GEOGRAPHICAL AND TEMPORAL MOVEMENTS OF HUMPBACK WHALES IN WESTERN AUSTRALIAN WATERS

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ABSTRACT

Through compilation of historical whaling data, together with recent aerial and boat-based survey data, a general framework for the overall peaks of migration has been estimated for the temporal and spatial movements of Group IV humpback whales along the Western Australian coast.

The migratory paths of humpback whales along the Western Australian coast lie within the continental shelf boundary or 200 m bathymetry. Major resting areas along the migratory path have been identified at Exmouth Gulf (southern migration only) and at Shark Bay. The northern endpoint of migration and resting area for reproductively active whales in the population appears to be Camden Sound in the Kimberley. A 6,750 square km^2 area of the Kimberley region, inclusive of Camden Sound, has also been identified as a major calving ground. The northern and southern migratory paths have been shown to be divergent at the Perth Basin, Dampier Archipelago and Kimberley regions. In all cases the northern migratory route is further off-shore.

KEYWORDS

Humpback whale, Western Australia, migration, timing.

INTRODUCTION

Humpback whales (*Megaptera novaeangliae*) migrate seasonally from polar feeding grounds to tropical breeding/calving grounds in every ocean. In the Southern Hemisphere, the summer feeding grounds of these whales have been divided by whale biologists into six separate areas (Fig. 1). The humpback whale stock that winters off Western Australian is known as the Group IV population. Their migratory path covers some 3,600 nautical miles (nm) from calving grounds in the Kimberley (Jenner and Jenner, 1996), to feeding grounds south of 56° S and between 70° E and 110° E (Chittleborough, 1965).

Migration patterns of these whales in mid-to-high latitudes (south of 22° S) were originally described from high seas and coastal whaling data (Chittleborough, 1959a, 1959b, Dawbin, 1964). Data collected using Discovery marks allowed scientists of that time, in attempting to determine stock status, to track the movements of whales over great distances and periods of time. Unfortunately, these stainless steel tubes, engraved with a serial number and then shot through the blubber deep into the muscle layers of a live whale, could only be recovered from dead animals on the flensing decks (Brown, 1977a, Chittleborough, 1959a). None the less, the concept of marking whales for positive identification of individuals was a useful research methodology.

In the summer of 1958–59, two whales marked within Antarctic Area IV (70–130° E) were recovered in Area V (130-170° E, south of Eastern Australia) while 10 whales originally marked in Area V had been recovered in Area IV. Two of these 10 whales not only changed feeding grounds but also breeding grounds, as was discovered when they were harvested off the Western Australian coast later that winter. Although this exchange of individuals between what were previously described as discreet populations was of interest and proved the usefulness of Discovery marks, both Dawbin (1966) and Chittleborough (1965) determined that, based on all of the data available to them, there was very little exchange between the Group IV and V populations.

In 1979, a report by Katona et al revolutionised the way whale biologists monitored the movements and life history of individual humpback whales by introducing the techniques of photographic identification of individual whales. Discovery marks, and the necessary whaling industry to make them useful, were no longer the only means of establishing long-term life history information. Like the Discovery marks, photographs can be used to track whales over time and distance. Unlike the marks, the same whales can be repeatedly sighted (resighted) so that a more comprehensive depiction of an individual's natural history gradually emerges.

SCOPE

Historical and present day knowledge of humpback whale movements along the Western Australian coast are described here as completely as is currently possible in terms of the peaks of both the northern and southern migratory movement past particular regions.

Significantly, a discrete calving ground for the Group IV population is identified along with other concentration and resting areas along the migration route. Sources of data include historical whaling (Chittleborough, 1953, 1959a and b, 1965; Dawbin 1964, 1966), aerial surveys (Bannister, 1991a and b, 1994; Coastwatch data 1994-1996; CWR data 1991-1993; Jenner and Jenner, 1993; McCauley et al, 1998) shipboard surveys (Burton, 1991; CWR data 1990–1998; Nishiwaki et al, 1997) and photographic catalogues (CWR data 1990–1998).

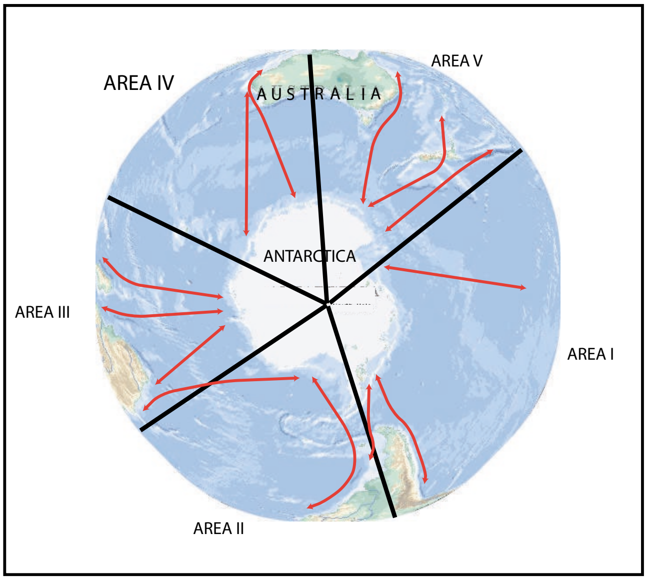

Figure 1. Southern hemisphere feeding/breeding areas 1–V. Modified after Slijper, 1958.

Although every effort has been made to represent the temporal movement of the Group IV stock as accurately as possible, the following information should be kept in mind when planning activities based on the migratory time periods for each of the regions described.

The exact time that the peak density of the migratory body passes a given point on the coast can vary by as much as three weeks from year to year and is attributed to annual variation in food availability in the Antarctic (Chittleborough, 1965). For example, cooler than normal climatic conditions may slow the thinning of the polar ice cap and delay primary productivity in the whales' preferred feeding areas. Thus, to gain sufficient energy reserves (blubber) to migrate north for the following season, a humpback whale may remain on the feeding grounds for an extended period. To further complicate interpretation of the current results, calculations of migratory movements based on historical whaling data and presented here may not be consistent with the migratory patterns of today's recovered population of whales.

Historical whaling data were based on a relatively large population of whales, presumably with a normal balance of age and sex classes. When whaling ceased in 1963, the Group IV population was thought to number no more than 500 whales (Chittleborough, 1965). Since whalers selected larger whales to fill their increasingly small seasonal quotas, the majority of older, breeding animals as well as females (which attain greater size than males) were removed from the population. What was left at the end of the 1962 whaling season was a population of mostly immature males (Chittleborough, 1965).

Consequently, the results presented here are based on descendants of this unbalanced parental stock. More detailed analysis of these current data sets may reveal how closely the present day populations' migratory movements follow those of previous generations.

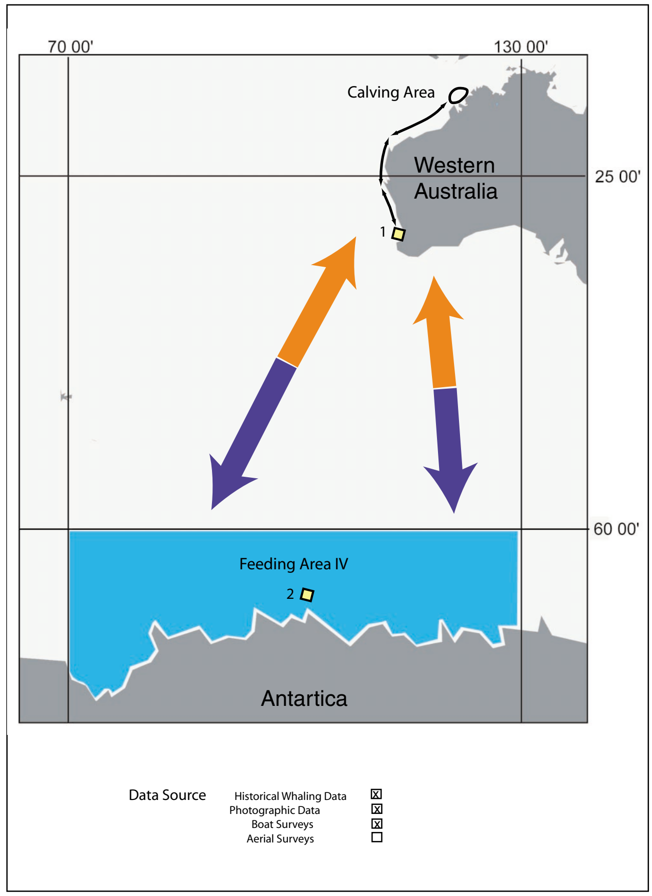

Figure 2. Area IV feeding grounds and presumed migratory paths to and from Western Australia. Photographic resight between 1–Perth 30/09/1989, and 2–Antarctic feeding grounds, 14/02/1993, documented by Gill and Burton (1995).

MIGRATORY PATHS AND TIMINGS

South-west Australian Coast (35° S)

The most complete source of data regarding humpback whale movements near the Australian south coast comes from the Albany whaling station where humpbacks were slaughtered up to 1963. Chittleborough (1965) reported that the vanguard of northward migrating whales reached the Australian south coast as early as April, but the peak of the northbound herd reached the coast in June. Assuming a similar wide geographic distribution of whales on the feeding grounds as observed by Nishiwaki et al (1997), these whales were possibly part of the eastern most feeding groups in feeding Area IV (Fig. 2) and represented only a portion of the overall Group IV migratory body. Whales feeding in the western-most region of the feeding grounds were, and are, likely to follow a more oblique path to the tropical breeding grounds and may not approach the Western Australian coast until they have migrated to lower latitudes (Fig. 3). This theory is supported by aerial survey data collected by the Centre for Whale Research (CWR) in 1993 in the Perth Basin area and is discussed in the next section.

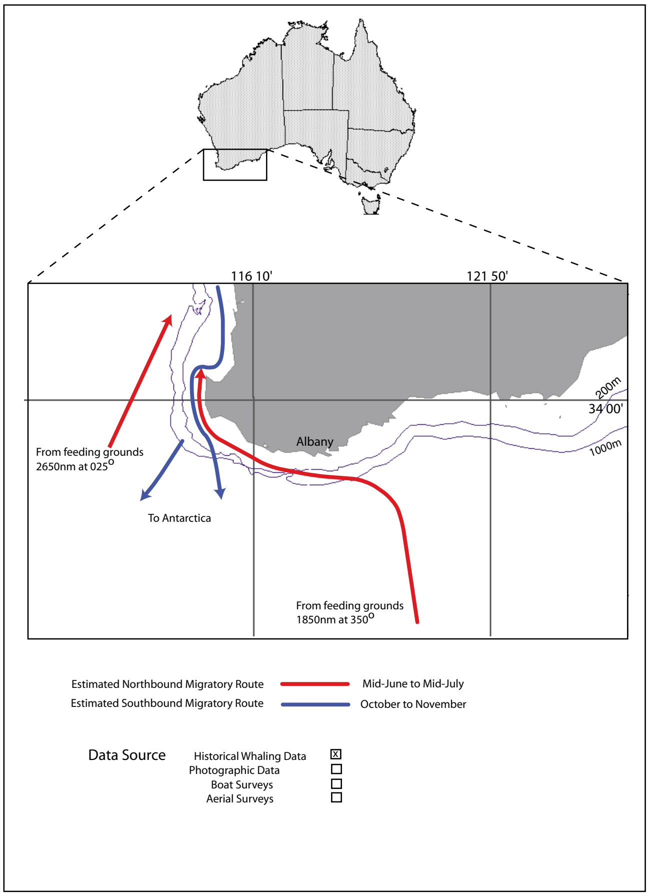

Figure 3. Estimated migratory routes for the southwest Australian coast.

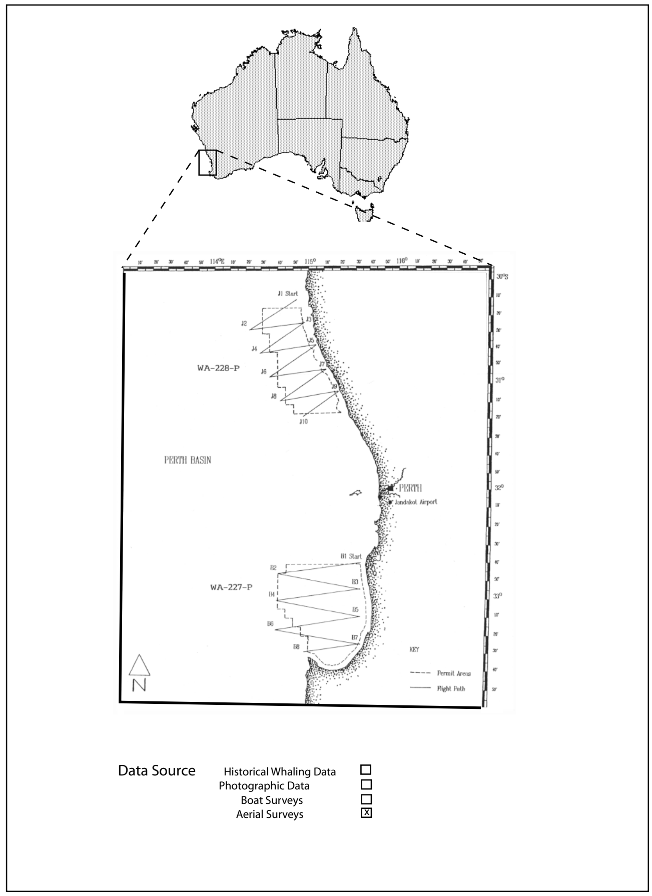

Figure 4. Aerial Survey design for two areas in the Perth Basin during 1993. Five migratory per area were flown during both the northern and southern migratory peaks.

Chittleborough (1965) stated that the southern migratory body does not pass Albany en route to Antarctic feeding grounds. In recent years, however, the authors have been made aware of commercial whale watching operations in this area during the months of October and November which have had regular sightings of southbound humpback whales (N.Gales, pers. comm.).

Perth Basin to Jurien Bay (33° 40' S to 30 ° 15'S)

Aerial surveys designed by CWR for Woodside Offshore Petroleum (now Woodside Energy) in 1992 examined the location and timing of the northern and southern migratory bodies through the Perth Basin (Jenner and Jenner, 1993). Two separate study sites, one in off-shore petroleum lease WA–227–P (Bunbury) and the other in off-shore petroleum lease WA–228–P (Jurien Bay), were surveyed (Fig. 4). 20 flights were conducted during the predicted north and southbound migratory peaks (Table 1).

Data reported by Chittleborough (1965) from Albany, which showed the northbound migratory peak to be early July, was extrapolated for these Perth Basin sites in order to plan flights to monitor the peak of the northern migration. At an average migratory rate of between 1.3 and 2.5 knots (Dawbin, 1966 and Chittleborough, 1965), the main migratory herd was expected to cover the distance of 210 nm (Bunbury) to 340 nm (Jurien Bay) within three to 11 days. The peak of the northern migration in the Perth Basin was, therefore, estimated to be early to mid July. The observed migratory peak was June 30 as measured by whales per observation hour over the 10 northern migration surveys flown between June 17 and July 8, 1993 (Jenner and Jenner, 1993).

Table 1. Number and species of whales observed in the northern and southern permit areas during the southern migratory period (Sept 09–October 25, 1992) and northern migratory period (June 17–July 08, 1993).

Survey Period	Sightings	Whales	Area	Mig. Direction
09/09/92–24/10/92	12	21	Jurien	South
10/09/92–25/10/92	11	24	Bunbury	South
21/06/93–08/07/93	12	28	Jurien	North
17/06/93–05/07/93	3	8	Bunbury	North

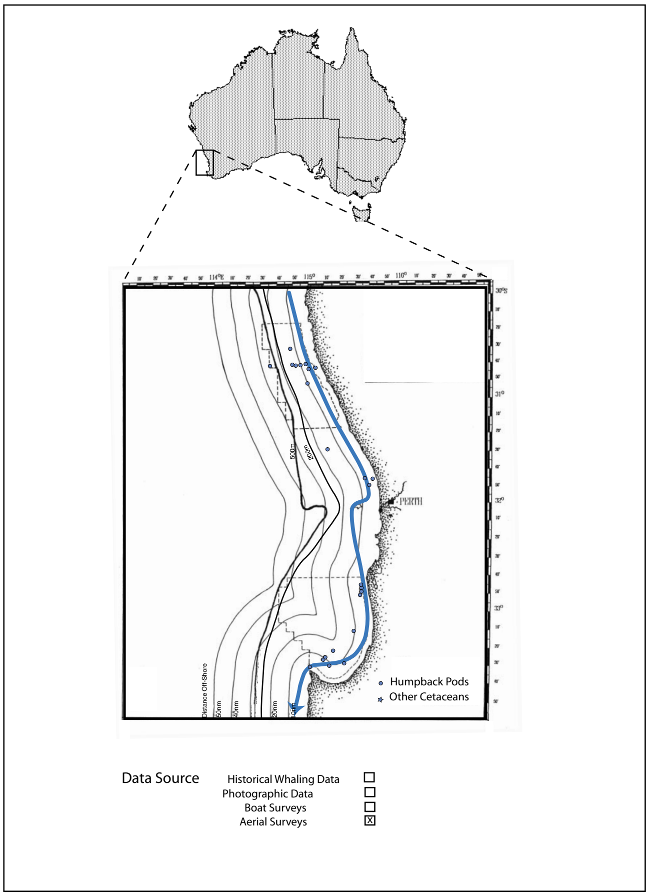

Figure 5. Estimated southbound migratory route in the Perth Basin with positions of pods and whales sighted during 1993 surveys (from Jenner and Jenner, 1993). Timing of peak: mid-October.

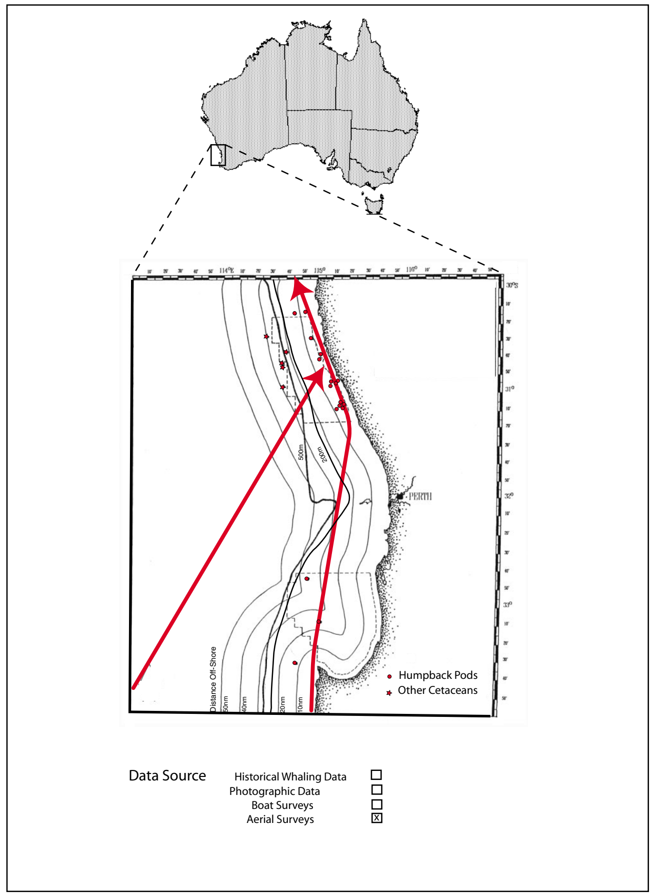

Figure 6. Estimated northbound migratory route(s) in the Perth Basin with positions of pods and whales sighted during 1993 surveys (from Jenner and Jenner, 1993). Timing of peak: Mid-late June.

Similarly, the peak of the southern migration was calculated from migratory data collected at Dampier (August 22 to September 4, Jenner and Jenner, 1992), Perth ("months of September and October", Burton, 1991) and from the timing between resights of whale WA0041 photographed first off Dampier (August 18, 1990) and later off Cape Naturaliste (October 17, 1990) within the same season. The southern migration peak was estimated to be during the first two weeks of October. The observed migratory peak was October 13 as determined by whales per observation hour over the 10 southern migration surveys flown between September 9 and October 25, 1992 (Jenner and Jenner, 1993).

During both the Bunbury and the Jurien Bay surveys southerly migrating whales were consistently sighted within 20 nm of the coastline (Fig. 5). During the northern migration surveys, however, only 3 pods were sighted during 5 flights between June 17 and June 24 in the Bunbury permit area compared with 13 in the Jurien permit area during 5 flights between June 21 and July 8. The lower number in the Bunbury surveys can be attributed to either the timing of the flights (i.e. too early) or to a lateral off-shore displacement of the bulk of the animals beyond the survey boundaries. The data collected can be interpreted to support both theories.

If the timing of the Bunbury flights was too early due to food availability in the Antarctic, even by one week, it is possible that there would be a lower density of whales in the area. This is assuming whales migrate within the boundary of the continental shelf at these latitudes.

If whales do not migrate within the continental shelf at these latitudes, and thus avoided detection during the CWR surveys, the increase in sightings in the Jurien survey area may be due to an influx of off-shore whales closing with the coastline from the central or western end of the Area IV feeding grounds (see off-shore migratory path in Fig. 6).

At this point there is no data to support either theory.

Jurien Bay to Carnarvon (30 ° 15'S to 24° 38'S)

No long term research has been conducted on the migratory habits of humpback whales between Jurien Bay and the Shark Bay area. Rock lobster fishers (D. Stiff, pers. comm.) operating near the Houtman Abrolhos Island group have observed whales migrating between the islands and the mainland (> 30nm off-shore, Fig. 7). This migratory path limit is consistent with the data collected in the previously described aerial

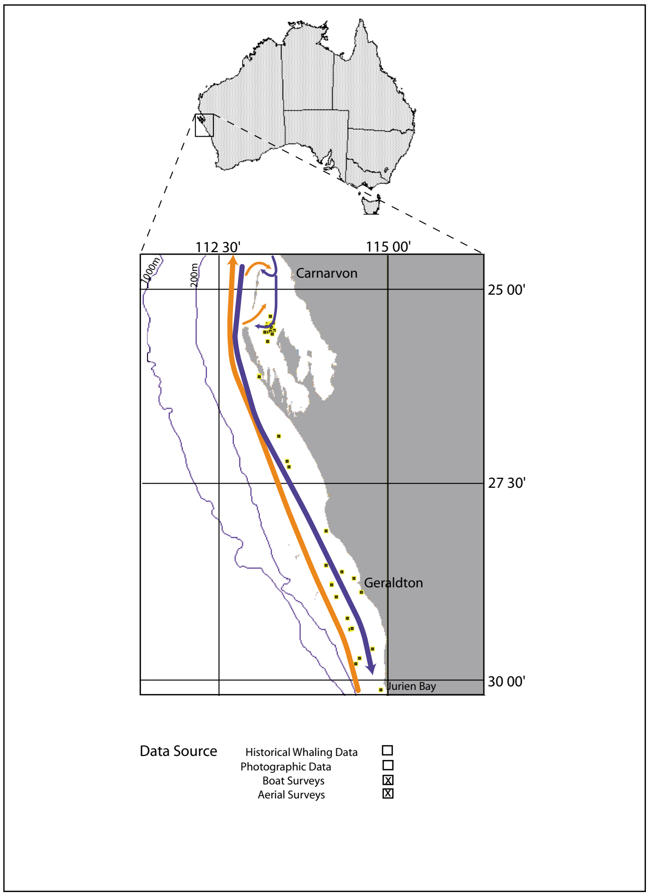

Figure 7. Estimated northern and southern migratory routes between Jurien Bay and Shark Bay. Positions are of southerly migrating pods (n=36) sighted during annual CWR boats transects from 1995–1998.

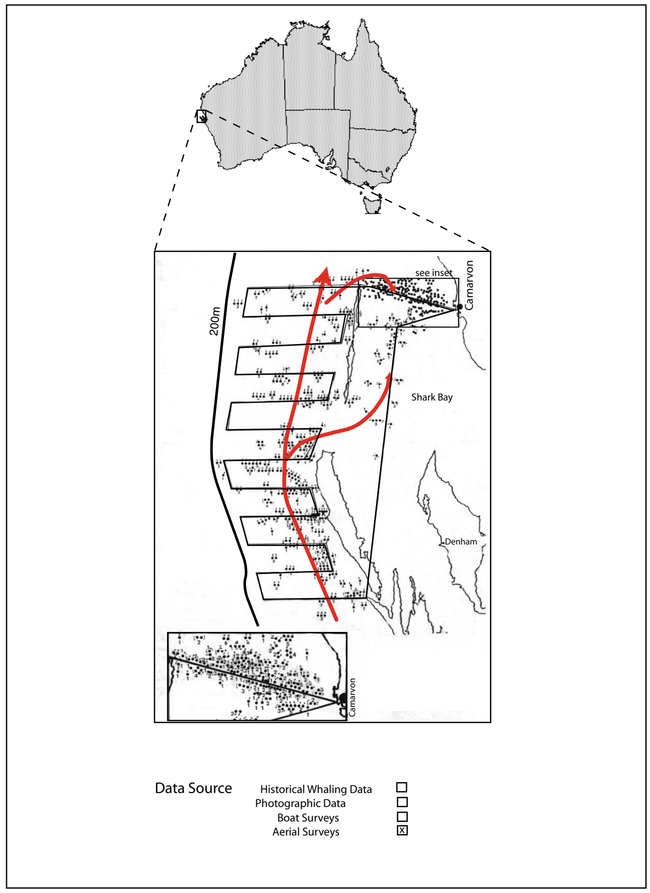

Figure 8. Flight path and positions of humpback whale sightings, Shark Bay area, July 1994 (modified from Bannister, 1994). Survey was conducted to coincide with the northern migration through this area.

surveys (Sec. 4.3) and also with CWR boat surveys conducted while travelling from the north west to Fremantle.

Because coastal topography and bathymetry changes little within 30 nm of the coast between Jurien Bay and Shark Bay, it is likely that the whales follow a predictable migratory path and migrate both north and southbound within the continental shelf boundary (200 m bathymetry). Fishermen report sightings of northbound humpback whales around the Abrolhos Islands between May and the end of the fishing season in June. Reports of large concentrations of northbound whales, that would be expected around the peak of the migration (early to mid July), have not been recorded. Based on the Perth Basin aerial surveys, peak numbers of southbound humpback whales could be expected in the region between Jurien Bay and Shark Bay in late September.

Carnarvon to Point Cloates (24° 38'S to 22° S)

Dawbin (1997) showed, from data collected at the Carnarvon (25° S) and Point Cloates (22° S) whaling stations during the 1950s and early 1960s, the northward migratory body begins passing these latitudes in mid June. Further, he reported the peak of the northern flow to be during the last week of July. Chittleborough (1965) showed the mid-way point between the northern and southern migrations to be close to the beginning of the third week of August at Point Cloates. From Chittleborough's data, the peak of the southern migration appears to be mid September.

Aerial surveys at Carnarvon, conducted in order to lead whale chaser boats to pods of whales in the 1950s and early 60s, were replaced by a long term population recovery monitoring program which surveyed the area covered by the early spotting planes. Bannister (1991a, 1994) showed concentrations of northward migrating whales occurred within 15 nm of the western islands of Shark Bay. A similar distribution was shown for the same area in 1963 (Bannister, 1991b) (Fig. 8). Kills plotted by the Carnarvon whaling station in 1962 showed the maximum range of whales from the coast of Bernier and Dorre Islands to be 40 nm or the edge of the 200 m line. The great majority were killed within 10 nm of the coast in less than 100 m of water. Interestingly, 11 years earlier in 1951, the vast majority of whales were actually

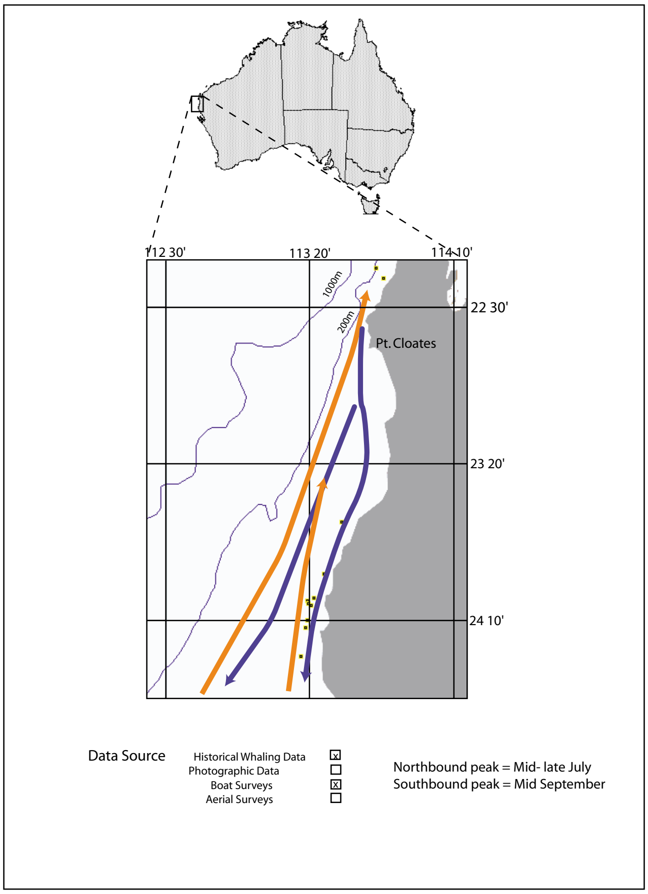

Figure 9. Estimated northern and southern migratory paths for humpback whales between Shark Bay and Pt Cloates. Shown are Gps positions of southbound pods sighted during CWR transects from 1995–1998 (n=33).

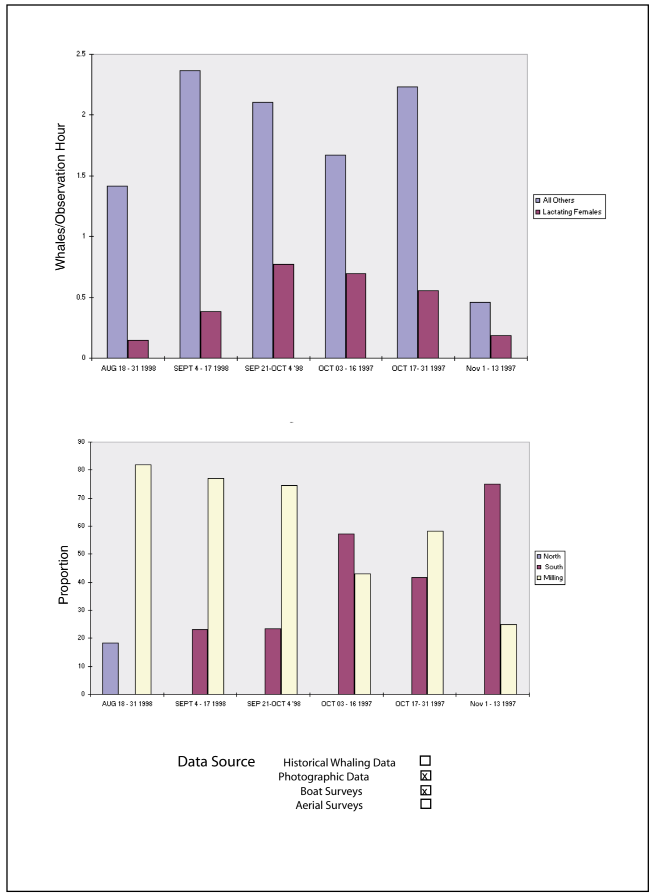

Figure 10. Density of lactating females with calves observed, Exmouth Gulf, October to November, 1997, August to October, 1998 with observed migratory directions for all age and sex classes.

killed within Shark Bay where depths are less than 20 m. Bannister (1994) reported increasing sightings of non-migrating whales within northern Shark Bay and speculated about its use as a migratory resting or staging area. Vessel surveys in recent years (Fig. 7) show increasing numbers of whales in Shark Bay, particularly during the southern migration.

At Point Cloates, where the 200 m line approaches the coast to within 11 nm, the migratory habits of the whales were exploited by the whaling station that was positioned there between 1913 and 1955. There are no current sightings available from this area, although this is considered to be due to a lack of effort than a lack of whales (Fig. 9).

Exmouth Gulf (21° S)

The peak of the northern migration past this area can be estimated from average migratory swimming speeds to be approximately one to three days later than the peak noted for the Point Cloates region i.e. also within the last week of July. To travel the 70 nm north from Point Cloates, at an average migratory speed of between 1.3 and 2.5 knots (Dawbin, 1956, Chittleborough, 1965), the progression of the main body of the migratory herd to Exmouth should take 54 to 28 hours.

Applying similar speed/distance assumptions to data compiled by CWR for the Dampier area, the peak of the southern migration could be expected to be in the Exmouth region as early as the first and second weeks of September. Furthermore, CWR 1997 and 1998 observations show peak numbers of cow/calf pods in Exmouth Gulf during the first week of October (Fig. 11). Chittleborough (1953) indicated that the main flow of cow/calf pods followed the peak of the main migratory body by approximately 2–3 weeks during the southern migration near Point Cloates. Therefore, using Chittleborough's estimation of the progression of lactating cows relative to the main migratory heard, the peak of the southbound migration near Exmouth should be in mid September.

Results of the CWR 1995–1998 surveys suggest the north and southbound migratory paths along the west coast of the Exmouth peninsula occur within 9 nm of the coast (Figs 9 and 11). In 1996, aerial surveys were flown over the area north east of Exmouth Gulf. The surveys were a component of a study investigating the effect of an operating seismic vessel on the migratory behaviour of humpback whales (McCauley et al, 1999). That study found that the majority of sighted whales migrated south in depths of less than 200 m. The mean water depth whales were sighted in was 96 + 11m, with a maximum depth of 240 m (the outer limit of the flight path). The swimming direction and position of some whales sighted during these surveys also suggest that although some whales may enter Exmouth Gulf to socialise or rest, others, further off-shore, may continue south along the western side of Ningaloo Reef in water deeper than 50 m. CWR data from the 1998 season also suggest a similar split in the southbound migratory body. On August 15, a dense concentration of mostly southbound whales (southbound– 28; northbound–3; milling–19) was sighted on the western side of Northwest Cape while the Research Vessel WhaleSong was moving towards Exmouth Gulf (Fig. 12). Commercial whale watching vessels operating inside the Gulf on the same day and previous two days, did not observe similar high concentrations of whales.

USE AS A RESTING AREA

Chittlebough (1953) described the shallows (less than 20 m) of Exmouth Gulf as a possible nursery based on aerial surveys conducted in 1952. Vessel based surveys conducted by CWR during the southern migratory period from 1995–1998 support this hypothesis. In particular, the 1997 and 1998 surveys show high proportions of milling, lactating females sighted from mid August to early October (Table 2 and Fig. 11). Peak densities of lactating females were observed in late September to early October. The majority of all whales (68%, 558/823) sighted in the Gulf during these periods were milling, not migrating, which is indicative of a resting area. During the 1997 season, surveys were conducted only from the north western side of the Gulf, an area now presumed to be the main exit point for southbound whales leaving the Gulf. Whales photographed swimming north in that area while in the process of leaving the Gulf would be less likely to be resighted within the Gulf and may explain why no resights have been found within the 99 whales photo-identified in the 1997 Exmouth season.

Table 2. Density of whales sighted per search hour during three seasons in Exmouth Gulf.

Survey Period	1996 (Whl/Hr)	1997 (Whl/Hr)	1998 (Whl/Hr)
Aug 08–21	–	–	1.175 (16/13.62)
Aug 22–Sept 04	–	–	1.899 (115/60.55)
Sept 05–18	–	–	3.127 (213/68.12)
Sept 19–Oct 02	–	–	3.646 (197/54.03)
Oct 03–16	–	3.058 (185/60.5)	3.673 (21/5.72)
Oct 17–30	–	3.344 (72/21.53)	–
Oct 31–Nov 13		0.484 (18/37.22)	–

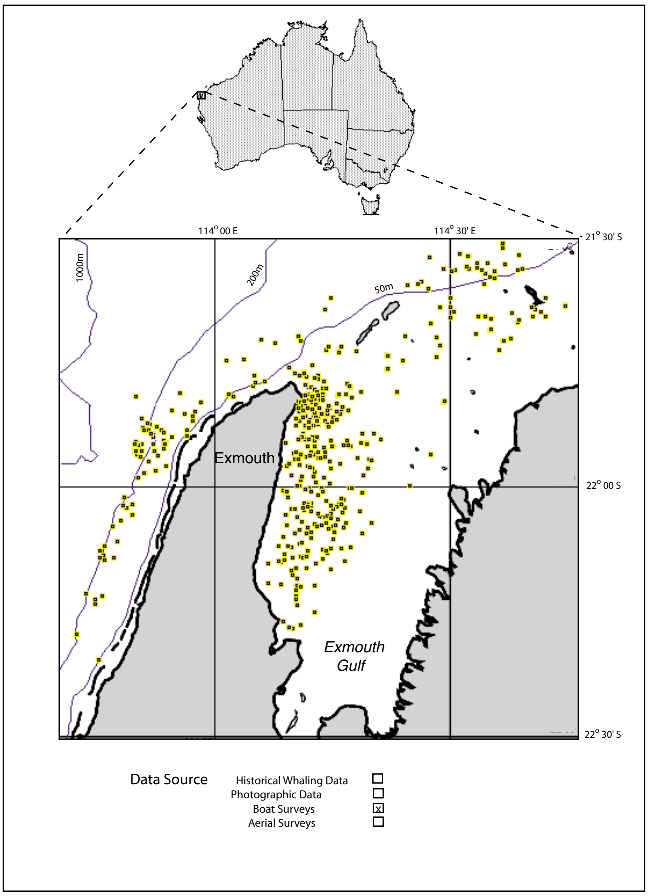

Figure 11. GPS positions of pods of humpback whales (n=590) sighted during the 1995–98 survey seasons.

The CWR 1998 season survey design sought to address the question of residency periods within the Gulf by beginning earlier in the season than in 1997 (August 18). Southbound whales were photographed as they entered the Gulf through the island group immediately to the north east of the Gulf. The hypothesis was that they could be later resighted by systematically examining different areas within the Gulf and photographing whales encountered through to, and past, the peak of the season (Fig. 11). Analysis of information from the 365 whales photo-identified during the six week study period is as yet incomplete, but should reveal residency patterns that will be useful for planning activities such as seismic exploration and commercial whale watching.

Monte Bello Islands (20° S)

The timing of the northern migratory peak past this area was extrapolated from whaling data at Point Cloates (Chittleborough, 1965). The peak is likely to be near to the end of July. During a four week period from late June to mid-July 1992, CWR monitored the northern migration from the western side of the Monte Bello Islands with the intent of determining the migratory path of northbound whales as they pass this area on their way to the then presumed Kimberley calving grounds. The mi-

Table 3. Observed migratory directions from June 20 to July 14, 1992 off the northwest of the Monte Bello Islands.

Migratory Direction	# Whales	Proportion (%)
10–25°	9	13
30–45°	31	43
50–65°	15	21
70–85°	10	14
90–105°	1	1
Milling	6	8

gration at the estimated time of peak density was not monitored due to research commitments for that time period at the Dampier Archipelago.

Whales that were followed by a small boat north past the reef on the western side of the islands, consistently headed in a north easterly direction (Table 3). This added weight to the authors hypothesis that northbound whales migrated directly towards the Kimberley from the Monte Bellos Islands (Fig. 12). This direct migratory path also helps to explain why the northern migratory body is not seen as close to the Dampier Archipelago as had been observed for southbound whales (Jenner and Jenner, 1993).

The southbound peak, estimated from CWR data (Table 4) between 1990 and 1994 off Dampier (70 nm eastward) is likely to pass to the north of the Monte Bello Islands, during a period between the last week of August and the first week of September (Fig. 12). This period is consistent with historical whaling data which showed a similar peak for the southern migration at Point Cloates, which is approximately 3–6 days migration south of this area (190 nm @ 1.3–2.5 kts). The majority of whales sighted during the period of the southern migration at Dampier were heading between 260–290 °, suggesting that the southern migratory path flows west from Dampier directly towards the northern end of the Monte Bello Islands before turning south again (Table 5). Whales are seldom reported from the area between Barrow Island and the mainland, possibly due to the extensive shoals and strong currents found there.

Sightings of whales from 1991 to 1996 recorded by the crews of rig tenders, seismic vessels and platform personnel and reported to CWR, show whales migrating as far off-shore as the 1,000 m bathymetry or approximately 50nm west of the islands (Fig. 12). From these data, northbound whales appear to remain on or within the 200 m bathymetry while the southern migratory body appears more dispersed.

Dampier Archipelago (20° S)

As described above, the northern migratory path is separate from the southern migratory path at the Dampier Archipelago (Fig. 12) and is likely to diverge at the Monte Bello Islands 70 nm to the west. Due to the off-shore limits of the research vessel during the 1990–1994 period that CWR operated from this area, only the southern migration has been observed in detail (Table 4 and Table 5).

The northern migration can be calculated, from Pt. Cloates whaling data, to pass off-shore of the Dampier Archipelago during the last week of July and the first week of August. Regular flights are flown across the presumed migratory paths by helicopters en route to off-shore oil rigs. Data collected by the pilots show that northbound whales in this area are generally further off-shore than 10 nm of the island group where the southern migration was monitored (Fig. 13). The lack of clustered sightings for northbound whales suggests that the northern migratory path is wider and less distinct than the southern migratory path, and may extend north to the continental shelf edge at 70 nm off-shore.

The peak of the southern migration, as determined from maximum whales per observation-hour past the Dampier Archipelago, is during the last week in August and the first week of September (Fig. 14). Examination of the helicopter data and the more clustered boat data during the period of the southern migration suggests that the main southern migratory body follows a more inshore route in this area (Figs 12 & 13).

Table 4. Peak (bold areas) of the southern migration at the Dampier Archipelago as indicated by whale density during the 1990–1994 seasons. Monte Bello Island figures (*) are for northbound whales.

Survey Period	1990 (Whl/Hr)	1991 (Whl/Hr)	1992 (Whl/Hr)	1993 (Whl/Hr)	1994 (Whl/Hr)
June 13–26	0.00	0.06 (2/34.33)	*0.79 (29/36.83)	0.00	0
Jun 27–Jul 10	0.00	0.08 (2/24.7)	*0.39 (21/54.13)	0.00	0
July 11–24	0.00	0.00 (0/63.3)	*0.83 (43/51.67)	0.00	0
Jul 25–Aug 07	0.24 (10/41.84)	0.33 (18/53.75)	0.29 (23/80.22)	0.84 (23/27.42)	0
August 08–21	0.93 (69/74.32)	0.76 46/60.25)	**0.89 (50/56.10)**	0.52 (28/53.35)	0
Aug 22–Sept 04	**1.00 (38/38.14)**	**1.12 (78/69.50)**	0.85 (72/84.88)	0.60 (40/66.75)	**0.92 (36/39.12)**
Sept 05–18	0.68 (47/69.03)	0.54 (27/50.84)	0.75 (68/91.17)	**0.74 (70/95.00)**	**0.92 (55/59.55)**
Sept 19–Oct 02	0.51 (40/78.40)	0.52 (44/84.50)	0.63 (42/66.57)	0.37 (23/63.08)	0
October 03–16	0.11 (4/37.74)	0.14 (1/7.17)	0.66 (20/30.08)	0.68 (28/41.03)	0
October 17–30	0.30 (13/43.99)	0.00	0.72 (61/85.17)	0.27 (7/26.08)	0
Oct 31–Nov 13	0.62 (2/3.25)	0.00	0.00 (0/6.25)	0.00	0

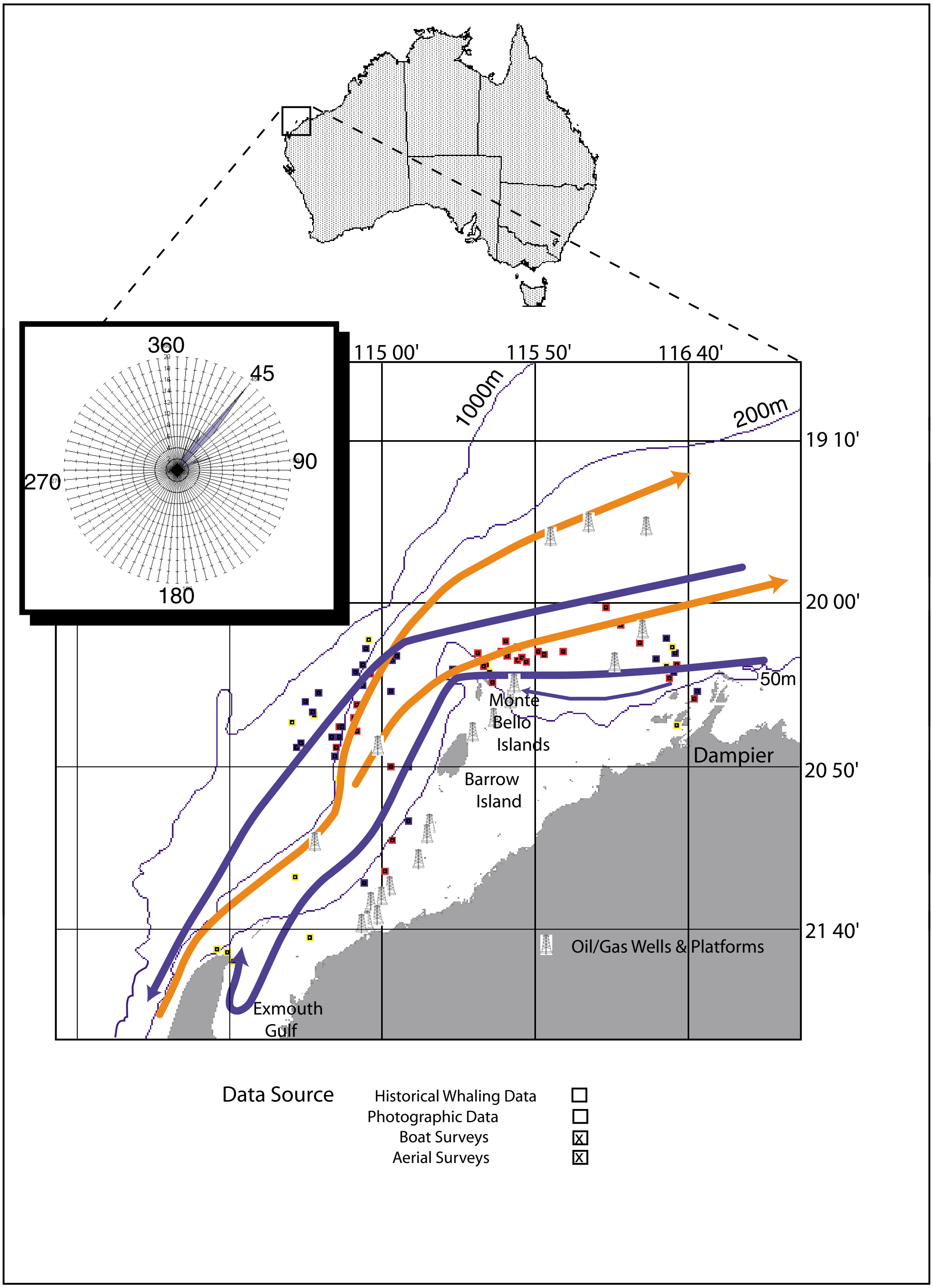

Figure 12. Assumed north and southbound migratory paths of humpback whales between Exmouth Gulf and the Dampier Archipelago. Inset charts are observed headings of northbound whales off NW Monte Bello Islands in June/July 1992. Sightings reported from the oil and gas industry between 1991 and 1996 are shown as red (northbound), blue (southbound) or yellow (milling) squares.

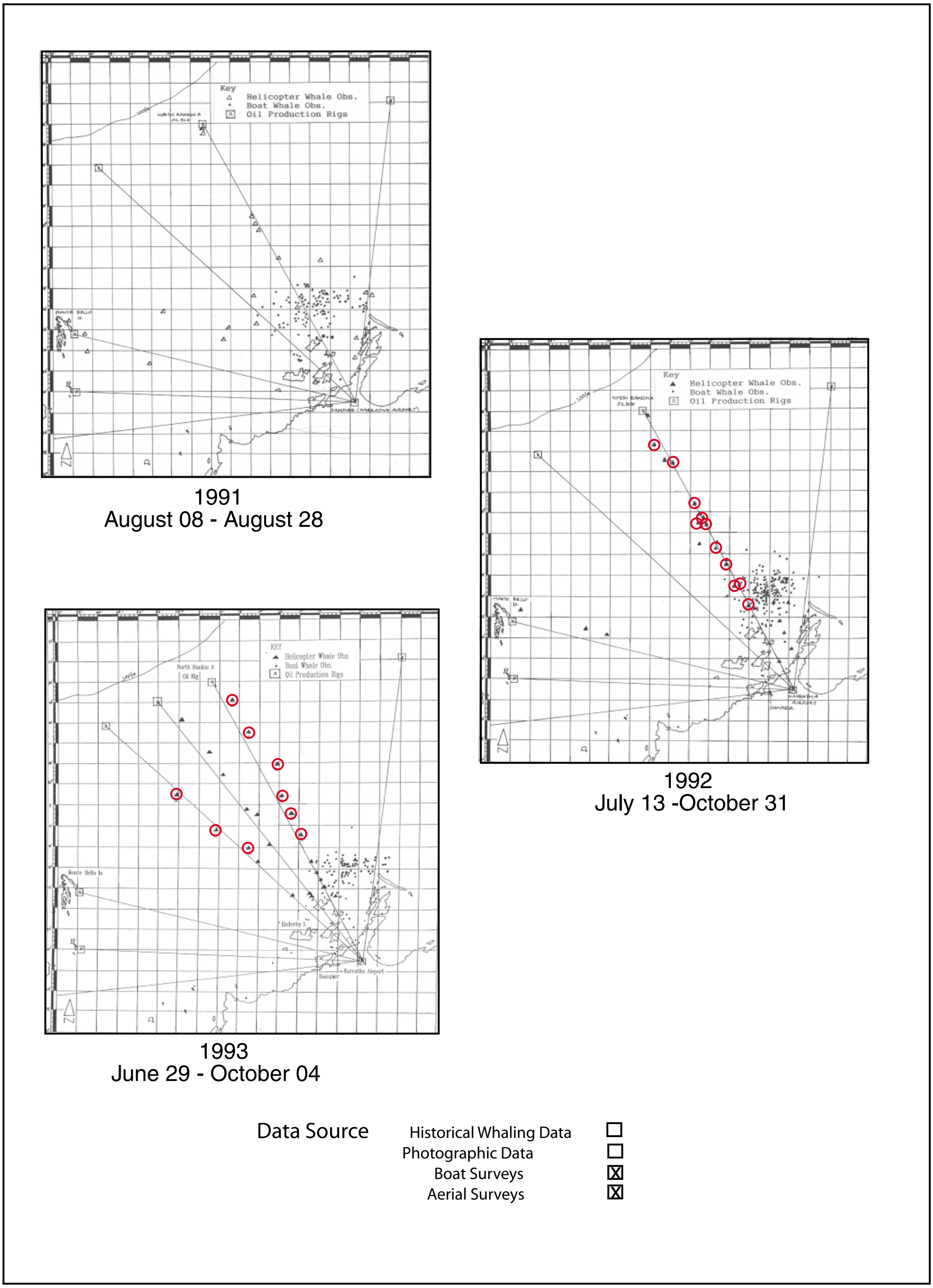

Figure 13. Distribution of north and southbank humpback whales near the Dampier Archipelago as sighted by boat (dots) and helicopter (triangles) surveys. Northbound whales sighted in June/July are circled red.

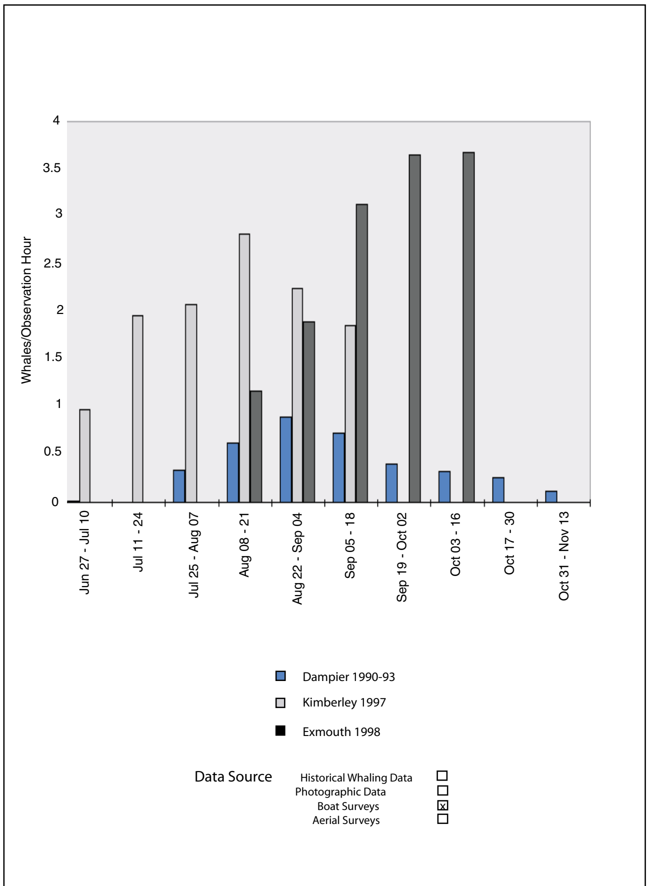

Figure 14. Peaks of season, as measured by number of whales sighted per observation hour, for the Dampier Archipelago, Kimberley and Exmouth study sites. The Dampier data has been averaged.

However, the aerial surveys also revealed that a smaller, but now understood to be significant, portion of the southern migratory body passes off-shore from the area monitored during the CWR boat survey. It was initially not possible to estimate how large this portion of the population was until sampling in an area that was presumed to contain the bulk of the migratory body was conducted.

The 1997 Kimberley study, which is discussed later in the Broome to Camden Sound section, revealed that whale densities in the Dampier study site at peak season were possibly less than one third of that which could have been expected if the entire migratory herd were present (Fig 14). The CWR 1997 Kimberley survey, which most closely replicates the study design and methodology of the CWR 1990 to 1993 surveys, records peak densities of whales at 2.82 whales/observation hour, while the highest peak density recorded for the averaged 1990–1993 Dampier data was 0.95 whales/observation-hour. Although a natural increase in population size would be expected between the 1990–1993 surveys and the 1997 survey, it is unlikely that the measured relative density would have tripled in this time period. Assuming relative density increases to be consistent with population increases, CWR calculations made using a 10% rate of increase (Bannister 1994) over the maximum period between samples, seven years (1990 to 1997), resulted in an expected relative density of 1.68 whales per hour for the Dampier study site, i.e. less than double. Therefore, either Bannister's (1994) rate of increase, as measured from 1977 to 1991, is very conservative or the CWR boat surveys missed a large portion of the migratory herd as it passed the Dampier area. The latter assumption is more likely since the continental shelf (water depths up to 200 m) extends to 70 nm off-shore and the CWR boat surveys were limited, by vessel size, to 15 nm off-shore.

Table 5. Numbers of whales and migratory direction observed by small boat survey off the Dampier Archipelago during five seasons.

Season	North (0–90°)	South (260–290°)	Milling
1990	48	161	14
1991	28	174	16
1992	58	222	56
1993	32	142	45
1994	18	69	4

Thus, if the CWR surveys at Dampier did not adequately sample the entire migratory path, there would be an unequal chance for photographic recapture of individual whales between any two seasons at Dampier. One of the initial aims of the CWR small boat survey at Dampier was to calculate a population estimate by analysing photographic resight ratios between separate seasons. The second assumption of the mathematical model applied for the estimate is that there is an equal probability for capture (photographic) of individuals in the first sample (season) (Petersen method, Seber, 1982). If this assumption was compromised because the southern migratory path is more dispersed than originally realised and because heterogeneity (variation) may exist in any captured whales' migratory path between seasons, a negative bias resulting in an underestimate would be apparent in any calculations (Jenner and Jenner, 1994).

Dampier Archipelago to Broome (20° S to 18° S)

Little is known of the migratory paths of humpback whales through this region. Most information comes from linear shipboard surveys, usually conducted within 30 nm of the coastline (Dawbin and Gill, 1991, CWR, unpub.). From 09–14 August, 1994, CWR conducted whale migratory path surveys between Broome and Dampier aboard the STS *Leeuwin II*. North and southbound whales were encountered in equal numbers near the 30 m depth contour off-shore from Eighty Mile Beach (Fig. 15). The surveys covered areas up to 20 nm further off-shore and no denser concentration of whales were found. However, scattered sightings from Coastwatch flights and dive charter boats travelling from Broome to the Rowley Shoals (approxi-

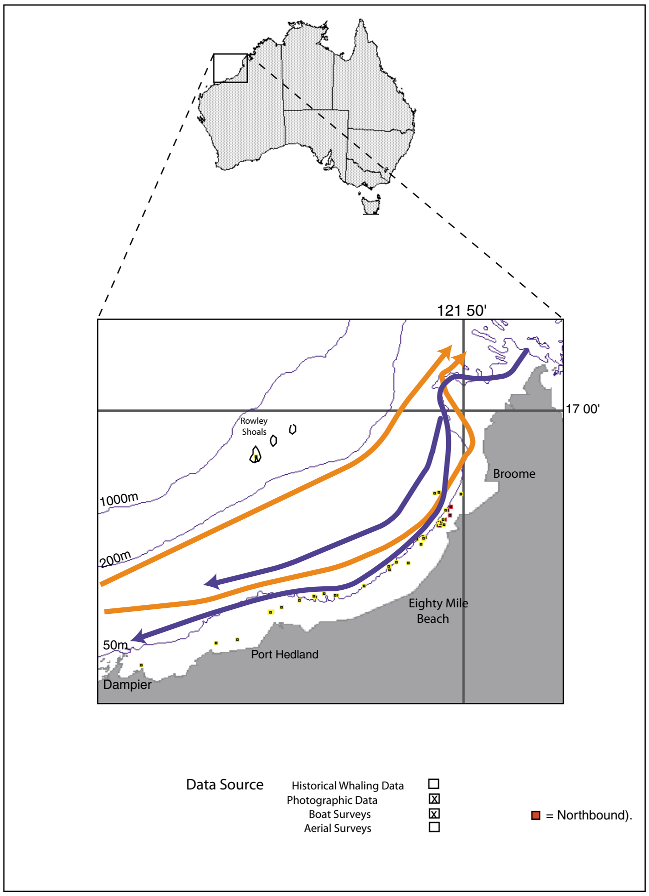

Figure 15. Estimated northern and southern migratory paths between the Dampier Archipelago and the Kimberley calving grounds. Sightings of humpback whale pods bewteen Broome and Port Hedland during CWR line transit surveys (September/October, 1995–97, n=13 pods) and opportunistic sightings from the LFB *Rachel* (26/6/98 to 24/08/98, n=31, yellow = northbound).

mately 150 nm off-shore) reveal that humpback whales can be found at least as far off-shore as the edge of the continental shelf.

During 1998, the licensed fishing boat *Rachel* opportunistically recorded sightings of humpback whales while mackerel fishing between Cape Leveque and Port Hedland. A total of 56 pods were sighted, 31 of which were south of Broome (Fig. 15). The majority of sightings reported, both north and southbound, were near the 30 m depth contour, similar to the 1994 CWR survey and subsequent transit surveys conducted by CWR travelling south from Broome to Fremantle.

Broome to Camden Sound (18° S to 15° S)

CWR data collected between 1995 and 1997 indicate that the Kimberley area is used as calving grounds by Group IV humpback whales between June and mid November. The period of peak northern migration into the calving grounds is during the last week of July. The peak of the southern migration out of the calving grounds is during the first and second weeks of September (Table 7). Over this four month period, the highest numbers of cows with calves were present from the middle of August to the middle of September and were amongst the last whales to leave the calving area each year.

Table 6. Numbers of whales per sighting hour swimming northbound, milling or southbound during the 1997 Kimberley season. Peaks of migration are bold.

Survey Period	North	Milling	South	Whl/hr
June 27–July 10	0.03	0.94	0.00	0.97 (72/74.2)
July 11–24	**0.72**	1.03	0.21	1.96 (95/48.5)
July 25–Aug 07	0.31	1.42	0.36	**2.08 (156/74.9)**
Aug 08–21	0.37	**1.96**	0.50	**2.82 (192/68.0)**
Aug 22–Sept 04	0.50	1.33	0.42	**2.25 (203/90.4)**
Sept 05–18	0.17	0.99	**0.70**	1.85 (188/101.4)

CWR observed peak numbers of northbound humpback whales approaching the Kimberley coast near Quondong Point and the Lacepede Islands in mid to late July. Relatively few boat (CWR) or aerial sightings (Coastwatch) exist of whales in the tidally swept Lacepede Channel. Therefore the majority of northbound whales in this region must pass to the west of the Lacepede Islands (Fig. 16). From the Lacepedes, CWR observations indicate that the whales remain off-shore until they reach Camden Sound. Having crossed King Sound, northbound whales tend to congregate at Frost and Tasmanian Shoals. We hypothesise that these are perhaps staging areas used by the whales to rest or to wait for favourable tidal conditions on their way to Camden Sound. Strong currents, consistently varying in direction every 6 hours, could either greatly assist or greatly hinder a whale's forward progress. By mid August the bulk of the migratory body ends its northern migration having reached Camden Sound where peak numbers of resting and milling whales congregate (Fig. 17). Coastwatch aerial sightings reported to CWR between 1994 and 1997 show scattered plots of humpback whales further north of this area although no large aggregations were apparent north of Camden Sound.

The peak of the southern migration past Frost and Tasmanian Shoals is during the first two weeks of September (Fig. 17). As observed for the northern migration, whales tend to congregate here before crossing King Sound to continue south along the coast. The southern migration follows the coastline between Cape Leveque and Pender Bay before diverting west around the Lacepede Islands and then south, paralleling the coast on the 20–30 metre bathymetry, approximately 20 nm west of Broome (Fig. 16).

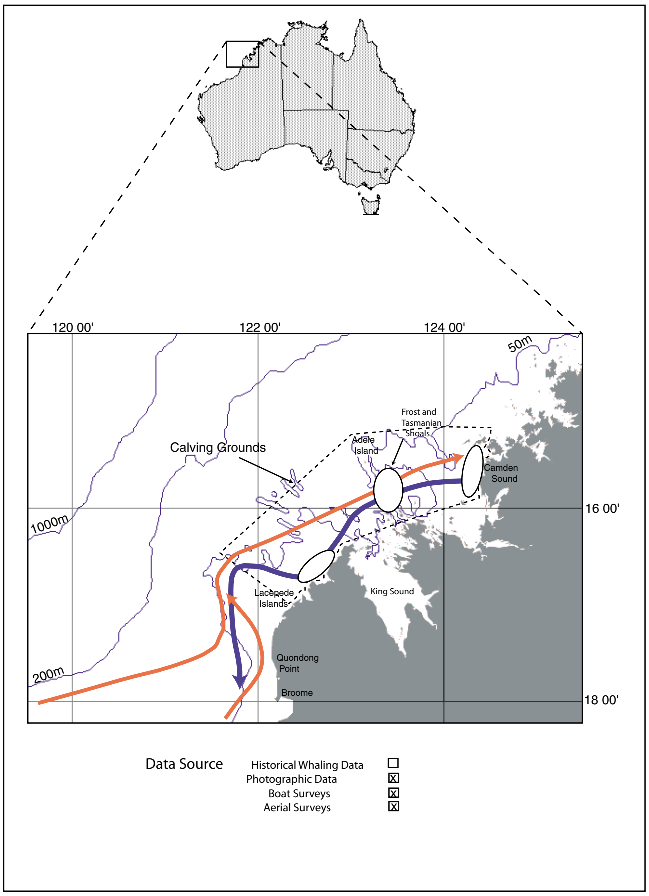

Figure 16. Positions of the Group IV humpback whale carving ground and migratory routes leading to and from the area. Circled areas has the highest concentrations of whales, and were the focus of the 1997 surveys.

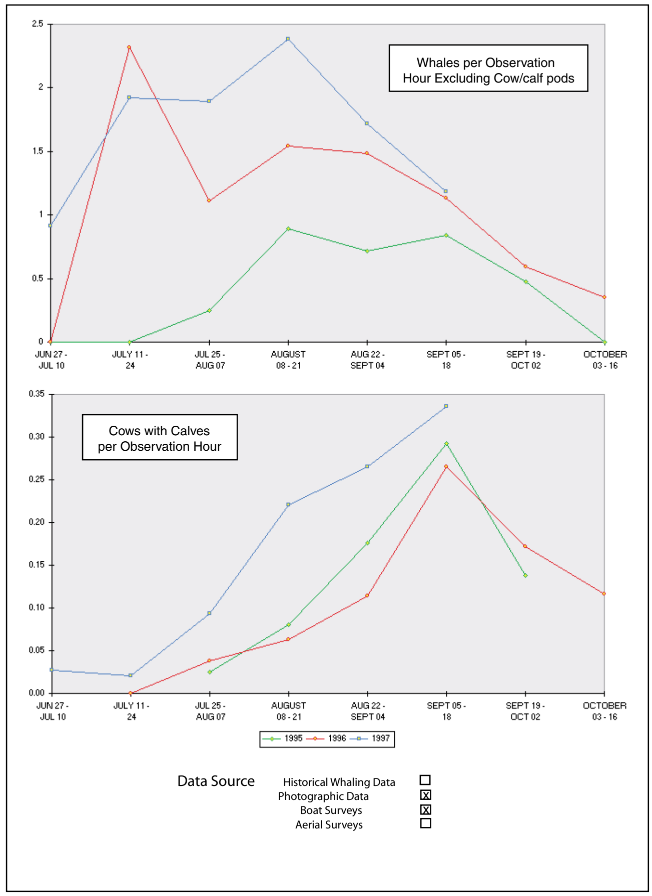

Figure 17. Comparison of the peak season in the Kimberley area for cow/calf pods (September 5–18) and non-cow/calf pods (August 8–21) over three seasons.

USE AS A CALVING GROUND AND RESTING AREA

Surveys conducted between 1995 and 1997 by CWR were designed to determine the location and boundaries of the calving grounds for this population and also to establish the time period that the area was used (Jenner and Jenner, 1996). The 1995 and 1996 surveys were exploratory programs based initially on detailed, non-dedicated, aerial surveys conducted by Coastwatch. When a better understanding of the whales' use of this region had been gained, a survey strategy similar to that employed off Dampier, utilising photo-identification, was undertaken in known high density areas for the 1997 season. The data compiled in the 1997 season are, therefore, the most useful so far in determining trends in migratory movements through the region.

During the first two seasons, 4,728.1 linear nautical miles were surveyed by vessel in the July to early October period. From these surveys, 262 of 1,039 sighted whales were photo-identified and three areas of high density were mapped (Fig. 18). During the 1997 surveys, 377 of 904 observed whales were photo-identified in and between the three chosen locations (Fig. 19).

During the 1997 season, the first high density area examined was Frost and Tasmanian Shoals. Large numbers of whales congregate in this area, apparently before moving further north east during the northern migration or south west during the southern migration. The second area of concentration examined was Camden Sound, 65 nm to the east–north–east of the Shoals. It is this area which appears to be the northern migratory endpoint for the majority of this population. The third location examined in detail was Pender Bay which was chosen to monitor the flow of whales out of the calving area at the end of the season.

Peak numbers of cow/calf pods were sighted in mid September in all 3 seasons (Fig. 17). The same areas, between Adele Island and Pender Bay, were surveyed in all three seasons during these two weeks. During this time period in 1997, 60% (50/83) of cow/calf pods were milling or resting while southbound pods accounted for 28% (23/83) and 12% (10/83) were northbound. Examination of the 3 seasons for all age and sex classes (excluding cows with calves) reveals an indistinct peak during the period from August 8 to 21 which subsequently falls during the period of the peak of the south-

Table 7. Temporal movements of Group IV humpback whales along the Western Australian coast.

Region	Northbound Peak	Southbound Peak
South-west (35° S)	June	Late October–Early Nov. Australian Coast
Perth Basin to Jurien Bay (33° 40′ S to 30 ° 15′S)	Mid–Late June	Mid–October
Jurien Bay to Carnarvon (30 ° 15′S to 24° 38′S)	Early–Mid July*	Late September*
Carnarvon to Pt. Cloates (24° 38′S to 22° S)	Mid–Late July	Mid September
Exmouth Gulf (21° S)	Late July*	Mid September
Monte Bello Islands (20° S)	Late July	Early September*
Dampier Arch Islands (20° S)	Late July–Early Aug.*	Late August–Early Sept.
Dampier to Broome (20° S to 18° S)	Late July–Early Aug.*	Late August–Early Sept.*
Broome to Camden Sound (18° S to 15° S)	Late July–Early Aug.	Late Aug.–Early Sept.

* estimated from interpolation of closely related data sets.

ern migration—September 5–18 (Fig.17, Table 6). Thus, it appears that as the concentration of cow/calf pods reaches peak levels in the calving area, the main migratory herd is beginning to move south, out of the region.

This timing is in agreement with Chittleboroughs'(1965) calculations which show the peak of southbound cow/calf pods past the Pt. Cloates whaling station (28° S) to be 4–6 weeks later than the main southern migratory peak.

CONCLUSIONS AND RECOMMENDATIONS

Of the 9 coastal regions described in the text above, only four have had base-line data compiled regarding their use by migrating humpback whales during periods of both the northern and southern migration. These include the Perth Basin to Jurien Bay area, the Exmouth Gulf area, the Dampier Archipelago and the Broome to Camden Sound area. Shark Bay has been extensively surveyed during periods of the northern migration. The first four areas have been examined using both aerial and boat based surveys which improve the quality of both the temporal and spatial migratory data collected. Timings for both the northern and southern migrations past all other coastal regions have then been interpolated from the first four data sets (Table 7). Both the South west Australian coast and the Carnarvon to Pt. Cloates estimates are closely comparable to historical whaling data collected at those sites.

In 1996, the International Whaling Commission (1996) reviewed photo-identification studies in the Southern Hemisphere. They confirmed the importance of being able to sample the entire migratory corridor in order to minimise variation in capture probability when conducting or designing a population estimation study. This proved to be particularly difficult at our Dampier Archipelago study site. However, despite these and other difficulties in satisfying assumptions for absolute population estimation, they also point out that photo-identification studies provide very useful information on survival rate, temporal and geographic movements, and reproductive intervals. These are precisely the parameters that are of most use to government and industry when planning management strategies for areas of coastline in which humans and whales share a mutual interest. Data to be obtained from the analysis of approximately 2,000 individually identified whales using a computerised matching system is expected to add further detail and accuracy to the data sets at the completion of the next phase of this project (May 2001).

For the purpose of managing human impact on this recovering species, the authors believe that the information presented here can provide a basic but useful framework around which to plan potentially disruptive activities. However, due to the vastness of the Western Australian coastline, there are still many areas that have yet to be examined in adequate detail for such planning to take place. These areas include the south west coast, Jurien Bay to Carnarvon and Dampier to Broome. Even areas that have been the focus of long term boat surveys (i.e. Dampier/Monte Bellos, Broome to Camden Sound and Exmouth Gulf) would greatly benefit from comprehensive aerial surveys which would serve to set more accurate boundaries on the temporal and geographical limits of the migratory paths there.

A potentially more cost-effective and precise technique for determining these boundaries for the migratory herd may come with the future inclusion of satellite and radio telemetry in the research programme. However, even given a complete migratory map for different age and sex classes of the population, the timing of their migrations along the coast will always be in flux due to climatic conditions which affect their feeding patterns (Chittleborough, 1965). If the whales leave the Antarctic either two weeks earlier or later in the year than the previous year, (say due to an abundance or lack of food brought on by weather conditions), the time that they reach each of the nine coastal regions will reflect this change. Therefore, the absolute timings for migration presented in this report should be regarded as a guideline only and more emphasis should be placed on the relative timings between each region

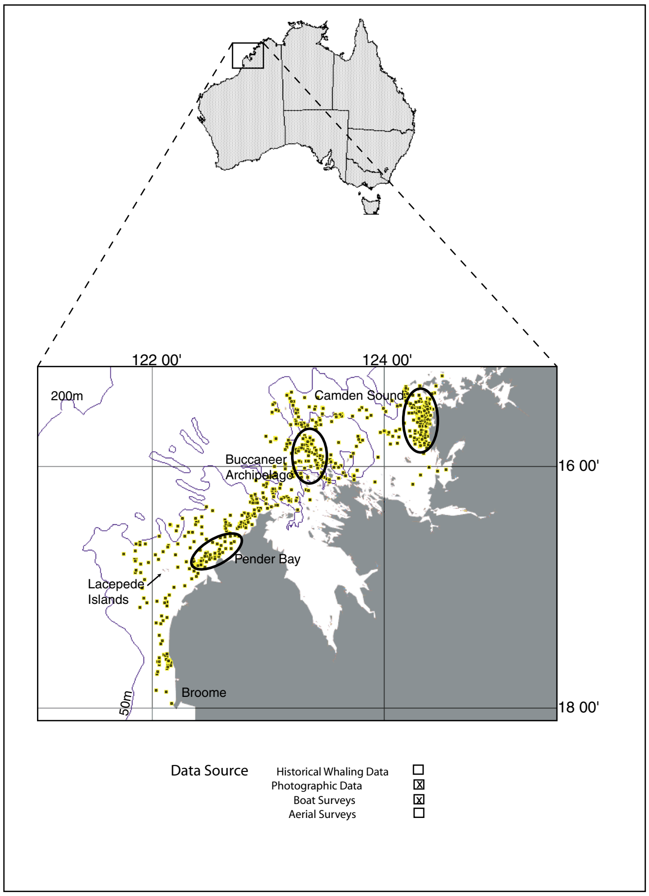

Figure 18. Positions of humpback whale pods sighted during the CWR 1995–96 exploratory surveys of the Kimberley coast. A total of 593 pods were sighted representing 1,039 whales, of which 110 were calves. Three high-density areas (circled) were identified for a more detailed photo-id study in 1997.

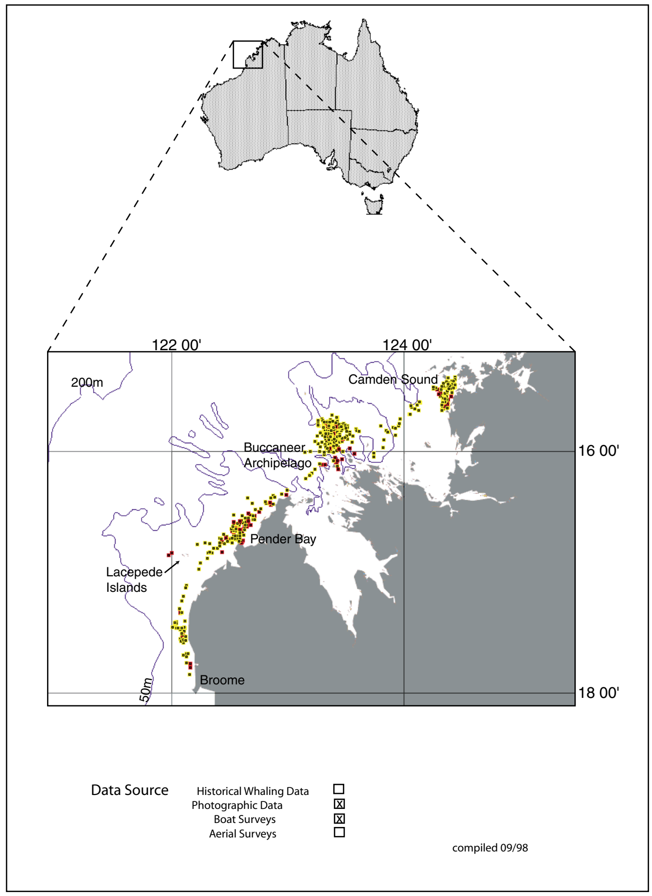

Figure 19. Positions of 562 pods of humpback whales sighted in the 1997 survey season. A total of 904 individuals, inclusive of 83 calves (red squares) were sighted.

once the peak of migration , either north or south, is known for a particular area along the coast in a given year.

We suggest that annual measurements of the peak of the northern migration past a constant point(s) along the coastline could be used to establish the rate of progression of the migratory herd along the coast for a given season. Once established, this information could be used, in conjunction with data such as in Table 7, to predict within one to two weeks the arrival of the migratory peak in a particular area of interest.

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