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Assessing Gray Whale Abundance: A Review

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Introduction

Recent estimates of gray whale abundance from two parts of the population's range are quite different in magnitude. Shore station censuses conducted during the north and south migrations range from about 15,000 to 20,000 for 1978 through 1980 (Chapters 10 and 13, this volume; Poole, 1984; Reilly *et al.*, 1983). The most recent estimate from an aerial census of the winter grounds is 7,600 for 1981 (Rice *et al.*, 1983). This is close to winter range estimates from the early 1970s (approximately 7,000 from Gard, 1974, 1978). The twofold disparity between estimates from different areas is an apparent dilemma. The two census types use different methods for data collection, different assumptions to infer total abundance, and have different problems.

This chapter reviews the history of gray whale population assessment and the methods and assumptions used by the two primary techniques. Estimating gray whale abundance is a difficult problem throughout their range. Each geographic–seasonal area presents specific difficulties, necessitating field and analytic techniques tailored to deal with differences in local abundance, distribution, habitat, and temporality of occupation. Neither assessment method is fully verified in its present state. (My personal bias favors the shore counts as being nearer to verification.) The winter range estimates

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are probably too low, but it is uncertain by how much. The shore station estimates are too high if gray whales in migration slow their rate of travel at night. There are reasonable scenarios under which the data from both locations can indicate similar population sizes.

In the following pages I first review the winter range assessments, then those from along the migratory route. Finally, I suggest how alterations in some of our assumptions for which little data exist can result in comparable population estimates from the data on hand.

Winter Range Assessment

On their winter grounds, gray whales occupy a vast area. The known range includes a number of physiographic settings within major and minor lagoons, near and offshore from lagoon entrances, and offshore zones throughout much of the west coast of the Baja Penninsula (Scammon, 1874; Gilmore, 1960; Rice *et al.*, 1981, 1983), parts of southern California (Chapter 14, this volume) and mainland Mexico (Gilmore *et al.*, 1967). Each subsection of each lagoon and alongshore area potentially requires individual and intense study for the design and execution of surveys of abundance.

Most winter range surveys have been made in small aircraft. Whales observed in the nearshore zone and within the lagoons were recorded (Gilmore, 1960; Hubbs and Hubbs, 1967; Gard, 1978; Rice *et al.*, 1981, 1983). The resulting raw data have consisted of counts per lagoon or per alongshore stretch. For abundance estimation, the problem is inferring total population size from these counts. This is essentially the same problem in any wildlife sighting survey, but the Baja situation presents some unique problems.

HISTORY AND METHODS

The history of population assessment on the winter grounds has been briefly outlined by Gard (1978), Rice *et al.* (1981), and Storro-Patterson (1981). Table I and the discussion which follows were drawn largely from those sources and from the original papers for some details.

There have been at least 21 separate aerial surveys of some portion of the winter range between 1952, when Carl and Laura Hubbs (1967) began the enterprise, and one in 1981 conducted by Rice *et al.* (1981, 1983) (Table I). Rice *et al.* (1981) stated that the winter range survey data are not comparable over time because of unstandardized field and analytic techniques, and I agree. The surveys were flown over varying portions of the winter range, along different track lines, at different times, and at different altitudes in varying visibility conditions, and so forth. Data treatment in analysis has been similarly nonstandardized.

This is not meant to depreciate past winter range aerial surveys. In the context of its time, each series contributed significantly to our knowledge. Our present understanding of the vastness of the area inhabited, and the complexity of the task of assessing abundance there, has emerged slowly. The logistic constraints (e.g., fuel limits, lack of

Table I
Aerial Censuses of Gray Whales on the Winter Range

Dates	Observers	Areas surveyed[a]	Verification[b]	Source
1952 (Feb. 16–20)	Hubbs and Hubbs	1,2		Gilmore (1960)
1953 (Feb. 25–27)	Gilmore	1,2		Gilmore (1960)
1953 (Jan. 31–Feb. 4)	Rechnitzer	1,2		Gilmore (1960)
1954 (Feb. 14–21)	Hubbs and Hubbs	1,2		Gilmore (1960)
1954 (Feb. 1–7)	Gilmore	1,2,4		Gilmore (1960)
				Gilmore *et al.* (1967)
1955 (Feb. 26–Mar. 3)	Gilmore	1,2,4		Gilmore *et al.* (1967)
1956 (Feb. 14–17)	Gilmore	1,2,4		Gilmore *et al.* (1967)
1957 (Feb. 27–Mar. 3)	Gilmore	1,2,4		Gilmore *et al.* (1967)
1959 (Feb. 20–26)	Hubbs and Hubbs	1,2		Hubbs and Hubbs (1967)
1960 (Feb. 18–21)	Hubbs and Hubbs	1,2		Hubbs and Hubbs (1967)
1961 (Feb. 25–27)	Hubbs and Hubbs	1,2		Hubbs and Hubbs (1967)
1961 (Feb. 23)	Harrison	4		Gilmore *et al.* (1967)
1962 (Mar. 8–22)	Harrison	4		Gilmore *et al.* (1967)
1962 (Feb. 18–21)	Hubbs and Hubbs	1,2		Hubbs and Hubbs (1967)
1963 (Feb.–Mar. ?)	Harrison	4		Gilmore *et al.* (1967)
1964 (Feb. 20–24)	Hubbs and Hubbs	1,2		Hubbs and Hubbs (1967)
1965 (Jan. 3–Apr. 20)	Harrison	4		Gilmore *et al.* (1967)
1966 (Mar. 6–27)	Harrison	4		Gilmore *et al.* (1967)
1970 (Jan. 31–Feb. 1) and Mar. 4)	Gard	1		Gard (1974)
1973 (Feb. 27–28, Mar. 4)	Gard	1		Gard (1974)
1974 (Feb. 14–22)	Gard	1,2		Gard (1978)
1975 (Feb. 15–27)	Gard	1,2	1	Gard (1978)
1976 (Feb. 11–19)	Gard	1,2	2	Gard (1978)
1980 (Jan. 17–Mar. 28)	Swartz and Jones	5	3	Swartz and Jones (1980b)
1980 (Feb. 4–15)	Rice *et al.*	1,2	1,3	Rice *et al.* (1981)
1981 (Feb. 5–15)	Rice *et al.*	1,2,3	4	Rice *et al.* (1983)
1981 (Feb. 23–25)	Swartz and Jones	5	3	Swartz and Jones (1981)

[a]Areas: (1) nearshore Baja west coast, (2) calving lagoons, (3) offshore zones, (4) mainland calving areas, (5) Laguna San Ignacio only.

[b]Verification: (1) air versus lagoon tower, (2) ground-based behavioral observations for aerial correction factor, (3) air versus lagoon boat, (4) air versus offshore boat.

radio contact in case of emergency) imposed on anyone venturing to fly down Baja in a small plane in the 1950s and early 1960s effectively precluded offshore ventures and repetitious patterns over any one area (R. M. Gilmore, personal communication).

The early surveys conducted by Hubbs and Hubbs (during 1952, 1954, 1959, 1960, 1961, 1962, and 1964) and Gilmore (during 1953, 1954, 1955, 1956, and 1957) were pioneering efforts. However, the details of their efforts and methods are not made entirely clear in the published literature (e.g., Hubbs and Hubbs, 1967; Gilmore, 1960). They reportedly flew the entire coast from San Diego to the Cabo San Lucas area and over the major calving lagoons, tallying the whales seen. Hubbs and Hubbs (1967) discussed many potential sources of error and inconsistency in the methods used, including different aircraft, varying visibility conditions, dates surveyed, and number and experience of persons involved.

Gilmore (1960) gave a year-by-year summary of some further details of the early aerial censuses, enough to lend the reader a sense of the variation in methods used. Gilmore (1960, p. 29) also stated that early aerial surveys of the winter grounds were unreliable for estimating population size: "Because the air-survey method introduced many variable factors, and information needed to apply corrections was not available, it is unwise to estimate the size of the total population on air-survey data."

Although the early efforts conducted no ground-based verification experiments, it was acknowledged that many whales were not seen from the aircraft. Gilmore (1960) speculated that "About one-fourth of the whales beneath the plane could perhaps be seen by the observers at any one time." Hubbs and Hubbs (1967) assumed that "about half of the total population was observed in the area covered, and that almost all the individuals were concentrated in that area at the time of the counts . . ."

After a lapse of 5 years following the 1964 Hubbs survey, Gard (1974, 1978) conducted a series of six surveys in 1970 and in 1973 through 1976. In 1970 and 1973, only the major lagoons were surveyed; in later years coverage included the "entire western shore of Baja California." The distance offshore was not reported nor were full details on data-recording protocol. For the first time, separate censuses were made outside the entrances to the major lagoons to 3 km (1.8 mi) offshore. Gard's surveys were conducted during varying time periods in February and March. As with the earlier aerial surveys, track lines flown at each location, dates, and times of day were not reported. Consequently, it is not possible to determine to what extent his surveys were replicates of each other or of earlier attempts.

Gard was the first to address the problem of extrapolating from recorded counts to the total numbers present by directed data collecting during the winter ground surveys. He estimated the proportion of time gray whales spend at the surface, to determine what proportion might be missed by passing aircraft. Gard also compared his aerial estimates for Laguna Ojo de Liebre with ground-based counts made by White (1975). These verification experiments are discussed further in the section Assumptions and Summary (Winter Range).

In 1980 and 1981, Rice *et al.* (1981, 1983) conducted winter range aerial censuses, including the nearshore area between San Diego and Boca del Colorado (24° 20′N) and the known Baja calving areas. They also surveyed offshore areas in the large bays. To verify the overall surveys, tower, small boat, and aircraft studies were made in and near Laguna Ojo de Liebre in 1980. In 1981 they conducted a vessel survey of Vizcaino Bay during the same period as the aerial survey of that area. In both years replicate surveys were made of Lagunas Ojo de Liebre, Guerrero Negro, and San Ignacio. Dates, locations, and other details of survey segments were reported.

No estimate of population total was made by Rice *et al.* (1981) for the 1980 census, as the survey was considered exploratory for determination of total range and relative importance of areas within the range. A limitation of the 1980 (and 1981) surveys by Rice *et al.* is their southern termination at Boca del Colorado near Magdelena Bay. Both Norris *et al.* (1983) and Storro-Patterson (1981) report sighting congregations of gray whales in the Cabo Falso–Cabo San Lucas Region [174 were actually sighted by Norris *et al.* (1983)].

Rice *et al.* conducted the 1981 survey using three methodologies and related analysis schemes: "systematic transects" of open areas followed predefined straight parallel lines. Data were analysed as strip censuses for density estimates and variances; "coastline transects" were made along most of the outer coast covered. Only raw counts were used, and no extrapolations were made from these data; "channel transects" were made along narrow lagoon channels by flying along the channel sides so that its entire width was visible from one side of the plane. Again only raw counts were used for the population estimates, with no extrapolations for whales missed.

Total population estimates were made by Rice *et al.* (1983) for both adults and calves. For adults, statistical estimates from "systematic" transects were summed with raw counts from coastline and channel transects to produce an estimate of 7601.

Estimation of the number of calves was yet more complex, including ratio correction schemes for some areas and raw counts for others. The total estimate, summed from the combination of raw counts and various types of estimates, was 1439 calves. In relation to the estimate of 7601 "adults" by Rice *et al.* (1983), this indicates a crude birth rate near 19%. Other information, discussed below, suggests that either the "adult" estimate is too low or the calf estimate is too high, or both.

ASSUMPTIONS AND SUMMARY OF CURRENT STATUS

A list of factors affecting or involved in estimating total abundance from winter range aerial surveys is presented in Appendix A. This list is admittedly armchair in nature (and in extent), but I believe that all of the points mentioned require at least minimal attention before we can have a great deal of confidence in population estimates from the winter range. Fortunately, many of these points have been or are being addressed by past or present research. A quantitative synthesis of the winter range assessment situation is the most outstanding current need. Some of the verification work done to date is discussed in the following sections.

Behavior

A considerable amount of information on behavior has been accumulated by ground-based research projects in the calving lagoons: in Laguna San Ignacio (LSI) by

Swartz and Jones (1978, 1980a,b, 1981, this volume); in Laguna Guerrero Negro (LGN) by Bryant *et al.* (this volume); in Laguna Ojo de Liebre (LOL) by Rice *et al.* (1981, 1983), Fleischer (1984), and White (1975); and by Norris *et al.* (1977, 1983) in and near Magdelena Bay.

In conjunction with his overall surveys, Gard (1978) timed the above- and below-surface occurrence for 25 groups of whales for a minimum of 3 min each, in and outside of LSI and LOL. Pooling the data by location and type of social group (cow–calf versus others), Gard estimated that gray whales on average spent 29.7% of their time at the surface. Consequently he multiplied observed aerial counts by a factor of 1/0.297 or 3.37.

Recent attempts by S. L. Swartz and M. L. Jones (personal communication) to replicate this study in LSI met with severe logistic problems. They found it extremely difficult to identify and follow individuals or groups for periods sufficiently long to record meaningful data. According to Swartz and Jones, a wide variety of types of behavior can be noted from any one vantage point, ranging from rapid traveling to quiescent lolling. They found surface times in general to be markedly variable in the lagoons. Consequently, the use of the mean surface time as a correction factor without considering its variance is questionable.

Much less detailed observation has been made outside the lagoons, where Rice *et al.* (1981, 1983) recorded nearly 70% of the whales observed in their survey during the peak occurrence period in February. Rice *et al.* (1983) performed a ship-based strip transect survey in Vizcaino Bay (see below), and Norris *et al.* (1983) recorded occurrences and some behavioral observations at the entrance to the Magdalena Bay complex. We now need additional detailed, systematic observations on behavior outside the lagoons in open coast and other areas of whale concentration which emphasize age, sex, temporal, and physiographic differences in activity. These data are necessary to determine if whales in along shore regions are differentially "available" to our observation from passing survey aircraft, and how much variability should be expected from replicate flights over each area.

Geographic Distribution

As recent surveys have expanded their efforts, new, and in some cases large, concentrations of whales have been seen in previously under- or unsurveyed areas: Vizcaino Bay is one example. Even the latest surveys probably did not cover the entire winter range.

It is apparently appropriate to consider the winter range as extending from about Point Conception in the north to Cabo San Lucas, including the Gulf of California and parts of the Mexican mainland (Chapter 14, this volume). In February when the Baja occupation is at its peak, there are still a few individuals passing Monterey (California) both north and southbound. There is probably no one time when the entire population is between San Diego and Magdalena Bay, the termination points of the latest surveys. There has been considerable coverage of smaller scale distribution in and near the major calving areas.

Interplatform Comparisons

Aerial to ground comparisons have been made for LOL and Vizcaino Bay (Gard, 1978; Rice *et al.*, 1981, 1983), and LSI (Swartz and Jones, 1981). Gard (1978) first compared counts obtained from the air and on the ground, for LOL. For a comparison period in mid-February 1975, he estimated 2013 adult whales inhabited LOL. For approximately the same period, White (1975) estimated 1963 as the adult population within LOL. This is compared to a February 1980 estimate of 895 for LOL by Rice *et al.* (1981).

That the aerial and land estimates were within 3% suggests either that both Gard (1978) and White (1975) had developed accurate assessment procedures or that the procedures perhaps were similarly biased. Even with the benefit of hindsight, it is not yet possible to distinguish between these possibilities, but some points regarding their methods are worth considering.

First, White's (1975) method consisted of monitoring the lagoon entrance from a tower for varying periods per day and week, subtracting weekly average exits per hour from average entrances per hour and multiplying the difference by 168 hr/week. Recent, similar observations of all daylight hours for 7 days per week (Rice *et al.*, 1981) have shown a great deal of variation in turnover rates. This and other lagoon studies (Swartz and Jones, 1978, 1980a,b, 1981; Norris *et al.*, 1977, 1983) suggested that turnover rates are probably more reflective of tidal fluxes and visibility conditions than actual abundance of whales in the lagoons. Second, Gard's (1978) aerial data also showed a great deal of variation between replicate surveys of the same areas. Third, as discussed above there is some question regarding estimation of the surface time statistic and its use as a correction factor.

In the lagoon comparisons, small single-engined aircraft were the principal platform. Because of this, results may not be equally applicable to the larger twin-engined aircraft (which were used for the comprehensive surveys) due to possible differences in visual perspective from the two types of planes. If air speed and altitude are not duplicated, this would exacerbate any such lack of comparability.

Visibility Conditions

Rice *et al.* (1983) found that weather and visibility conditions had a major effect on sighting efficiency in their repeated vessel and aerial censuses of Vizcaino Bay. Their results implied that other censuses made in less than adequate visibility conditions, such as nearly every afternoon on the Baja west coast when the strong prevailing wind blows, are probably negatively biased. I am aware of no other winter range data which represent visibility effects on census results.

In summary, the recent surveys have made notable progress toward an effective, standardized field methodology for estimating gray whale abundance on the winter range. We now need (1) a survey effort that covers the entire range and somewhat beyond to effectively define its limits. Further refinement of area- and time-specific field methods would also contribute to a reliable data base. (2) A more rigorous analytic methodology is also needed. All counts from an airplane are in fact estimates, with inherent variance. The basic properties, at least, of each type of estimate must be defined before they can be combined to give crudely comprehensive estimates of total and variance.

There are many nontrivial problems involved in the development of a more rigorous analytic methodology for the Baja survey situation, and much difficult work remains. Some important points which have emerged from winter range surveys to date are (1) aircraft are necessary to cover the entire area in a short time, but censuses from them systematically underestimate whale presence; and (2) interreplicate variation is high and is greatly affected by visibility conditions.

Migratory Route Assessment

Gray whales travel very close to shore, especially during their southward trek from feeding to calving grounds (Pike, 1962; Rice and Wolman, 1971). It is consequently feasible to census, from strategic points, whales passing during daylight hours. As with winter range aerial surveys, the essence of the resulting estimation problem is inferring total population size from recorded counts. There are still a number of problems to confront when inferring population size from these data, but the magnitude and scope of these problems is considerably smaller and more tractable than those resulting from winter range aerial surveys. The relative simplicity results largely from having only one site's complexities to deal with and not having to rely on instantaneous glimpses from airplanes for measuring absolute abundance. Also, the vast majority of the population is likely to pass a location that is well chosen.

HISTORY AND METHODS

An outline summary of in-migration censuses is presented in Table II. Townsend (1887) reported the first shore census of migrating gray whales from a sighting effort that was limited to December, 1885. Townsend identified three of the basic problems common to all shore counts made to estimate total abundance: How many whales pass unseen at night? on days before and after the census? too far offshore to be seen? Regarding his observed total, Townsend stated "What proportion this number bears to the number passing offshore would be hard to say, but it is certainly less than half. . . ."

Carl Hubbs, of the Scripps Institution of Oceanography in La Jolla, organized the next attempts at censusing southbound migrating gray whales 61 years later, in 1946–1947 (Walker, 1949). These counts, made by students from a campus rooftop, were continued through 1951–1952 (skipping 1950–1951). The details of effort expended are not clear in the published accounts (Walker, 1949; Gilmore 1960). The recorded annual counts were 250, 500, 600, 600, and 880, respectively.

During 1952–1953, the U.S. Fish and Wildlife Service conducted censuses of southbound migrating gray whales from San Diego, supervised by Dr. Raymond Gilmore (1960). Point Loma was the principal census site, although some concurrent censusing was done at La Jolla. These early San Diego censuses are of questionable utility as measures of population abundance for a number of reasons. By the mid-1960s, it became clear that a large (but as yet undefined) proportion of southward migrating whales passed far offshore through the Southern California Bight (Rice, 1965). This

Table II
Shore Station Censuses of Gray Whales

Dates	Migration direction	Observers	Location	Source
1885–1886 (December)	S	C. H. Townsend	San Simeon, California	Townsend (1887)
1946–1947 (Dec.–Jan.?)	S	Hubbs and students	La Jolla, California	Gilmore (1960); Walker (1949)
1947–1948 (Dec.–Jan.?)	S	Hubbs and students	La Jolla, California	Gilmore (1960); Walker (1949)
1948–1949 (Dec.–Jan.?)	S	Hubbs and students	La Jolla, California	Gilmore (1960); Walker (1949)
1949–1950 (Dec.–Jan.?)	S	Hubbs and students	La Jolla, California	Gilmore (1960); Walker (1949)
1951–1952 (Dec.–Jan.?)	S	Hubbs and students	La Jolla, California	Gilmore (1960); Walker (1949)
1952–1953 (Dec. 15–Feb. 15)	S	Gilmore	Pt. Loma and La Jolla	Gilmore (1960)
1953–1954 (Dec. 15–Feb. 15)	S	Gilmore	Pt. Loma and La Jolla	Gilmore (1960)
1954–1955 (Dec. 15–Feb. 15)	S	Gilmore	La Jolla	Gilmore (1960)
1955–1956 (Dec. 15–Feb. 15)	S	Gilmore	La Jolla	Gilmore (1960)
1956–1957 (Nov. 2–Mar. 25)	S	Gilmore	La Jolla	Gilmore (1960)
1959–1960 (Dec. 14–Feb. 22)	S	Gilmore	La Jolla	Rice (1961)
1966–1967 (Nov. 27–Feb. 17)	S	Adams	Point Lobos, California	Adams (1968)
1967–1968 (Dec. 18–Feb. 3)	S	Rice and Wolman	Yankee Point, California	Reilly *et al.* (1983)
1967–1968 (Dec. 18–Feb. 5)	S	Rice and Wolman	Point Loma	D. W. Rice and A. A. Wolman (unpublished)
1968–1969 (Dec. 10–Feb. 6)	S	Rice and Wolman	Yankee Point	Reilly *et al.* (1983)
1968–1969 (Dec. 20–Feb. 14)	S	Rice and Wolman	Point Loma	D. W. Rice and A. A. Wolman (unpublished)
1969–1970 (Dec. 8–Feb. 8)	S	Rice and Wolman	Yankee Point	Reilly *et al.* (1983)
1970–1971 (Dec. 9–Feb. 12)	S	Rice and Wolman	Yankee Point	Reilly *et al.* (1983)
1971–1972 (Dec. 18–Feb. 7)	S	Rice and Wolman	Yankee Point	Reilly *et al.* (1983)
1972–1973 (Dec. 16–Feb. 16)	S	Rice and Wolman	Yankee Point	Reilly *et al.* (1983)
1973–1974 (Dec. 14–Feb. 8)	S	Rice and Wolman	Yankee Point	Reilly *et al.* (1983)
1974–1975 (Dec. 10–Feb. 7)	S	Rice and Wolman	Yankee Point	Reilly *et al.* (1983)
1975–1976 (Dec. 10–Feb. 3)	S	Rice and Wolman	Granite Canyon, California	Reilly *et al.* (1983)
1975–1976 (Dec. 15–Feb. 11)	S	Rice and Wolman	Point Loma	D. W. Rice and A. A. Wolman (unpublished)

(*continued*)

Table II (*Continued*)

Dates	Migration direction	Observers	Location	Source
1976–1977 (Dec. 10–Feb. 6)	S	Rice and Wolman	Granite Canyon	Reilly *et al.* (1983)
1976–1977 (Dec. 15–Feb.?)	S	Rice and Wolman	Point Loma	D. W. Rice and A. A. Wolman (unpublished)
1977 (?)	N	Hall *et al.*	Unimak Pass, Alaska	Hall *et al.* (1977)
1977 (Nov. 20–Dec. 9)	S	Rugh	Unimak Pass, Alaska	Rugh and Braham (1979)
1977–1978 (Dec. 15–Feb.)	S	Rice and Wolman	Point Loma	D. W. Rice and A. A. Wolman (unpublished)
1978 (Nov. 7–Dec. 20)	S	Rugh	Unimak Pass	Rugh (Chapter 10, this volume)
1978–1979 (Dec. 2–Feb. 1)	S	Herzing and Mate	Newport, Oregon	Herzing and Mate (Chapter 12, this volume)
1978–1979 (Dec. 10–Feb. 8)	S	Rice and Wolman	Granite Canyon	Reilly *et al.* (1983)
1979–1980 (Oct. 31–Jan. 3)	S	Rugh	Unimak Pass	Rugh (Chapter 10, this volume)
1979 (Feb. 27–?)	N	Herzing and Mate	Newport, Oregon	Herzing and Mate (Chapter 13, this volume)
1979–1980 (Dec. 11–Feb. 4)	S	Herzing and Mate	Newport, Oregon	Herzing and Mate (Chapter 13, this volume)
1979–1980 (Dec. 10–Feb. 6)	S	Rice and Wolman	Granite Canyon	Reilly *et al.* (1983)
1980 (Feb. 21–?)	N	Herzing and Mate	Newport, Oregon	Herzing and Mate (Chapter 13, this volume)
1980 (Mar. 10–May 31)	N	Poole	Piedras Blancas	Poole (Chapter 16,this volume)
1980–1981 (Dec. 10–Feb. 9)	S	Herzing and Mate	Newport, Oregon	Herzing and Mate (Chapter 13, this volume)
1981 (Feb. 22–?)	N	Herzing and Mate	Newport, Oregon	Herzing and Mate (Chapter 13, this volume)
1981 (Feb. 9–May 30)	N	Poole	Piedras Blancas	Poole (Chapter 16, this volume)
1981 (Mar. 23–Jun. 17)	N	Hessing	Unimak Pass	Hessing (1983)

proportion may have changed throughout the years, in response to increasing levels of boating and other human activities nearshore (Gilmore, 1978a). The method used to correct for whales missed due to poor visibility was rather arbitrary for the first 3 years, being based on a subjective appraisal of the percentage reduction in visibility each day. Effort expended varied between years. For these and other reasons (discussed in Reilly,

1984) it is inadvisable to look to the early Point Loma censuses for accurate measures of abundance. However, through trial and error these early shore censuses did establish much of the basic field methodology that was used by subsequent censuses through the 1979–1980 Monterey study.

Five more censuses were conducted at Point Loma between 1967–1968 and 1977–1978. Although field and data recording procedures were well systemized in those years, including detailed observations on visibility conditions, these data are also of questionable accuracy because of the unknown proportion passing offshore.

In 1966–1967, Adams (1968) conducted a fall census from Point Lobos, near Monterey, California. Rather than censusing all day during each day of the migration, he counted only during periods of good visibility and when convenient (his was a privately conducted and funded venture). The period of November 27 through February 17 reported includes the full duration of the southern migration near Monterey (Reilly *et al.*, 1980). Actual effort expended and raw counts are not reported. From average counts during hours watched, Adams extrapolated over the remainder of the day. The method sounds reasonable, but the results are questionable. A histogram (his Fig. 1) shows a maximum of about 55 whales per hour counted, with a number of days above 40/hr on average. This is almost certainly too high. In the highest days during the 13-year NMFS Monterey series, the average observed daily count was never more than 25 whales/hr. In no single hour did more than 30 whales pass the station (Reilly, 1981). Using arbitrary extrapolations of 70% daylight count for whales passing at night and 5% for whales passing offshore, Adams estimated the total population in 1966–1967 to be 18,300. As with the average hourly count, this is probably too high. The upper 95% confidence limit for the 1967–1968 census from Monterey was only 15,597 (Reilly *et al.*, 1983). This comparison assumes that the Monterey census was unbiased.

In 1967–1968, Dale Rice and Allen Wolman of the Marine Mammal Laboratory (Seattle) began a 13-year series of consecutive annual censuses near Monterey, California. These censuses were made from Yankee Point until 1973–1974, and from Granite Canyon (3.7 km south of Yankee Point) in the remaining years. Boat traffic is at a minimum in the vicinity of these sites along the beginning of the "Big Sur" coast. Further, there are no nearshore islands which might divert some whales offshore, as suggested for the southern California Bight south of Point Conception (Rice, 1965; Gilmore, 1978b).

At Monterey, counts were conducted for 10 hours per day (the duration of daylight) during approximately 2 months each year. Estimates were recorded of the number of whales present in each passing group and the distances of the groups offshore. Details of visibility conditions were also recorded. Areas considered in abundance estimation included the effects of varying visibility conditions, observer accuracy in estimating the number within and distance to passing pods, whales missed as a function of their distance offshore, those passing at night, and those passing before the first and after the last days of censusing. Raw counts recorded during 10 daylight hours ranged from a low of 2,667 in 1971–1972 to a high of 4,924 in 1979–1980. For this final year the "best estimate" of total abundance was 15,647, with 95% confidence limits of 13,450 and 19,201. (Confidence limits refer to precision here and assume an unbiased estimate.)

In November and December of 1977, 1978, and 1979, David Rugh conducted censuses from Cape Sarichef in Unimak Pass, Alaska (Rugh and Braham, 1979; Chapter 10, this volume). This is the point at which the population filters into and out of the Bering Sea. The first season comprised only 20 days during which 2,055 whales were observed in 82.6 hr of systematic watch. During 1978 and 1979, the duration of the census was extended in an attempt to cover the entire migration. Mean counts recorded those years were 5,050 and 4,061. Rugh also conducted experiments to verify some of the assumptions necessary to extrapolate to total population size. As with the California censuses, the most important estimation problem regarded the number of whales passing at night (approximately 16 of 24 hr at Unimak Pass are in darkness during November and December). Other areas considered but not applied to the abundance estimation included the "tails" of the migration, whales missed due to varying visibility and storm conditions, offshore distribution, differences among observers, and accuracy in counts even in ideal conditions. A "best estimate" was given for 1978 only of approximately 17,000.

The first attempt to census northbound gray whales during their spring migration was made by Hall *et al.* (1977) at Unimak Pass in 1976. The duration of the spring migration, nearly 4 months, makes it more difficult to census than the 2-month (or less) fall migration. The duration of the Hall *et al.* census was less than 2 months, and they estimated that only 9000 whales passed into the Bering Sea during the census.

During 1978, 1979, and 1980, counts were conducted by Herzing and Mate (Chapter 13, this volume) (of Oregon State University) from Yaquina Head in Newport, Oregon. They surveyed both north- and southbound whales, observing only on a "sampling" basis during good conditions in daylight hours. Population estimates were made from southbound counts only. Raw counts were 253 in 1979–1980 and 653 in 1980–1981 (actual effort was not reported). Estimates for 1980 ranged from 13,627 to 21,854, depending upon factors corrected for. The minimal figure considered whales missed due to lack of effort during all night and some daylight hours. The maximal figure included corrections for underestimating pod size and whales missed offshore.

During 1980 and 1981, Poole (1984; Chapter 16, this volume) conducted censuses of northbound migrants from Point Piedras Blancas along the central California coast, just north of San Simeon. In 1980, 1,496 whales were sighted during 659 hours of effort; during 1981, 3,296 were seen during 755 hours. Population estimates of 15,725 and 16,140 included corrections for whales passing at night, bias in estimating pod size, and whales passing too far offshore to be seen.

In 1981, Hessing (1983) conducted the second spring census at Unimak Pass. Between March 23 and June 17, 3,851 whales were sighted. From 2 to 10 of ~18 daylight hours were censused each day. Hessing estimated that 14,146 whales passed into the Bering Sea in 1981. A constant night travel rate was assumed, and no corrections were made for poor visibility conditions or for whales passing before and after the census.

ASSUMPTIONS AND SUMMARY OF CURRENT STATUS

Five major topics must be quantitatively addressed in order to estimate population size from shore station counts of migrating whales [Appendix B; see Reilly *et al.* (1983) for a more complete discussion].

Offshore Distribution

Most recent shore censuses have included verification of the offshore distribution of passing whales via aerial surveys [see "History and Methods" (Migratory Route)]. The offshore distribution appears to change during the course of the migration, both southbound (Reilly *et al.*, 1980) and northbound (Chapter 16, this volume). Consequently it is important that aerial observations be compared only to shore observations made at roughly the same time. Observers to date have assumed that all pods passing within some fixed distances are seen. The proportion assumed missed outside of this zone is corrected for by comparing the inshore proportions seen from aircraft and land. At Monterey the results indicated about 20% were missed for this reason (Reilly *et al.*, 1983); for the Newport, Oregon counts the estimate was 38% (Chapter 13, this volume); for Piedras Blancas, 28% during "phase a" only (Poole, 1984). For Unimak Pass in autumn, it was shown that few if any whales were missed solely as a function of their distance offshore (Chapter 10, this volume).

Migratory Timing

To quantify migratory timing, we fit a probability density function to the observed daily Monterey counts, for each year individually. This was useful to compare annual timing between years at one location and between locations for any one year. In assessment, the timing models were used to estimate population proportions passing on days with poor visibility (next section) and on days before and after the censuses.

For the Monterey censuses, extrapolations for whales passing before and after the field efforts increased the total estimates only by ~5% per year. For other censuses which cover a smaller proportion of the migration, estimating the tails is of greater importance. Rugh (Chapter 10, this volume) compared a core period of days between two years, estimating the tails of the earlier, less well-covered year by the ratio of the core periods (but did not estimate total abundance for the earlier year). Poole (Chapter 16, this volume) used a similar procedure for 2 years' data from Point Piedras Blancas. Herzing and Mate (Chapter 13, this volume) did not account for missed "tails" but their censuses may have been long enough for this not to matter.

Visibility Conditions

Lack of fit of the Monterey migratory timing models for any 1 day (after finding model parameters that produced the best overall fit) was highly correlated with visibility conditions, recorded in an ordinal scale (Reilly *et al.*, 1983). For days with conditions worse than "fair" on average, the predicted values from the probability function were used instead of the raw data to estimate the number of whales passing. If in fact there are daily pulses of whales passing the site, independent of weather, this method may bias the resulting estimate. The direction such a bias would take is difficult to predict.

Rugh (Chapter 10, this volume) used an empirical approximation of this method for the Unimak Pass data but worked on a finer time scale of hours rather than days. He noted drops in hourly rate by visibility code and corrected data from hours of "poor" and "unacceptable" conditions by interpolating between periods before and after. Others have used variations of this same technique (Rice, 1961; Poole, 1984; Chapter 13, this volume).

There should be no additional problems in resulting estimates of total abundance from the above visibility corrections, unless gray whales actually slow down during periods of poor visibility (as suggested by R. M. Gilmore, personal communication). If this is so, we are all overestimating population size by some amount which would vary by the method used and the amount of poor weather for which correction was made. The variance of the Monterey estimates increased proportionately with the number of poor visibility days, so this is at least partially reflected in the results for that site. Rugh (Chapter 10, this volume) used deviations from migratory course to suggest that gray whales do not slow down as a function of elevated Beaufort conditions. Perhaps some radio tracking or other electronic-based observation could help clear up the remaining ambiguity on this point.

Observer Accuracy and Precision

When an observer at a shore-based counting station records the passing of a whale or pod, at least two estimates are usually made: the number of individuals present and their distance offshore. To test a sample of "whale counters" for systematic biases in the above estimates, experiments were conducted at the Granite Canyon site during the 1978–1979 migration, involving independent estimates from a mixture of experienced and naive observers for 50 events of passing whales. Results from these experiments included (1) People vary widely in their accuracy and precision in estimating both number and distance; (2) even considering this variability, there are consistent (i.e., significant) biases for both estimates; (3) there is no benefit from experience in accuracy of distance estimation, although there is some benefit in precision. That is, over time a person is likely to become consistent in his inaccuracy if it exists (Reilly, 1981; Reilly *et al.*, 1980, 1983).

Correction for whales missed offshore (Section III,C,1) is confounded by any systematic inaccuracy in estimating distance to passing whales. For the Monterey data, such inaccuracy was detected and corrected for by redistributing the observed data according to results of the observer bias experiments. The overall change in the Monterey population estimates as a result of this correction was quite small. There are potential problems even with this correction before correction, relating to the range of between observer variability. This is discussed further in the following section.

Some results from the Monterey observer bias experiments have been applied to other surveys (Poole, 1984; Chapter 13, this volume). There are two possible problems with this, the first applicable to our original use as well. First, the "sample" of people was relatively small (12, 3 experienced and 9 naive). Second, the sample size of observed pods (50) was not large enough to allow partitioning of pod size estimates by distance to test for interaction. If such interaction exists, the results may not be applicable to sites with migratory corridors significantly different than those at the Monterey sites.

Night Travel Rate

The very limited data applicable to the determination of night travel rate were reviewed in Reilly *et al.* (1980) and Reilly (1981). Only indirect evidence exists: There are no systematically collected data of sufficient sample size which unequivocally measure night travel rate during migration. The indirect information available is more suggestive of a constant 24-hr rate than not, and most recent studies have assumed this (Reilly *et al.*, 1983; Poole, 1984; Chapter 13, this volume; Rugh and Braham, 1979). Rugh (Chapter 10, this volume) collected data using night-vision goggles at Unimak Pass. (These were not useful at Monterey because the whales were farther offshore there.) Two slightly different experiments were run during dusk, comparing sightings made with and without the goggles. These gave two different results. The whales either maintained their daytime rate or slowed to about 73% of that rate. Rugh chose the latter result in computing total abundance. Gilmore (1960, and personal communication) feels that gray whales slow at night in response to limited visual cues for orientation.

Because it is necessary to interpolate more than one-third to two-thirds of the total migration due to darkness (depending on season and latitude), estimation of whales passing at night is the single most important aspect of inferring abundance from shore counts. To date, it is not clear what migrating gray whales do at night or if this behavior changes between locations or between seasons. Considering the relative importance of this, and the relative paucity of our knowledge, it is instructive to investigate how our total estimates would change if gray whales slowed their travel rate at night by various hypothetical amounts. This topic is pursued in the following section.

Discussion

Both the winter range and in-migration censuses require further research before we can be reasonably assured of the accuracy of our population estimates. As stated, my personal bias favors the present estimates from shore counts over those from the winter range. Aside from this, there are reasonable scenarios in which the data from the two sites can indicate similar population estimates.

The following is an exercise in the nature of "what if"? It is not intended as a postulation that the true population size is at any particular value intermediate between shore and winter range estimates. Rather, I wish to demonstrate that within the regions of our uncertainty about night migration rate and the overall accuracy of winter range estimates, there are population sizes that are consistent with data from both sources.

All of the recent shore count estimates are relatively close, about 15,000 to 20,000 for 1980. This is not surprising in view of the essentially common assumptions and corrections used. If gray whales do slow down at night, our data would indicate a smaller population. I have used the 1980 Monterey estimate of 15,647 as an example to indicate how the population estimate would be reduced as a function of a reduced night travel rate (Table III). For example, if the animals traveled at 75% of the day rate, the estimate would be about 13,365. It is logically possible that gray whales speed up their

Table III
Total Population Size Estimates for 1980 from the Monterey Shore Census, as a Function of Hypothetical Night Travel Rates

If night rate is this proportion of day rate	The 1980 population estimate is
1.00	15,647
0.75	13,647
0.67	12,635
0.50	11,083
0.33	9,532
0.25	8,801
0.10	7,432[a]

[a]The 1980 winter range estimate from Rice *et al.* (1983) is 7,601.

rate of travel at night, rather than slowing or maintaining the daylight rate. I can think of no reason why this would be probable and therefore have not pursued an increase in rate in Table III.

In spite of the assumption that night travel is reduced to 73% of the day rate at Unimak Pass in the fall, Rugh (Chapter 10, this volume) produced a 1978 estimate of 17,648 from a maximum raw count of 5,050. This may be increased evidence in support of the magnitude of other shore census estimates but does not clarify the issue of night travel rate. There are other possible ways in which his methods could result in an overestimate, but the amount would be minimal. Previously discussed ways include the possibly inappropriate application of the Monterey pod-size adjustment (because whales pass closer to shore at Unimak, accurate estimation of pod size may be less of a problem there), and Rugh's method of correcting for whales missed in periods of poor visibility. But, if these two corrections are removed entirely, his estimate would still be more than 15,000. It is perhaps relevant to note that the average daylight period is almost 8 hr at Unimak Pass during the fall migration, whereas it is about 10 hr at Monterey. Rugh consequently had a larger proportion of the day over which to extrapolate.

The present status of population estimation from the winter range suggests that 7,600 adults (from the 1981 effort) is an underestimate. These efforts are substantially limited by the physiographic vastness and complexity of the study area. This is exacerbated by the protracted migration into and out of the area, such that the entire population is not present at any one time. Other factors pointing to an underestimate from the winter range are that airplane censuses systematically miss whales (this has not been consistently accounted for), and that the observed ratio of calves to adults from the 1981 survey (Rice *et al.*, 1983) implies a reproductive rate higher than that which gray whales are likely to achieve under any conditions.

The ratio of calves to adults from the 1981 count was 0.19 (Rice *et al.*, 1983). If our current interpretation of gray whale vital rates and age structure is reasonably accurate (Rice and Wolman, 1971; Reilly, 1984) a crude birth rate greater than 0.14 is quite unlikely. This is calculated from a pregnancy rate of 0.467, a sex ratio of 0.5, and a mortality schedule that results in 60% mature ($0.467 \times 0.5 \times 0.6 = 0.14$). If we assume that Rice *et al.* (1983) gave an accurate calf estimate, then 1,439 calves and a maximum crude birth rate of 0.14 indicate a minimum adult population of 10,279. Summing adults and calves gives 11,718. Removing ~7% for 1 year mortality (from 0.10 net for whales under the age of sexual maturity and ~0.05 for those over that age; Reilly, 1984) gives a minimum figure of about 10,900 passing central California the next autumn. If in fact the calf estimate is low, for example, 30% (as suggested by the data of Swartz and Jones, Chapter 14, this volume), then the number passing Monterey would be approximately 14,300. This is within the 95% confidence limits for the 1980 Monterey census (Reilly *et al.*, 1983).

Again, I am not postulating that the population size is exactly 14,300, or that gray whales do in fact slow down at night. Lacking new evidence, it still seems most probable that the night travel rate is on average not different from the daytime rate, and therefore that the population size in 1980 was approximately 15,600. The most important point here is that the Baja estimate is probably an underestimate of total population size. Also, if *not* accurate, the shore station estimates are probably too high. Perhaps research in some key areas will help us reinterpret our census data and result in a resolution to the present dilemma. Unequivocal documentation of night travel rates during migration is needed. Further field work on the winter grounds, directed at verification of specific problem areas and coupled with a comprehensive, quantitative appraisal of the entire estimation problem there, are prerequisite to reliable population estimation.

Appendix A. Factors Affecting or Involved in Estimating Total Abundance from Winter Range Aerial Surveys

I. Specific research topics
   A. Behavior of animals
      1. Time spent at the surface
         a. Age/sex group differences
         b. Group size differences
         c. Location differences
         d. Diel differences
         e. Intraseason changes
         f. Response to platform
      2. Immigration emigration
         Same factor list as in 1. above
   B. Geographic distribution
      1. Lagoon channel
      2. Lagoon mouth
      3. Lagoon open area
      4. Alongshore bay

5. Alongshore exposed, sandy beach
6. Alongshore exposed, rocky beach

C. Interplatform comparisons
1. Lagoons
a. Air to boat
b. Air to tower
c. Boat to tower
2. Alongshore
a. Air to boat

D. Visibility conditions
1. Quantity (scale effects)
2. Confounding with behavior?
3. Confounding with field methods?

E. Observer accuracy and precision
1. Experience
2. Fatigue
3. Intraobserver variation
4. Interobserver variation

II. Methods

A. Field methods
1. Altitude
2. Air speed
3. Location
4. Track line repetition
5. Data recording
6. Intraseason timing
7. Boat, land-based verification experiments

B. Analytic methods
1. Post factor stratification, pooling
2. Sighting model definition
3. Parameter estimation
4. Parameter comparison
i. Between platforms
ii. Between locations
iii. Between observers
5. Data, parameter "adjustment" (i.e., application of correction factors)
6. Estimation of total abundance and variance
i. Model derivation
ii. Computation conventions

Appendix B. Factors Affecting or Involved in Estimating Total Abundance from Shore Station Censuses for Migrating Whales

I. Specific research topics
  A. Offshore distribution
    1. Site characteristics
    2. Season
      a. Between (fall versus spring) changes
      b. Within-season changes
    3. Group size differences
  B. Migratory timing
    1. Model estimation
    2. Comparisons between years
    3. Comparisons between sites
    4. Estimation of "tails"
    5. Estimation of poor visibility periods
  C. Visibility conditions
    1. Establish scale of effect
    2. Confounding with A., B.
  D. Observer accuracy and precision
    1. Distance estimation
      a. Change with distance?
      b. Change with pod size?
    2. Pod size estimation
      a. Change with distance?
      b. Change with pod size?
    3. Interobserver differences
    4. Intraobserver differences
  E. Diel migration rate
    1. Night versus day rates
    2. Change during daytime?
II. Methods
  A. Field methods
    1. Site choice
    2. Data collection conventions (i.e., variables chosen, frequency recorded, etc.)
    3. Verification experiments (for distance, pod size)
  B. Analytic methods
    1. Post facto stratification, pooling (distance only)
    2. Parameter estimation
      a. Distance offshore
      b. Pod size
      c. Number per time interval

3. Parameter adjustment (re: verification experiments)
   a. Offshore distribution
   b. Pod size
4. Estimation of total abundance and variance
   a. Model derivation
   b. Computation conventions

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