

The Development of Line Transect Methods  
for Estimating Cetacean Abundance

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The abundance of cetacean populations has been estimated in several different ways, initially with sighting surveys in the 1930s in the Antarctic (see Mackintosh and Brown 1956) and in the Black Sea (see Tomilin 1967 for references). These estimates were based on the rate at which animals were seen during shipboard and aerial surveys, respectively, making various assumptions about the distances over which animals are detected and the total range of the cetaceans being studied. Although estimates based on this approach were used to a limited degree, they were generally not thought to be very reliable. Subsequently estimates were made using mark and recapture methods (where the marks were fired into the whales and recovered during the harvests) and using catch per unit of fishing effort (cpue). Estimates made using each of these three methods, sightings, mark-recapture, and cpue, were used during the April 1963 meeting of the Scientific Committee of the International Whaling Commission, when recommendations for greatly limiting Antarctic catches of blue whales were first made (Mackintosh 1964, p.108).

While results from all three methods were used during the 1963 meeting, the Scientific Committee placed most confidence in the cpue based estimates. The Committee relied on such methods throughout the 1960s and 1970s as it successively assessed the other smaller whale species in the Antarctic and in other oceans. Over this period the cpue based methods were gradually refined, accounting increasingly for details about the searching and catching processes in the face of uncertainty about the relationship between catches and fishing effort. By the time a world-wide moratorium on commercial whaling was agreed to in the mid-1980s many of the underlying assumptions necessary for the use of cpue methods had been called into questions, and analytic and simulation studies had been completed to demonstrate that violation of many of these assumptions made the estimates that had been relied on of doubtful validity.

While primary emphasis was given to cpue based methods of estimating abundance, the method of extrapolating from numbers of animals sighted was developed further, especially by Japanese scientists using data from a fleet of scouting vessels that worked with the whaling fleet. Nasu and Shimadzu (1970) addressed the problem of declining detectability of whales with increasing distance from the observer on the ship, estimating abundance of fin and sei whales in the Antarctic based on data collected aboard Japanese scouting vessels. Although the Scientific Committee did not appear to make much use of these estimates, further work was done the following year (Doi, Ohsumi, and Shimadzu 1970) to elaborate this method, accounting more specifically for the patterns of searching done by the sighting teams. This time the Scientific Committee formally acknowledged this approach as "a valuable contribution but more work remains to be done on checking the validity of the model and in obtaining observations to estimate parameters in the model" (Anon. 1971, p. 37).

Both the cpue and sightings methods were critiqued by an FAO sponsored review of marine mammal research that began in 1973. An early report from that review (Holt 1975) noted that the underlying assumptions of both methods needed to be investigated further, especially the "biases in effort data" for cpue methods and the "number of variables, such as weather, for which allowances are made" for sighting methods (Holt 1975, p. 257-258). The FAO review began a critical inspection of the scientific methods used for developing management advice for large whales, a review that resulted in the reduced reliance on cpue based methods due to analytic and simulation demonstrations that the uncertainties on the relationship between cpue and abundance could seriously distort the resulting estimates of abundance and population productivity.

The FAO review had also raised many questions about sighting based estimates of abundance, but these did not initially receive as much attention within the IWC. Outside that forum, the need for estimates of abundance of populations of several species of dolphins killed incidentally in the eastern tropical Pacific yellowfin tuna purse seine fishery prompted aerial and shipboard sighting surveys based on a method developed in terrestrial mammal studies called line transect surveys. Conceptually similar to the methods developed by the Japanese, the terrestrial line transect methods were developed for animals such as grouse. The act of sighting was due, in that case, to the animal flushing at the approach of the observer. The behavior of the animal was so noticeable that the results of a survey did not depend on the observer's abilities. The mathematical methods were applied to both aerial and shipboard research vessel surveys (see Smith 1981) and to sightings data collected aboard commercial tuna fishing vessels when they were searching for dolphin schools associated with tuna (Smith 1975, 1981), but the underlying mechanisms of observer searching rather than animal flushing was not attended to. These methods were adapted also for surveys of bottlenose dolphin populations in Florida, where estimates of absolute abundance were also required for management of the live capture fishery (see Leatherwood et al 1978), and were soon applied rather widely to cetaceans.

Facing the increasing concern with cpue based methods, the IWC sponsored a workshop on the design of sighting surveys in 1980, during which results from several major ongoing sighting survey programs were discussed and the appropriate mathematical models to use were discussed. In addition to scientists familiar with marine mammal studies, experts in surveys for terrestrial animals and in at-sea search procedures used in military operations participated. Two basic analytic approaches were considered. One was that developed by Japanese scientists and related approaches in at-sea search procedures where the factors considered included:

many biological and behavioural aspects of both the whale (diving time, blowing time) and the observer (angular velocity of eye scanning, physiological discrimination), as well as characteristics of the viewing platform (speed, mast height, sighting range) (Anon. 1982. p. 535).

The second was described during the meeting as the "descriptive statistics" approach (Koopman, 1982, p. 543), who argued against the approach, noting that

statistical curve-fitting may give a condensed representation of bodies of past observations, but they are too often made under heterogeneous varieties of conditions, usually too complicated to be stated in sufficient detail to serve as a basis for logical conclusions (Koopman 1982, p. 544).

The workshop recommended that the "curve-fitting" approaches were likely sufficient, but noted that further studies on many of the underlying factors involved in visual search and animal behavior needed to be looked into. The development and application of line transect sighting surveys continued apace throughout the 1980s both within the IWC and elsewhere, with further methodological studies being conducted, primarily within the International Decade of Cetacean Research program sponsored by IWC. Many new analytic methods were developed, some of which accounted better for the behavior of the animals and had better statistical properties, and many experimental tests were conducted to determine the effects of factors such as visibility and height of the observers. See the Reports of the International Whaling Commission during the late 1980s for details.

The gradual replacement of cpue-based assessment methods by sighting survey based methods of population estimation and assessment continued within the IWC through the 1980s. In December of 1990 during a meeting of a sub-committee on developing revised management procedures all participants agreed that cpue based methods would not be further considered in any new management procedure that might be developed. Indeed, it was agreed that the behavior of the new management procedures under development was satisfactory when only catch and sighting survey data were used.

But is this really true? During the development of sighting surveys since 1969 many factors have been identified as potentially affecting the reliability of the resulting population estimates. A complete list would be very long, and while some of these factors have been addressed, many have not. What is increasingly being observed during these surveys is that the results vary with different observers and platforms, and that methods appropriate to one species are often not appropriate to another, even though most surveys encounter a number of species.

The following is a partial list of the outstanding issues:

1. reaction of animals to the vessel;
2. the fraction of animals which were directly ahead of the vessel which were seen;
3. the effect of random movements, especially if the likelihood of sighting differs with direction of movement;
4. the effect of pooling sighting results obtained under heterogeneous sighting conditions, where detectability may vary;
5. methods of measuring distance to sighted animals;
6. methods of estimating the variances of density estimates
7. the effect of pooling sighting results across observers with different abilities.

We can anticipate that as the concern over the effects of whaling and by-catch of cetaceans continues the now accepted sighting surveys will come under increasing scrutiny. At present the management procedures being explored within the IWC rely on having estimates of abundance from sighting surveys that are not upwardly biased, and on having estimates of the sampling variability of these estimates. To ensure that these management schemes are useful, it will be necessary to remove the sources of downward biases and to ensure that robust estimates of sampling variability are available. This will require further experimental and theoretical examination of the many of the factors listed above. By having survey methods which produce estimates which are as nearly unbiased as possible and which properly account for the many sources of uncertainty, the new management regimes that are being explored will be more likely to be accepted.

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