Encountering whales: How encounter rates became the basis for managing whaling

Tim D. Smith

World Whaling Project, 1744 Sterling Drive, Redding CA 96003, USA

ABSTRACT

Declining rates of encountering whales, including both sighting and catching, were noted by whalers throughout the 19th century, and these declines became the first indication that whaling was adversely affecting whale abundance. The interpretation of declines in both sighting and catch rates proved to be a difficult scientific task. Satisfactory quantitative methods of interpreting changes in whale encounter rates were not developed until the second half of the 20th century. Rates of encountering whales played a key role in the International Whaling Commission (IWC) Scientific Committee from its beginning in the early 1950s, as well as in the US in implementing its Marine Mammal Protection Act beginning in the early 1970s. The development of methods of collecting and interpreting sighting and catch data was intimately interwoven with the development of the management of whaling and cetacean by-catches in fisheries throughout the world, but especially within the context of the Scientific Committees of the IWC and the North Atlantic Marine Mammal Commission (NAMMCO). Although overfishing of whales was initially identified through the use of sighting rate data, catch rate data provided the IWC's Committee its first firm footing for management advice. However, it was sighting rate data that ultimately became the basis for the scientific advice on whaling and for management advice in other settings. This led to the development of large scale cetacean sighting programmes, such as the IWC's International Decade of Cetacean Research surveys in Antarctic aboard Japanese ships, the North Atlantic Sighting Surveys (NASS) aboard Norwegian, Icelandic, Spanish, Greenlandic and Faroese vessels and aircraft (coordinated by NAMMCO through its Scientific Committee from 1995), and surveys under the US's Marine Mammal Protection Act and the European Union's Small Cetacean Abundance in the North Sea (SCANS) programme. Fishery independent cetacean sighting surveys have proven to be both central and essential to understanding and regulating of human impacts on cetaceans.

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INTRODUCTION

The universal experience of whalers has been the gradual reduction in frequency of encountering (sightings and catches) whales. Two 19th century whalers interpreted these reductions in frequency of encounters differently. Scoresby (1820, p. 178) interpreted it as a response of whales to whaling: "but when the trade increased, and the annoyance to their species became so very great that they took the alarm and gradually receded from their favourite haunts, a suitable change in the fishery was requisite." Roys (1854) in contrast understood the declining frequency of encounters differently, noting about the lack of whales on the "southern grounds": "There is no longer whales enough upon them to make it pay to cruise there. Although more than 20 years since these grounds were abandoned, still they do not revive, which shows the increase of these whales to be very slow." Later, Starbuck (1878), who was not a whaler, agreed with both Scoresby and Roys, suggesting ambivalently that the decline in whaling was due to the "scarcity and shyness of whales." Even by the late 20th century both interpretations were still tenable, with Bockstoce and Botkin (1983, p. 119) suggesting based on data from logbooks of 19th century whalers that declining sightings and catches of bowhead whales in the Bering Sea were the result of either the sequential elimination of smaller more regional populations or alternately the result of the whales shifting their range in response to the whalers. That is, they suggested, the whales "responded rapidly to the presence and activities of the whaling ships, and fled areas of intensive hunting, receding farther and farther north and east to the comparatively safer areas either near the ice or where exploitation had not yet occurred."

By the beginning of the 20th century the interpretation of cetacean sightings was emerging as a scientific question. Racovitza (1903) attempted to interpret cetacean sightings made during voyages of exploration including one by the *R/V Belgica*. He addressed one important methodological difficulty in interpreting cetacean sightings, the identification of cetacean species from visual observations at sea rather than from inspection of the carcass. He based his consideration on a careful description the nature of whale blows and movements, concluding that the various species can be distinguished visually (Racovitza 1904, p. 643):

> "In combining the results derived from observations of movements, with data supplied by dimensions, form, and color, one becomes able to recognize readily every kind of whale with as much certainty as if one had the animal at one's disposal to dissect—an opportunity which presents itself but rarely."

Racovitza's claim that species could be identified from visual observation had been the experience of 19th century whalers, men who made their living based on distinguishing among the few species that they targeted. But the potential for confident identification of species by scientists and non-specialists would prove to be a major question about interpreting cetacean sightings.

What would become a long-term quest for methods of collecting and interpreting cetacean encounter data can be traced over the latter half of the 20th century, entwined with the difficult and often contentious history of the development of methods of managing the often excessive killing of cetaceans through whaling and through fishery by-catch. I trace this development by decade, and attempt to show the complex interaction between the scientific issue of interpreting sightings and the larger issue of managing cetacean catch and by-catch.

HISTORY OF WHALING AND ASSOCIATED DEVELOPMENT OF RESEARCH AND MANAGEMENT

Before 1950

The concerns of the declining encounter rates of 19th century whalers faded under the onslaught of modern whaling in the early 20th century. Greatly improved efficiency of mechanical over sail powered vessels and the corresponding ability to capture the still-abundant faster whale species, and the expansion into the unexploited Antarctic grounds resulted in increasing encounter rates. Nonetheless, there were still concerns for the sustainability of whaling. For example, such concerns contributed to the formation of national research projects, such as in the 1920s the State Institute for Whale Research in Norway and the "Discovery" Committee in Great Britain. Norwegian studies initially focused in the North Atlantic (Ruud 1953), and included both biological studies, for example whale age composition and population modelling such as Hjort's application of the logistic equation (Hjort 1933).

The "Discovery" Committee, in contrast, focused in the Antarctic on oceanographic studies and biological data collected from whaling stations, also initiated a number of fishery independent oceanographic studies that included systematic collection of cetacean sightings. By the 1930s the sightings observations were organized as standardized lookout system that included adding another biologist to the crew (Mackintosh 1942). In his classic "Discovery" Report, "The southern stocks of whalebone whales," Mackintosh recognized the low reliability of the identification of the species of whales sighted, noting the need for close approach and special expertise to distinguish especially between blue and fin whales. He nonetheless estimated relative abundance as numbers of all species of large whales per mile of trackline searched, and even prorated those values to species using a selected subset of sightings where the identifications were more reliable.

By the end of the 1940s agreement was reached on an international treaty for the regulation of whaling, and by the early 1950s scientists associated with the resulting International Whaling Commission took up the issue of developing a scientific basis for the management of whaling.

1950s

As the IWC began to organize the scientific input called for in the treaty, scientists involved emphasized the importance of whale marking 'on as large a scale as possible' (IWC 1951, p. 5), and accepted Mackintosh's priorities for additional research in his "Outline of Recommended Whale Research" (IWC 1951, p. 15). Neither the population modelling approach that Hjort had developed nor the sightings approach as Mackintosh had previously developed were explicitly identified by the scientists. Further, Mackintosh's list focused almost entirely on the biology of individual whales, for example morphology, species and stock identity, food for whales, and reproductive rates. The focus was decidedly on biology and life history of whales, especially as could be gleaned from inspection of whales on the flensing platforms.

However, Mackintosh's list had included two additional items that suggest he was thinking about the utility of sightings data: information on cetacean swimming and breathing habits and on school sizes. He had described the importance of studying these topics even in his 1942 "Discovery" Report, where a lack of information had proven to be weak points in his analysis of whale sightings. This interest appeared again in another study that Mackintosh initiated in 1951, a systematic programme for collecting sightings data from merchant vessels world wide (Mackintosh 1951). Drawing on his experience with the "Discovery" Investigation, which had by then been incorporated into the National Institute of Oceanography, Mackintosh engaged the British Meteorological Office in a programme of recording sightings of whales from the bridge of merchant vessels. Because, he argued, "existing knowledge of world distribution is inadequate" (p. 87), opportunistic sightings data could play an important role in "as part of a plan of research on the general distribution of whales." His programme continued throughout the 1950s, and resulted in descriptions of whale distributions in the Indian and in the Atlantic Oceans that suggested broad aspects of cetacean distribution: lower densities in mid-ocean water and patchy distributions of cetaceans more generally (Brown 1957, 1958). By the end of the decade other such "vessels of opportunity" sighting programmes were being set up, notably by the Dutch in 1954 (Slijper 1962, p. 330, Slijper *et al.* 1964). Many such programmes were to follow in subsequent decades. All such projects, however, would be plagued by Racovitza's problem of at-sea species identification, especially by non-specialists. In addition, the non-representativeness of tracklines chosen for other purposes, inconsistency in sighting effort, and lack of ability to approach sighted animals for species identification, would substantially limit the utility of such data.

Sightings of dolphins were being systematically recorded by the 1930s, when Russian scientists used aerial observations in the Black Sea to estimate dolphin abundance (see Smith 1982). In 1952 Gilmore (1960) began collecting shore-based sightings of the southbound migration of California gray whales, and Doan and Douglas (1953) recorded aerial based sightings of white whales in Hudson Bay. Although interpretation of these sightings in terms of abundance was difficult, especially for the gray whales, some of the obvious factors affecting the rates of sighting were quickly identified.

Beginning in mid-1950s analyses of Antarctic whale sightings advanced rapidly. The relationship between research on individual animals, on sighting surveys and on population modelling came into focus in a series of intersecting arguments about the effect of Antarctic fin whale catches. Hylen *et al.* (1955) presented results of the Norwegian State Institute for Whale Research on individual animals where baleen plates were used to estimate age. The authors demonstrated a strong decline in estimated numbers of fin whales in the Antarctic with increasing age, a reflection of both natural and fishing mortality. Their conclusion, that the total mortality rate implied by this decline exceeded population recruitment rates suggested by the reproductive cycle, was immediately challenged in the often polarized IWC Scientific Committee because it required the unproven albeit not unreasonable assumption that recruitment had not been increasing in recent years.

Ottestad (1956) defended his colleague's conclusion that fin whales were 'overfished by the present rate of whaling' using an argument based on both sightings data and population models. He started with Mackintosh and Brown's (1956) reanalysis of the 1930s "Discovery" Investigation sightings, which had yielded an improved estimate of abundance. This was a better estimate because it incorporated data on whale breathing rates and on sighting distances for a subset of the sightings. Ottestad used these new abundance estimates to compute possible historical population trends, calculating backward in time from the present abundance and the previous years' catches. He followed Hjort's (1933) thinking on density dependent changes in reproduction and natural mortality, demonstrating that the fin whale population had likely been declining steadily since modern whaling began, especially in more recent decades as the focus of Antarctic whaling shifted from blue whales.

Although arguments such as described above convinced most of the Scientific Committee that at least in the Antarctic large whales were being over fished, there was dissension (Schweder 2000) and the Commission continued to be unable to deal with the Committee's somewhat fractured advice (IWC 1959, p. 20). In this, the Commission repeatedly failed to reduce large whale catch limits over the 1950s. The methodologies of whale sightings and population modelling that had proven convincing by mid-decade were in the end not to be followed up, and the focus began to shift in the early 1960s to changes in catch rates rather than in the more difficult to obtain sightings rates.

1960s

Recognizing the persistent split in the scientific advice it was receiving from its Scientific Committee, the Commission in the early 1960s arranged for an independent team of scientists, specifically selected from countries not involved in pelagic whaling, to apply the tools of population dynamics that were being developed in the field of fisheries biology. The initial analyses by the so-called Committee of Three was based not on the sightings data of Mackintosh and Brown, but rather on the ratio of the numbers of whales caught to the number of days of whaling activity, so called catch per unit of effort (CPUE) used routinely in studies of finfish fisheries since the early 1900s (Smith 1994). The analysis was conclusive, at least given its assumptions, and successfully quantified the by then apparent severe over harvesting of the blue and fin whales (Chapman 1964). This work marked the beginning of a too-slow process of reducing catch limits. Anticipating that the Commission would respond to their analyses by restricting whaling, the Committee of Three had identified the potential value of cetacean sightings to offset the lack of CPUE information that would result from diminished catches. Although they were more confident in the IWC's ability to use their results to regulate the fishery than proved to be warranted, they recommended that "advantage should be taken of any opportunities for obtaining independent evidence from sightings from ships sailing in the Antarctic waters" (Chapman 1964, p. 110). This point was refined and reiterated the following year, with a specific recommendation that the Commission organize "systematic records of sightings" (IWC 1965, p. 47), identifying both sightings from whaling vessels (especially of prohibited species) and if necessary from dedicated sighting surveys.

There were four responses to this recommendation; two types of fishery-independent and two types of fishery-dependent sightings soon began to be collected (Table 1). Some of these efforts continued for a few years, and some for decades. These four approaches had decidedly different characteristics, and the nature of the platform greatly influenced the development of methods of collection and analysis of sightings data.

Fishery-independent sightings

The "Discovery" Investigation sightings data from the 1930s were re-examined to determine how much sighting effort would be required to obtain statistically reliable data (Gambell and Gulland (MS) 1964). This resulted in a proposal to the Scientific Committee on Antarctic Research (SCAR) to collect fishery-independent sightings from oceanographic research vessels that they coordinated (Brown and Mackintosh 1969, p. 93). The plan called for two vessels to be working for three months, and SCAR began collecting sightings data for the IWC in the 1964/65 season. Constrained by cost and the dedicated nature of the SCAR research vessels, the sightings data suffered from many of the same problems as that from earlier opportunistic surveys, but at least broad scale distribution patterns were detectable, albeit because of weaknesses in the species identification, only for aggregations of large whale species (Brown and Mackintosh 1969, p. 93). Although the programme continued for several more years, without more reliable species identification and school size estimates the Scientific Committee's use of the data proved limited.

Already by 1965 Japan was reporting sightings data collected aboard a research vessel, the Umitaka-Maru working south of Australia (IWC 1966, p. 51). This was followed in 1966 by an invitation from Japan (Brown and Gaskin 1967, p. iii) for international participation on two experimental voyages, one an oceanographic oriented cruise aboard the Umitaka-Maru and the other a sightings dedicated cruise aboard the Chiyoda-Maru #5. While the oceanographic focus of the Umitaka-Maru limited the numbers of sightings (Brown 1967), the data from the Chiyoda-Maru #5 (Gaskin 1967) were used immediately in by FAO in its assessment of sei whales (FAO 1968, p. 23-49).

Fishery dependent sightings

The Chiyoda-Maru #5 results would also be used later in developing methods for analyzing fishery dependent sightings from scouting vessels used by the Japanese whaling fleets to lead the fleets to higher concentrations of whales (Japanese Scouting Vessels, JSV). Systematic recording of sightings aboard this scouting fleet began in 1964 in the North Pacific and in the 1965/66 in the Antarctic. While the research vessel surveys in the 1960s systematically recorded estimated distances and sighting effort, the JSV sightings were reported only as numbers of whales by species and numbers of miles surveyed per day. Nasu and Shimadzu (1970) developed a method for estimating abundance by combining the JSV sightings with the distances at which whales were sighted during the Umitaka-Maru and the Chiyoda-Maru #5 research vessel surveys. This method was immediately applied to fin whales (Doi *et al.* 1970, Doi, *et al.* 1971), and set the stage for substantial improvements in methods of analysis (Doi 1970, 1974). Abundance estimates from the JSV data continued to be made throughout the 1970s (see IWC reports).

The Scientific Committee also attempted to obtain sightings directly from the whaling operations, establishing its "Sightings Programme." Initiated in 1967, under this programme whaling companies were asked "to assist in reporting sightings of prohibited species… in the same detail in respect to area, time and effort as the reporting of catch data" (IWC 1968, p. 52). One apparent response to the Scientific Committee's "Sightings Programme" was conducted starting in 1969 aboard Icelandic whaling vessels (Brown (MS) 1972, 1976). Originally aimed at the then protected blue, humpback and right whales, the study was designed to obtain "indications of any possible changes in the numbers of each species in the area" (Brown 1976 p. 297). By 1972 Brown had compared the accumulating data to information extracted from Icelandic radio station logs for a decade

Table 1. Fishery-dependent and fishery-independent forms of sighting data collected beginning in the mid 1960s within the IWC Scientific Committee classified by the nature of the voyage, the time period when the data were collected, and the nature of the platform.

	Nature of Voyage	Time Periods	Platform
Fishery-independent	Oceanographic research	1962/63-1970/71	SCAR vessel of opportunity
	Whale research	1965/66-1966/67 1978/79-present 1960-present	Japanese research vessels IDCR Antarctic surveys Shore based sightings: gray whales
Fishery-dependent	Whale scouting	1964-87 1965/66-1987/88	Japanese whaling fleet scouting vessels North Pacific Antarctic
	Whaling	1967-1980	Whale catcher boats

earlier (1957-1959), suggesting a considerable increase in reported sightings of both blue and humpback whales (Brown (MS) 1972). Despite the success of the Icelandic programme, similar data were not forthcoming from other countries. The "Sightings Programme" was continued on a seemingly tenuous basis, with the Scientific Committee later noting that the reports for the 1976/77 season were inadequate, subsequently suggesting ways of improving the data, and finally terminating the programme when no data were submitted from the 1979/80 Antarctic whaling season. Nonetheless, the Icelandic programme was continued up to the termination of commercial whaling in the late 1980s (Sigurjónsson and Gunnlaugsson 1990).

The Committee of Three's recommendation for collecting sightings in response to anticipated decreases in catches was responded to in the U.S. as part of a research programme on gray whales. That programme included marking, capture, and shore-based sightings. The latter had been pioneered for this species by Gilmore as early as 1952 (Gilmore 1960) from near San Diego. Subsequently, as this research programme developed shore-based observations were continued from a more northerly site where a larger proportion of gray whales passed closer to shore. The methods of collecting sightings have evolved over time, and the analyses of the data have become ever more sophisticated.

Although the Scientific Committee was making progress in its understanding of the effects of whaling, the Commission's translation of that progress into needed reductions in catch limits lagged far behind. Further, the seeds of another problem had been germinating over the 1960s, the by-catch of dolphins in the US tuna fishery off of Mexico as it switched from bait boat to purse seine methodology (Perrin 1969). The growing global awareness of the IWC's weakness in regulating whaling and the enormous by-catch of dolphins of the tuna fishery would have major implications for the management of whaling and of cetacean by-catch over the next decade.

1970s

Concerns about marine mammals generally, and the by-catch of dolphins during tuna purse seining in particular, lead to the 1972 passage of the U.S. Marine Mammal Protection Act (MMPA). Charged with finding an immediate answer to the question of the biological significance of the dolphin by-catch, US scientists adopted an approach not unlike, but independent of, that developed more than a decade earlier by Ottestad (1956). Observers placed on tuna vessels to record rates of by-catch and collect biological samples of the dolphins killed also recorded the fishermen's sightings of dolphin schools. They searched for dolphins as those schools that signalled the presence of yellow fin tuna. The fishery observer data were used to estimate total by-catch by species, biological rates and relative abundance from sighting rates over the fishing grounds. In addition, research vessel sightings were collected aboard airplanes over portions of the fishing grounds accessible from shore and aboard ships seaward to the edges of the range of dolphins (Smith 1974, 1975, 1981). In both the aerial and the shipboard work line transect methods from in terrestrial studies were adapted to cetacean sightings, with visual estimates of range and bearing to the sighted schools along with visual estimates of group size being recorded.

These data were used to estimate density of schools of and numbers of dolphins in the survey areas, and ultimately total population sizes. The question of biological significance was then addressed by comparing the proportions of the populations of dolphins being killed annually to the biologically feasible rates of population increase. Further, estimates of dolphin by-catch since the beginning of the purse seine fishery in 1960 were made using historical sources, and those were used to compute how many dolphins must have been present in 1960 given the current abundance following a very simple backward calculation. Like Ottestad (1956), this involved computing the previous year's abundance as the present year's plus the difference between the year's by-catch and natural increase to the population (Barham 1974, Smith 1983). The initial analyses suggested that dolphin by-catches in the 1960s and early 1970s had been biologically significant, and further that some dolphin populations had declined substantially. As reductions in the by-catch levels came slowly over the next decade the purpose of the research surveys shifted from documenting population decline to documenting anticipated recovery.

Instead, however, subsequent sighting surveys have shown a relatively unchanging abundance of these populations, quite unexpected when the populations were expected to be increasing as the reported by-catches of dolphins have been greatly reduced (Gerrodette and Forcada 2005).

Similar use of research and fishery based sightings was made in a number of other cetacean by-catch and directed catch situations in the US over the 1970s, with various methodological issues being addressed. For example, sightings studies of the effect of the by-catch of Dall's porpoise in North Pacific drift gillnet fisheries dealt with the tendency of the dolphins to approach vessels in part of their range but to avoid them in other portions (see Buckland *et al.* 1993a). The effect of live capture of bottlenose dolphins in the Gulf of Mexico resulted in studies of the effects on aerial sighting survey of visual constraints and of elevation (Leatherwood *et al.* 1978, Leatherwood *et al.* 1982). These problem-oriented research programmes were supplemented with regional monitoring programmes, such as the Cetacean and Turtle Assessment Program (CeTAP) aerial sightings from 1978 (Scott and Gilbert 1982) and the Manomet Bird Observatory sightings aboard fishery research vessels from 1980-88 (Smith *et al.* 1990). The use of vessels of opportunity was also taken up again (see Breiwick 1996).

Outside the U.S., we have identified a few other examples of the use of cetacean sightings. As note above, in response to concerns about the on going commercial harvest of dolphins in the Black Sea, Russia scientists developed an aerial sighting survey in the 1930s (Zemsky and Yablokov (MS) 1974). The methodology was essentially strip transect analyses, and the variability of the data was very high (Smith 1982). In Japan Kasuya (1971) reported analyses of aerial sightings made from 1959 to 1970 during survey of fishing grounds along the Pacific side of Japan. These data were essentially opportunistic, and lacked species identification for many of the dolphins, but were important in that they overcame limitations of whaling-based sightings due to whaling regulations and operational constraints.

Relative to whaling, changes within the IWC Scientific Committee's work in the 1970s were being prompted by outside forces. There were numerous concerns about the Commission's unwillingness to follow the Scientific Committee's increasingly strong advice, yet at the same time concern were developing about the robustness of that advice, especially in its dependence on the difficult to interpret catch rates. In 1971 the US convened "an international meeting of leading cetologists" in Shenandoah National Park in response to the recent inclusion on the US Endangered Species List of eight large whale species (Schevill 1974 p. v). This meeting occurred just prior to the meeting of the IWC Scientific Committee that year, with many scientists attending both and with some of the same scientific papers being presented to both meetings.

The research recommendations coming from the Shenandoah meeting anticipated the discussion within the IWC Scientific Committee a year later in response to the recommendation for a global moratorium on whaling made by the Stockholm Conference on the Environment in 1972. The Committee rejected the proposed blanket moratorium on whaling for all species, arguing that this would be a step backward because the Committee had only recently succeeded getting the Commission to replace its use of aggregate multispecies catch limits with individual stock catch limits. However, the Committee did respond to the Stockholm recommendations for strengthening the IWC, identifying the need "for a decade of intensified research on cetaceans, particularly as regards problems relevant to their conservation" (IWC 1973, p 42). Key recommendations for research included improving methods of interpreting whaling catch rates as measures of abundance, expanding marking programmes, developing methods for stock identification other than mark recoveries, improving reporting of fishery data, and conducting sighting surveys. Relative to the latter, they noted: "There needs to be systematic sampling on a scale that will yield useful results and in addition studies on whale behaviour so that sighting data can be properly interpreted" (IWC 1973, p. 43).

The Shenandoah Conference did not identify the then-developing concern about the Alaska Eskimo harvest of bowhead whales, even though that species had been one of the eight included in the U.S. Endangered Species Act that had motivated the conference. But by 1972 the Scientific Committee had begun to question the effects of that ongoing fishery, especially given high proportion of the whales that were struck but not recovered. Drawing on some earlier ice-based whale sightings by Foote (MS 1964) and the example of the gray whale shore based sightings, a programme of visual sightings was begun in the 1970s, a programme that continues today. There were a number of factors affecting the counts similar to those for the gray whales that had to be addressed, as well as some additional factors unique to conditions of migration through gaps in the ice (see Zeh *et al.* 1993).

The IWC Scientific Committee also noted that to understand the biological significance of this hunt additional information was needed on the magnitude of earlier, primarily 19th century, whaling. In 1975 the Committee wrote "Catches of bowhead whales are recorded in logbooks and elsewhere in the records of earlier whaling for this species and they could provide information on past population levels" (IWC 1976a, p. 13). This idea had arisen from time to time within the Scientific Committee, for example in 1972 over concern about sperm whales in the North Atlantic. Analyses of such historical records had been suggested "to attempt to reconstruct the original sperm whale stock status in the North Atlantic" (IWC 1973, p. 37), perhaps thinking along the line of Ottestad (1956).

The Committee reiterated its objection to a global moratorium in its 1973 annual meeting, and it continued discussing research needs, drawing specifically on the results of the Shenandoah workshop (Schevill and Allen 1974). The Commission in its next meeting, which immediately followed the Committee's meeting, also again rejected adopting a moratorium on at 8 to 5 vote, with 10 affirmative votes having been required under its rule requiring a three quarters' majority. The Commission did, however, agree to strengthen the IWC Secretariat and to support proposals for expanded cetacean research. The Committee in 1974 followed up with an ambitious US$ 3,300,000 proposal (IWC 1976b) with high priority components in the Antarctic, the North Pacific and the North Atlantic (Best (MS) 1974). The Antarctic proposal included a major effort at collecting whale sightings, based on survey design following the approach of Gambell and Gulland (MS 1964).

At the same time the Scientific Committee was responding to the Stockholm Conference recommendations, the UN's Food and Agriculture Organization initiated in 1973 a review of the "the identity, distribution and the state of stocks of all marine mammals, particularly those … subject to exploitation by man" (FAO 1975, p. 25). The first report to the IWC from this project included discussion of the difficulties but yet potential importance of using sighting rather than catch rates (FAO 1975, p. 257). The Scientific Committee's response (IWC 1976a, p. 29) identified the difficulties of estimating abundance from fishery-dependent sightings, as had continued to be computed from the JSV data, stating that 'Current sighting indices [based on fishery-dependent sightings] may not, consequently, be much better than CPUE indices in indicating true abundance." The Committee went on to argue the importance of sightings collected independently of fishing operations.

The FAO review also confirmed and expanded the proposal for studies of historical whaling records to include other oceans and species, and recommended that a workshop be held to review the potential of such records (FAO 1978, p. 181-184). That workshop was held in 1977 and several pilot studies were conducted in the years following the workshop (Tillman and Donovan 1983).

The FAO review culminated in a workshop in Bergen in 1976. That workshop echoed the IWC Scientific Committee's cautious endorsement of the potential of fishery-independent sightings for population assessment, and also endorsed other methods such as analyses of catch and effort data, and endorsed expanded marking programmes (FAO 1978, p. 63-73). In the 1977 meeting the IWC Scientific Committee set priorities among the proposed IDCR projects, with systematic sightings consequently being collected in the Antarctic during a marking cruise in the 1977/78 season (IWC 1978). Initial estimates of abundance based on the sightings and separately on the marking data (Best and Butterworth 1980) precipitated a discussion of the relative reliability of the two methods for assessments. The sightings-based estimate was made using geostatistical methods that did not allow its uncertainty to be measured. In lieu of this, Chapman (1980) constructed a stratified estimate that accounted for the correlation between sighting distance and estimated school size and provided a measure of the uncertainty of the estimate of abundance.

The IDCR Antarctic marking and sighting cruise was conducted again in the 1979/80 season, and again the question of the utility of the two types of data arose. The difficulties with mark-recapture estimates of abundance were apparent because no tags had been recovered (Horwood 1981). In lieu of a direct estimate of abundance in such a case, the Committee was reduced to considering the relationship between population size and the probability of recovering no tags (Horwood 1981 p. 291). This outcome was unsatisfactory, and focused attention on the importance of accurate reporting of recovered tags and on the possibility of tag shedding. The sightings data from that cruise also raised a number of questions, but at least an estimate of abundance was possible, and indeed an estimate with rather good estimated statistical precision (~12% coefficient of variation). The experience with the now two Antarctic marking and sighting surveys raised a number of specific questions, but also the more general question of the relative reliability of the two methods. In addition, it was becoming apparent that there were also field operation concerns that highlighted "the conflict between the marking and the sightings programme. Each could be done much better in the absence of the other" (Horwood 1981 p. 305).

1980s

Consistent with the push throughout the 1970s for expanded research in lieu of a commercial whaling moratorium, the 1980s saw a virtual explosion of research on large whales. Within the IWC, the IDCR programme gained momentum, incorporating research recommendations from FAO's "Working Party on Marine Mammals" and from the related UN Environmental Programme's "Global Plan of Action for the Con-

Table 2: Aspects of collection and analysis of cetacean sightings discussed during the 1980 "Workshop on the Design of Sightings Surveys", identifying for each of seven issues the workshop's analysis, survey design and data collection consideration.

Issue	Analysis	Survey Design	Data Collection
Platform	Effect of platform visibility and height	Shipboard vs aerial Vessels of Opportunity	Vessel characteristics: (Platform height, obscured visibility, etc.)
Geographic coverage	Trackline distribution; Spatial stratification; Geostatistical integration; Estimation of variances; Heterogeneity of clusters of whales	Tracklines to estimate gradient; Stratification accounting for gradients; Estimating density or determining geographic range	
Vessel behaviour	Use only sightings made before closing.	Methods of closing on sighted groups versus not closing.	Changes of estimates of group sizes with distance.
Observer behaviour	Accounting for observer behaviour and fatigue	Observer rotation schemes	Training and instruction given; Video monitoring; Observer's on watch
Whale behaviour	Reaction to vessel; Random movement	Parallel vessels to determine; Varying vessel speed to see effect on sightings	Whale dive patterns for disturbed and undisturbed whales
Relative probability of detecting whales with distance from trackline	Sighting process models vs distribution free methods; Whales in view; Effect of closing on sightings (bias with spatial heterogeneity); Interaction of factors	Calibration of visual estimates of angles and distances; Closing on sighted groups	Environmental conditions (wind speed, sea state, swell, glare, overall visibility, glare, water temperature); Range and bearing or perpendicular distance estimates; Sighting cues; Observer identify and platform
Absolute probability of detecting whales near trackline	Analytical methods needed	Following vessel to count number missed	

servation, Management and Utilisation of Marine Mammals." (IWC 1982a, p. 44). The IDCR Antarctic marking and sighting cruises continued, with increasing emphasis on sightings over marking, and a proposal was developed for a "multi-year IDCR programme in the North Atlantic" (IWC 1982a, p. 130). Indicative of this expansion of research, the decade began with a series of "Special Meetings and Workshops" driven by or reported to the IWC Scientific Committee. For example, the 1980 and 1981 annual meeting reports list species-specific workshops on killer, sperm, minke and humpback whales, workshops on whale sightings and on whaling management procedures, a meeting titled "Humane Killing Techniques", and finally a meeting intriguingly titled "Cetacean Behaviour and Intelligence and the Ethics of Killing Cetaceans."

Methods of interpreting cetacean sightings were improved significantly in the 1980s. The starting point was the IWC Scientific Committee's "Workshop on the Design of Sighting Surveys," held in mid-1980 (IWC 1982b). Drawing on the increasing experience with cetacean sightings over the 1970s both within and outside of the Scientific Committee, discussion was organized into three topics: analysis, survey design, and data to be collected (Table 2). The many areas discussed under these three topics are grouped into seven issues. Basic concerns included the geographic region to be surveyed and the platform to be used. Experiences with stratified distribution of vessel tracks to account for cetacean abundance were discussed at length, as were estimation of sampling variances. It was recommended that determination of the area inhabited by a species and its density over that area could not efficiently be determined on the same survey. The suitability of different platform types was contrasted, especially ships versus airplanes. Further, the utility of and limiting factors for use of opportunistic vessels were discussed, noting again, as was learned in the "Discovery" sightings in the 1930s, the importance of observer training and experience, without which "the resulting data may be of little use for any purpose" (IWC 1982b, p. 538).

The workshop identified uncertainties about the behaviour of the vessels, the observers and the whales themselves that may need to be accounted for. One example was whether the vessel should deviate from its pre-assigned trackline to approach sighted animals, termed 'closing mode.' The refocusing of sighting effort during the time that sighted animals are being approached needed to be accounted for, most likely by omitting that time, and any new sightings made during the approach from analysis. Closer approach allows more reliable species identification and improved estimates of group size and, potentially, improved estimates of the range at which animals were sighted. However, the loss of survey time inherent in such approach would be greater in regions where greater numbers of sightings are made, potentially biasing density estimates downward, as was seen more recently in a Japanese combined whaling and sighting programme (see Clarke and Borchers (MS) 1997).

Changes in the behaviour of the observer and the observed have the potential to bias estimates of abundance from sightings data, and several mechanisms where this might occur were noted during the workshop. For example, observer search patterns and fatigue may need to be accounted for. Similarly, whales reacting to the vessel or even moving randomly as the vessel passes may introduce some biases. More fundamentally, however, the analysis problem of greatest concern was determining the overall probability that a whale is detected. The workshop broke this into two problems. First was to determine the relative sighting probability. That is, given a whale or group of whales was present at a given distance from the vessel track, what is the probability of detecting compared to the probability of detecting it if it had been near the trackline. Second was to determine the probability of detecting a whale or group of whales near the trackline, known as the "$g(0)$" problem.

The first problem, the relative sighting probability, was the essence of the "finding rate" calculation of Mackintosh and Brown (1956). The answer must come from the declining numbers sighted with increasing distance from the vessel. However, a number of concerns about that were identified, including the tendency for larger groups of whales to be detectable at greater distances. Two approaches were discussed, one focusing on models of the process of sighting and the other focusing on fitting statistical models to the aggregate data. The first drew on experience with search and rescue, essentially pointing to the work of Doi more than a decade earlier (Doi 1970). The second approach was not dependent on detailed knowledge of the sighting process, but rather focused just on the resulting geometry of the sightings that were made, that is the radial distance and the bearing to the sighted whales. Various parametric and non-parametric statistical models for describing this were discussed, and special focus was given to the robustness of the non parametric models to variation in sighting conditions.

The second problem, estimating "*g*(0)", was less tractable because it did not appear possible for observers to know what they had not seen. Various ideas were discussed, including the possibility conducting experiments with independent teams of observers. The discussion was not promising but the problem was seen as central to getting estimates of absolute density of whales, where unlike surveys for schooling dolphins (Smith 1983), it was not possible to assume that nearly all of the whales on the trackline would have been detected.

Despite the uncertainties identified by the workshop (Table 2), momentum continued to build in the IWC towards relying on sightings rather than marking, By the 1981 meeting the Committee would note that it "believed the sightings estimates to be the most reliable ones available this year, even though it could not calculate their standard deviations" (IWC 1983, p. 51). The latter problem was soon overcome, and much of the interest of the Committee and of other national and regional groups in the 1980s became focused on sightings data.

Throughout the 1980s the use of cetacean sightings to address management concerns for direct catches and fishery by-catches expanded rapidly. Prompted in part by the need for more reliable and less biased estimates of abundance because of the negative management implications of downwardly biased abundance estimates, issues identified in the Sightings Workshop were being addressed. For example, the long-running dolphin sighting surveys associated with the tuna purse seine fishery in the Eastern Tropical Pacific was using helicopters to address animal behaviour issues such as ship avoidance (Au and Perryman 1982). Aerial sighting experiments were being conducted as well to estimate the probability of detecting schools of dolphins on the trackline (Holt 1983).

Within the IWC, the development of cetacean sighting methods focused on estimating the probability of detecting whales that were on the trackline (Buckland *et al.* 1993b, p. 200-216). The Antarctic sighting surveys continued throughout the 1980s and addressed several of the issues identified in the Sighing Survey Design Workshop. During the 1980/81 survey experimental studies were conducted using two vessels in surveying in parallel to study the behaviour of whales and a single vessel surveying at different speeds to estimate the probability of detecting whales on the trackline (see Butterworth *et al.* 1982). Similarly, during the 1981/82 survey attempts were made to address the issue of the accuracy of visual estimates of sighting distance and angle. Based on that information, methods were developed for smoothing the perpendicular sighting distance distributions to account for the observers' tendency to report rounded values (see IWC 1983, p. 114-118). Initial analyses of the experimental data addressed many of the concerns, and suggested that the probability of detecting Southern Hemisphere minke whales on the trackline was perhaps not greatly less than one.

In the North Atlantic a research programme was pursued along the lines of the Antarctic surveys programme. Field work was conducted around Iceland in 1982, with a shipboard component focused on marking whales and an aerial component that compared line transect and other methods (Hiby *et al.* 1984, Martin *et al.* 1984). Although an international IDCR programme did not develop, various national interests continued studies throughout the 1980s, including Iceland's sightings aboard whaling vessels (see above) and also under the general title of North Atlantic Sighting Surveys (NASS). These surveys addressed several national objectives that were closely related to the interests of the IWC Scientific Committee, although unlike the IDCR studies in the Antarctic, they did not formally fall under that committee. Later the NAMMCO Scientific Committee would provide oversight for what has become an ongoing series of sighting surveys.

The NASS surveys have been important in the development of sighting survey methodology in several ways. For example, uncertainty in interpreting an assessment of minke whales based on CPUE lead Norway to examine the possibilities of whale sightings, and they conducted feasibility studies in 1984 and 1985. Too-limited collaboration with those conducting similar work in the Antarctic through the IWC's IDCR programme made progress in developing appropriate methods slower than necessary (N. Øien pers. comm.). In 1987 a multinational survey (NASS-87) was conducted (*e.g.* Gunnlaugsson and Sigurjónsson 1990 and cruise reports published in IWC 1989a pp. 395-455), with the results suggesting that unlike in the Antarctic, the probability of sighting minke whales on the trackline was likely substantially less than one. This stimulated ongoing research, especially within Norway (IWC 1989b, p. 46), on sightings data collection and analysis methods, and also the continuation of international surveys in the North Atlantic (NASS series) which were coordinated by NAMMCO from 1995 onwards at approximately 6 year intervals. In this programme experiments were conducted as they had been in the Antarctic surveys earlier in the decade, for example a parallel ship experiment in 1989 off Spitsbergen (Schweder *et al.* 1991). This resulted in an estimate of the probability of detecting a whale on the trackline that was in fact substantially less than one, and indeed less than one half. Another approach to accounting for the probability of detecting whales on the trackline that was developed in this period was termed 'cue-counting" (Hiby and Hammond 1989). This involved different assumptions that the rapidly developing line transect methods, and proved especially valuable for aerial surveys. Other concerns from the 1980 Sighting Survey Design Workshop were also addressed, including the effects of whale behaviour, observer behaviour and measurement errors in visual estimates of range and bearing. Further, the effects of whale surfacing behaviour on sighting rates, a topic that had been identified as important since Mackintosh's study in 1942, were addressed. Although the Antarctic and the North Atlantic were the primary focus of the IDCR research programme, there were also a few other sighting surveys conducted elsewhere. For example, in the Pacific one was conducted off Peru in late 1982. It focused on pygmy blue whales, and included experimental collection of information on diving behaviour (Donovan 1984).

The IWC Scientific Committee continued to address the concerns raised in the Sighting Survey Design Workshop throughout the 1980s, with the effort shifting from the Antarctic to the North Atlantic by the end of the decade. That the probability of detecting North Atlantic minke whales on the trackline was clearly substantially less than one implied that abundance estimates that might be used in management would be biased downward unless that fact were accounted for, and hence the allowable catches would be less than what they might be. Thus it was in Norway's interest in particular to develop a solution, something that would not be clearly solved until well into the 1990s.

During the last half of the decade concerns about harbor porpoise by-catch were arising in the U.S. in California and the Gulf of Mexico, and in countries around the North Sea (Philip Hammond pers. comm.). In the U.S., abundance survey methods began to be developed (Barlow 1988, Polacheck and Smith 1989). The latter authors suggested the Gulf of Maine as a convenient laboratory for testing line transect sighting methods. Westgate *et al.* (1995) identified key aspects of porpoise diving patterns and Polacheck and Thorpe (1990) conducted some experiments focusing on the behaviour of porpoise relative to the ship. An ongoing series of surveys in the Gulf of Maine were to continue through the 1990s and again several of the issues identified in the Sighting Survey Design Workshop would be addressed.

Despite a decade's resistance, the IWC finally agreed to the 1972 Stockholm Conference's recommendation for a moratorium on whaling, which came into full effect in the 1987/88 Antarctic season, nominally marking a pause in commercial whaling. This event was a major shift in the regulation of whaling, but not the end of whaling in and of itself. One reason was that aboriginal whaling, which the Commission had taken care to define, was allowed to continue. Another reason was that the treaty language that the IWC operated under allowed for countries to grant themselves permits to catch whales for purposes of conducting scientific research. This was the treaty provision that many countries had used prior to the moratorium. Further, the moratorium was not agreed to by all nations, and one nation used another provision of the treaty that allows countries not be bound by Commission decisions by notifying the Secretariat of its "objection."

Outside of the management authority of the IWC, the U.S. began to readdress the issue of the fisheries by-catch of marine mammals, with various congressionally mandated management schemes being adopted over time.

Rapid changes in the management of cetaceans within and outside the IWC during the late 1980s created a need for more and better scientific information for management, as began to be addressed in the 1990s.

1990s

The development of methods of managing human impacts on cetaceans continued to be addressed in studies connected with the International Whaling Commission, but also work was being pursued in a much broader arena, including the North Atlantic Marine Mammal Commission (NAMMCO), the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS), the International Council for the Exploration of the Seas (ICES), and numerous national and regional governmental bodies.

The value of relying on sightings based estimates of abundance had emerged in a process of an IWC Scientific Committee evaluation of methods of managing whaling that had its beginnings in the 1980s. One of the many workshops held in the first years of the 1980s was the "Third Meeting of the Special Scientific Working Group on Management Procedures" (IWC 1981). Following on some earlier discussions, this meeting agreed that "for whale stocks in a stable environment and for which sufficient information is available, a target level should be identified and management measures should aim at bringing the stocks to that level…" (IWC 1981, p. 45-46).

The development of a more formal and quantitative approach to setting such "target levels" continued, for example in the "Comprehensive Assessment Workshop on Management Procedures" in 1989, where an approach to evaluating the behavior of five candidate management algorithms was agreed (IWC 1989c). Over the next two years the Scientific Committee engaged in a vigorous management procedure development phase, during which mathematical algorithms were tested and revised, and during which the importance of information on historical catches was confirmed and sources of information on abundance other than sightings were discarded as unreliable. The Committee agreed on one algorithm during in 1991 (IWC 1992, p. 55-58), and quickly established the specifics of the selected approach. This approach set catch limits based on the historical status of the population and the statistical precision of abundance estimates, and included provision for spreading the catches spatially. The Committee was soon in a position to calculate catch limits should the Commission choose to lift the moratorium (IWC 1993, p. 62).

To implement the Scientific Committee's new management approach, the Revised Management Procedure (RMP), required estimates of catch history and periodic estimates of abundance in a set of so-called "small areas." The work that the Scientific Committee had done on both of these needs, abundance estimates and catch history, over the 1970s and 1980s was drawn together, with implementations of the RMP being agreed upon for the minke whales in the North Atlantic and Antarctic in 1992 and 1993 (IWC 1993, p. 62-66, IWC 1994, p. 48-50). The catch history was relatively well understood because minke whaling had occurred only in the 20th century, during a period when catch data were being reported to the Bureau of International Whaling Statistics (Allison and Smith (MS) 2004). The necessary abundance estimates were also available, in the Antarctic through the IDCR programme starting in 1978/79 and in the North Atlantic through the North Atlantic Sightings Surveys (NASS) in the 1980s.

With the IWC Scientific Committee's agreement to an implementation of the RMP for North Atlantic minke whales, the question became as to whether the catch limits would prove satisfactory to Norway's commercial interests. Although the small area abundance estimates from the 1989 sighting survey could be used in calculating catch limits, new and hopefully substantially improved estimates would be required. In 1995 an 11 vessel sighting survey was conducted in the Barents, Norwegian and North Sea. The many improvements in field and analysis methods that had been developed over the 1980s were adopted, including using two independent sighting teams to estimate the probability of detecting animals on the trackline, accounting for minke whale surfacing patterns, measuring whale orientation to the ship, and adjusting for bias in estimates of radial distances. The data collection scheme was complex logistically and the data analysis required two years to obtain agreement within the Scientific Committee (IWC 1997, p. 71-77), but in the end most of the factors that had been identified in the Sighting Survey Design Workshop were addressed. Including these various factors resulted in an abundance estimate that Schweder (1999, p. 153) estimated was 'nearly 7 times larger than what would have been estimated by the traditional methods…".

Not all of the issues that had been identified in the 1980 workshop had been addressed. One concern that proved elusive was responsive movement. By mid-1990s cetacean sighting surveys were collecting data that was relevant to this concern, through coordination of the NASS series by the NAMMCO Scientific Committee, and with input from Norway, Iceland and the Faroe Islands. These data included the orientation and movement of animals at the time of sighting. During Norway's 1995 survey the whalers routinely recorded their traditional descriptions of movement (Øien 1990), and similar data had been recorded in harbour porpoise surveys in the North Sea in 1994 (Hammond *et al.* (MS) 1995) and in the Gulf of Maine in 1995 (Palka 1995). Specialized survey methods had been developed that accounted for movement simultaneously with estimating the probability of detecting animals on the trackline (Buckland and Turnock 1992), but these have not been widely applied. In contrast, Palka and Hammond (2001) developed a less specialized approach using data from all three of these surveys to demonstrate that both minke whales and harbour porpoise avoided the survey vessels, and that this had occurred at distances of roughly one half and one km, respectively. Further, they demonstrated that the effect could be substantial.

Another issue that has been explored is possible inefficiency of using random tracklines in sighting surveys for species that have highly aggregated distribution patterns. For example, in 1996 Palka and Pollard (1999) conducted experimental harbour porpoise sighting surveys in the Gulf of Maine where they compared the operational and statistical efficiency of using random tracklines versus tracklines that adapt to the frequency of sightings. They demonstrated an 8% greater efficiency for the adaptive trackline survey, similar to what had been predicted theoretically (Pollard and Buckland 1997).

The development of sighting methodology continued in the 21st century with its focus on management of commercial whaling, but now also with attention to additional management settings, especially aboriginal whaling, scientific permit whaling and fishery by-catch of cetaceans.

21st Century

The developments in sighting methodology shifted somewhat in the 21st century as the management issues changed and other management contexts became important. For example, The US and the EU began to focus on management of fisheries by-catch of cetaceans. In addition to ongoing interest in management of commercial whaling, the IWC began to also focus on more active management of aboriginal whaling. At the same time, the NAMMCO Scientific Committee began to respond to requests for management advice for fin and minke whales around Greenland and the Faroes. In this decade methods of collection and interpretation of sightings data more appropriate to unique aspects of those management settings were addressed.

Fishery by-catch of cetaceans

Within the U.S. and Europe the need for scientific advice on managing fishery by-catch of cetaceans has become increasingly urgent. In the U.S., this has been addressed through variations on a formula that sets limits as a proportion of estimated abundance, where the proportion depends primarily on the precision of the abundance estimate itself, and specifically does not depend on the historical status of the populations (Wade 1998). The targets limits set are then considered in the context of formal discussions among fishermen, scientists, managers and interested public. This approach does not depend on knowing the history of by-catch, information that is seldom available because of the lack of a landed catch. The potential success of this approach of setting by-catch limits depends critically on the adaptive consultation process. In Europe approaches that are similar to the US's have been adopted, for example by the ASCOBANS, although a parallel legal context has not been established. In many of these cases (*e.g.*, NOAA 2002, Berggren *et al.* 2002) the estimates being used have substantial downward bias. If the constraints on by-catch levels that are being set constrain fisheries, then there would likely to be greater effort at developing abundance estimation methods that are less biased. In other settings, for example the by-catch of dolphins in the eastern tropical Pacific tuna purse seine fisheries, the question is not setting limits but rather monitoring population recovery. Here there is little incentive to improve data collection of analysis methods, unless the improvements can be retrofitted to the data from the now quarter of a century of sighting survey data. Instead, the incentive is to maintain consistency over time so that biases are consistent and trends can be accurately detected.

Whaling

The IWC had not placed a moratorium on aboriginal whaling, and the Scientific Committee began to address a long-standing concern about the adequacy of the scientific basis for some such whaling operations. Following the success of the Committee in developing the RMP, there was interest in the Commission and the Scientific Committee to develop a parallel approach for aboriginal whaling. This would occupy the early part of the first decade of the 21st century, and would draw on sightings based estimates of abundance for both California gray whales and western Arctic bowhead whales, estimates that had been under development since the 1960s and the 1980s, respectively (see above). The approach that was eventually adopted by the Committee for those two species (IWC 2003, p. 23, IWC 2005) also relied on catch history, and biologically significant whaling had begun for both species in these areas substantially before whaling catches had been systematically recorded in the 20th century. Whaling on both groups of animals had a long history and this could be reconstructed to some degree based on archaeological observations. Further, for both groups of animals, American open-boat whaling had nearly decimated the populations by the end of the 19th century. The analyses of early and pre-20th century historical documents that the Scientific Committee had initiated in the late 1970s (Tillman and Donovan 1983) had become important as the management basis for aboriginal whaling had been developed in the 1980s and 1990s. The Aboriginal Whaling Management Procedure (AWMP) codified how such data should be used, and that work has set the approach that the Committee would take in determining the status of other now depleted whale populations subjected to aboriginal whaling. However, the IWC continued to have difficulties addressing Greenland whaling for fin and minke whales under this scheme, and the NAMMCO Scientific Committee began to provide management advice for these species as well as humpbacks off Greenland using more traditional forms of management advice based on current abundance relative to carrying capacity (*e.g.* NAMMCO 2007).

The IWC Scientific Committee also continued to respond to questions about the implementation of its Revised Management Procedure in different areas, despite the fact that the IWC has not lifted the moratorium. For this reason, the IWC Scientific Committee and for other reasons the NAMMCO Scientific Committee have focused on extending methods for analysis of sightings data. One particular focus has been in developing methods for estimating whale abundance by area. This arose, for example, for minke whales in the North Atlantic and the Antarctic because it became apparent that any future catch limits should be set to spread whaling spatially. Simple contouring methods of estimating relative density patterns had been found unsatisfactory, for example in not allowing the estimation of sampling uncertainty for the abundance estimates. More sophisticated methods of spatial analysis were developed through an interaction between the IWC and the NAMMCO Scientific Committees, especially in the context of interpreting the long term results of the NASS North Atlantic and the IDCR Antarctic surveys. Although some substantial advances have been made, further development is required (IWC 2005). Despite the difficulties experienced with this issue, the Scientific Committee nonetheless was able to agree on the details of using the RMP for both North Pacific minke and Bryde's whales, and to revise the details for minke whales in the eastern North Atlantic. All of these implementations depended heavily on sighting surveys, and one might expect further developments of data collection and analysis methods.

However, despite the development of the IWC's Revised Management Procedure and the technical capability of implementing it using sighting surveys, whaling has been conducted in the 21st century under catch limits set not according to the RMP, but rather set by national governments using a variety of *ad hoc* approaches. For example, Japan has continued whaling in the North Pacific and the Antarctic under the provision of the IWC allowing for research catches under scientific permits, and levels of take have been set independent of abundance estimates. Similarly, Norway has set increasing catch limits in the North Atlantic under its objection to the moratorium, limits that have increased more rapidly than have the corresponding population estimates. Both of these developments have resulted in expansions of whaling both in numbers of animals and the range of species being taken. However, these expansions are not based on data on abundance as much as on a different balance of management objectives. Because abundance estimates are not the primary basis for management goals in either case, there is little reason to expect substantial developments in methods of estimating abundance under the present situation.

DISCUSSION

Declining rates of encountering whales were noted by whalers throughout the 19th century, and these declines became the first indication that whaling was adversely affecting whale abundance. These rates were used by the managers of 19th century whaling to direct their ships towards or away from specific whaling grounds. They were also used in the 20th century, for example by Japanese whalers sending scouting vessels out in advance of the whaling fleet. The development of methods of interpreting encounter rate data occurred in the context of the development of methods of managing a high profile industry that was seen by the mid-20th century to be out of control and depleting the very whale populations that it depended on.

Initial attempts in the 1940s to use sighting rates from oceanographic research vessels for understanding the size and changing size of whale populations proved difficult both politically and scientifically. This was especially true because there were insufficient data, as vessel time was limited, and because the species of the whales sighted was difficult to identify from such platforms. In the 1960s attempts to utilize not sightings but catches by whaling fleets were initially more successful, following methods termed catch per unit effort that had been used in finfish fisheries since early in the 1900s. Those analyses provided a stronger footing for advice on managing whaling, but included the seeds of their own destruction. It was recognized that implementing the catch limits implied by the results would reduce whaling to a degree that it would undermine the very source of such data. Further, although results of the analysis of catch rates were not surprising, the inference was arguably not strong. Whalers in fact did not randomly encounter whales, but rather searched using both historical and in some cases contemporary knowledge of whale locations. Thus catch rates would not be expected to decline as rapidly as had the populations, a necessary assumption of the analyses using these data. Similarly, catch rate data was even more complex for fisheries that had by-catches of cetaceans, situations that began to be identified as a problem in the 1970s.

The development of methods of collecting and analyzing encounter rate data continued and became increasingly interwoven with the development of the management of whaling and cetacean by-catches in fisheries throughout the world, but especially within the context of the Scientific Committee of the International Whaling Commission. However, it was sighting rate data collected aboard fishery independent surveys that ultimately became the basis for the IWC's committee's scientific advice on whaling and for management advice in other settings. This lead to the development of large scale cetacean sighting programmes, such as the IWC's International Decade of Cetacean Research surveys in Antarctic aboard Japanese ships, the North Atlantic Marine Mammal Commission's North Atlantic Sighting Surveys from 1995, the US National Oceanographic and Atmospheric Surveys, for example for dolphins in the eastern tropical Pacific, and surveys under the European Union's and ASCOBANS' leadership, for example the SCANS surveys in the North Sea.

The development of methods was a story of gradually overcoming the many uncertainties that were identified about the process of sighting cetaceans. This work was funded by national and international research groups that had strong interests in the management of human impacts on cetaceans. Thus those uncertainties that had greatest relevance to developing management issues were addressed more strongly, and progress was critically dependent on this interest. We can anticipate less development in the future than we have seen in the last few decades because of reduced need for improving the reliability of abundance estimates. In some cases this is because the information we have is sufficient for management purposes while in other cases management decisions no longer depend directly on abundance estimates.

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