Assessing Sperm Whale Populations Using Natural Markings: Recent Progress

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ABSTRACT

Decades of research on living sperm whales using photo-identification was started in 1982. The data from the studies carried out since then have allowed us to gain our understanding of the population biology of sperm whales. Many recent studies have shown sperm whale populations are larger than previously thought, based on sightings data. The number of mothers males found in the breeding grounds was much lower than expected, suggesting that males may not breed every season. Some population parameters have been estimated successfully from photo-identification and other non-invasive data. This review will summarize the data on the size and structure of sperm whale populations, with particular emphasis on the potential of non-invasive techniques for assessing and monitoring sperm whale populations.

INTRODUCTION

Compared to many of the more coastal cetacean species, the use of photo-identification techniques on sperm whales (Physeter macrocephalus) is in its infancy. Between 1982 and 1994, during the World Wildlife Fund Indian Ocean Sperm Whale Study, it was shown that sperm whales could be identified individually from photographs of their flukes and dorsal fins (Whitehead and Gordon, 1986; Gordon, 1987a and b). The presence of a callosity on the dorsal fin is also a good indicator of a mature female (Kasuya and Obinata, 1980; Whitehead and Gordon, 1986).

Arntz (1986) made a thorough study of sperm whale photo-identification techniques, primarily from flukes, using a large sample (794 photographs of flukes) collected off the Galapagos Islands in 1985. His analysis suggested that at least 91% of sperm whales can be individually identified from good quality photography (those with sufficiently large, clear and favorably oriented images) of their flukes. Another large sample (1,461 photographs of flukes) was obtained from the Galapagos in 1987, and numbers of flukes have also been obtained from the Azores, Norway and Nova Scotia and the West Indies (Whitehead and Waterhouse, 1989; Arntz, 1989). These have been used to compare the data with the large sample collected off the Galapagos Islands to compare the data with the large sample collected off the Galapagos Islands in 1985.

The purpose of this paper is to describe how identification of individual sperm whales from photographs of natural markings, in conjunction with other non-invasive techniques, can be used to study the size and dynamics of sperm whale populations. From a management viewpoint, uncertainty about the population biology of a species can be seen as being separated into three categories: (1) form of population model; (2) parameters of model; and (3) population size. Although not a perfect solution to the problems facing accurate population biology (where do we place uncertainty about stock identity?), this is a useful framework to describe recent attempts at sperm whale population assessment. This paper will look at all these forms of uncertainty about sperm whale populations, discussing how studies of naturally marked animals are helping to address it; and, in a few instances, estimate how much more effort is required to obtain accurate estimates. Some aspects of this paper are based on an update of Whitehead and Gordon's (1986) discussion of the potential of non-invasive techniques for assessing and monitoring sperm whale populations.

THE MODEL

The 'sperm whale model' as it was developed and used by the IWC Scientific Committee (e.g., 1982) is a collection of assumptions about the natural history of sperm whales. It has been used by the Scientific Committee to estimate the dynamics of sperm whale populations. Some parts of the sperm whale model are generally acceptable, while others, especially those concerned with density dependence, are more questionable.

Male mating strategies

With sperm whales, there has been special concern about a particular form of density dependence: how does a relative decrease in the number of mature male sperm whales (caused by selection for males in the whaling industry) affect the pregnancy rate of the females? In the sperm whale model, this is modeled by assuming that the number of sperm whales each year per group of females, and that as long as there are sufficient mature males present for there to be one per group of females, plus a few in reserve (the 'harvest reserve ratio'), the pregnancy rate of the females is not affected by a reduction in male abundance.

From the 1983 Galapagos data, Whitehead and Armstrong (1987) found that individually identified male sperm whales associated with a group of females and vice versa. The average duration of an interaction between a male and a group of females is typically a few hours. These details have recently been confirmed from analysis of the 1987 Galapagos data (Whitehead and Waterhouse, 1990), which suggests that the males are moving between groups of females searching for numerous females rather than holding harems, and Whitehead and Armstrong (1987) have shown...
that if the males were attempting to maximize their reproduction, we would expect to see males attempting to do this. Changing the sperm whale male model to incorporate a 'searching' male mating strategy suggests that the female pregnancy rate is a better measure of male depletion than in the traditional 'harem' model (May and Bedingfield, 1989; Whitehead, 1987).

Proportion of mature males on breeding grounds
Another potentially important observation during the Galapagos study was the proportion of mature males on the breeding grounds. At the height of the mating season, in the mid-July-March period, mature males formed 41-61% of the population (Whitehead, Wellington and Waters, 1981). A similar proportion of mature males in the population is seen in the other major breeding grounds (Whitehead, 1987). Using life history data presented by Best (1987), Whitehead (1987) showed that the proportion of mature males expected in a population of mature males and breeding groups of females is about 22%.

Six possible reasons have been suggested for this discrepancy (Whitehead, 1987: 1) relative depletion of males by the whaling industry; (2) the Galapagos may not be the 'true' principal mating ground; (3) mating may take place at a season other than when the studies were taking place; (4) a larger proportion of mature males may be breeding groups than observed every year; and (5) mature males may have higher natural mortality than females (Adams, Brownell and Slijper, 1961).

Data from the Galapagos study (Whitehead et al., 1987) suggest that the sperm whales observed off the Galapagos during the study period and in the Galapagos area, so that factors (2) and (3) are unlikely to be important. Best (1987) suggests that the low proportion of mature males in a population of mature males and breeding groups of females is about 6% (following Whitehead, 1987), still much greater than the observed 3-23%. Sperm whales may not be breeding groups during the period between mating seasons (IWC, 1981), and mature males not taking part in breeding every year precludes because of energetic constraints (Whitehead and Arnould, 1987).

If mature males do not take part in breeding every year, there are major consequences for the future of the species. If attachment problems are solved, long-term satellite-based telemetry may help to determine these movements.

PARAMETERS OF THE MODEL

The considerations which have been discussed in the previous sections are incorporated into the model of the Scientific Committee of the IWC (e.g., IWC, 1983) that the current 'sperm whale model' is not realistic and that a more realistic model needs to be assessed. An improved model would have parameters different from those in the current model. These might include factors such as the ratio of the travel time of breeding males between groups of females to the straying period of the females (Whitehead, 1987) and the probability that a mature male enters the breeding grounds in any season. However, it would also include most of the parameters that will be considered in the current model. Therefore, an illustration of how well we can estimate population parameters using data collected from sperm whales may provide some insight into the current model, or potential substitutes.

Age at recruitment for males and females
Recruitment as defined at recruitment is defined by a minimum length requirement. So, to estimate recruitment we need length (or possibly age) distribution data and an assessment of the relationship between age and recruitment for sperm whales, specifically for the Galapagos.

Age at sexual maturity for males and females
While a study of the age of sexual maturity for sperm whales using long-term studies of the species (e.g., O'Shea, 1981) shows an age of 12 years for the minimum age of sexual maturity, it does not provide information on the distribution of ages between mature males and females. This is because even if a mature male is caught at age 12, it is possible that he has not yet reached sexual maturity. Similarly, even if a mature female is caught at age 12, it is possible that she has not yet reached sexual maturity. Therefore, the age at which sexual maturity is reached is not a stable parameter and must be considered in the model.

Proportion of mature females per school
Using the proportion of individuals with a sexually active female per school, we can estimate the proportion of mature females per school. This proportion is required to estimate the proportion of mature females per school, but this may not be possible because of energetic constraints (Whitehead and Arnould, 1987).

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Harem reserve ratio

The results of Whitehead and Arnould (1987) and Whitehead and Waters (1990) show that the harem reserve ratio is an important parameter. As an indicator of the proportion of mature males in the population, it is possible to estimate the harem reserve ratio for the Galapagos by assuming that the ratio of the mean time interval between successive successful matings of females by a mature male on the breeding grounds is the same as that of the females. This is because the mean time interval is a measure of the harem reserve ratio for the Galapagos.

The straying period of the females is not considered in the model, but it is reasonable to assume that the straying period of the females is the same as that of the males. Therefore, the harem reserve ratio is an important parameter to consider in the model.
information on this from which populations subject to protection or sustained exploitation as there is unlikely to be much change except in the very long term. Even in cases where populations have been drastically reduced over relatively short periods, results are unreliable (Arntzen and Decker 1981).

Indications of the magnitude of density-dependent effects might possibly be obtained if changes in population parameters (e.g., birth rate) could be related to environmental conditions. For example, the amount of food availability, is related to environmental conditions. In some circumstances, the reaction of a population to changes in the feeding rate might be equivalent to its response to the density of the population size.

Whitehead (1987) showed that the searching strategy of males implies that if whaling reduces the number of groups of females, and not just the mean group size, then males will take longer to travel between groups of females, and females will be less likely to meet a male during their estrous period. Thus a lower population density would tend to produce a lower pregnancy rate, accounting for the usual density-dependent effects based on food limitation.

**Summary - estimation of population parameters**

*Of the parameters in the current sperm whale need, we are able to estimate population demography and the non-intensive data. For two of these, denmark social size and length at social maturity for males, the estimates are close to those obtained using data (e.g., Besant, 1979; WCR, 1982).

However, the percentage of first-year calves is lower than expected from the eastern North Pacific (Besant et al., 1980; Besant and Grahame, 1985) and the percentage of mature females per school higher than expected. These are consistent with each other if the mean reproductive rate of Galápagos sperm whales are considered lower, but this has not been measured elsewhere. A possible reason for the low mean reproduction rate is the presence of mature individuals in post-reproductive females and older females with decreased reproductive rates in the schools. In many cases, the presence of post-reproductive females is considered lower than expected.

**Mark-recapture studies**

For the male sperm whale population in the Galápagos Islands, Whitehead and Gordon (1980) suggested three principal techniques by which sperm whale population size might be estimated in the Galápagos: mark-recapture methods, acoustic census and mark-recapture methods. Visual census of sperm whale groups have been attempted in the Galápagos (e.g., Rice, 1977; Labelle and Hainmouwe, 1984) but acoustic surveys appear more potentially effective: they can be carried out at times of poor visibility generally audiable at larger ranges than they are visible, and provide a greater proportion of the day than they have in the aerial survey. (Whitehead and Gordon, 1983).

These surveys have marked a dramatic and substantial reorganization to be discussed. In the latter the survey, it will also permit the distribution of the data on the number of sperm whales which have been identified in the eastern North Pacific region. These are therefore particularly important for photo-identification studies of sperm whale, which have been done by Besant and Whitehead (1980).

For the male sperm whale population size, we need to photo-identify in areas where we are asking questions about. This in the North Atlantic, with effort to the Azores, Norway, and Galápagos and elsewhere (Arntzen et al., 1988).

When samples sizes do not need to be expected to be less than the number of male sperm whales which are photographed in each of two studies, Fig. 1 gives the relationship between the number of observations and the number of individuals in the sample, and the number of individuals in the sample. These are mostly based on the accuracy of the Peterson estimate based on the photo-identifications between them.

As there are about 9,000 males in the population of sperm whales, perhaps very roughly within, it is expected that the number of sperm whales which are photographed in each of two studies, Fig. 1 gives the relationship between the number of observations and the number of individuals in the sample. These are mostly based on the accuracy of the Peterson estimate based on the photo-identifications between them.

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