018	6	14	32	2
12/10/2018	7	27	101	1
23/10/2018	8	9	38	3
2/11/2018	9	8	21	2
Total	9	179	556	10

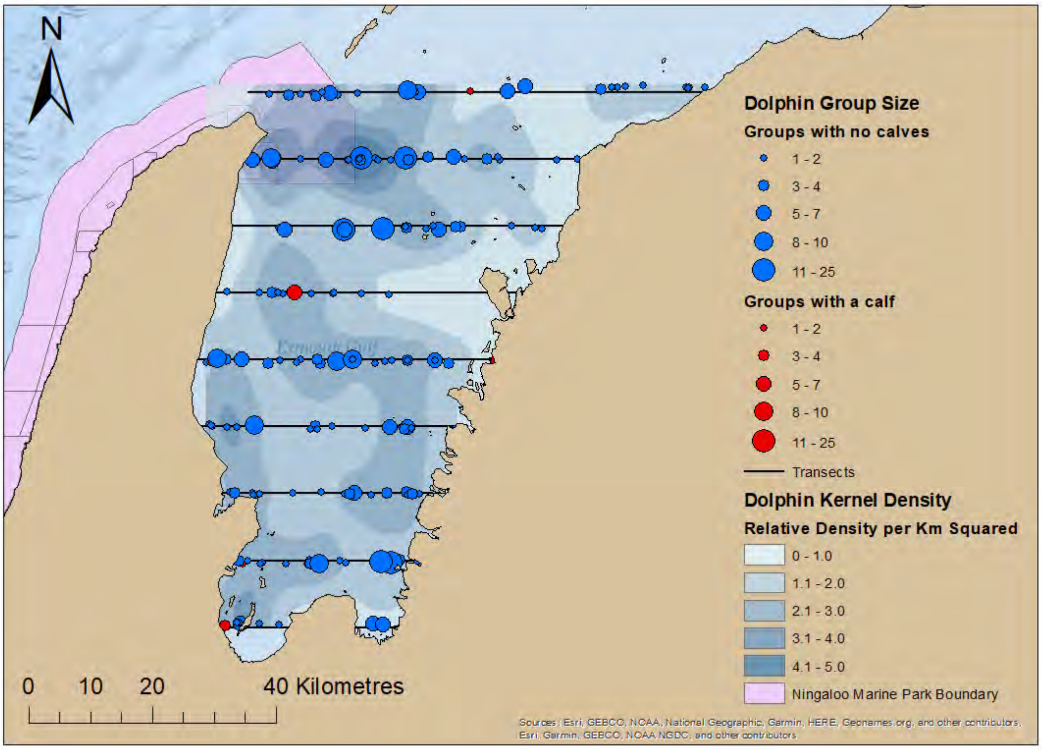

Figure 7. Distribution of dolphins within Exmouth Gulf during aerial surveys. Transects are marked in black lines.

4.4. Turtles

4.4.1. Relative abundance and distribution

A total of 1472 turtles were sighted in Exmouth Gulf during the nine surveys conducted between 08 August and 02 November 2018 (Table 6). This ranged between 80 and 308 turtles (mean ± sd = 163.6 ± 68.9), in each survey (Table 6), with highest numbers being observed in September to early October (Table 6). Turtles could not be identified to species level during the surveys, however based on previous vessel based surveys, the majority of the turtles sighted are likely to be green turtles (*C. mydas*) with hawksbill turtles (*E. imbricata*) in the shallow mangrove areas (Jenner and Jenner, 2005). Turtles had a broad distribution throughout Exmouth Gulf, with the highest numbers in the shallow waters in the southern and eastern areas of the Gulf (Figure 8).

Table 6. Numbers of turtles, manta rays, sharks and sea snakes sighted each survey.

Date	Survey Number	Turtles	Mantas	Sharks	Sea snakes
8/08/2018	1	117	52	13	15
18/08/2018	2	126	8	10	1
27/08/2018	3	80	24	33	3
8/09/2018	4	308	59	12	8
20/09/2018	5	175	20	8	1
2/10/2018	6	222	47	17	3
12/10/2018	7	184	38	23	5
23/10/2018	8	141	65	20	5
2/11/2018	9	119	16	17	0
Total	9	1472	329	153	41

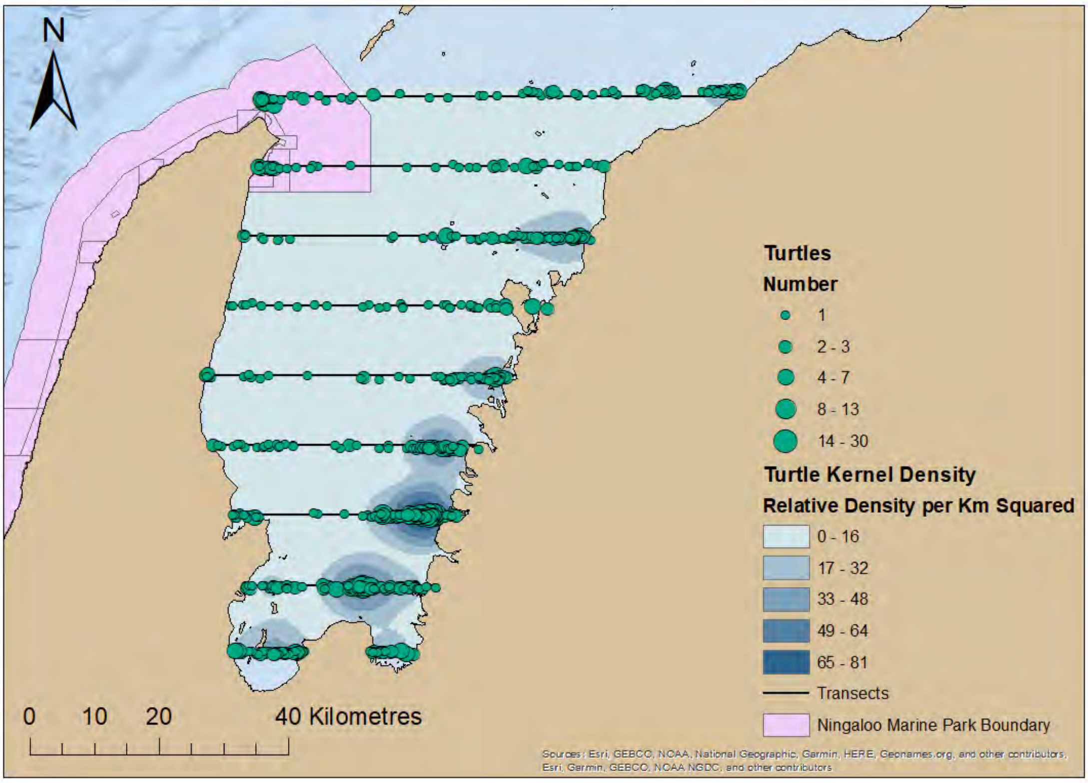

Figure 8. Distribution of turtles within Exmouth Gulf during aerial surveys. Transects are marked in black lines.

4.5. Manta rays

4.5.1. Relative abundance and distribution

A total of 329 manta rays were sighted in Exmouth Gulf during the nine surveys conducted between 08 August and 02 November 2018 (Table 6). This ranged between 8 and 65 manta rays (mean ± sd = 36.6 ± 20.4), in each survey (Table 6). Manta rays were identified by their distinctive shape and white cephalic lobes however it is possible that some were assessed as eagle rays in the turbid, shallow waters in the southern area, and thus not documented. Manta rays were distributed in the north-western areas of Exmouth Gulf and also the shallow waters in the southern third of the Gulf (Figure 9).

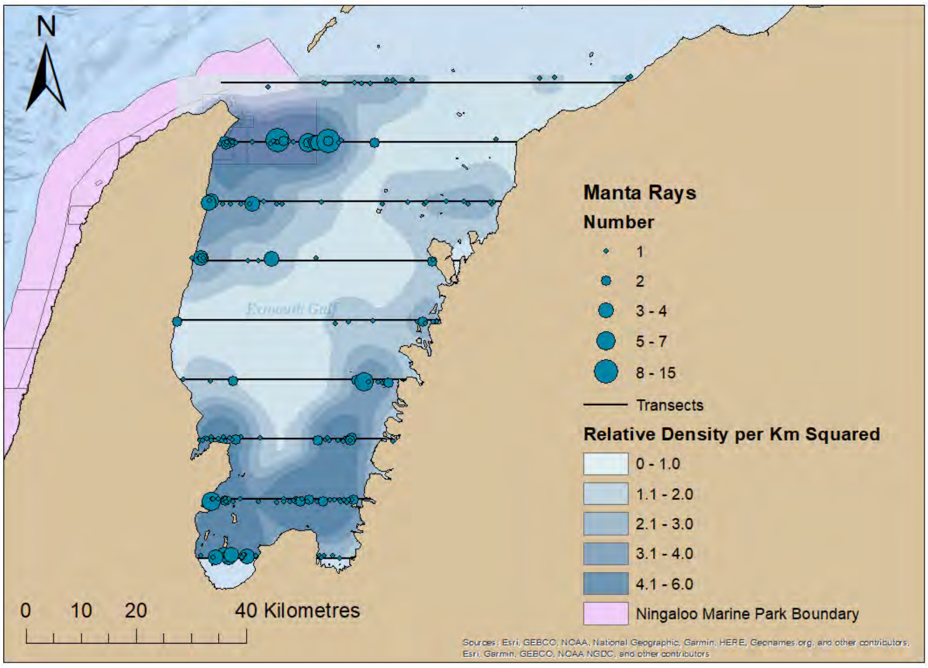

Figure 9. Distribution of manta rays within Exmouth Gulf during aerial surveys. Transects are marked in black lines.

4.6. Sharks

4.6.1. Relative abundance and distribution

A total of 153 sharks were sighted in Exmouth Gulf during the nine surveys conducted between 08 August and 02 November 2018 (Table 6). This ranged between 8 and 33 sharks (mean ± sd = 17.0 ± 7.7), in each survey (Table 6). Sharks were distributed mainly along the shallow waters of the southern and eastern shores of Exmouth Gulf (Figure 10).

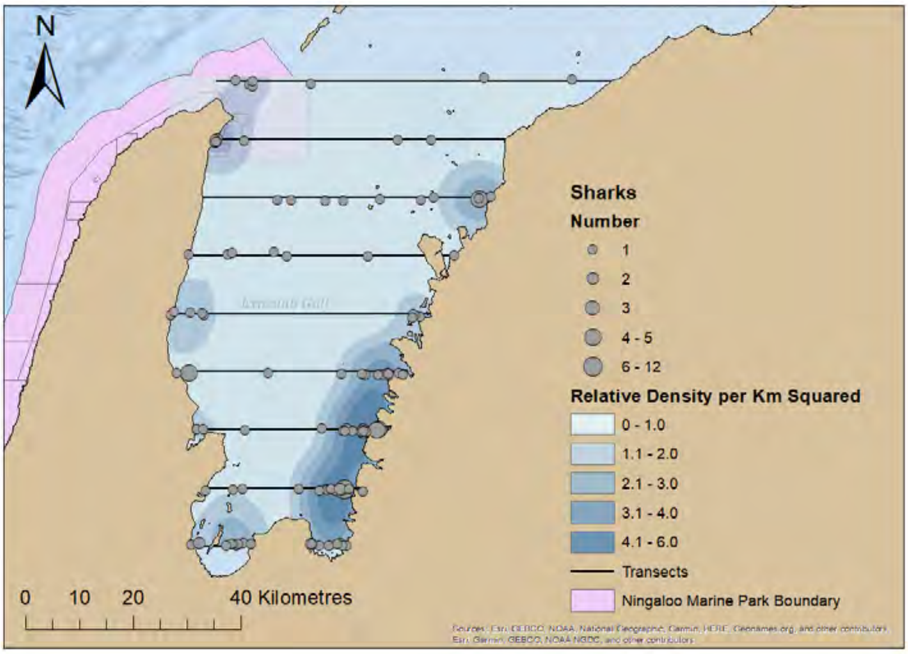

Figure 10. Distribution of sharks within Exmouth Gulf during aerial surveys. Transects are marked in black lines.

4.7. Sea snakes

4.7.1. Relative abundance and distribution

A total of 41 sea snakes were sighted in Exmouth Gulf during the nine surveys conducted between 08 August and 02 November 2018 (Table 6). This ranged between 0 and 15 sea snakes (mean ± sd = 4.6 ± 4.6), in each survey (Table 6). Sea snakes were distributed mainly in the north-western sector of Exmouth Gulf (Figure 11).

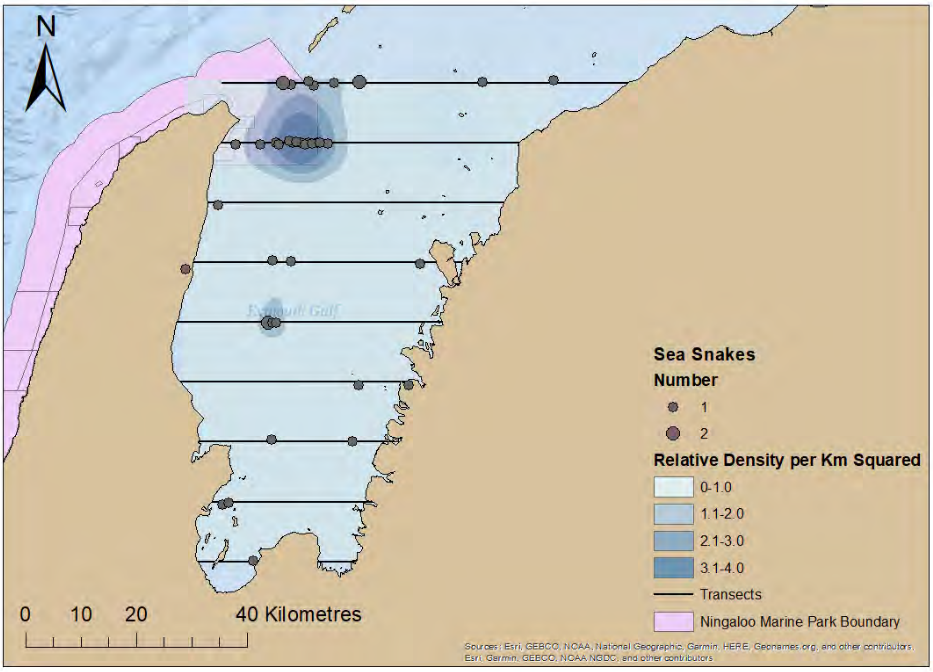

Figure 11. Distribution of sea snakes within Exmouth Gulf during aerial surveys. Transects are marked in black lines.

5. DISCUSSION

Aerial surveys in Exmouth Gulf were successfully conducted during the period, 08 August - 02 November, providing data on the distribution and relative abundance of humpback whales during the majority of the period that they are known to utilise Exmouth Gulf. The relative abundance changed temporally, with the highest numbers of humpback whales being recorded between mid-September and mid-October and lower numbers in August and November. Lactating females and their suckling calves were present in Exmouth Gulf between early August and early November, with small neonate calves being present between early August and late October and larger post-neonate calves being present in all surveys.

In addition, a large number of other mega-fauna species, including dugongs, dolphins, turtles, manta rays, sharks and seas snakes were sighted opportunistically, providing some information on the importance of Exmouth Gulf for these species. It is important to note that due to humpback whales being the priority species for the aerial surveys, sightings for other mega-fauna species are likely under-estimated and their distribution an estimate only, as angles (for determining accurate positions) were not recorded.

5.1. Humpback whales

Exmouth Gulf is a recognised resting area for the BSD humpback whales (Chittleborough, 1953, Jenner et al., 2001, Department of the Environment and Heritage, 2005), the largest population on the globe (Branch, 2011, Salgado Kent et al., 2012, IWC, 2014). Humpback whales are a protected species in Australia, being listed as Vulnerable under the *EPBC Act 1999* and Species of Special Conservation Interest under the *Biodiversity Conservation Act 2016*. Each year, between July and November, large numbers of humpback whales, including mature males, mature females, juveniles and calves occupy Exmouth Gulf, for breeding purposes, during their annual migration. Importantly, lactating females (mothers) and calves use Exmouth Gulf for nursing, with the sheltered, quiet waters providing a suitable environment for energy conservation and suckling. Lactating females, who fast whilst in the breeding grounds, must conserve energy and maximise energy transfer to their dependent calves to ensure maximum fitness of both themselves and their offspring for the ensuing migration to their Antarctic feeding grounds. Results presented here illustrate that in 2018, a large number of humpback whales were present in Exmouth Gulf between at least early August and early November. A high percentage of these humpback whales were calves, including small, neonate calves.

During 2018, the timing of peak humpback whale abundance in Exmouth Gulf, between mid-September and early October, was similar to that observed in 2005, but different to that observed in 2000, 2001 and 2004, when peak abundance occurred between 2-11 October, 12-21 October and 7-14 October, respectively (Jenner and Jenner, 2005). This is consistent with the timing of humpback whale occupancy in Exmouth Gulf varying by up to four weeks inter-annually. The numbers of whales present in Exmouth Gulf at peak abundance increased more than 4-fold between 2005 and 2018, from 174 in 2005 (25 Sept) to 754 in 2018 (20 Sept). This is consistent with the BSD population increasing at a rate of over 10% each year (Salgado Kent et al., 2012). Along with this increase in abundance was an expansion in distribution, from the central and western portions of the gulf in 2004-05 (Jenner and Jenner, 2005) to almost the entire gulf in 2018, other than the shallow waters along the eastern and southern shores. If the BSD population continues to increase, the density of humpback whales in Exmouth Gulf, and their period of usage, may also continue to increase.

An average of just over 40% of the groups sighted in Exmouth Gulf during the 2018 aerial surveys contained calves. At peak, this reached just over 60% of all groups. It should be noted that these percentages are likely underestimates as calves can be difficult to see from a distance and can also be screened by their mothers (i.e. underneath the mother's body or pectoral fin). The majority of the mother-calf groups were resting and milling confirming previous findings that Exmouth Gulf is an important resting and nursing area for the BSD population (Chittleborough, 1953, Jenner et al., 2001, Jenner and Jenner, 2005). Whilst in Exmouth Gulf, calves spend approximately 20% of their time suckling (Videsen et al., 2017). The energy transferred during suckling supports the rapid calf growth that is typical of baleen whales during early development and likely essential for the ensuing long distance migration (up to 7000 km) (Double et al., 2010) to the Antarctic feeding grounds. Large offspring size increases swimming and diving abilities (Thomas and Taber, 1984) and the ability of the calves to avoid predation (Ford and Reeves, 2008, Pitman et al., 2015). Whilst resting in Exmouth Gulf, mothers and their calves maintain close contact and communicate with other via low-level vocalisations (Videsen et al., 2017). Any noise from anthropogenic sources, including that from marine vessels, could increase the risk of mother-calf separation and potentially reduce suckling rates (Videsen et al., 2017). This could negatively impact calf growth rates and their ensuing fitness (Bejder et al., 2019).

Although Exmouth Gulf is known to be used by larger (post-neonate) calves during the southward stage of their migration (Jenner et al., 2001), small, light grey neonate calves (those <1 month of age) have not previously been documented in Exmouth Gulf. Recent research, however, has illustrated that the calving grounds of the BSD population extend from the waters of the Kimberley (15°S) to at least North West Cape (22°44'S) and suggested that some neonate calves may move into Exmouth Gulf, rather than travelling to more northern waters before beginning their southward migration (Irvine et al., 2017). The small size of the neonate calves sighted in Exmouth Gulf indicates that some of these calves may have been born in the gulf or nearby, rather than travelling to the gulf from more distant birthing sites. The timing of occurrence of these small, neonate calves is consistent with the breeding cycle of the Breeding Stock D population where parturition occurs between June and October, and peaks in early August (Chittleborough, 1958). Neonate calves are at a very vulnerable stage in their life history as they are small and weak and have limited swimming and diving abilities (Thomas and Taber, 1984).

5.2. Other marine mega-fauna

All other marine mega-fauna species, including dugongs, dolphins, turtles, manta rays, sharks and sea snakes were resident in Exmouth Gulf between August and early November. Although the information that can be interpreted for these mega-fauna species is limited (due to the aerial surveys being designed for humpback whales) the data is useful for indicating the distribution, and thus preferred habitat, of these other mega-fauna species in Exmouth Gulf between August and early November. For further information on mega-fauna species other than humpback whales, surveys optimised for the species are recommended.

Dugong distribution was restricted predominantly to the shallow waters along the southern and eastern areas of Exmouth Gulf. The high numbers and presence of calves suggest that Exmouth Gulf is an important breeding area for dugong. The data supports previous surveys in Exmouth Gulf (designed for dugongs) that have reported dugong populations of about 1000 individuals, and illustrated that Exmouth Gulf is a significant dugong habitat (Preen et al., 1997, Gales et al., 2004).

The shallow waters of the eastern and southern portions of Exmouth Gulf were the preferred habitat for turtles, sharks and manta rays. The turtles in Exmouth Gulf were likely predominantly green turtles (*C. mydas*) with this area known to support a very high density of turtles compared to other locations around Australia (Preen et al., 1997). Very little can be interpreted from the shark sightings as species other than hammerhead, leopard and whale sharks are difficult to identify from an altitude of 1000 ft. Manta rays were also found in high numbers in the north-west portion of the gulf along with sea snakes. Limited information about either taxon in Exmouth Gulf currently exists.

Dolphins had a broad distribution throughout Exmouth Gulf with high densities in the north-western portion. The low numbers of calves most likely reflect the difficulty in sighting animals of small size from high altitudes. Although both bottlenose and humpback dolphins were identified during the surveys, this information was not included due to the unreliability of identifying dolphin species at high altitude. Indo-pacific bottlenose (*Tursiops aduncus*), Australian humpback (*Sousa sahulensis*) and Australian Snubfin dolphins (*Orcaella heinsohni*) are all known to occur in Exmouth Gulf (Allen et al., 2012, Hunt et al., 2017). Recent research has illustrated that the waters around North West Cape, including those of Exmouth Gulf, are an important habitat for the Australian humpback dolphin, with the density recorded (1 / km^2) being the highest recorded for this species (Hunt et al., 2017).

The distributions of all mega-fauna species recorded are likely indicative of the feeding requirements of each species, and generally agree with the findings of the mega-fauna surveys carried out in Exmouth Gulf in 2004-05 (Jenner and Jenner, 2005).

5.3. Limitations of the study

This study describes relative abundance and distribution of marine mega-fauna between early August and early November 2018, with a focus on humpback whales. Being a single season study, this study did not aim to describe any inter-annual variability in occupancy for humpback whales in Exmouth Gulf or any changes that may occur if the population continues to increase at >10% per year (Salgado Kent et al. 2012). In addition, this study could not describe the distribution and relative abundance of whales occupying Exmouth Gulf outside the survey dates (i.e. before 08 August and after 02 November 2018). In addition, the aerial surveys were designed for humpback whales and thus likely under-estimate the relative abundance of the smaller mega-fauna species such as dugongs, dolphins, turtles, manta rays, sharks and sea snakes.

5.4. Implications of vessel activity in Exmouth Gulf

5.4.1 Vessel strike

Humpback whales are prone to injury or death as a result of vessel strike, particularly when vessels are travelling at high speeds. Exmouth Gulf is a recognised resting area for humpback whales during the Austral winter (Department of the Environment and Heritage, 2005). Whilst in Exmouth Gulf, lactating females spend 53% of their time within 3 metres of the water surface, where they are at risk of vessel strike (Bejder et al., 2019). The likelihood of vessel strike is highest in the areas where densities of whales and boats are the highest. Neonate calves are particularly vulnerable as they have limited swimming and diving abilities and low breath-hold capacity.

5.4.2 Vessel noise

Humpback whales, like all baleen whales, use sound for long- and short-range communication. The sound produced by commercial ships overlaps the frequency that humpback whales use for communication, potentially causing acoustic masking and thus interrupting communications between whales (Tyack, 2008). Mature male humpback whales can reside in Exmouth Gulf for up to four weeks each year, looking for receptive females to mate with, while mother-calf pairs can stay for up to two weeks for resting and nursing purposes (Jenner and Jenner, 2005). In Exmouth Gulf, acoustic masking could affect: i) mating behaviour, as the adult males rely on song for mating purposes; and ii) calf fitness; as mother-calf pairs use low-level sounds to maintain constant contact with each other (Bejder et al., 2019). This close association between mother and calf is essential for calf survival.

Any overlap in sound frequencies used by whales can also potentially interfere with their behaviour and physiology. Vessel noise has been shown to increase stress levels in baleen whales (Rolland et al., 2012) and cause both habitat displacement (Allen and Read, 2000, Bejder et al., 2006) and behavioural changes in baleen and toothed whales.

Behavioural responses of southerly migrating humpback whales to whale-watching vessels have been recorded in Hervey Bay (Queensland) and in NSW (Corkeron 1995 and Stamation et al. 2010, respectively). Groups of whales responded with a mixture of avoidance and approach behaviours and changes in surfacing intervals, diving rates and surface activity. Groups with calves are generally more sensitive to vessel traffic than those without calves (Bauer, 1993) with mother-calf pairs being the most sensitive cohort in the population (Nowacek et al., 2007).

Humpback whales rely on finite energy reserves whilst in the breeding grounds and mothers must maximise energy transfer to their calves, in the form of fat-rich milk, in order to support the rapid calf growth required for the long migration down to the Antarctic feeding grounds. Any energy that is allocated to cow activity other than lactation could reduce calf fitness or growth rates and thus affect their ability to migrate successfully to the feeding grounds (Bejder et al., 2019). Additional energy use could also potentially compromise the cow's ability to complete the migration as they cannot replenish their own energy reserves until they reach the Antarctic feeding grounds.

6. CONCLUSION

Exmouth Gulf is an important resting area for humpback whales and is also an important area for other mega-fauna species including dugongs, dolphins, turtles, manta rays, sharks and sea snakes. High numbers of humpback whales, including adults and calves, occupy Exmouth Gulf between at least early August and early November each year. The majority of these whales are resting or milling, leaving them vulnerable to vessel strike and prone to disturbance from vessel noise. Calves, in particular, have limited swimming and diving capabilities, and need to maintain close and constant contact with their mothers for survival. The risk of disturbance and injury from vessel activity is greatest where high densities of vessel activity overlap with areas of high animal densities. Adverse impacts of vessel activity in Exmouth Gulf can be minimised by restricting vessel activity to locations and time periods where low densities of humpback whales and other mega-fauna species exist.

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8. APPENDICES

8.1. Appendix A: Scales for environmental conditions

Table 7. The Beaufort scale (sea state).

Force	Description	Sea state	Wind speed (knots)
0	Calm	Mirror calm	<1
1	Light air	Ripples, no crests	1-3
2	Light breeze	Small wavelets, crests glassy	4-6
3	Gentle breeze	Large wavelets, scattered whitecaps	7-10
4	Moderate breeze	Small waves 0.5-1.25m high, numerous whitecaps	11-16
5	Fresh breeze	Moderate waves 1.25-2.5m high, many whitecaps	17-21
6	Strong breeze	Large waves 2.5-4m high, whitecaps everywhere	22-27

Table 8. Turbidity scale.

Turbidity	Water quality	Water Depth	Visibility of sea floor
1	Clear	Shallow	Clearly visible
2	Variable	Variable	Visible but unclear
3	Clear	>5m	Not visible
4	Turbid	Variable	Not visible

8.2. Appendix B: Humpback Whale Observations each survey

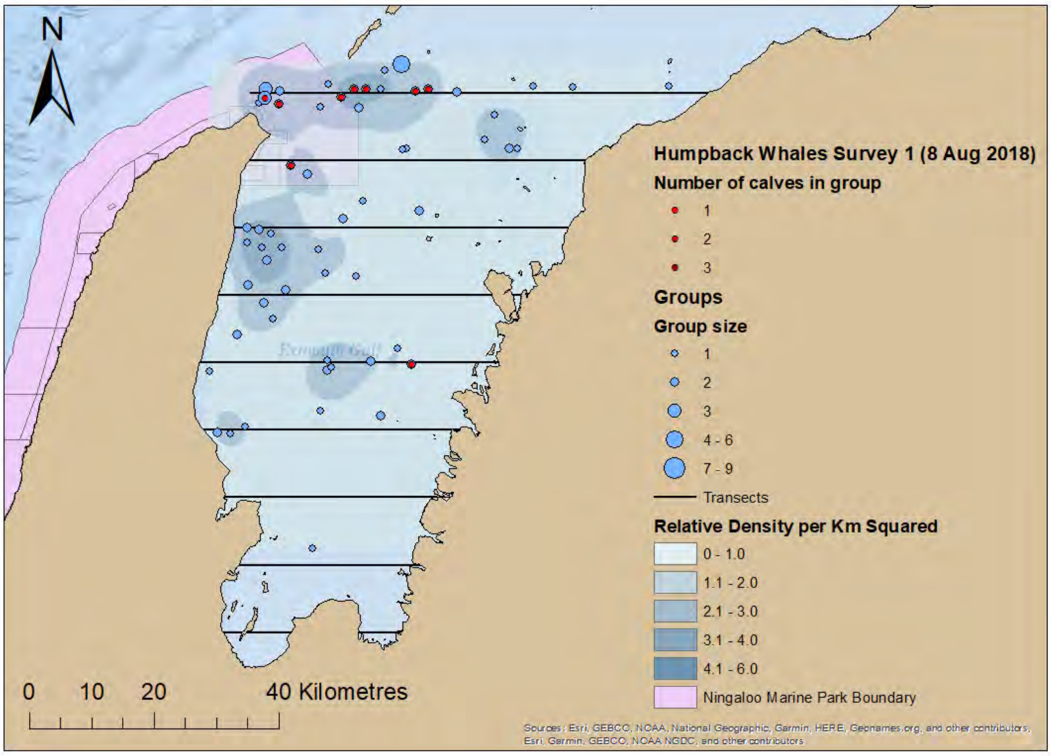

Figure 12. Distribution of humpback whales observed in Exmouth Gulf during survey 1 (08/08/2018).

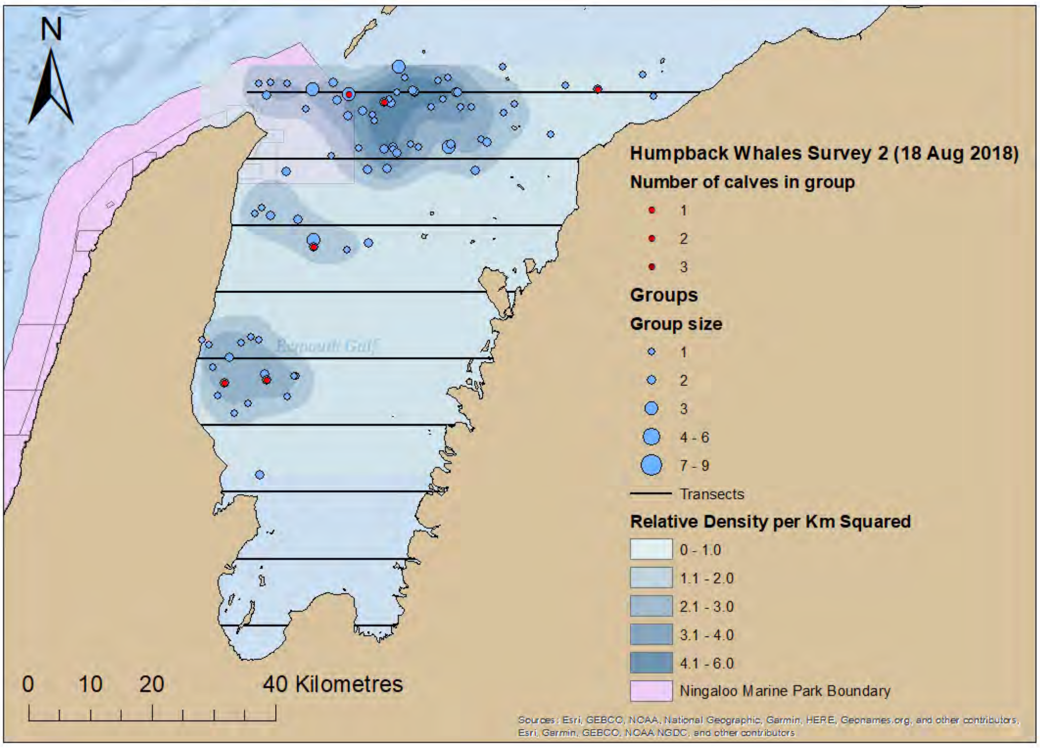

Figure 13. Distribution of humpback whales observed in Exmouth Gulf during survey 2 (18/08/2018).

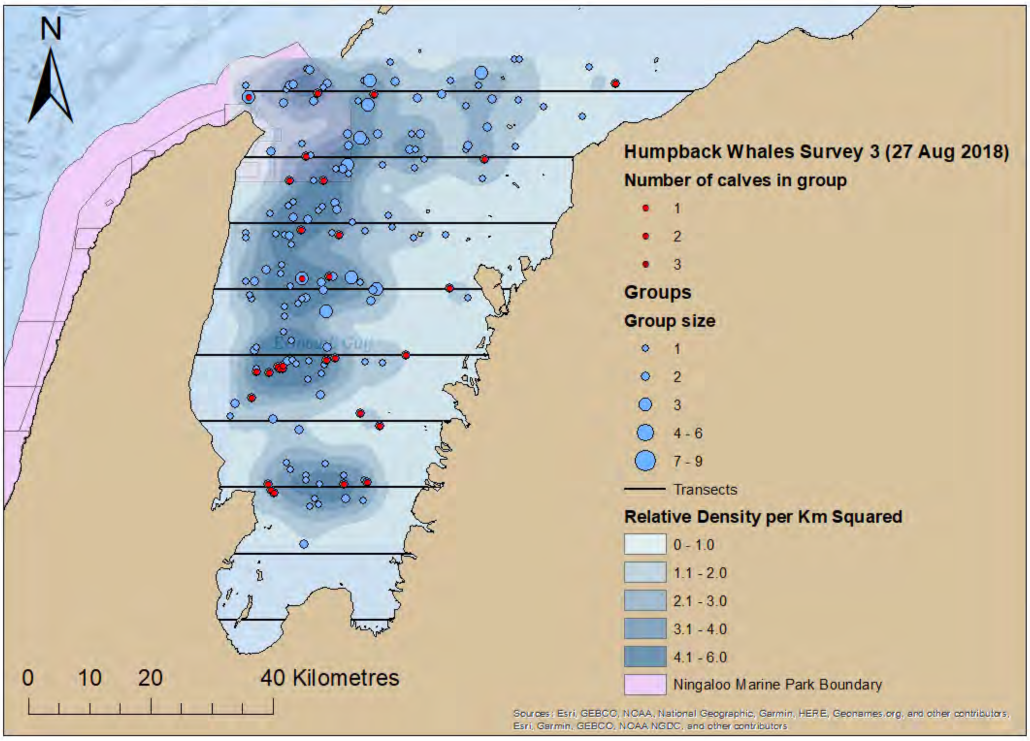

Figure 14. Distribution of humpback whales observed in Exmouth Gulf during survey 3 (27/08/2018).

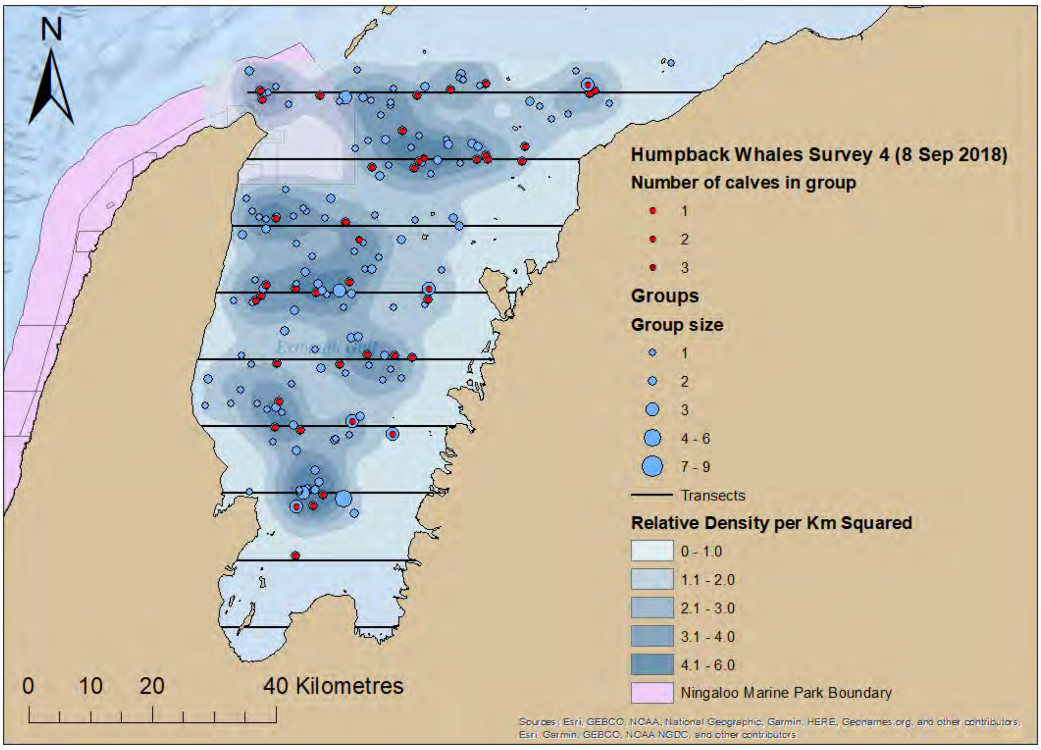

Figure 15. Distribution of humpback whales observed in Exmouth Gulf during survey 4 (08/09/2018).

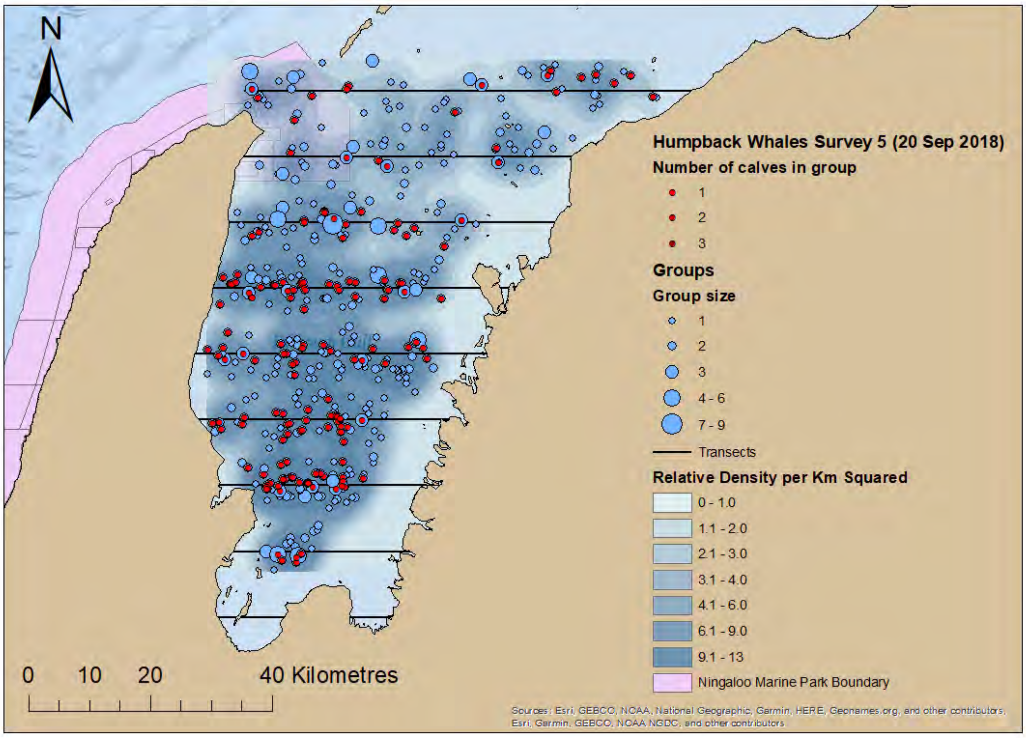

Figure 16. Distribution of humpback whales observed in Exmouth Gulf during survey 5 (20/09/2018).

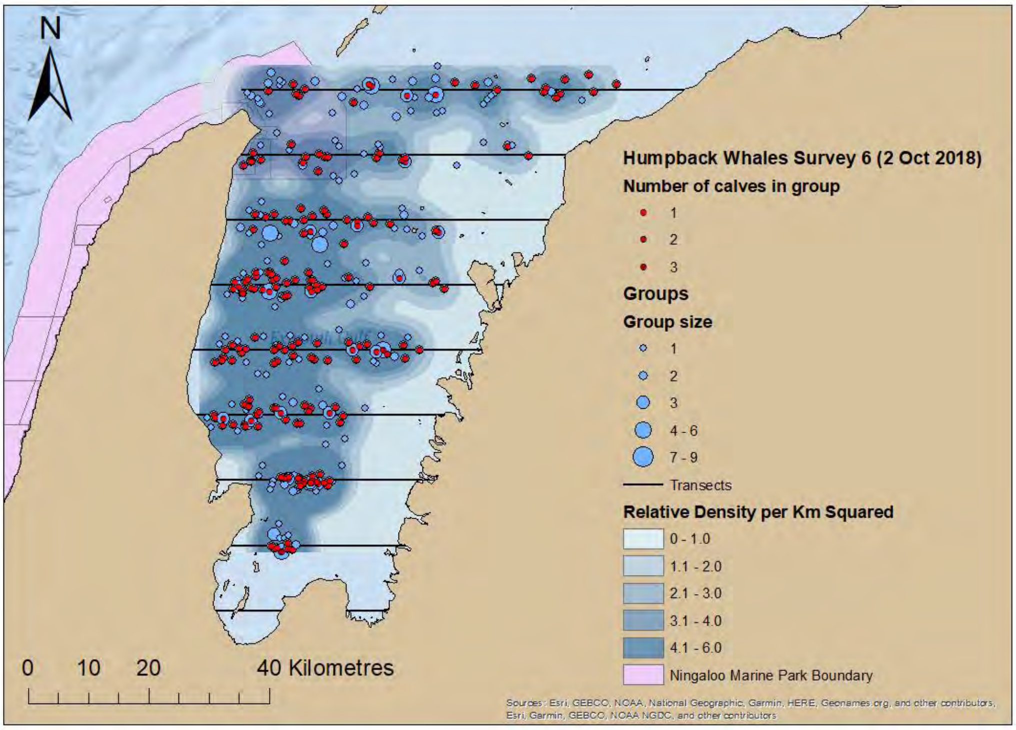

Figure 17. Distribution of humpback whales observed in Exmouth Gulf during survey 6 (02/10/2018).

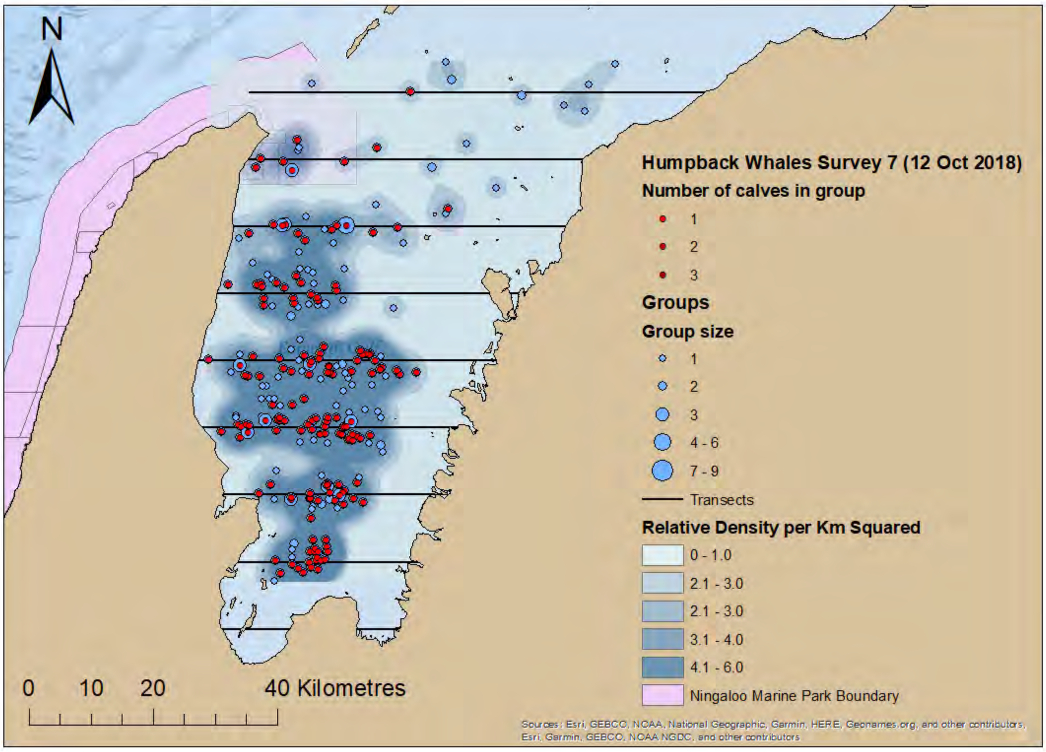

Figure 18. Distribution of humpback whales observed in Exmouth Gulf during survey 7 (12/10/2018).

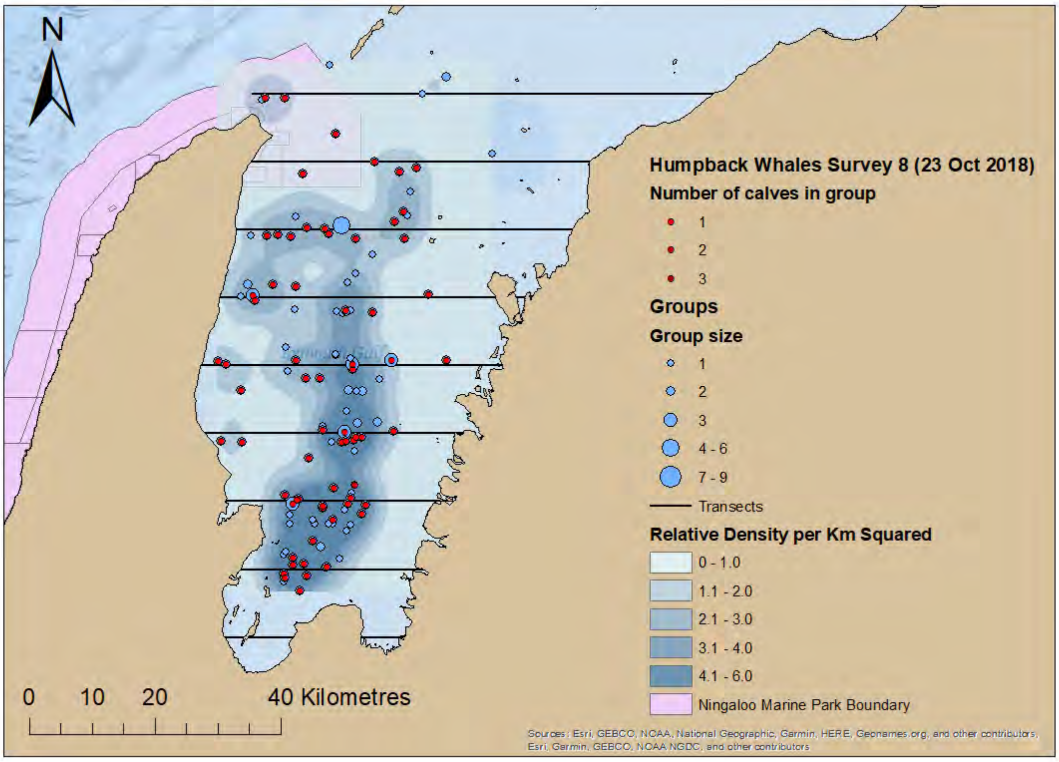

Figure 19. Distribution of humpback whales observed in Exmouth Gulf during survey 8 (23/10/2018).

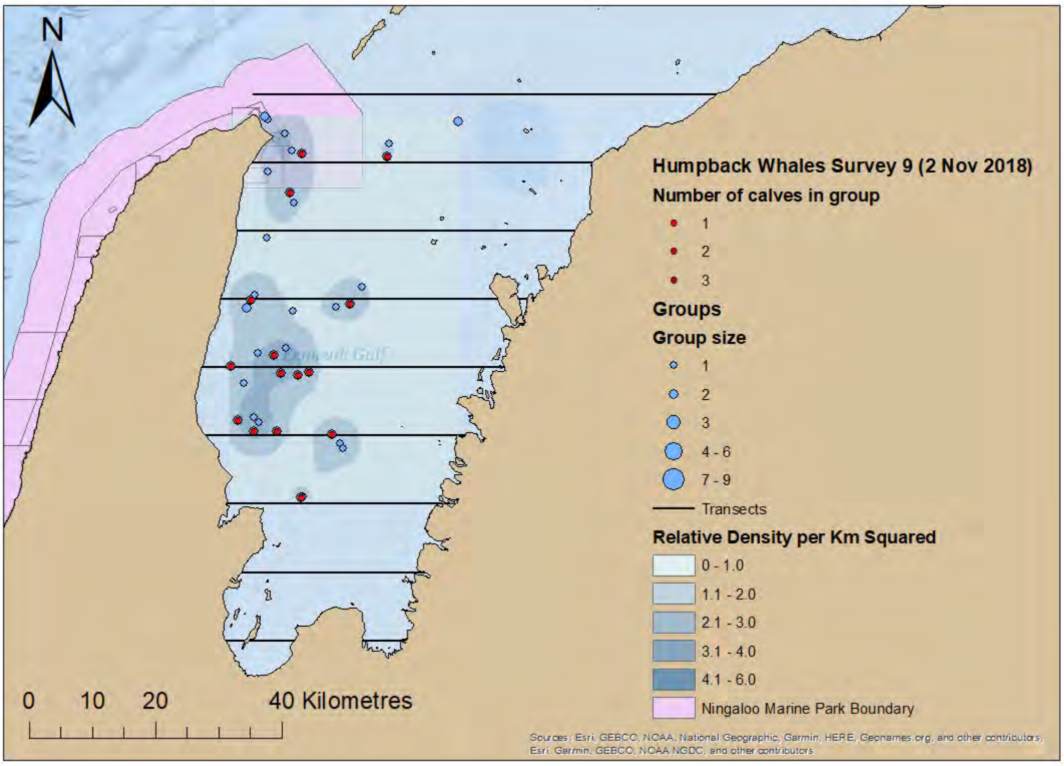

Figure 20. Distribution of humpback whales observed in Exmouth Gulf during survey 9 (02/11/2018).