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A Preliminary Population Estimate of the Group IV Breeding Stock of Humpback Whales off Western Australia

K.C.S. Jenner and M-N. Jenner

Centre for Whale Research Western Australia, PO Box 51, Dampier, Western Australia 6713

ABSTRACT

Data collected in 1990, 1991 and 1992 from a photo-identification study of humpback whales (*Megaptera novaeangliae*) off northwestern Australia have enabled the calculation of a preliminary population estimate of the Group IV breeding stock. The Chapman modification of the Petersen population estimate resulted in a 1990–1991 estimate of 2,736 (928; 9,928 95% CI) and a 1991–1992 estimate of 3,878 (1,319; 14,108 95% CI). The 1991–1992 estimate is considered the more accurate and is similar to a population point estimate of the same stock calculated from aerial surveys in a separate independent study.

KEYWORDS: HUMPBACK WHALE; SOUTHERN HEMISPHERE; INDIAN OCEAN; PHOTO-ID; ASSESSMENT; MIGRATION

INTRODUCTION

Studies reported here allow the abundance of humpback whales (*Megaptera novaeangliae*) in the Group IV breeding stock (originally the 80–100°E feeding grounds, Mackintosh, 1942) off Western Australia to be estimated by photographic mark-recapture methods. This technique has been widely used in comparable studies to estimate humpback whale abundance (Whitehead *et al.*, 1983; Balcomb and Breiwick, 1984; Baker and Herman, 1987; Alvarez *et al.*, 1990; Katona and Beard, 1990). Seber (1982) describes various methods of calculating mark-recapture population estimates and discusses the two sample Petersen estimator as an appropriate means of assessing closed populations (those in which the effects of immigration, emigration, mortality and recruitment are negligible for the period of investigation). The Petersen estimator has been a preferred method of analysis because of its adaptable interpretation of the two samples (e.g. Whitehead, 1982; Perkins *et al.*, 1984; Balcomb *et al.*, 1986; Calambokidis *et al.*, 1990).

From 1990, humpback whales have been photo-identified by the authors off the Dampier Archipelago, northwestern Australia (20°30'S, 116°40'E). The data collected during 1990 and 1991 are discussed in Jenner and Jenner (1992). The Petersen estimator has been used to calculate estimates of abundance based on between year samples from the first three seasons' data. Possible violations of the models' assumptions reported by Seber (1982, p. 59) are discussed.

METHODS

Photographic identification

The study area extends north from Dampier, Western Australia to 20°11'S and west from 116°55'E (off Legendre Island) to 116°25'E (Fig. 1). Effort was concentrated between 20°21'S and 20°11'S which has been suggested as part of the main southerly migratory path (Jenner and Jenner, 1992), although sightings within the Archipelago were also included in the calculations. During June and July 1992, a similar photographic study was conducted off the northern end of the Monte Bello Islands, 70 n.miles west of the Dampier Archipelago (Fig. 2). Whales encountered and photographed in this area were migrating northeast.

Data were collected daily, weather permitting, from a 5.3m *Novurania* inflatable powered by a 50hp outboard. In a total of 198 days' observation over the three years, averaging 7.6 hours per day, 870 whales were encountered, resulting in 431 usable identification photographs. Each whale or group of whales was followed until suitable fluke and lateral body photographs were obtained or, if other pods of not-photographed whales were sighted, for a period of 20 minutes per whale. As summarised in Table 1, the majority of effort was off the Dampier Archipelago, but 18 days off the Monte Bello Islands in 1992 resulted in 92 encounters (37 usable photographs).

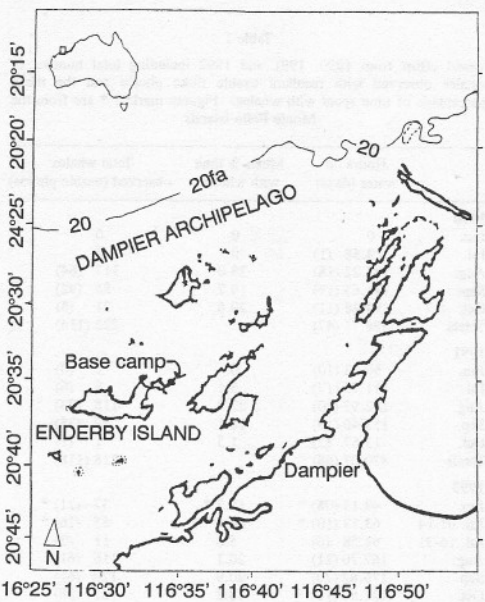

Fig. 1. The Dampier Archipelago study area.

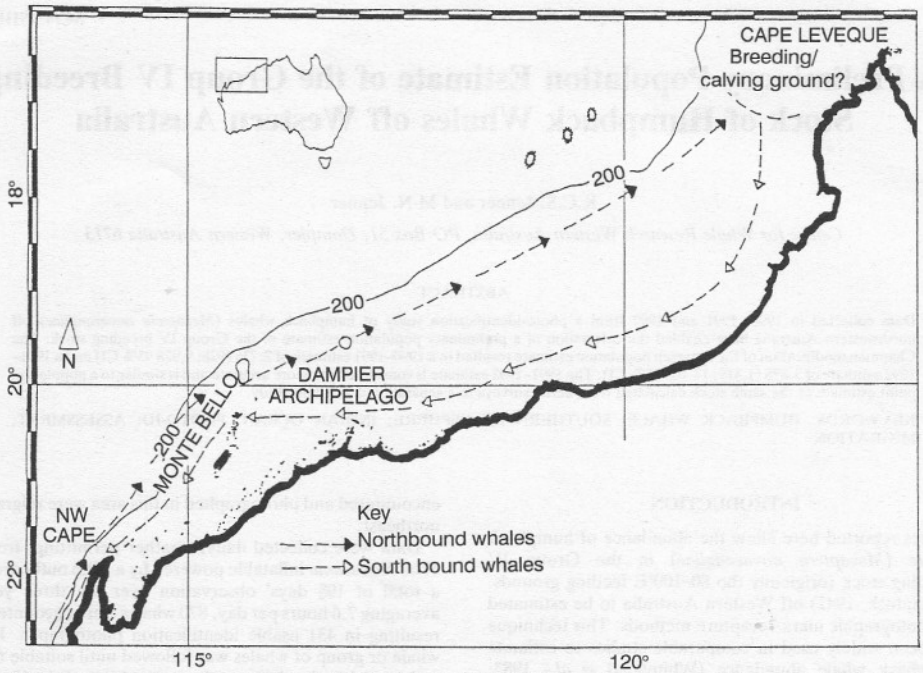

Fig. 2. The Monte Bello Islands and Dampier Archipelago study areas in relation to the proposed migratory paths of Group IV humpback whales.

Individual humpback whales were identified using established techniques of photo-identification from tail flukes (Katona *et al.*, 1979; Perry *et al.*, 1990) and dorsal fin shape, lateral body pigmentation and scarring (Nishiwaki, 1959; Katona *et al.*, 1979; Katona and Whitehead, 1981; Sears *et al.*, 1990). Motor-advance 35mm cameras were used with 300mm f4.5 and f4 lenses. *Ilford* HP5 Plus black and white film was shot at 1600 ASA in 1990 and then at its rated 400 ASA in 1991 and 1992 to decrease grain size. The techniques of Mizroch and Bigg (1990) were followed to make black and white prints (64mm × 90mm) of each observed individual. A catalogue of individually identified whales has been established.

Table 1

Vessel effort from 1990, 1991 and 1992 including total number of whales observed with resultant usable fluke photos and the mean percentage of time spent with whales. Figures marked * are from the Monte Bello Islands.

	Hours on water (days)	Mean % time with whales	Total whales observed (usable photos)
1990			
Jun.	0	0	0
Jul.	3.58 (1)	0	0
Aug.	147.22 (18)	25.0	117 (64)
Sep.	141.63 (17)	19.7	85 (42)
Oct.	94.28 (11)	20.6	21 (8)
Totals	386.71 (47)		223 (114)
1991			
Jun.	56.33 (10)	0	2 (0)
Jul.	111.75 (17)	5.1	8 (6)
Aug.	132.92 (20)	22.7	118 (73)
Sep.	153.40 (19)	18.1	89 (38)
Oct.	15.67 (2)	1.5	1 (1)
Totals	470.07 (68)		218 (118)
1992			
Jun.	49.13 (08) *	17.3 *	37 (21) *
Jul. 01-14	63.33 (10) *	14.9 *	55 (16) *
Jul. 16-31	64.58 (6)	5.8	11 (2)
Aug.	167.70 (21)	20.1	116 (61)
Sep.	176.82 (20)	20.9	129 (61)
Oct.	121.50 (18)	18.2	81 (38)
Totals	643.06 (83)		429 (199)

Only humpback whales identified from tail fluke photographs off the Dampier Archipelago in 1990, 1991 and 1992 were used in the calculations. Only tail fluke photographs of 'good' quality were used. Photographs that were out of focus, not properly exposed or that did not reveal more than 50% of both flukes above the water (including a full view of the trailing edge and central notch) were not included in the data set.

Data analysis

Population estimates of humpback whales wintering off northwestern Australia have been calculated using the Chapman modification of the Petersen estimator (Seber, 1982, p. 60):

$$N = \frac{(n_1+1)\,(n_2+1)}{(m_2+1)} - 1, \text{ with estimated variance}$$

$$v = \frac{(n_1+1)\,(n_2+1)\,(n_1-m_2)\,(n_2-m_2)}{(m_2+1)^2\,(m_2+2)}$$

where

n_1 = number of animals marked in the first sample
n_2 = number of animals marked in the second sample

m_2 = number of recaptures in the second sample (from the first sample).

Given the small number of recaptures (m_2 = 4 between each pair of seasons), the Poisson approximation table was used to calculate the 95% confidence intervals for N as is recommended for situations with small numbers of recaptures ($m_2 \leq 50$) in the second sample (Seber, 1982, p. 63).

There is no consensus on the most appropriate estimator to use in photographic studies of whales when sampling is conducted with replacement (Hammond, 1986; Calambokidis *et al.*, 1990). When sampling is without replacement, the most appropriate estimator for Petersen type experiments is Chapman's. In this study, sampling has been effectively without replacement due to the predominance of southbound whales moving past the Dampier Archipelago. The Archipelago is on the migratory path and whales do not remain in the area for extended lengths of time. This migratory pattern resulted in only two intraseason resightings in 1990, 3 in 1991 and 2 in 1992. We feel it is appropriate, therefore, to use the Chapman modification of the Petersen estimate, and the small number of within-season resightings have been included only once each per sampling period.

RESULTS AND DISCUSSION

Estimates

Population estimates are shown in Table 2. Pooling the Monte Bello Islands and Dampier Archipelago samples from a single year to obtain a larger within-season sample would be inappropriate since whales in the two locations are not likely to have had equal probability of being sampled within a year and also because sampling could not be considered to be effectively without replacement (ie. the Monte Bello samples come from whales migrating northward while the Dampier samples are from the same population moving southward). The sample size from the Monte Bello Islands is too small to provide meaningful estimates if it was to be used alone as one of the two samples in the Petersen estimate. One resighting between the 1992 Monte Bello sample and the 1991 Dampier sample has been identified, however, but not included in the calculations.

Table 2

Population estimates calculated with the Petersen estimator for between-year samples at the Dampier Archipelago.

Sample period	n_1	n_2	m_2	Est	Lower 95% CI	Upper 95% CI	SD
1990-1991	114	118	4	2,736	928	9,928	1,172
1991-1992	118	162	4	3,878	1,319	14,108	1,672

Assumptions

Possible violations of the Petersen estimates' assumptions as listed in Seber (1982, p.59) are as follows.

(1) The population is closed

Chittleborough (1959) and Dawbin (1964) have shown that small numbers of whales may change tropical breeding grounds between seasons. The extent to which this influences our estimates from one season to another will be evident only after the Western Australian catalogue has grown to a sufficient size as to represent a large portion of the population and is then compared to catalogues being compiled in other parts of the Southern Hemisphere. At this point, no matches have been found between our 1990 and 1991 catalogues and the several collections curated at the National Marine Mammal Laboratory in Seattle, Washington nor at the College of the Atlantic in Bar Harbor, Maine (S. Mizroch and J. Allen, pers. comm.) which include Southern Hemisphere and Antarctic animals. Also, no matches have been found between our catalogues and 19 individuals photo-identified by B. Abernethy in 1991 from Tongan waters. In addition, Baker *et al.* (In press) conclude that there is insignificant genetic overlap between eastern and western Australian humpback whale stocks. We feel that it is appropriate to assume that the effect of migration between breeding grounds is negligible for the one year sampling periods.

Immigration in the form of births into the population should not influence the estimates since calves have not been included in the calculations and animals considered yearlings are seldom seen and photographed. Other animals recruited into the capturable population over a one year period are unlikely to create an upward bias of the estimate of more than 11% (Hammond, 1986). Emigration in the form of deaths can be considered minimal over a one year time period.

(2) All animals have the same probability of being caught in the first sample

As we used only 'good' fluke photographs collected during the southern migration each season we feel that the second assumption is reasonable. However, heterogeneity or inherent individual variability both in fluking behaviour and in temporal/spatial position in the migratory pathways may have an unknown effect on the catchability of an individual (Hammond, 1990). Cows with calves, for example, are present in low numbers (54 from 1990–1992) and present flukes infrequently (18/54, 33%), suggesting a possible sampling bias. Consistent unavailability of this class should not be a problem during a two year period, however, if birthing intervals are two years, as is suggested by Chittleborough (1965), and they return to random migratory and fluking patterns between births. Other distinct age/sex classes that may bias sampling have not been identified at this point in the study.

During the 1990 season, 70% (138/196) of the photographed whales were identified with fluke photographs followed by 76% (156/206) in 1991 and 66% (187/282) in 1992. This high rate of fluking may help to minimise the effects of heterogeneity in fluking behaviour.

Another possible violation of this assumption may occur due to the off-shore limit of our vessel. Whales consistently migrating past the Archipelago outside the range of our vessel would not have an equal probability of being sampled. An approximate proportion of migrating whales that pass the Archipelago within range of our vessel can be calculated from data collected during non-dedicated helicopter surveys. Flights flown regularly at various but consistent angles to oil rigs across the presumed migratory path indicated that 74% (20/27) of the whales observed travelled along a route that is accessible to our vessel in 1991 followed by 50% (14/28) in 1992. There are inherent sources of error associated with the use of non-dedicated aerial surveys (Jenner and Jenner, 1992) and these figures will need to be verified by dedicated surveys in the future. Individual whales that always migrate outside our range

will simply be excluded from the estimate. This may not bias the estimate if it is a random assortment of age/sex classes.

The separate northern and southern migratory paths allows the progression of the southern migration to be readily observed and reduces the heterogeneity that would otherwise be introduced through interactions between animals passing each other on the migratory path. In addition, the temporal distribution of sighting effort (Table 1) could induce unequal marking probabilities if some whales were inherently late or early migrators.

(3) Marking does not affect the catchability of an animal
This assumption is probably valid since photography is a benign marking technique and it is rarely necessary to follow individual whales longer than 30 minutes to obtain the photographs.

(4) The second sample is a simple random sample
We feel that it is likely that our second sample is a simple random sample. We search the same area of the migratory path every day but 'new' whales traverse that area daily. This area allows us to photograph the majority of the southern migration within range of our vessel.

Sampling effort remained relatively constant between years and was mainly influenced by weather conditions which can be considered random. This is reflected in the proportion of usable fluke photographs obtained from the whales observed each season (51%, 1990; 54%, 1991; 48%, 1992). Rough weather reduces the time spent with each pod of whales and thus the number of good fluke photographs.

Although it is possible to violate the fourth assumption without biasing the estimate if certain further assumptions can be met (Hammond, 1986), it is only valid to do so if assumption 2, that the first sample is a random sample, can be shown to be true. The problems of heterogeneity discussed above in the violations of assumption 2 do not allow this and can also be considered relevant when considering assumption 4.

(5) Animals do not lose their marks between samples
We feel that this assumption is valid. Work presented by several authors, on which this project is based, confirm this (see Carlson *et al.*, 1990). Whales may, however, gain marks from attacks by predators or physical contact with other humpbacks although this should not affect resightability by trained workers except in the case of amputations. Both dorsal fin and tail-fluke (single and double) amputations are present in this population.

(6) All marks are reported on recovery
This assumption is also valid because only good quality photographs have been included in the analysis.

CONCLUSIONS

At this point in the research, with three years of a long term study completed, we cannot be certain that we are satisfying the second and fourth assumptions of the Petersen estimate that all animals in the population have an equal probability of being sampled and are randomly sampled in the recapture phase. Future research in different locations off northwestern Australia as well as dedicated surveys to the perimeter of the continental shelf in the Dampier area will either confirm or alter these assumptions. The population estimates presented are therefore preliminary. However, the point estimates obtained are similar to Bannister's (1994) estimate which is based on data for the northern migration from 1977 to 1991.

Of the two estimates presented, the 1991–1992 estimate of 3,878 (1,319; 14,108 95% CI) must be considered the more accurate. The 1990 season can be considered a pilot study since little was previously known of the migratory characteristics of the whales in this area resulting in an evolution of sampling technique during that season. Both of the point estimates have wide and largely overlapping confidence intervals associated with them and, as such, are consistent with each other. These wide confidence intervals are due to the small number of interseason resights. If more precise estimates are to be obtained, a substantial increase in searching effort is required.

The 1992 season had the most consistent weather resulting in the most even distribution of searching effort. Since a two sample estimate using the 1990 and 1992 data would violate more seriously the closed population assumption, we feel that the 1991–1992 estimate most completely satisfies the assumptions of the Petersen estimate and would therefore have the smaller biases. The sampling biases may exist if the southern migratory path is more dispersed and heterogeneity exists in the whales' migratory pathway. This, as well as other sources of heterogeneity, would result in a negative bias of the estimates. The 1991–1992 estimate is therefore more likely to be an underestimate than an overestimate of the population.

To further reduce sampling biases, a better understanding of this populations' migratory characteristics is necessary so that sampling can be conducted in a random manner across migratory paths. That understanding should be increased in the work planned for future seasons from various locations off northwestern Australia.

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