GOVERNMENT OF WESTERN AUSTRALIA

Browse LNG Precinct

Browse Liquefied Natural Gas Precinct
Strategic Assessment Report

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Appendix C-11

Draft Humpback Whale Distribution and Abundance in the Nearshore SW Kimberley During Winter 2008 Using Aerial Surveys

Humpback Whale Distribution and Abundance in the Near Shore SW Kimberley During Winter 2008 Using Aerial Surveys

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2. Summary

A total of 1984 humpback whales were sighted in 9 aerial surveys over the SW Kimberley region during July to November, 2008. The time period from early August to mid-September contained the majority of the sightings. A northern, transition and southern migratory phase was identified within the study period and study area. During each phase cow/calf pods swim directions across the entire survey area were predominantly reported as "milling'' , not northbound or southbound, supporting the prior designation of this region as a calving and nursing area for this population of humpback whales. Peak numbers of whales, and particularly cow/calf pairs, were sighted near North Head while the lowest densities of cow/calf pods were sighted near Willie Creek and James Price Point. Regular sightings of dugongs, dolphins and turtles where made throughout the survey.

3. Objective

The primary purpose of this study was to determine the seasonal distribution and relative abundance of humpback whales and other cetaceans along the south western Kimberley coast during the humpback whale migration season (July to October). Secondarily, sightings data regarding the distribution and abundance of other megafauna (eg. Dugongs, turtles, sharks, rays and sea snakes) sighted during the humpback whale surveys was to be collected.

4. Introduction

The Centre for Whale Research (CWR) was commissioned by the Department of State Development (DSD) and Woodside Energy Ltd. (WEL) to design, conduct and analyse a series of aerial surveys that would best compliment existing datasets and fill knowledge gaps for humpback whale and other mega fauna distribution and abundance along the SW Kimberley coastline.

In the mid 1990's, the south western Kimberley region between the Lacepede Islands and Camden Sound was described by Jenner *et al.* (2001) as a calving ground and nursing area for humpback whales (*Megaptera novaeangliae*) based on high numbers of sightings of resting cows with newborn calves (Figure 1).

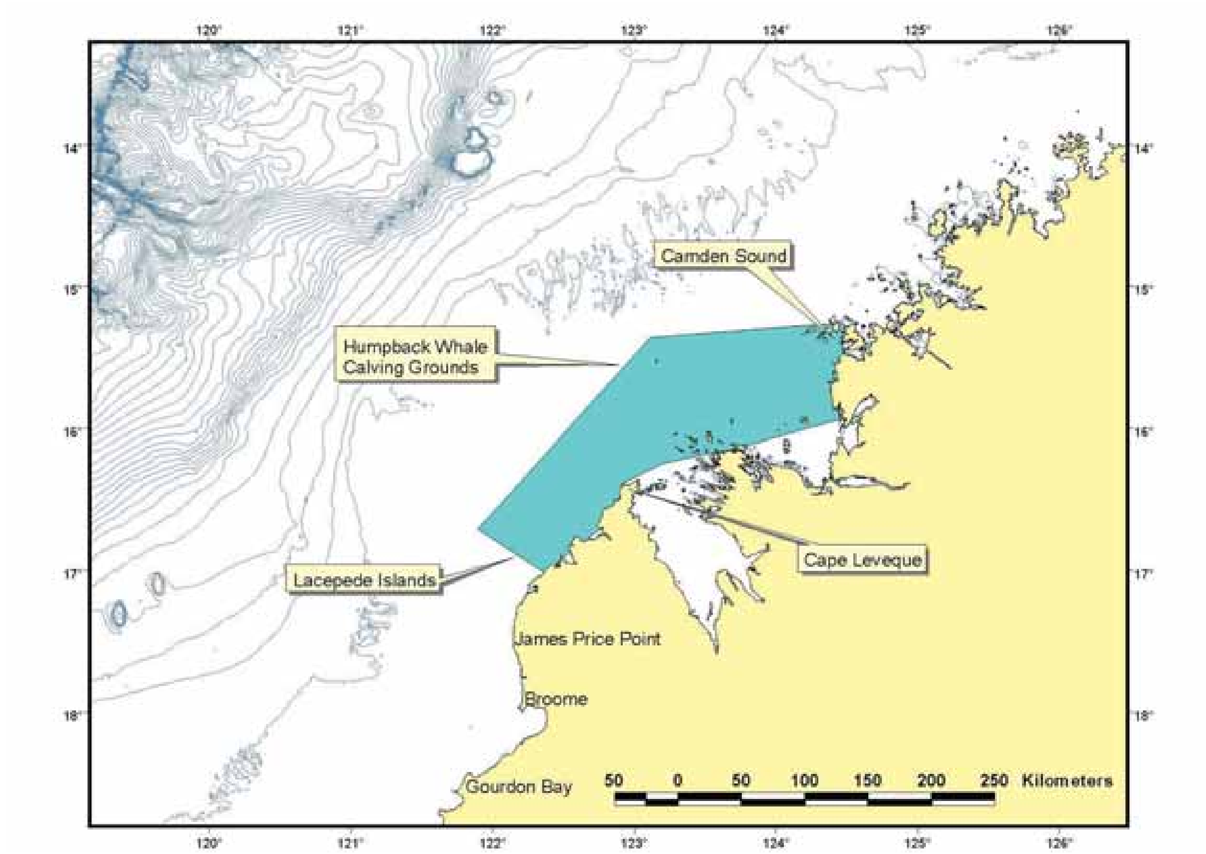


Figure 1. The Kimberley Calving Grounds for humpback whales (modified from Jenner *et al.* 2001).

As a result of this knowledge, and due to the humpback whales' protected status under the Environmental Protection , Biodiversity and Conservation (EPBC) Act, 1999, this species was selected for a focused research programme design to assist decision making processes for future state infrastructure projects.

The timing of the aerial survey flights described in this report were selected to coincide with the expected humpback whale migratory period through the region, and was based on knowledge developed during previous CWR surveys (Jenner *et al.* 2001, Jenner and Jenner, 2008). The surveys were also designed to be a logical spatial extension of similar aerial surveys conducted by CWR in 2007 for Inpex Browse Pty. Ltd. (Jenner and Jenner, 2008, Figure 2) which had surveyed the area from Broome north towards the Maret Islands.

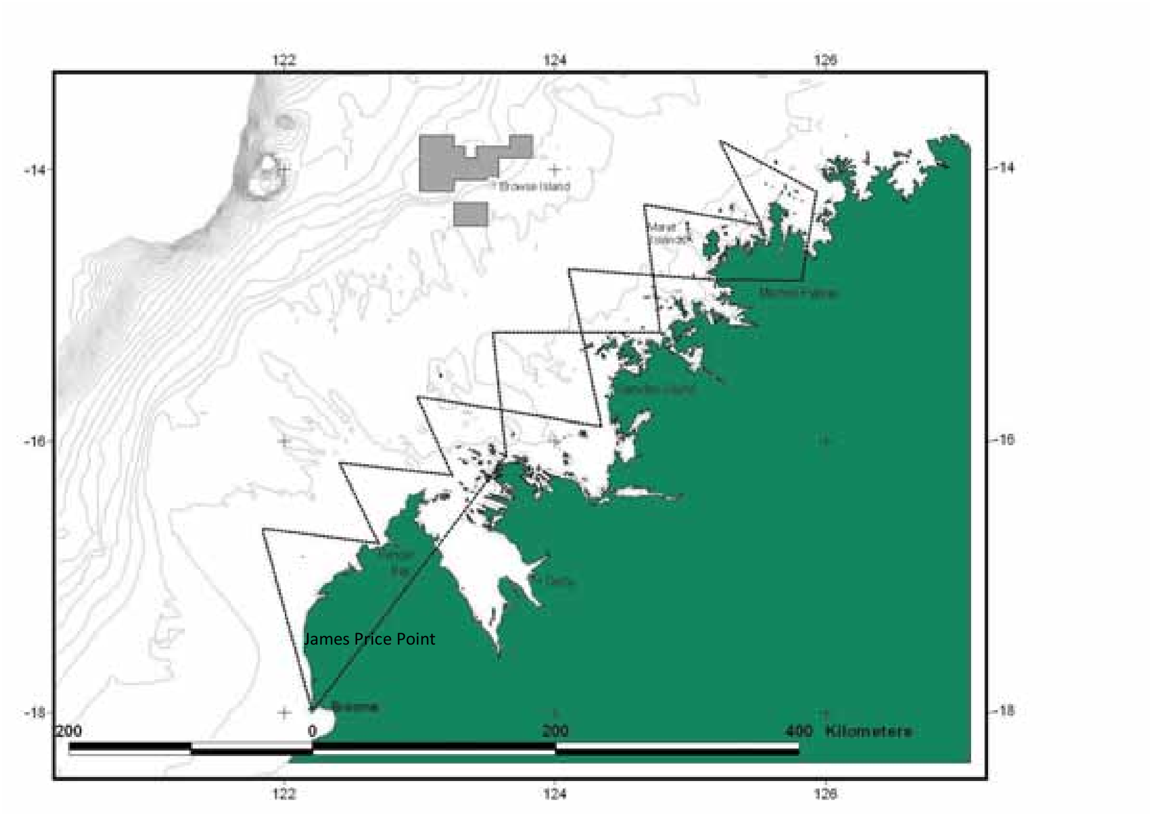


Figure 2. CWR aerial surveys conducted during 2007 on behalf of Inpex Browse Pty. Ltd. with similar study objectives (from Jenner and Jenner, 2008).

5. Materials and Methods

5.1 Timing

The off-shore area from Cape Leveque to south of Lagrange Bay has been systematically examined from mid-July (before the expected peak of the northbound migration) to late-October (the period after which most cow/calf pods are expected to have migrated out of the Kimberley). Transects have been designed to be consistent, comparable and a logical extension to transects described in Jenner and Jenner (2008). A total of ten samples of all transects were collected at 10 day intervals with the precise dates within these time blocks dependant on good weather conditions (winds less than 18 knots).

The design of the survey followed protocols defined in the Distance ver. 5.1 software programme (Buckland *et al.,* 2001, Buckland *et al.*, 2004). This programme specifically designs and analyses biological line transect sampling projects for the purpose of estimating density and abundance. As such, an “equal spaced zigzag” system of transects was constructed over the study area in order to maximise coverage probability during a single day of spotting, assuming an eight hour “day” of consistent daylight between 0900 and 1700(Figure 3). Zig zag transect design for convex coastlines are considered to be more efficient than conventional parallel transect lines because no time is spent moving from one line to the next (off effort) and is the preferred technique for covering large survey areas. However, in anything but a rectangular survey area, even coverage of the survey area can be difficult with this system (Buckland *et al.* 2001). The current survey design sought to use a rectangular survey area with equal sampling for the three northern-most transects (numbers 8, 9,

and 10)and then use a consistent design axis from which to sample, as best as possible, the complicated convex, then concave study area to the south (Figure 3).

The three northern-most transect lines were identical to those used during similar flights conducted during 2007 for Inpex (Jenner and Jenner, 2008).

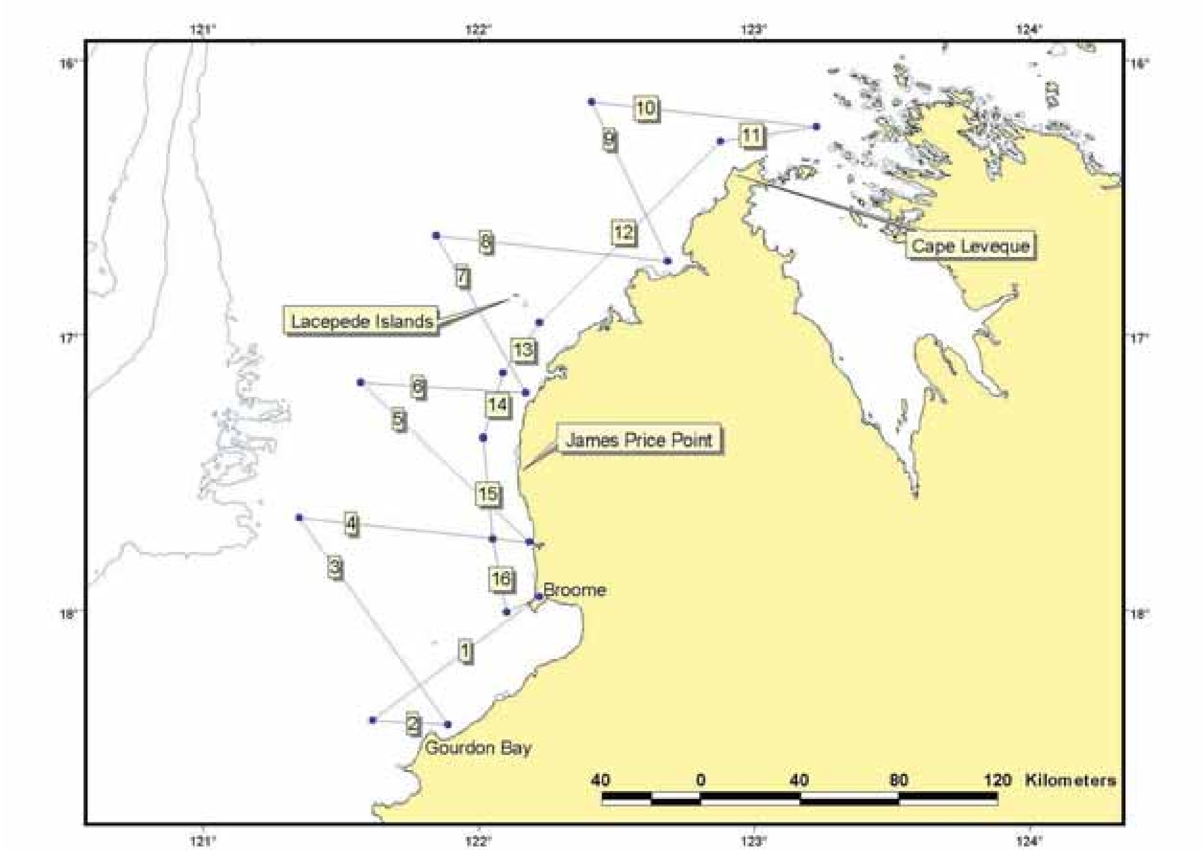


Figure 3. Zig zag line transects (numbered) for the SW Kimberley region in 2008, aimed at describing humpback whale and other mega fauna distribution and abundance in relation to the SW Kimberley coastline.

5.2 Survey Detail

Aerial surveys were conducted at an altitude of 305 m (1000 ft) and a speed of 222 km/hr (120 knots) using a twin-engine, over-head wing aircraft (Twin Otter or Cessna 337). The plane followed zig zag transects which were surveyed in passing mode (e.g. the plane did not deviate from the flight path). Surveys were only initiated in wind speed less than 33 km h^{-1} (18 knots) which has been shown to be adequate for spotting whales (Jenner *et al*. in prep). Each flight was of approximately 5.5 to 6 hours duration and take-off times varied between 8:40 and 10:55 so that the mid-day period was consistently sampled and glare would be a consistent factor for all flights.

Personnel for each survey included four people; two pilots and two observers. The observer team consisted of 4 trained personnel . One person flew all 10 flights, one flew 4 flights, one flew 3 flights and one flew 2 flights. The pilots were not responsible for spotting, and were separated acoustically from the two observers. The pilots were responsible for recording the planes' angle of drift on each transect, so that angles reported from the compass boards could be corrected relative to the flight

path. The observers were linked via a separate intercom system which was logged to a Sony Mini Disk Recorder NH900 which allowed the observers to search continuously and voice record all sightings to a time code which was synchronized to the Global Positioning System (GPS) before each flight. A Garmin III Pilot aeronautical GPS was used to log sightings (as waypoints) and coordinates of the flight path, including altitude, for every second of the flight.

Observers sighted and recorded positions of whales by measured vertical and horizontal angles from the aircraft to the whales (using Suunto PM-5/360PC clinometers, and a compass board). The location (latitude and longitude) of each sighted whale was later plotted by projecting a new GPS waypoint from the waypoint recorded at the time of sighting (using Oziexplorer ver 3.95 GPS software) from the calculated angle and distance of the aircraft to the whale. The angle was calculated with the following formulae: Angle to starboard = *AC* + (*MHA* + *DA*), and Angle to port = *AC* + (*MHA* - *DA*), where *AC* was the aircraft course, *MHA* was the measured horizontal angle and *DA* was the angle of drift of the aircraft. Distances were calculated using formulae in Lerczak and Hobbs (1998).

No vertical or horizontal angles were recorded for any other species and it was assumed (due to their small size) for plotting purposes that sighting positions were the same as the waypoint marked (ie. directly under the plane).

The sighting information that was recorded for whales included the direction of migration (north, south, milling, or undetermined) of each pod observed. Northbound pods were those sighted steadily swimming parallel to the coast in a northerly direction. Likewise, southbound whales were those sighted swimming parallel to the coast in a southerly direction. Pods reported as "milling" were swimming perpendicular to the coast (not northbound or southbound) or surface lying at the time of sighting with no obvious signs of swimming (ie. resting whales). Pods recorded as "undetermined" were sighted too far from the aircraft, or for too short a time period, to assess swim direction.

The level and direction of glare (scale 1-3) for each observer was recorded for each transect as well as environmental variables such as Beaufort sea-state (scale 0 -12), associated wind speed (knots) and direction, cloud cover below 1000 feet (percentage) and overall visibility (scale 1-3).

5.3 Analysis

The GIS program Arcview 3.2, with extensions Spatial Analyst and Animal Movement, was used to analyze the distribution of humpback whales. A Kernel home range estimator was used to compute tendency for clumping (preferred habitat) of whales within the sample area. This technique assumes an equal sample effort across a defined area which is not possible with zig zag survey designs, however a system to minimize bias was established and is described below. Probability contour maps were generated for each flight that display preferred home range on the day of the survey.

A smoothing factor ("*h*" statistic) controls the size of the home range reported and has been shown to be inconsistent for different sample sizes (Hooge and Eichenlaub, 1997). For this reason a second technique, the minimum convex polygon (MCP) method, was used to first confirm home range size. The MCP was used as the area of the home range and we adjusted the smoothing factor until the

area of the 95% kernel equaled the area of the MCP. This provides an objective method for selecting the smoothing factor (Hooge and Eichenlaub, 1997).

The same “h” statistic was used to calculate 50%, 75% and 95% probability density contours for each flight day where the 50% contour represents the highest density of whale pods (not whales) and the 95% contour represents the likely extent of all pods. However this “h’” statistic was recalculated for each flight day so that areas of high density at each stage of the migration can be viewed independently rather than assuming low numbers during one flight represent a less important habitat due to a smoothed representation of the migration based on the highest densities of the season.

For a second series of maps that sought to describe northern and southern migratory distribution densities as a collective dataset, the same “h” value was used and was based on the distribution density of the highest density measured from an individual flight. The resulting maps are therefore conservative in describing “high density”.

Kernel densities were analysed separately with the even numbered zig zag transects separated from the odd numbered transects. This approach was adopted to ensure that the survey design and inevitable flight path overlap (at turning points and between the long-shore and zig zag transects) did not artificially influence the extrapolations in the density plots. Similarly the long-shore transects were also analysed separately. The separate Kernel density contours for the even, odd and longshore transects were then spatially “merged” and “dissolved” in Arcview to generate a single map which more accurately represents the distribution patterns of the whales on the given flight day without biases that may be introduced in a more standard Kernel density plot due to overlapping flight paths and double counted whales.

This system was used for all flights and maps except the individual Oct 11 and Oct 20 maps where lower overall densities of whales permitted a single Kernel density calculation for each flight without positive bias caused by overlapping transects and double counting pods.

5.4 Long-Shore Analysis

The survey track flown parallel to the coastline was included in the probability density contour calculations described above, but also analysed separately so that a comparable density scale for humpback whales along the coast could be examined.

The long-shore survey track was divided into 5 coastal polygons, or zones, with width 10km based on the effective strip width of the transects and natural geographic boundaries. For example, the Lacepede Channel, where few whales were sighted in the mid 1990’s surveys (Jenner *et al.*, 2001), was used as the boundary between the North Head and Coulomb zones. This particular boundary is also useful as it represents the southern boundary to the humpback whale calving grounds as described by Jenner *et al.* (2001).

The longshore sightings were clipped using these polygons in Arcview 3.2 to exclude data outliers (those whales sighted beyond 5km either side of the flight path and therefore only available to the observers as breaching whales). Densities of whale pods (pods/km^2) and cow/calf pods were then plotted versus time for each coastal zone.

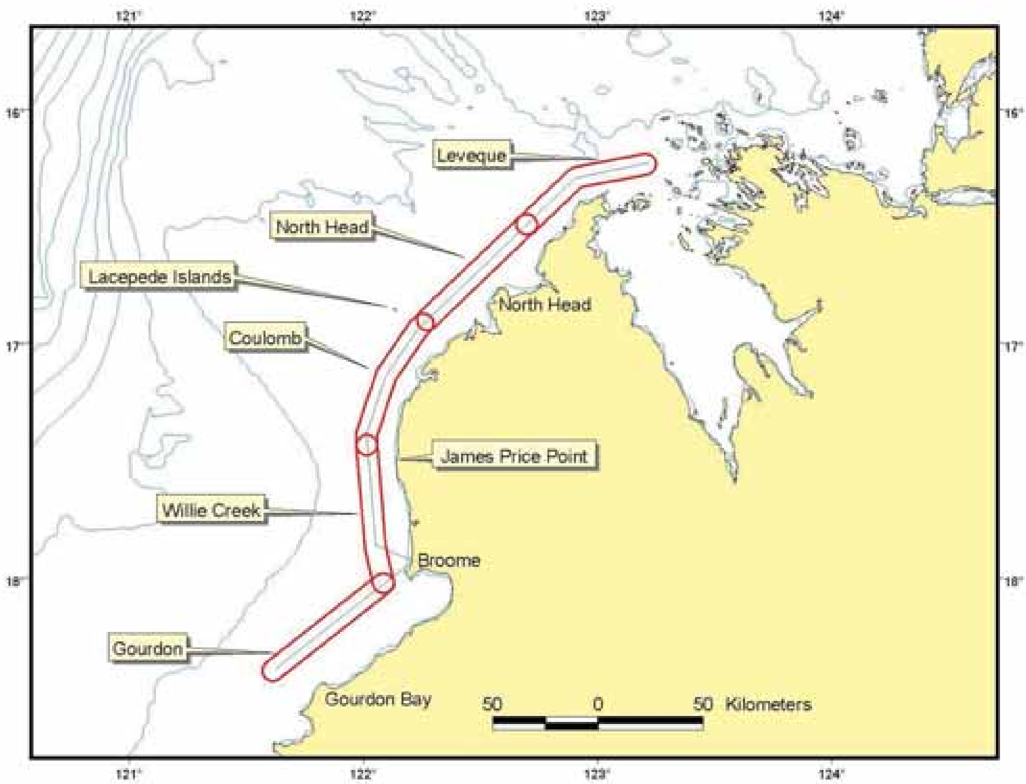


Figure 4. Coastal Zones used to evaluate near-shore whale density in relation to the SW Kimberley coastline.

6. Results

6.1 Humpback Whales

A total of 9 flights over the south western Kimberley region during 2008 resulted in sightings of 1345 humpback whale pods containing 1984 individual whales (Table 1). A total of 231 cows with calves of the year were sighted. Maps showing ranked kernel density polygons (highest to lowest) are presented in Figures 5 to 13 and show the changes in relative density and preferred habitat of migrating humpback whales between July 19 and October 20, 2008.

Table 1. Humpback whale sightings during each flight in the 2008 study period.

Date	No. Pods	No. Whales	No. Calves
19-Jul	110	144	1
2-Aug	254	328	24
10-Aug	-	-	-
23-Aug	153	231	17
24-Aug	206	330	32
3-Sep	275	410	68
16-Sep	174	295	50
1-Oct	79	118	27
11-Oct	65	91	9
20-Oct	26	33	3
Totals	**1345**	**1984**	**231**

A flight conducted on August 10, 2008, is not included in the totals discussed here due to a software problem with propriety Sony audio files from the flight recorder having been transferred between storage media. However, a total of 377 waypoints were recorded during that flight, and based on typical ratios of humpback whale waypoints to other species waypoints from 4 other flights immediately before and after this flight (2 before and 2 after), it is estimated that a further 245 (64%, +/- 0.14, 95%CI) sightings of humpback whales could be added to the season total from this single flight. At the time of writing this report, the un-decoded audio file that will enable each waypoint to be described is with Sony Japan for recovery, however it is not expected that the results from this one flight will affect the overall patterns of distribution and density described in this report (ie. this is unlikely to have been a peak season value).

Figure 5.

Flight 1, July 19, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.

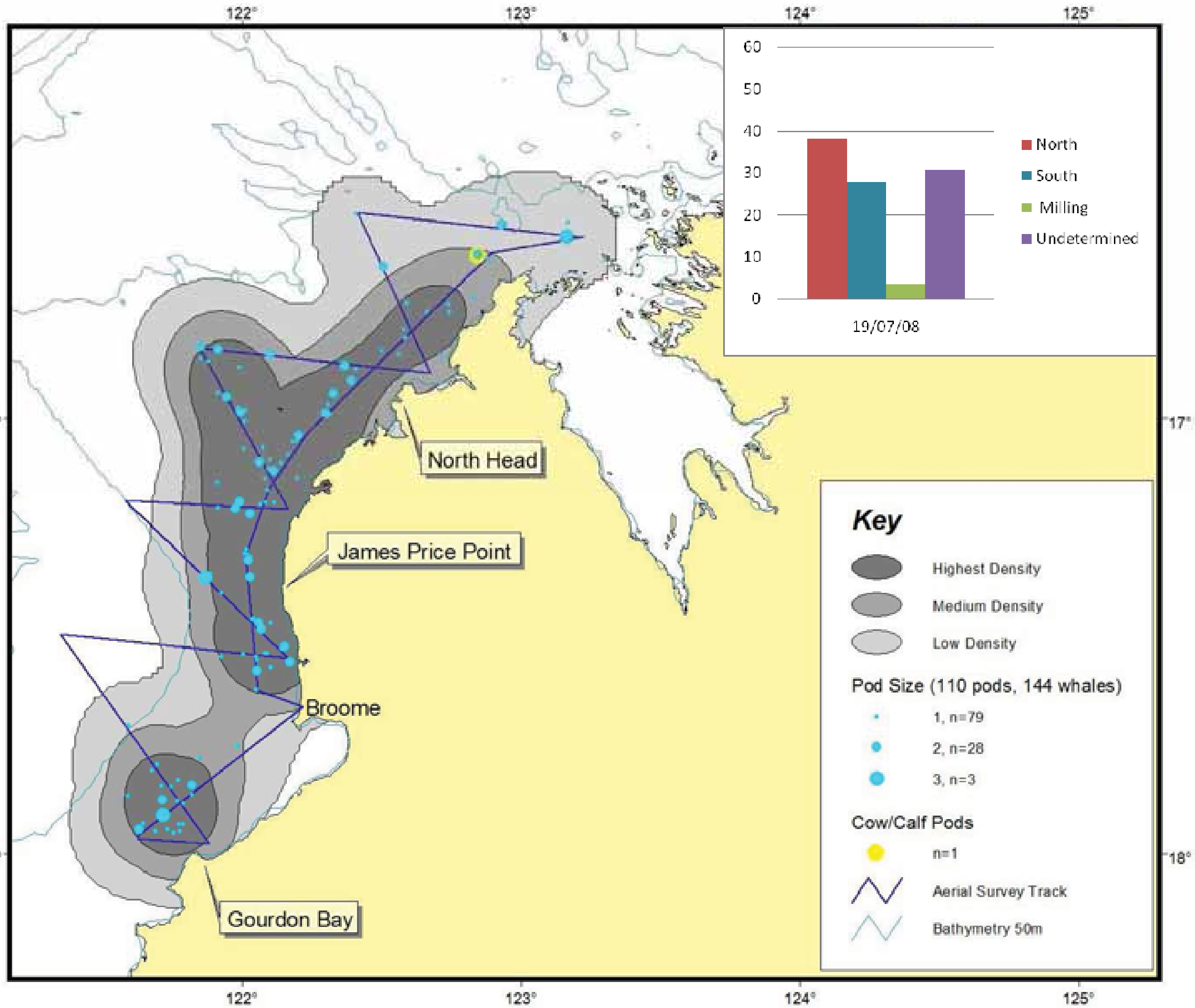


Figure 6.

Flight 2, August 2, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.

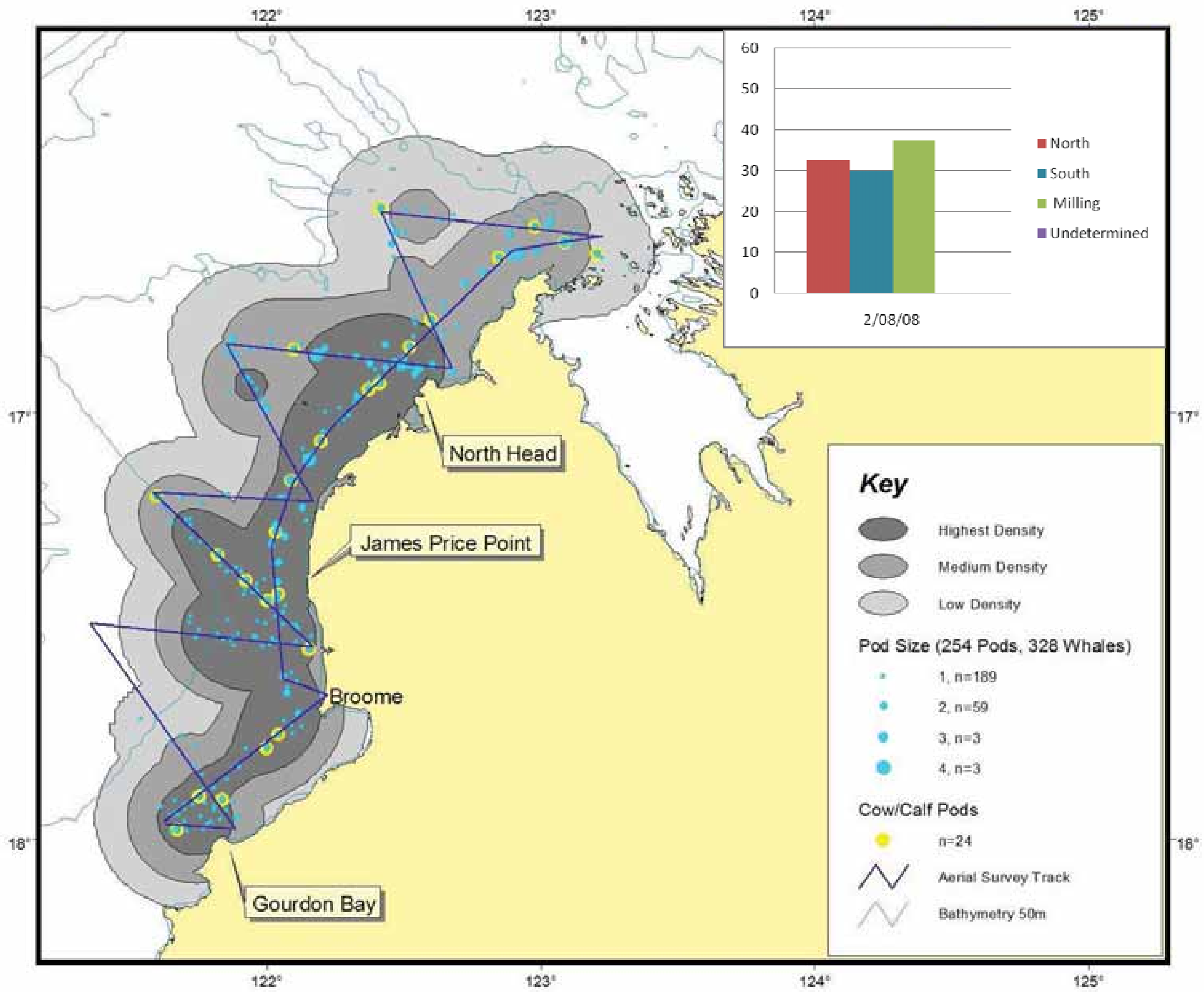


Figure 7.

Flight 4, August 23, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.

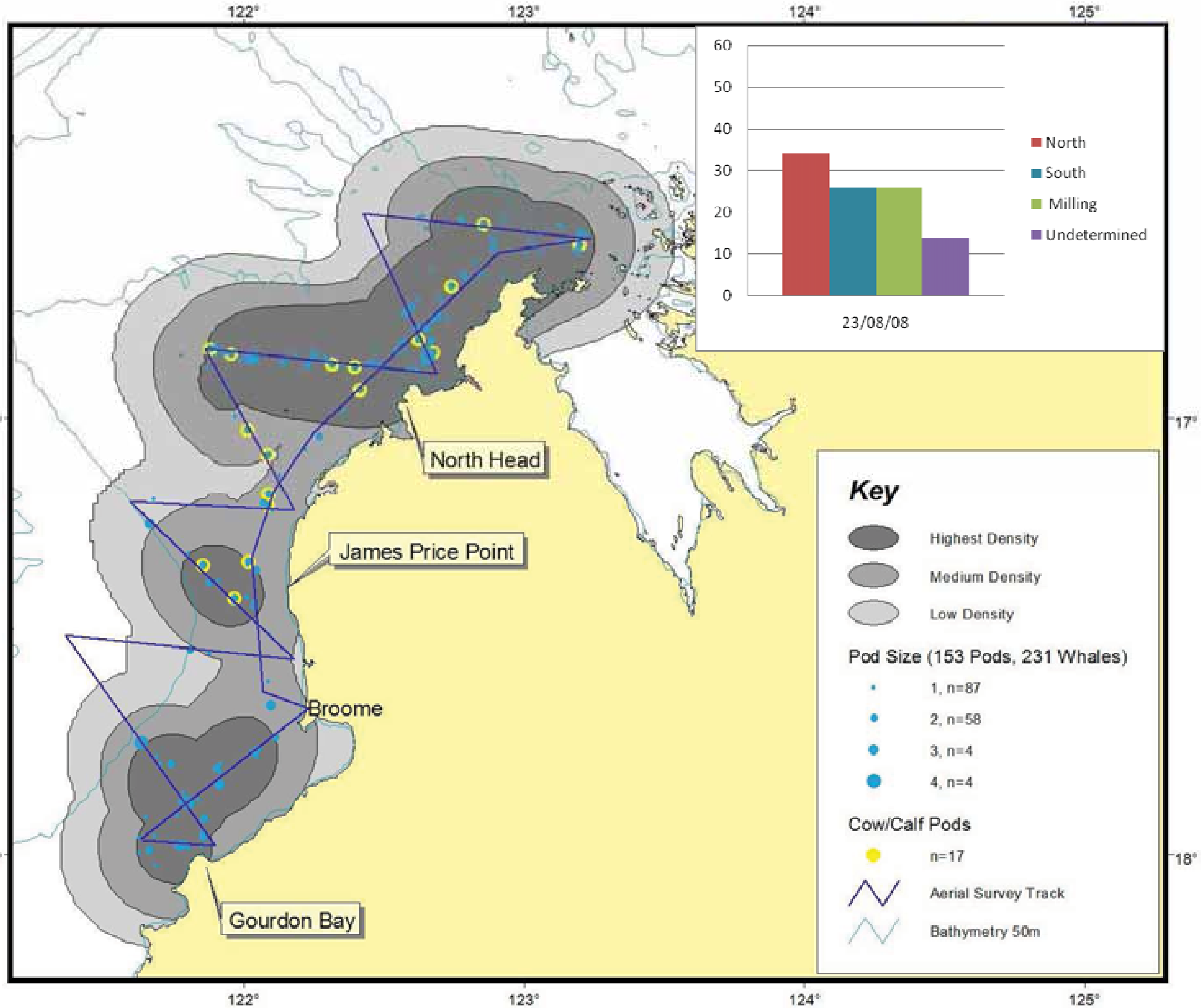


Figure 8.

Flight 5 August 24, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.

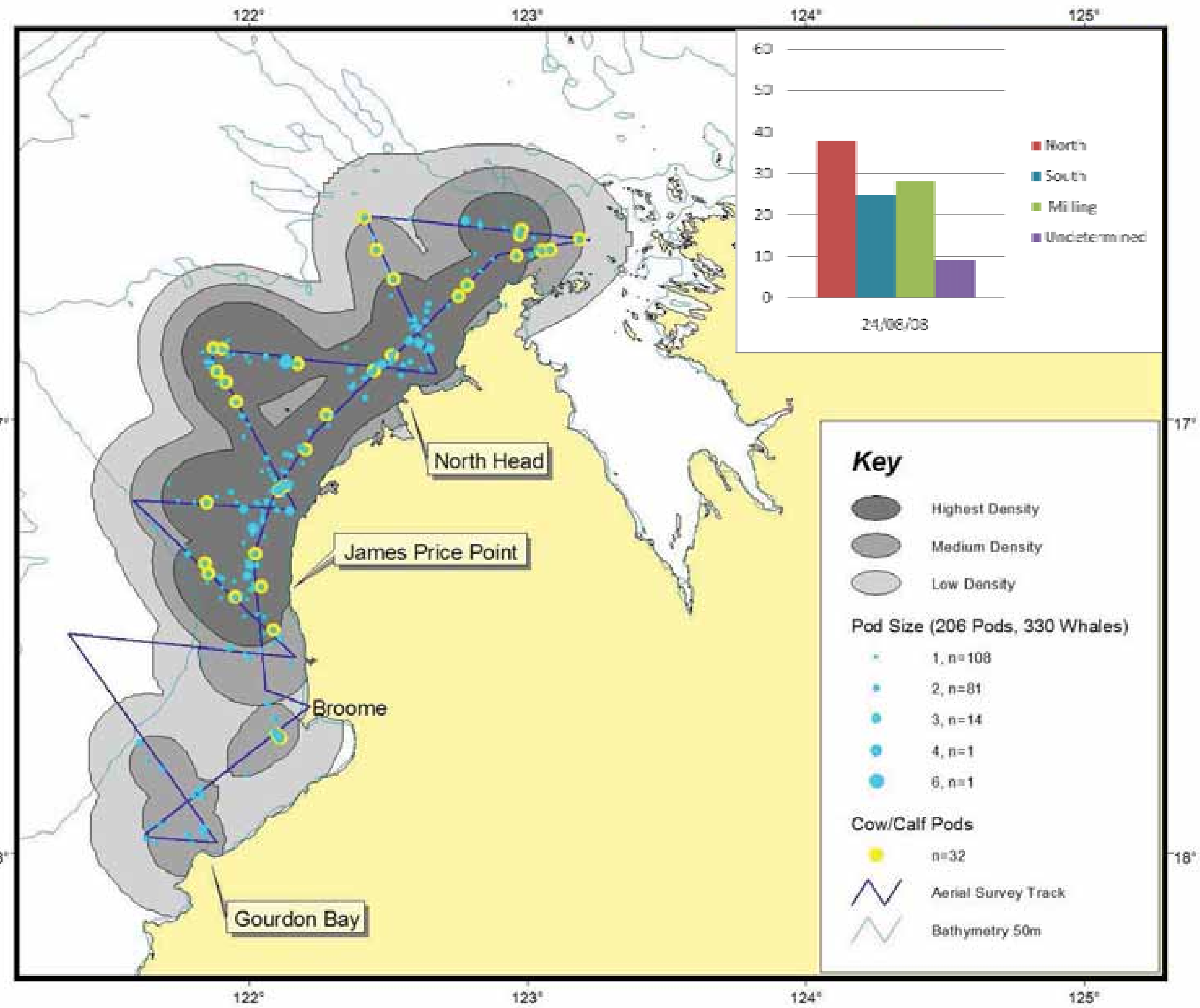


Figure 9.

Flight 6, September 03, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.

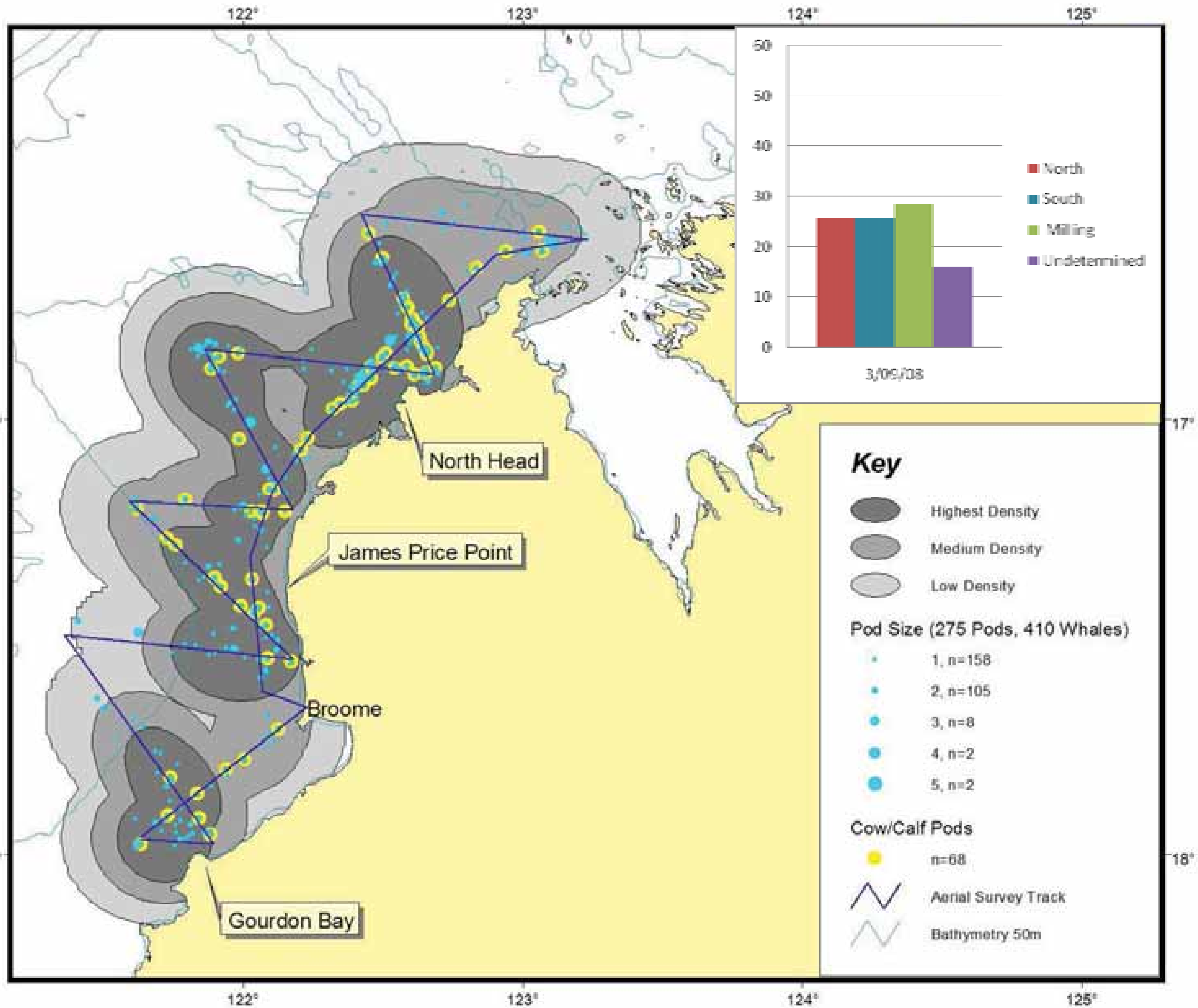


Figure 10.

Flight 7, September 16, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.

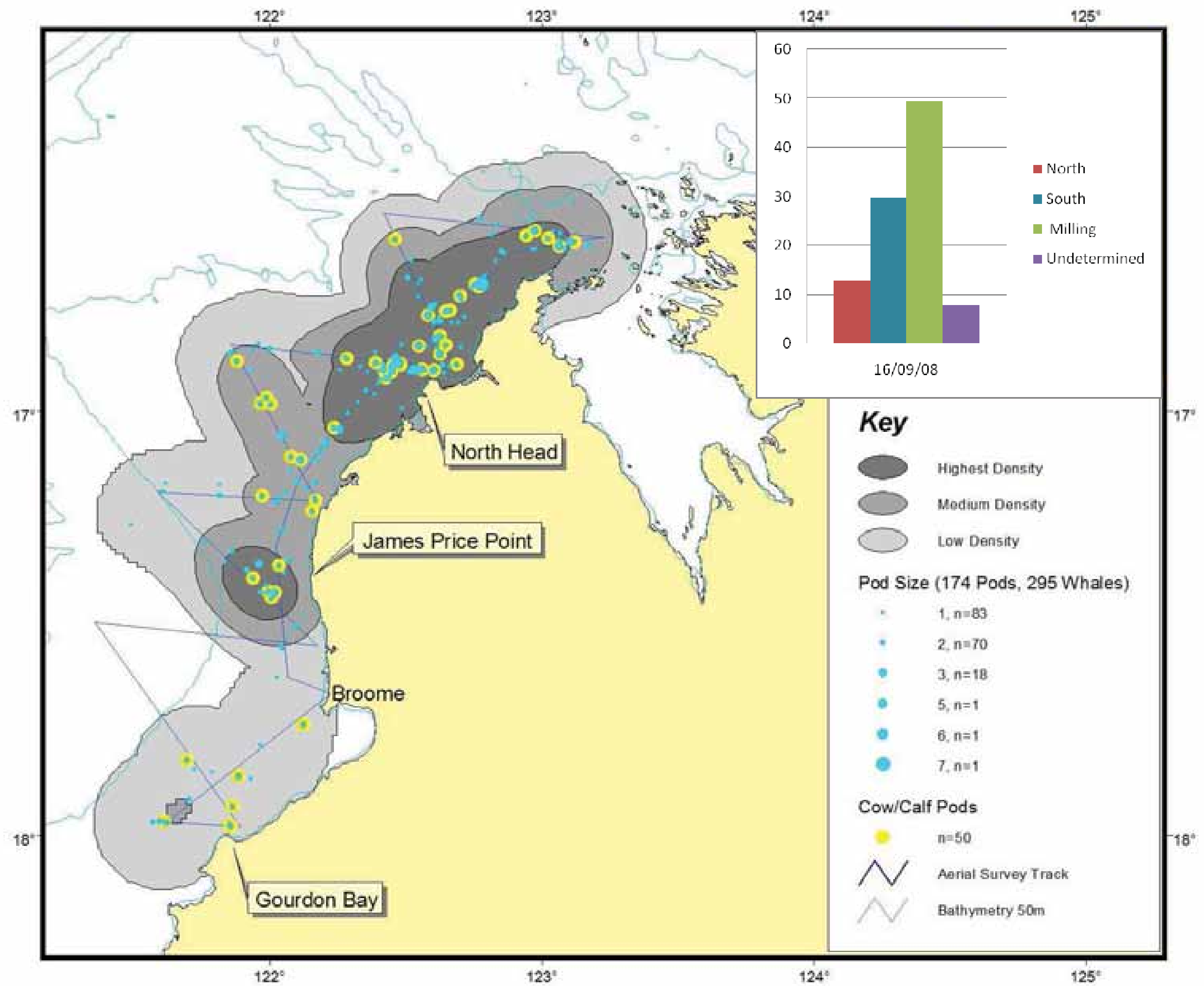


Figure 11.

Flight 8, October 1, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.

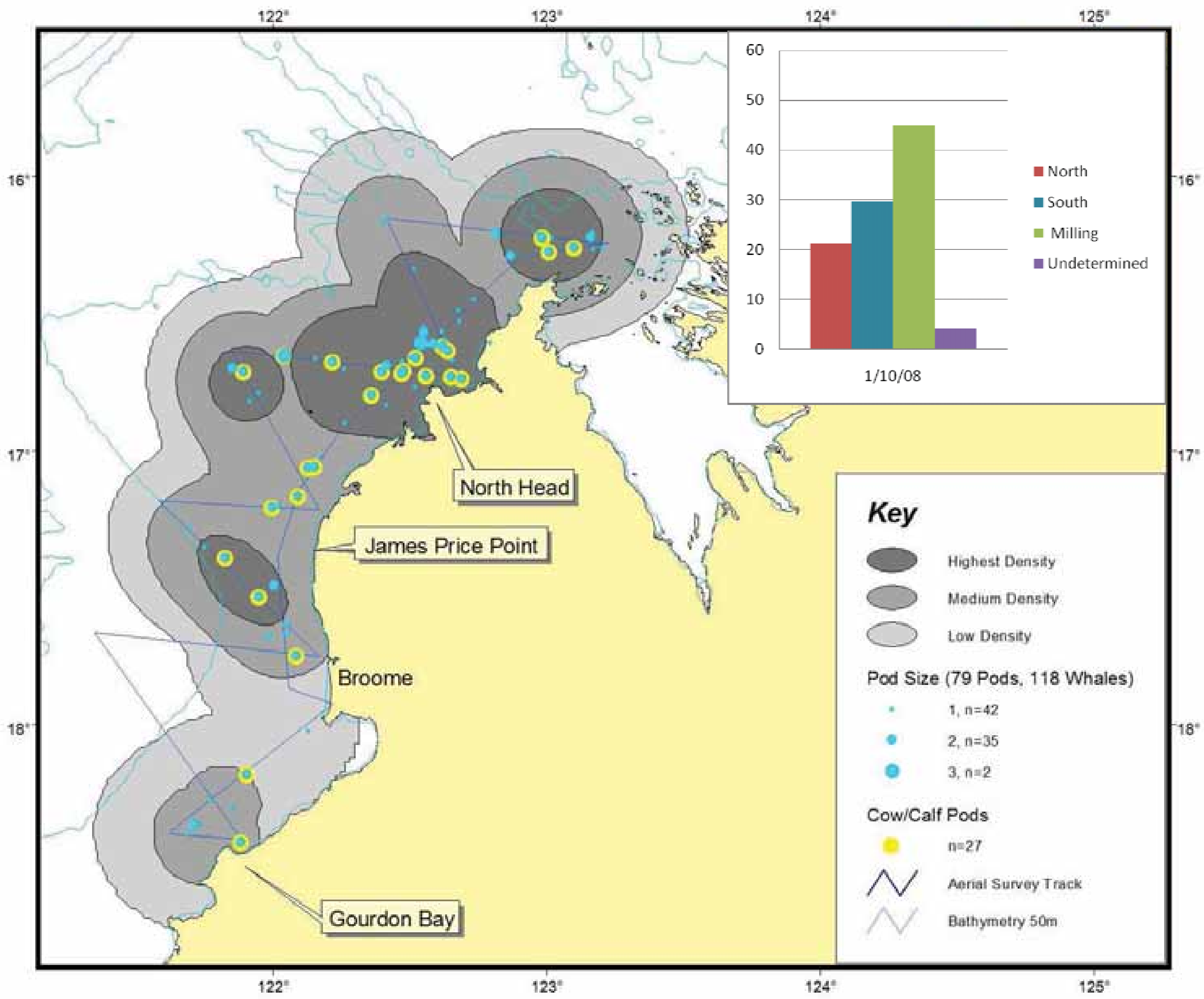


Figure12.

Flight 9, October 11, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.

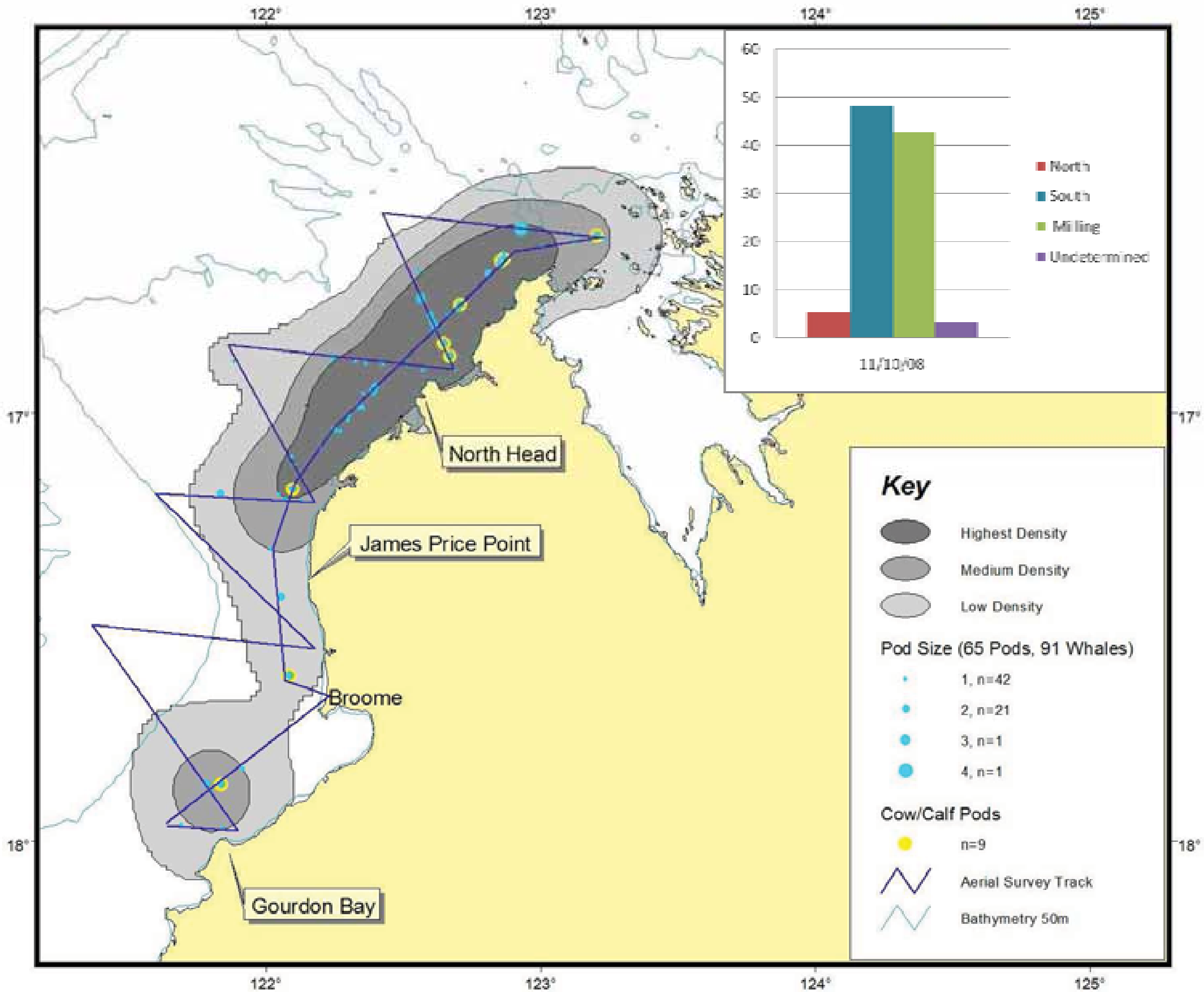
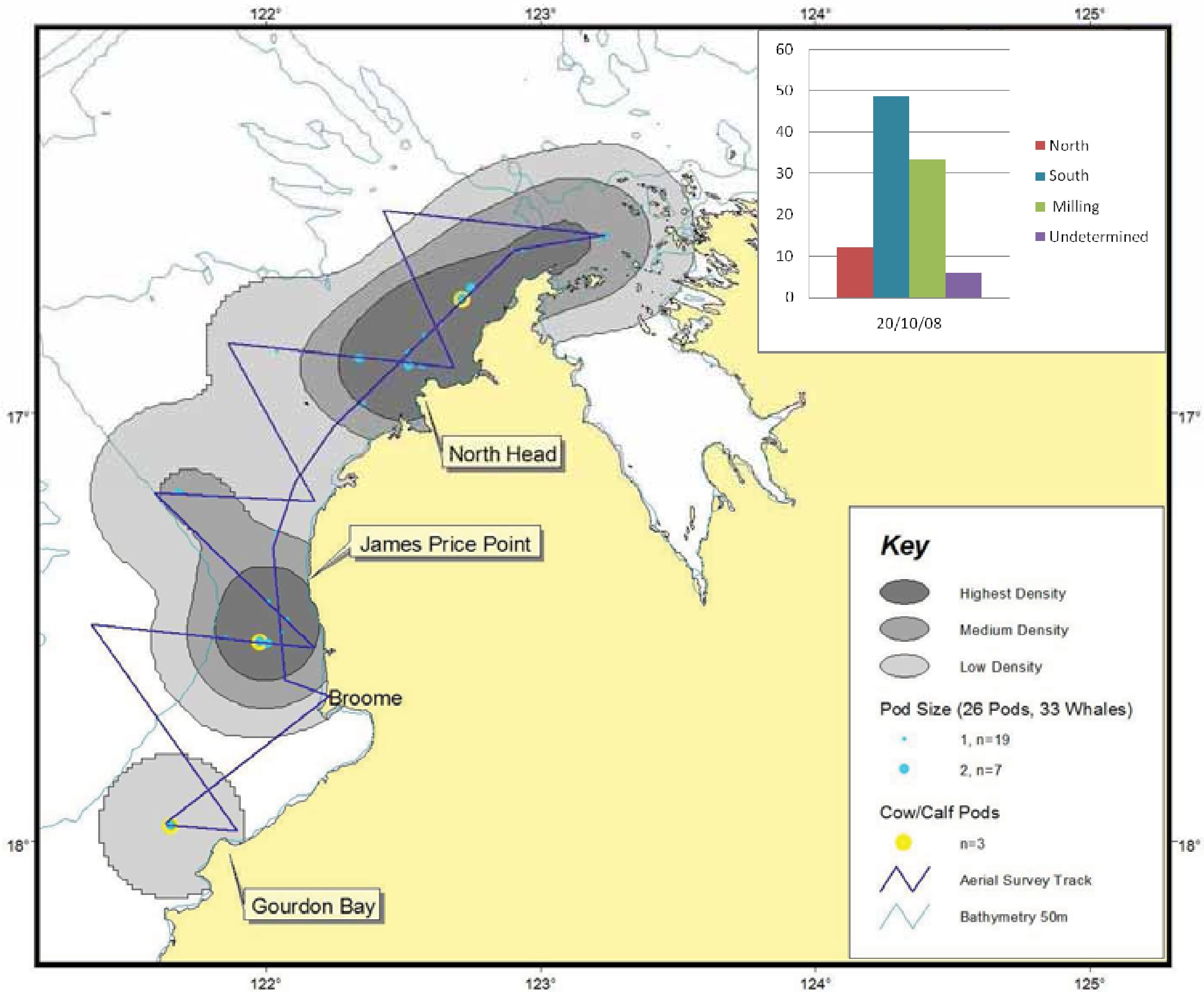


Figure 13.

Flight 10, October 20, 2008.

Relative density distribution of humpback whale pods with migration direction graph showing proportions of pods sighted northbound, southbound or milling.



An overall peak of season, including peak cow/calf numbers, was noted during the September 3, 2008, flight with a rapid decrease in adult whale numbers following mid-September (Figure 14). During the September 03 flight equal numbers of whales observed swimming were heading both northbound and southbound (Figure 15). Prior to the September 3 flight the majority of whales observed swimming were northbound and after that flight the majority of whales observed swimming were southbound. In general, early August to mid-September contained the main migratory pulse of humpback whales in the study area.

A predominantly northern migration was observed during the first four flights from July 19 to August 24 and a predominantly southern migration was observed during the flights from September 16 to October 20 (Figure 15). However during the northern migration, significant numbers of whales sighted each flight were noted to be southbound or milling (resting at the surface or swimming perpendicular to the coast) such that a clear northern migration phase, as observed near North West Cape, Western Australia (Jenner *et al.*, 2001) where up to 90% of whales sighted in July and early August are migrating north, was not observed.

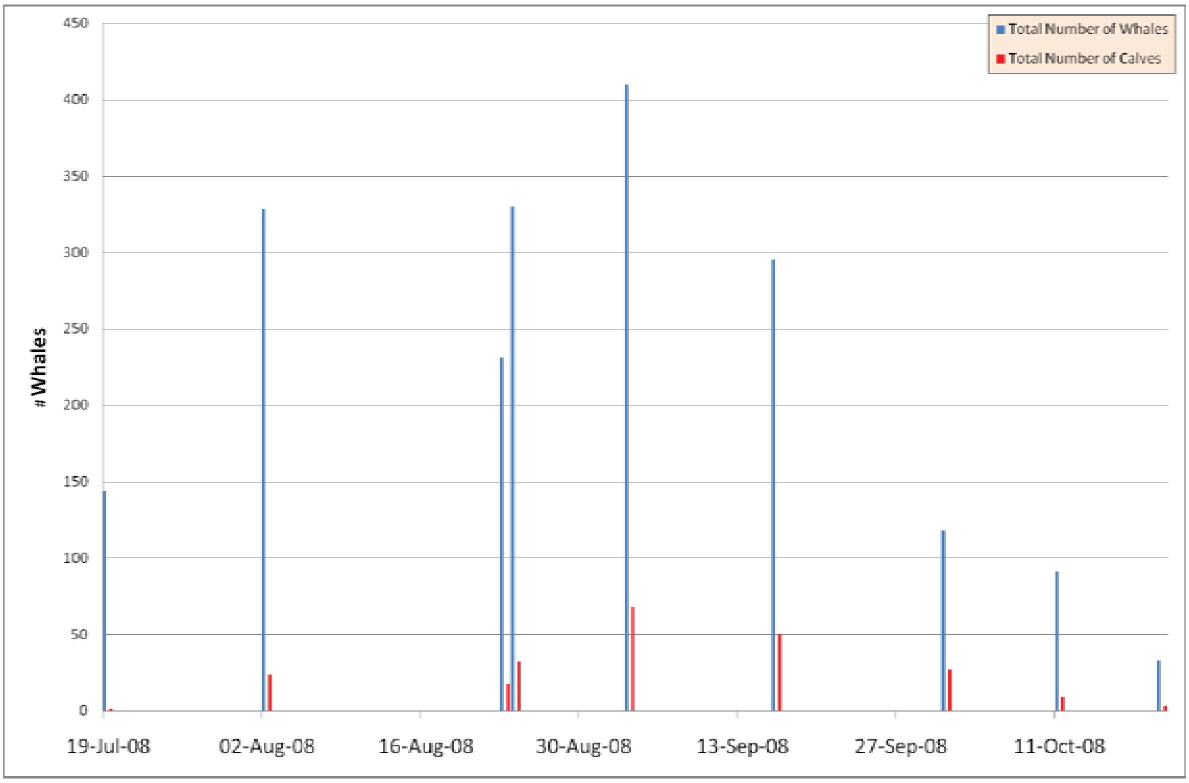


Figure 14. Peak of season for humpback whale sightings, including cow/calf pods was during early September.

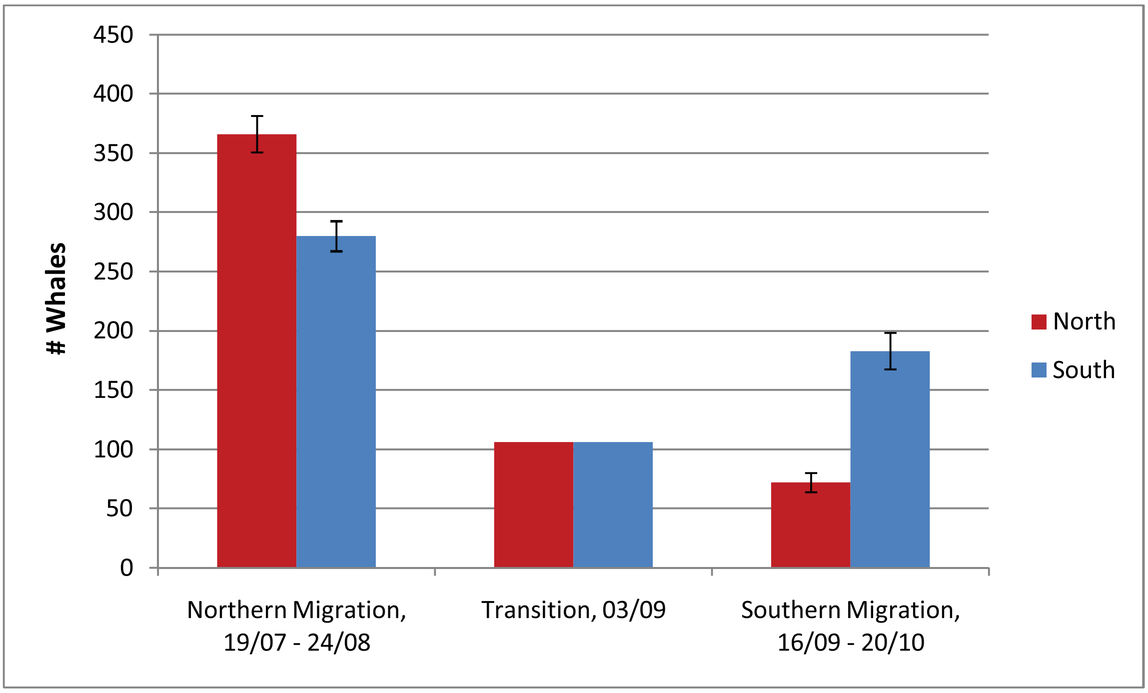


Figure 15. Swim direction of whales sighted during 3 stages of the observation period.

The highest densities of humpback whales were sighted within the 50m depth contour. The core migratory path appeared to be within the search area although arrival and departure migratory routes for this area were not fully revealed. The only off-shore survey leg(s) to contain high densities of whales was near the Lacepede Islands (latitude S 16.8^{o}) during the first 4 flights (Figures 16). Cow/calf pods were predominantly sighted in core high density areas and less so in fringe or low density areas.

During the southern migration period (Sep 16 to Oct 20) flights, a high density zone existed north of the Lacepede Islands along the Kimberley coast. Lower densities of whales were observed south of the Lacepede Islands during this period. During both the northern and southern migratory periods, whales were present in high densities in the Lacepede Channel (between the Lacepede Islands and the mainland).

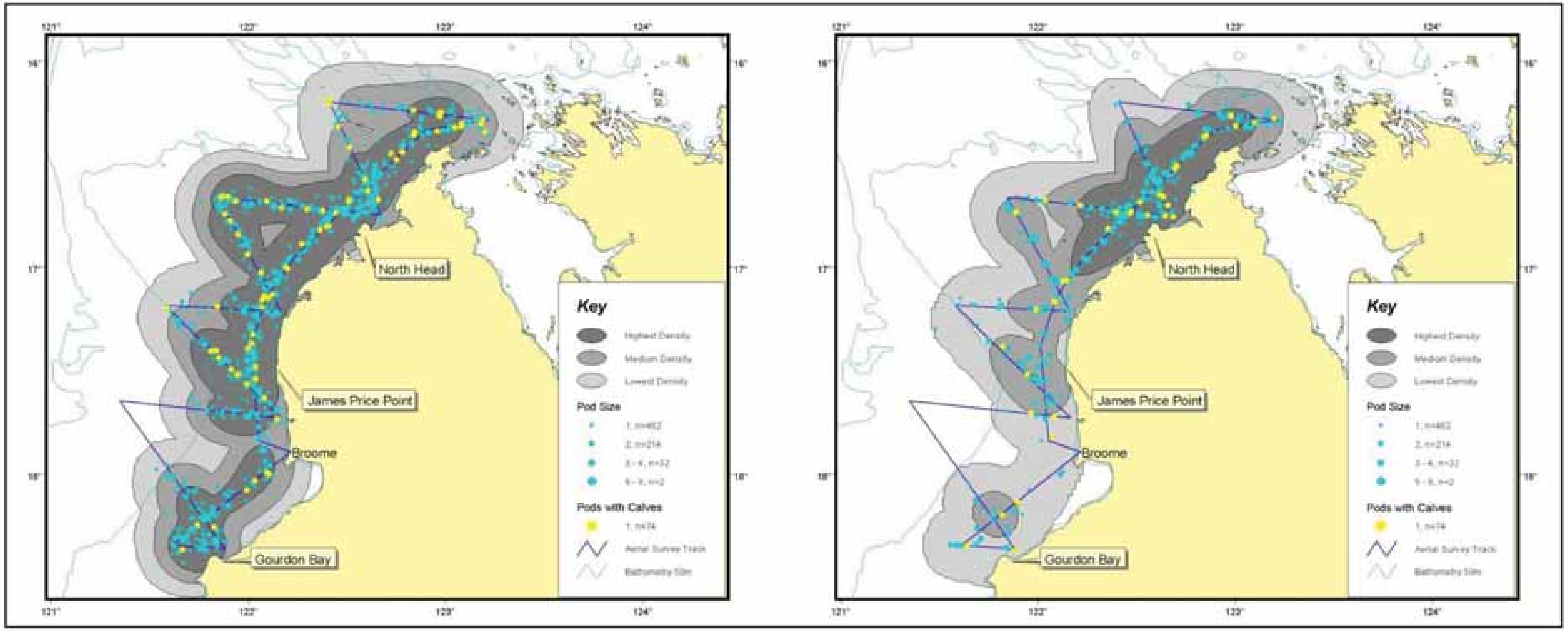


Figure 16. Relative density distribution of humpback whale pods sighted during the “northern” migration (map at left) and during the “southern” migration (map at right). Sightings from the September 03, 2008 flight when equal numbers of whales were swimming north and southbound are not included. The same density scale (h=0.15) is used for both maps.

The majority of cow/calf pods sighted during the flights were observed milling or resting at each stage of the migration (Figure 17)

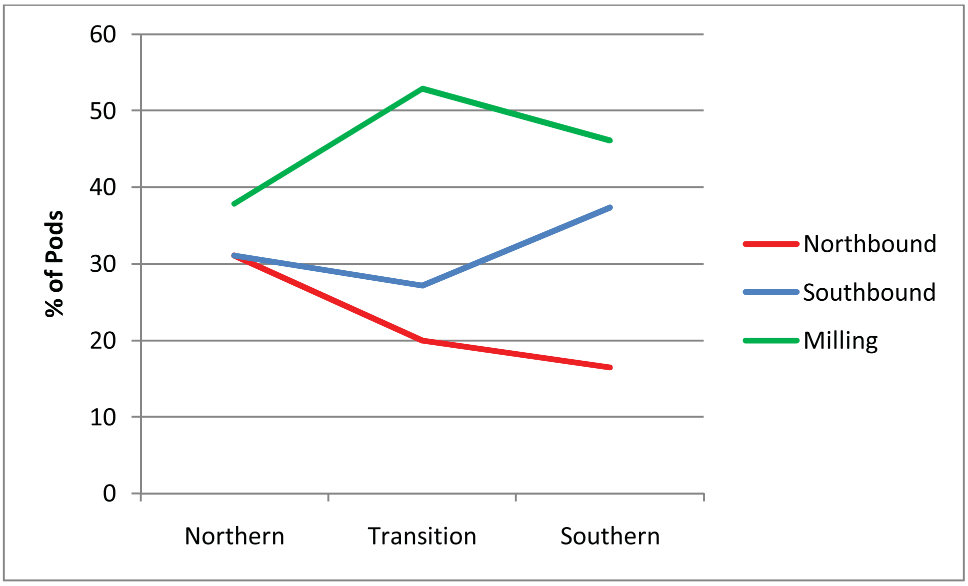


Figure 17. Proportion of cow/calf pods migrating north, south or milling during the Northern migration flights (Jul 19 to Aug 24, n=70), the Transition between the northern and southern migration (Sep 3, n=74) and the Southern migration flight (Sep 16 to Oct 20, n=91).

6.1.1 Whale Density by Coastal Zone

The flight path parallel to the shore line was analysed separately using approximately equal area polygons as a basis for density comparisons between coastal zones (Figure 18).

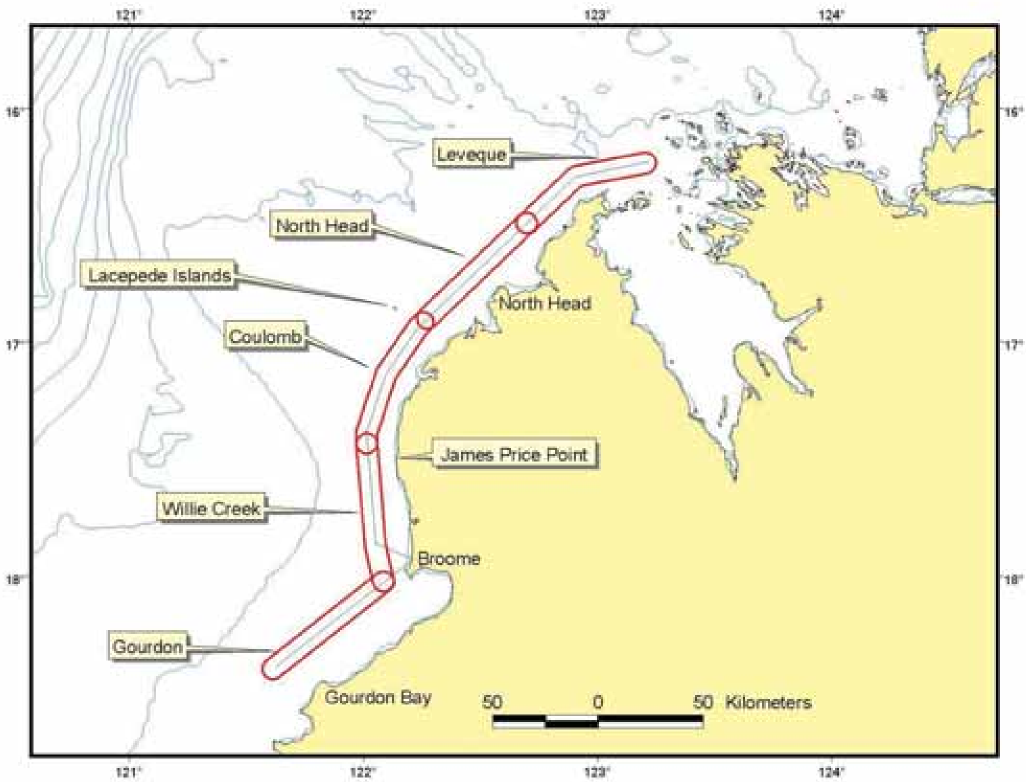


Figure 18. Polygons used for "clipping" and comparing the long-shore transect humpback whale sightings data, in relation to five coastal zones.

Preferred habitat, inferred by peak whale density (whales/km^2), was shown to change during the survey period (Figure 19, Table 2). The highest density of sightings (0.074 whales/km^2) was observed off-shore of North Head during early September and coincided with the peak density of cow/calf pods (0.016 pods/km^2) sighted during the survey period (Figure 20). In relative terms, this peak equates to sighting frequencies of one whale every 13.5 km^2 and cow/calf pods every 61 km^2.

Lowest overall densities of whales in all flights were sighted in the Gourdon Bay zone, followed by the Willie Creek zone (Figure 19). Distinct bi-modal peaks of similar whale densities were observed in the Willie Creek and Coulomb zones during the second and fifth flights. The whale densities in the two zones north of the Lacepede Islands, Leveque and North Head, did not show the same bimodal pattern and there was an apparent trend for the migration to peak in numbers earlier in the year towards the southern end of the study area and later in the north. Gourdon Bay peaked in early August while the areas to the north, such as Leveque, peaked in terms of overall whale densities as late as mid-September (Table 2).

Calf densities did not follow the same pattern and peaked across all areas, except Leveque, in early September. Leveque had peak densities of cow/calf pods in mid- September (Table 2).

Table 2. Humpback whale density, including cow/calf pods, during 2008 for adjacent coastal zones on the SW Kimberley coastline. Peak of season values for each zone are highlighted yellow.

	Leveque	(735.7 km-2)	North Head	(730.5km-2)	Coulomb	(719.5 km-2)	Willie Creek	(736.1 km-2)	Gourdon	(744.4 km-2)
Date	Whales km-2	#Calves km-2	Whales km-2	#Calves km-2	Whales km-2	#Calves km-2	Whales km-2	#Calves km-2	Whales km-2	#Calves km-2
Jul 19, 2008	0.010	0.000	0.018	0.000	0.022	0.000	0.015	0.000	0.016	0.000
Aug 02, 2008	0.024	0.003	0.041	0.004	0.050	0.004	0.034	0.001	0.035	0.004
Aug 10, 2008										
Aug 23, 2008	0.031	0.003	0.027	0.001	0.015	0.003	0.020	0.001	0.024	0.000
Aug 24, 2008	0.026	0.007	0.051	0.003	0.063	0.006	0.043	0.004	0.023	0.003
Sep 03, 2008	0.029	0.005	0.074	0.016	0.032	0.010	0.034	0.005	0.031	0.007
Sep 16, 2008	0.056	0.007	0.063	0.012	0.028	0.003	0.010	0.003	0.017	0.004
Oct 01, 2008	0.015	0.003	0.026	0.005	0.011	0.004	0.008	0.000	0.007	0.001
Oct 11, 2008	0.024	0.004	0.023	0.001	0.014	0.001	0.005	0.001	0.005	0.001
Oct 20, 2008	0.010	0.001	0.008	0.001	0.001	0.000	0.001	0.000	0.000	0.000

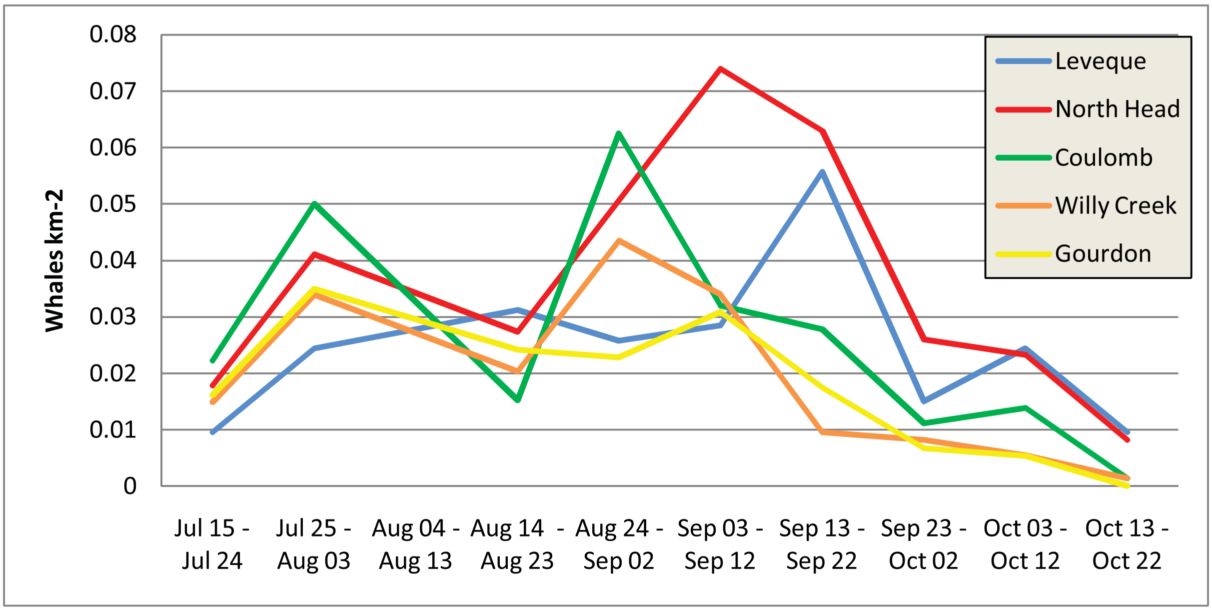


Figure 19. Density of humpback whales at each coastal zone during the survey period in 2008.

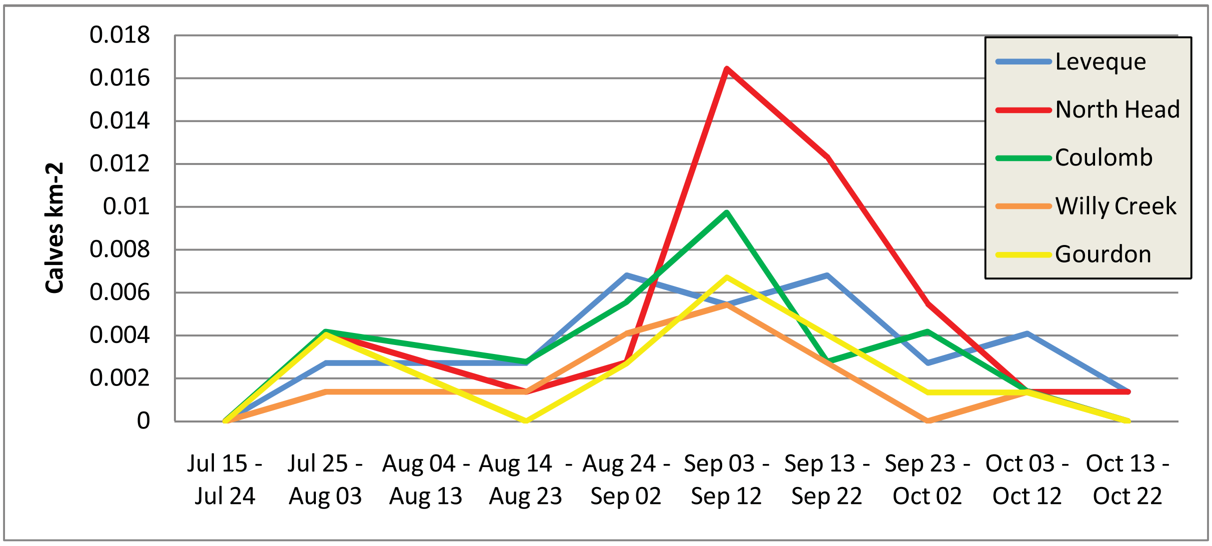


Figure 20. Density of humpback whale cow/calf pods at each coastal zone during the survey period in 2008.

6.2 Other Mega Fauna

Other mega fauna included large cetacean species other than humpback whales, ie. dolphins, dugongs, turtles, sea snakes, sharks and rays. Boat sightings were also recorded (Figures 21 – 28). Sightings of these species were generally greatest in early October but varied markedly from flight to flight (Table 3.)

Table 3. Numbers of other mega fauna and boats sighted during 2008. Peak of season values are highlighted yellow,

Date	Other Cet.	Dolphins	Dugongs	Turtles	Sharks	Rays	Seasnakes	Boats
19/07/2008	0	0	0	13	1	5	0	0
2/08/2008	0	138	8	62	9	3	10	0
11/08/2008								
23/08/2008	0	39	2	26	12	0	2	6
24/08/2008	0	5	7	51	12	4	3	5
3/09/2009	2	143	2	92	5	9	7	0
16/09/2008	1	183	1	78	13	5	29	2
1/10/2008	1	395	6	63	3	7	33	1
11/10/2008	3	283	4	129	46	4	57	4
20/10/2008	1	79	1	85	9	0	28	3
totals	**8**	**1265**	**31**	**599**	**110**	**37**	**169**	**21**

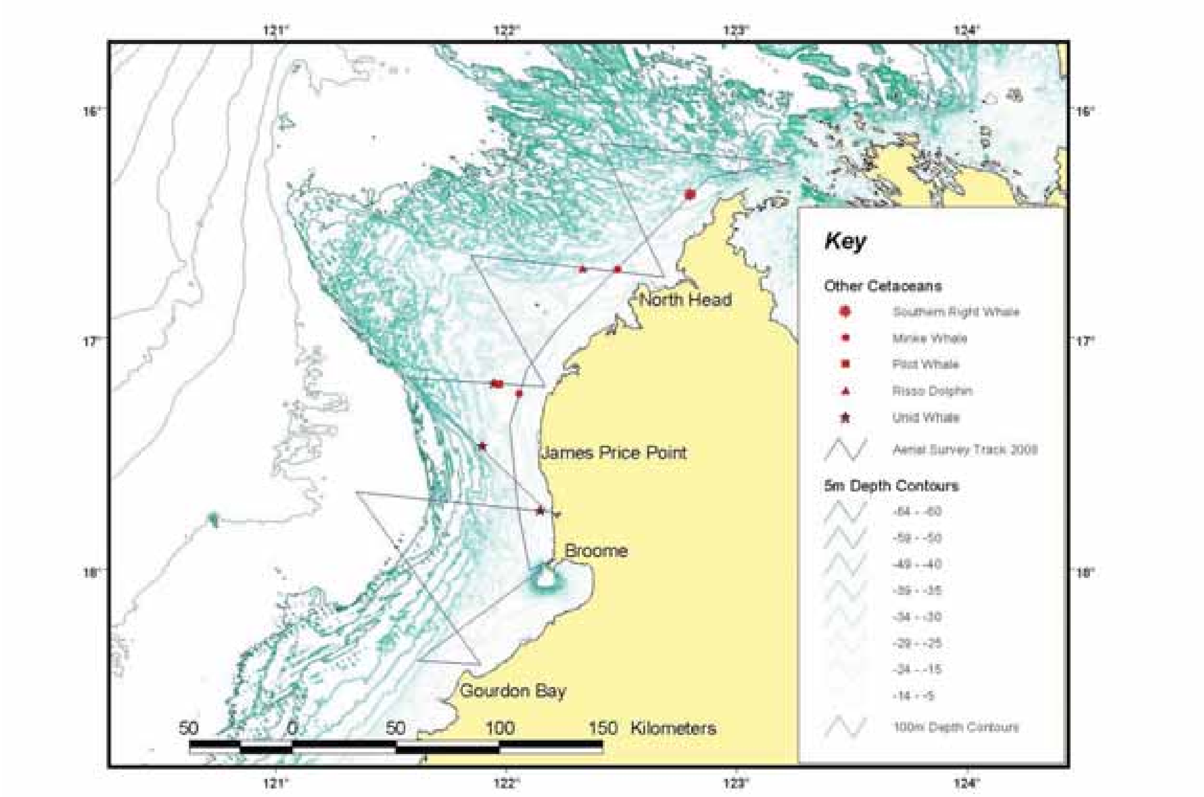


Figure 21. Large cetacean species sighted, other than humpback whales, during the 2008 study period.

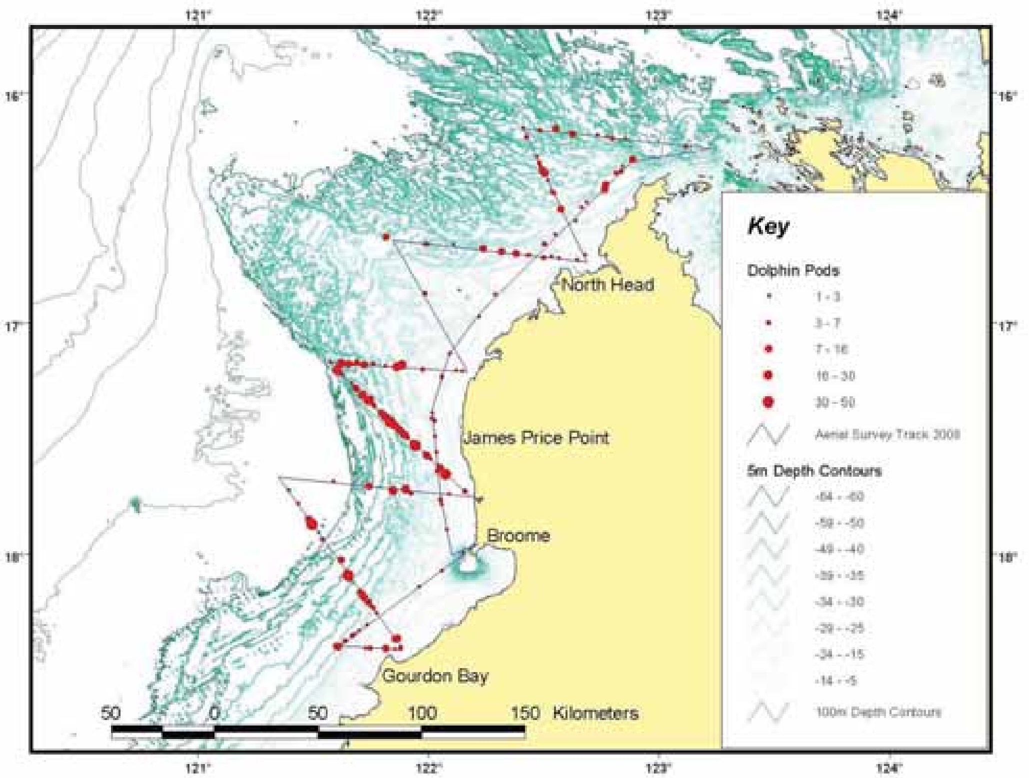


Figure 22. Dolphin species sighted during the 2008 study period.

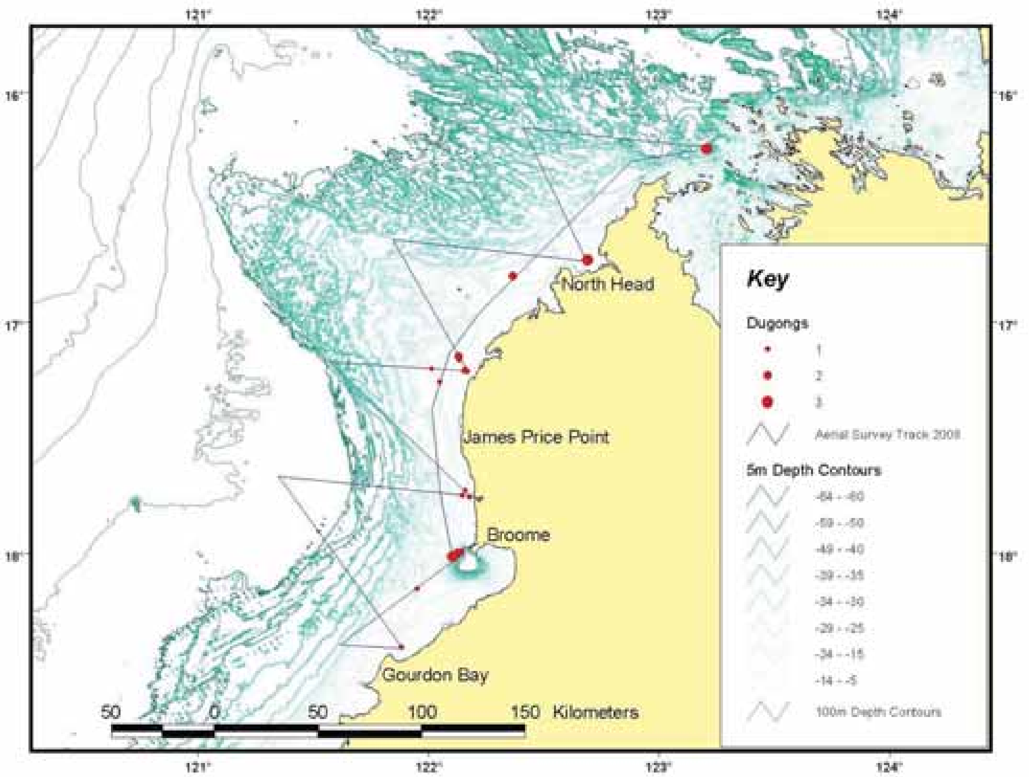


Figure 23. Dugongs sighted during the 2008 study period.

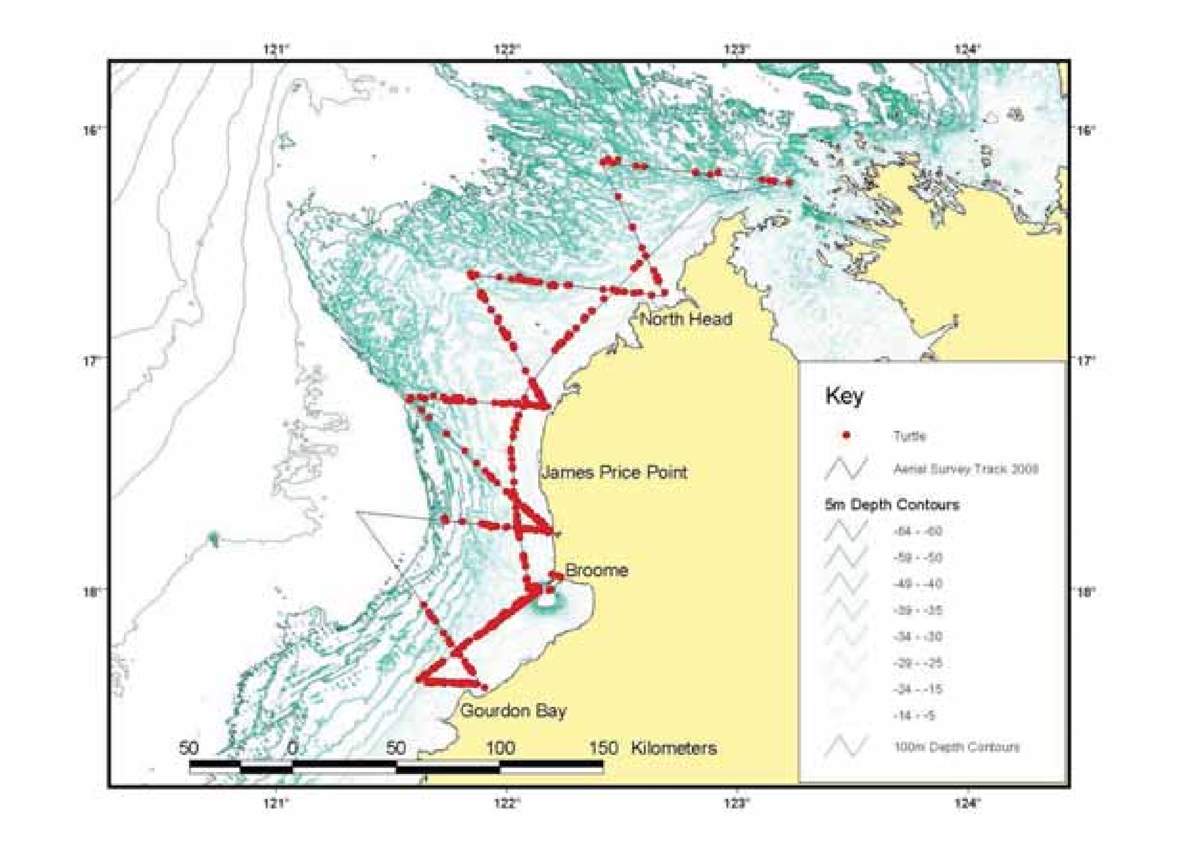


Figure 24. Turtle species sighted during the 2008 study period.

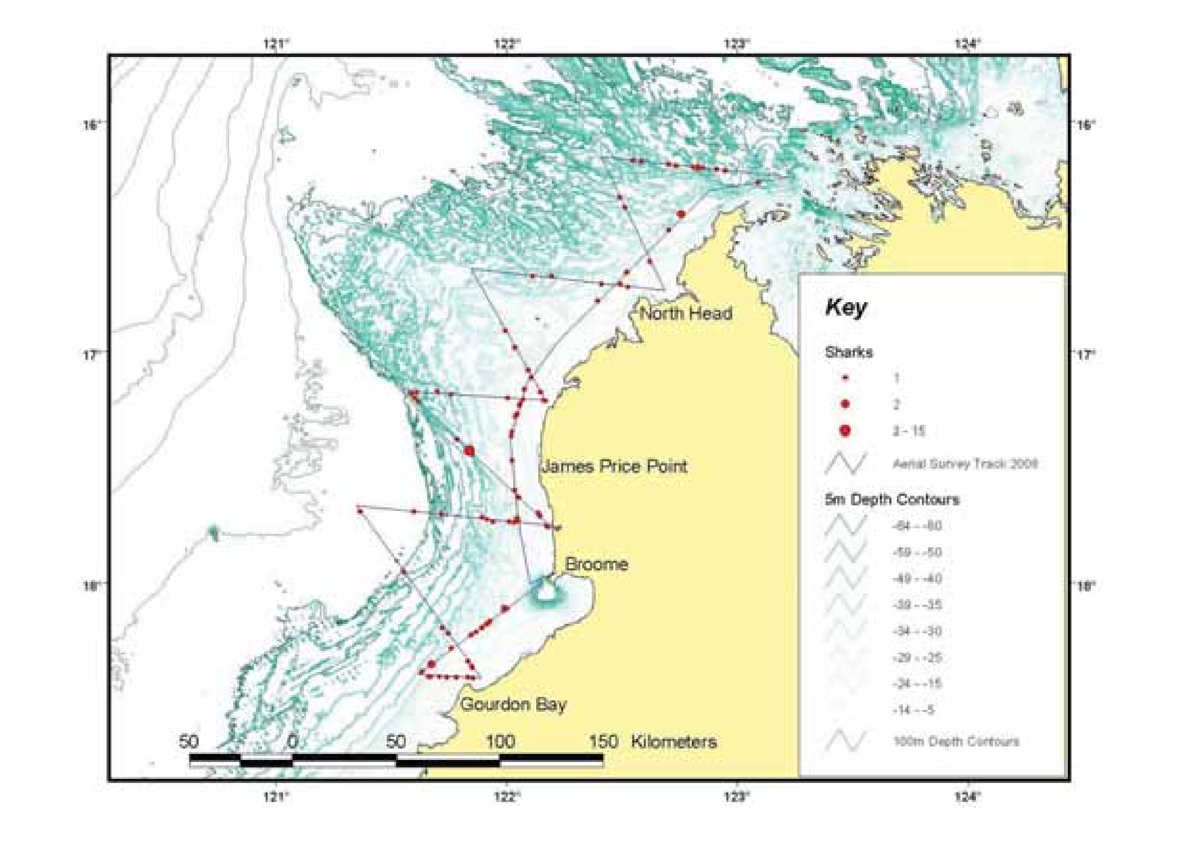


Figure 25. Shark species sighted during the 2008 study period.

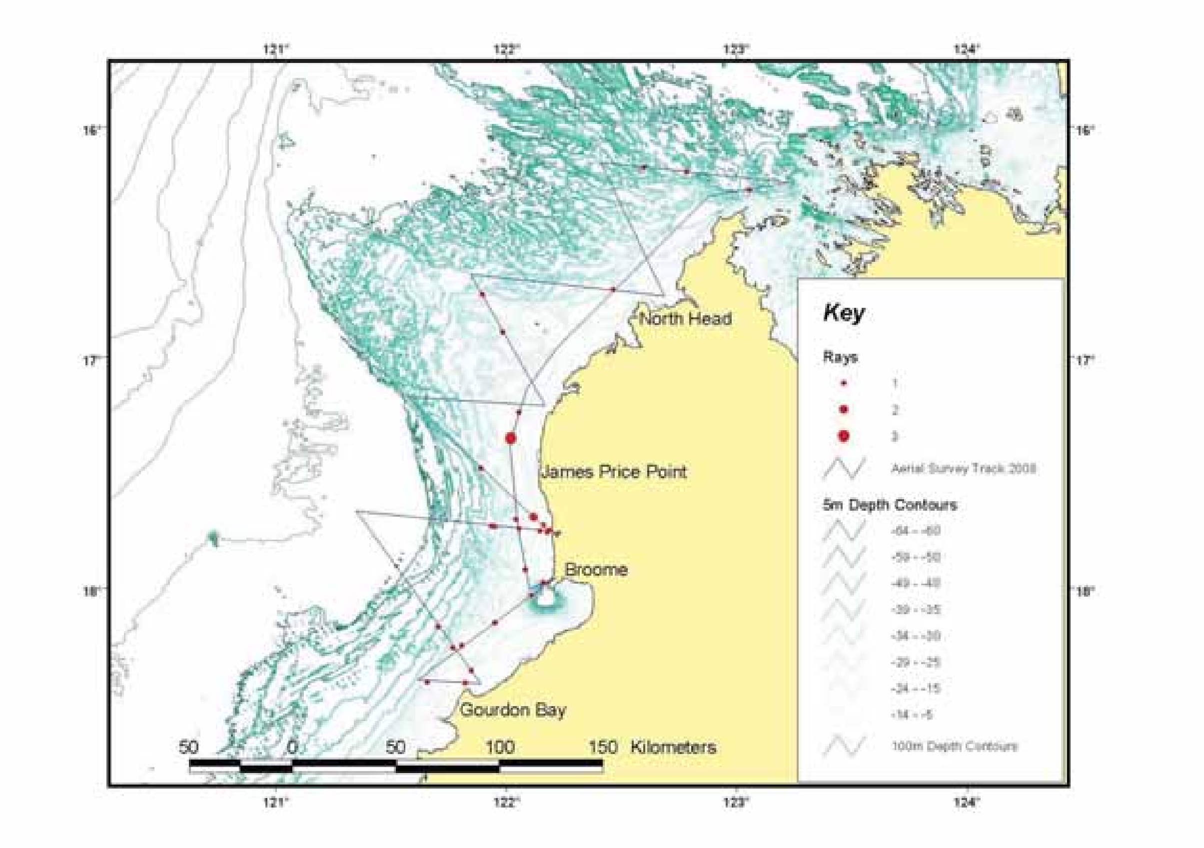


Figure 26. Ray species sighted during the 2008 study period.

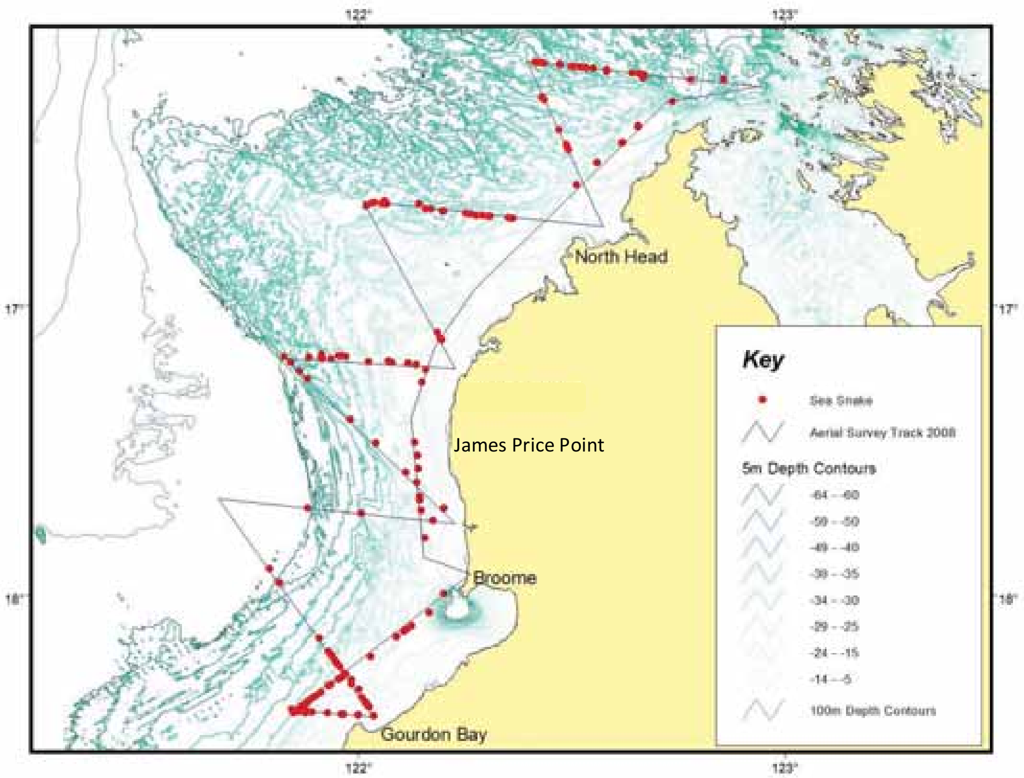


Figure 27.Sea snake species sighted during the 2008 study period.

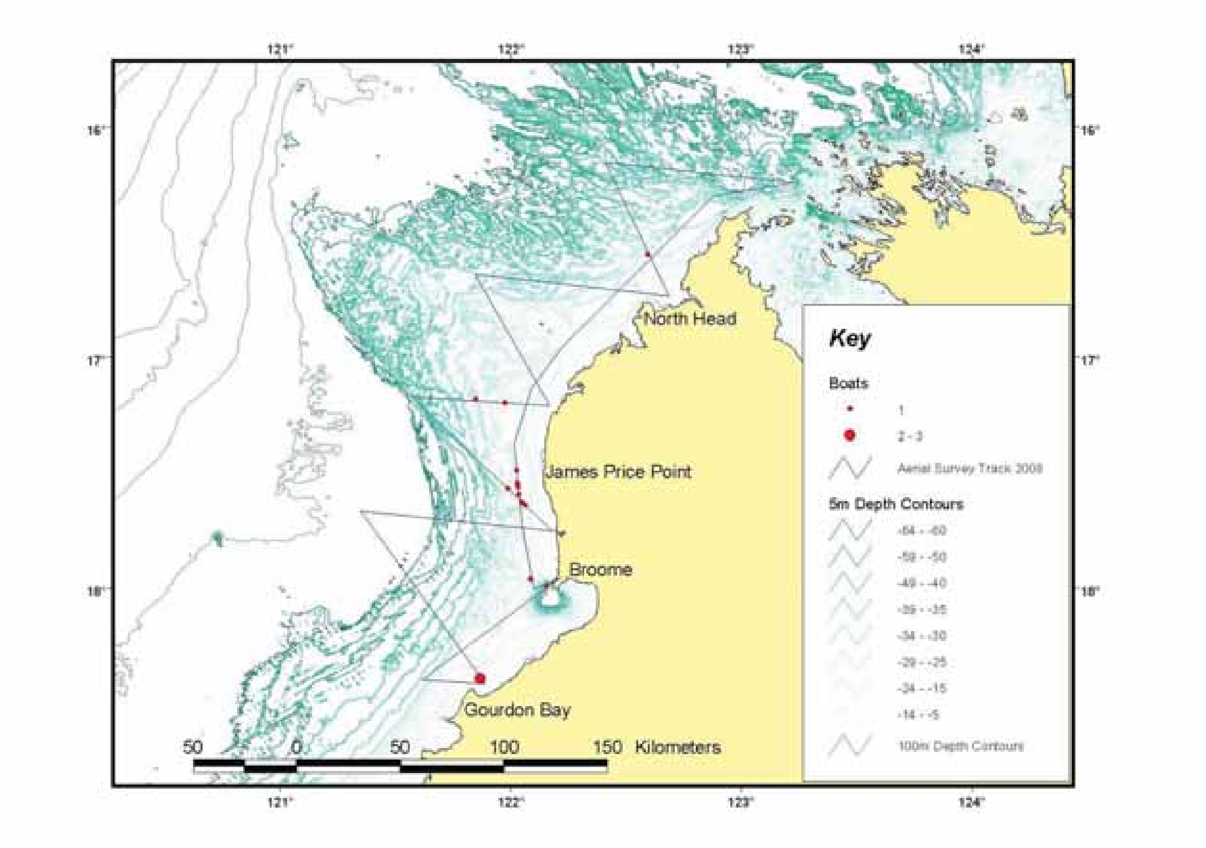


Figure 28. Boats sighted during the 2008 study period.

7. Discussion

This report summarises a study program carried out in the austral winter of 2008, on the near-shore southwest Kimberley region using aerial surveys at approximately 10 day intervals. The results indicate that humpback whales were present in the region during the entire study period from July 19 to October 20, although at differing numbers and density.

Previous data (Jenner *et al.,* 2001) indicates that the expected migratory pattern would result in a northbound influx of whales into the calving grounds during July, followed by a non-migratory or resting period in August, and then followed by a southern exodus of whales out of the calving grounds in September/October, with the cow/calf pods being the last to leave the Kimberley. The study area was considered to be primarily part of a migratory area into, and out of, the calving grounds with Pender Bay, immediately to the north of North Head, described as a resting or staging area for southbound cow/calf pods leaving the area (Jenner *et al.*, 2001).

This pattern of usage by cow/calf pods was observed in the surveys discussed here and a general peak abundance in the study area during August through to mid-September was also consistent with that reported by Jenner *et al.* (2001). However, the northern migratory period did contain a significant number of southbound whales as well as northbound cow/calf pods that evidently did not undertake parturition within the calving ground boundaries described by Jenner *et al.* (2001). These changes from patterns observed over a decade earlier may perhaps be attributed to an increase in individual heterogeneity as a result of population growth.

Bannister and Hedley (2001) estimated that the Stock D humpback population was increasing at over 10% per annum in 1999 from near 10-12,000 whales putting the population in 2008 at potentially over 20,000 individuals. As a result, variations in migratory spatial patterns, such as an increase in the latitudinal range of calving (as is suggested by this reports findings), may be more likely than changes in temporal patterns which are ultimately linked to seasonal cycles.

Possible explanations for the large numbers of southbound whales "early" in the migratory season may eventually be found in the understanding of age class structure of the migratory body. Sexually immature whales (sub-adults) have been reported (Chittleborough, 1965) to lead the annual northern migration past areas such as the Pt. Cloates whaling station (S22.6^{o}) and it likely that this age class of animals may be largely responsible for the early southbound migration out of the study area. This hypothesis could be easily tested using established photogrammetric techniques that would quantify lengths of whales at each stage of migration.

Density measurements of humpback whales across the season and along the near-shore SW Kimberley, in general, showed higher relative densities towards the north of the study area and lower densities towards the south. More specifically, the North Head longshore sampling zone had the highest densities of whales and cow/calf pods, with a distinct peak between mid-August and early October that coincided with peak numbers of milling whales. Jenner *et al.* (2001) reported the same pattern during early September from boat based observations, and identified the Pender Bay region, immediately to the north of North Head, as a major cow/calf resting and staging area prior to the beginning of the annual southern migration. The highest whale densities reported from the Leveque zone occurred in the mid-September milling period suggesting that the resting and staging area described by Jenner *et al.* (2001) may extend from Cape Leveque to the northern side of the Lacepede Islands.

The Coulomb zone, immediately to the south of the North Head zone, had the second highest cow/calf densities which, although peaking in numbers during the same early September period as North Head, had significantly lower overall numbers over a shorter time period (mid-August to mid-September). The Willie Creek zone, which contains James Price Point, had the overall lowest densities of cow/calf pods (peak values less than 33% of North Head) and ranked only slightly higher in terms of overall whale density than Gourdon Bay which had the lowest recorded densities.

Other cetacean sightings of note included a southern right whale near Cape Leveque (S 16.4^{o}), which is the furthest northern record for this species in Australia (John Bannister, pers. comm.). While this sighting is considered a rarity and not an issue for consideration in long-term management decisions, there were more regular sightings of other protected species known to be seasonal or resident in the region such as dolphins, dugongs and turtles. However, since the surveys were designed to cover a large area and target humpback whales, survey techniques necessary to increase the likelihood of spotting smaller animals (lower flight path and slower flight speed) could not be utilised. Further complicating interpretation of the results for other mega fauna (and possibly humpback whales) were sighting variables such as sea state, glare and perhaps moon phase (in relation to tidal current flow rate). These factors have been listed against the flights and species sighted in Appendices 1 -3, however an exhaustive analysis of these issues is beyond the scope of this report.

While the sightings of other mega fauna reported here are of limited use in determining actual densities of these species and should rather be used to infer presence (not absence, nor density) during a particular temporal period. However, in general terms, there were more frequent sightings of dolphins on the transect off-shore of Coulomb Point and more turtles sighted south of the Lacepede Islands than north of them. Very few dugongs were sighted, but those that were, were close to shore near each of the transect leg turning points.

8. Survey Methodology Limitations

Limitations in the survey methodology for the aerial surveys exist due to the enormity of the survey area which, due to logistical constraints, result in less than statistically ideal sampling effort per square kilometre over time (see explanation in Methods section). Similarly, temporal spacing of the flights at ten day intervals may be inadequate for some detecting trends in some parts of the population. For example, some whales arriving early in the season in the Kimberley may stay short periods that aren't able to be measured by flights at ten day intervals such as sexually immature whales. As well, aerial surveys can be expected to have limited ability to detect precise migratory direction trends since viewing time is typically in the order of seconds, rather than in minutes or hours as could be achieved with vessel surveys more suited to this work.

An example of the limitations of 10 day flight intervals used to assign trends to mobile populations of animals arose with 2 flights that although were designated to be in separate 10 day blocks, actually fell within a day of each other. The number and distribution of whales sighted on the August 23 and August 24 flights varied greatly (Figures 7 and 8). Suggestions of inconsistent weather conditions between the 2 days being responsible for the differences fall short of satisfactorily explaining the 3 -4 fold increase in sightings from August 23 to August 24. Appendix 1 shows that although sea state conditions were better for some of the legs during August 24 (transects 11 and 12), the largest differences in density were observed in identical sea states between the 2 days (Transects 13&14 and 15&16). The apparent pulse-like nature of humpback migration makes averaging of time series data an interesting problem and reinforces a basic scientific principle that multiple samples are necessary to prove trends. Multiple years of surveys over the same area, such as performed by Bannister and Hedley (2001), are necessary to smooth irregular outliers in this and any dataset.

Weather conditions are however likely to play a role in accurate determination of migratory direction. The flight on July 19, 2008 had consistent sea state levels of 3 and up to 4 throughout the flight and as a result recorded the highest number of "undetermined" migratory direction pods for the season. No other flight days had consistently high sea states throughout the flight nor high levels of "undetermined" whales.

Statistical manipulation (i.e., bootstrapping) of the data can smooth incomplete datasets so that trends appear evident, however, in closing, the 2008 season research programme should be viewed as a basis from which to continue future studies (perhaps more spatially focused with finer time scales) rather than as a complete study in itself. However we are satisfied that general migration spatial and temporal trends can be extracted from a 10 day interval dataset such as presented in this report and may be sufficient for some management purposes.

9. Conclusions

We can conclude that this survey was successful in accomplishing its primary objectives.

- Consistently high numbers of humpback whales were sighted in the study area between early August and mid-September.
- Cow/calf numbers peaked in early September.
- An high density area for humpback whales and their calves was observed between Cape Leveque and the Lacepede Islands during the period mid-August to early October.
- Outside of the above mentioned time and area, whales are more likely to be migrating than resting.
- Sighting of dugongs, dolphins and turtles were sufficiently frequent to assume a regular presence of these animals, at least during winter months, in the study area.

10. Knowledge Gaps

Knowledge gaps exist for this study area for time periods outside the scope of the current report (November to mid-July). In particular the June to mid –July period of the northern migration should be targeted for future studies so that the beginning of the northern migration can be examined. As well, knowledge gaps also exist within the July to November period due to low sampling effort at particular sites of interest to the site selection process. The process of describing the broader migratory processes, as was accomplished during the 2008 surveys, does not permit fine scale assessment of the role of specific sites to individual whales or the population as a whole.

11. Acknowledgements

The authors would like to acknowledge Woodside Energy and the Northern Development Taskforce for funding this important work. Pilot Peter Gash and his team from Queensland, as well as Eric Rolston and his team from Exmouth, provided excellent aircraft in demanding conditions with no complaints. Lyn Irvine, Emily Wilson, Jane Kennedy and Jennifer Thompson were our dedicated eyes in the sky and ably dealt with precocious equipment in soaring temperatures. A final thank-you is due to Priscilla Hubbard who patiently guided us through the miles of red tape necessary to complete this work safely.

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Appendix 1 – Sea State as a sighting variable for the long shore transects

		Transect 11			Transect 12			Transect 13 & 14			Transect 15 & 16			Transect 1		
		Leveque (735.7 km-2)			**North Head (730.5km-2)**			**Coulomb (719.5 km-2)**			**Willy Creek (736.1 km-2)**			**Gourdon (744.4 km-2)**		
Date Range	**Flight Date**	**Whales km-2**	**#Calves km-2**	**Sea State**	**Whales km-2**	**#Calves km-2**	**Sea State**	**Whales km-2**	**#Calves km-2**	**Sea State**	**Whales km-2**	**#Calves km-2**	**Sea State**	**Whales km-2**	**#Calves km-2**	**Sea State**
Jul 14 - Jul 23	19/07/2008	0.010	0.000	3	0.018	0.000	3	0.022	0.000	3	0.015	0.000	3	0.016	0.000	3
Jul 24 - Aug 03	2/08/2008	0.024	0.003	1	0.041	0.004	1	0.050	0.004	1	0.034	0.001	3	0.035	0.004	1
Aug 04 - Aug 13	11/08/2008															
Aug 14 - Aug 23	23/08/2008	0.031	0.003	3	0.027	0.001	2	0.015	0.003	2	0.020	0.001	2	0.024	0.000	3
Aug 24 - Sep 03	24/08/2008	0.026	0.007	1	0.051	0.003	1	0.063	0.006	2	0.043	0.004	2	0.023	0.003	1
Sep 04 - Sep 13	3/09/2009	0.029	0.005	1	0.074	0.016	1	0.032	0.010	1	0.034	0.005	1	0.031	0.007	1
Sep 14 - Sep 23	16/09/2008	0.056	0.007	2	0.063	0.012	2	0.028	0.003	2	0.010	0.003	2	0.017	0.004	2
Sep 24 - Oct 03	1/10/2008	0.015	0.003	1	0.026	0.005	1	0.011	0.004	1	0.008	0.000	3	0.007	0.001	1
Oct 04 - Oct 13	11/10/2008	0.024	0.004	1	0.023	0.001	1	0.014	0.001	2	0.005	0.001	2	0.005	0.001	2
Oct 14 - Oct 23	20/10/2008	0.010	0.001	1	0.008	0.001	1	0.001	0.000	2	0.001	0.000	3	0.000	0.000	2
Average Sea State Conditions for each site				2			1			2			2			2
Sandard Deviation				0.741			0.593			0.519			0.593			0.691

Appendix 2 – Sea State recordings per transect

Flight Date	19/07/2008	2/08/2008	23/08/2008	24/08/2008	3/09/2008	16/09/2008	1/10/2008	11/10/2008	20/10/2008
TRANSECT1	3	1	3	1	1	2	1	2	2
TRANSECT2	3	1	3	2	1	2	1	2	2
TRANSECT3	3	1	3	2	1	3	1	2	2
TRANSECT4	3	2	3	3	3	2	3	2	2
TRANSECT5	3	2	2	3	2	3	3	2	3
TRANSECT6	3	2	2	2	2	2	2	2	2
TRANSECT7	3	2	2	1	1	3	2	2	2
TRANSECT8	3	2	2	1	1	3	1	3	2
TRANSECT9	4	1	2	1	2	3	3	4	1
TRANSECT10	2	1	3	2	1	2	1	1	1
TRANSECT11	3	1	3	1	1	2	1	1	1
TRANSECT12	3	1	2	1	1	2	1	1	1
TRANSECT13	3	1	2	2	1	3	1	3	2
TRANSECT14	3	2	2	2	1	2	1	2	3
TRANSECT15	3	3	2	2	1	2	3	2	3
TRANSECT16	2	-	2	2	1	2	3	3	3
TRANSECT17	2	-	3	2	1	2	3	-	3
Mean	**2.9**	**1.5**	**2.4**	**1.8**	**1.3**	**2.4**	**1.8**	**2.1**	**2.1**

Appendix 3 – Lunar Phase for each flight in relation to other wildlife sightings

													Lunar Phase			
													Moon Rise/Set Predictions		Lunar Phase Predictions	
Date	Other Cet.	Dolphins	Dugongs	Turtles	Sharks	Rays	Seasnakes	Boats	Sea state	Highest %occuran	Sea state	Second highest	Moon Rise	Moon Set	Predicted Date	Lunar Phase
19/07/2008	0	0	0	13	1	5	0	0	3	70	2	23	17:27*p	7:48	18/07/2008	Full Moon
2/08/2008	0	138	8	62	9	3	10	0	1	46	2	42	7:33	18:41	1/08/2008	New Moon
11/08/2008													12:33	03:34*f	9/08/2008	First Quarter
23/08/2008	0	39	2	26	12	0	2	6	2	59	3	40	23:39*p	10:07	24/08/2008	Last Quarter
24/08/2008	0	5	7	51	12	4	3	5	2	49	1	43	0:48	10:55	24/08/2008	Last Quarter
3/09/2009	2	143	2	92	5	9	7	0	1	74	2	22	8:02	21:33	31/08/2008	New Moon
16/09/2008	1	183	1	78	13	5	29	2	2	66	3	34	18:10*p	6:23	15/09/2008	Full Moon
1/10/2008	1	395	6	63	3	7	33	1	1	50	3	25	6:32	20:20	29/09/2008	New Moon
11/10/2008	3	283	4	129	46	4	57	4	2	74	2	19	14:51	3:35*f	1/10/2008	First Quarter
20/10/2008	1	79	1	85	9	0	28	3	2	61	1	26	23:48*p	9:46	21/10/2008	Last Quarter
totals	**8**	**1265**	**31**	**599**	**110**	**37**	**169**	**21**								

*Note: "*p" Moon set the previous day. i.e. Moon didn't rise, and "*f" Moon will set the following day. i.e. Moon didn't set.*

Lunar Phase Predictions obtained from the Perth Observatory Website:
http://www.perthobservatory.wa.gov.au/information/rise_set_times_phases.html
Accessed 20/03/2009
Date website last updated: 31/08/2008