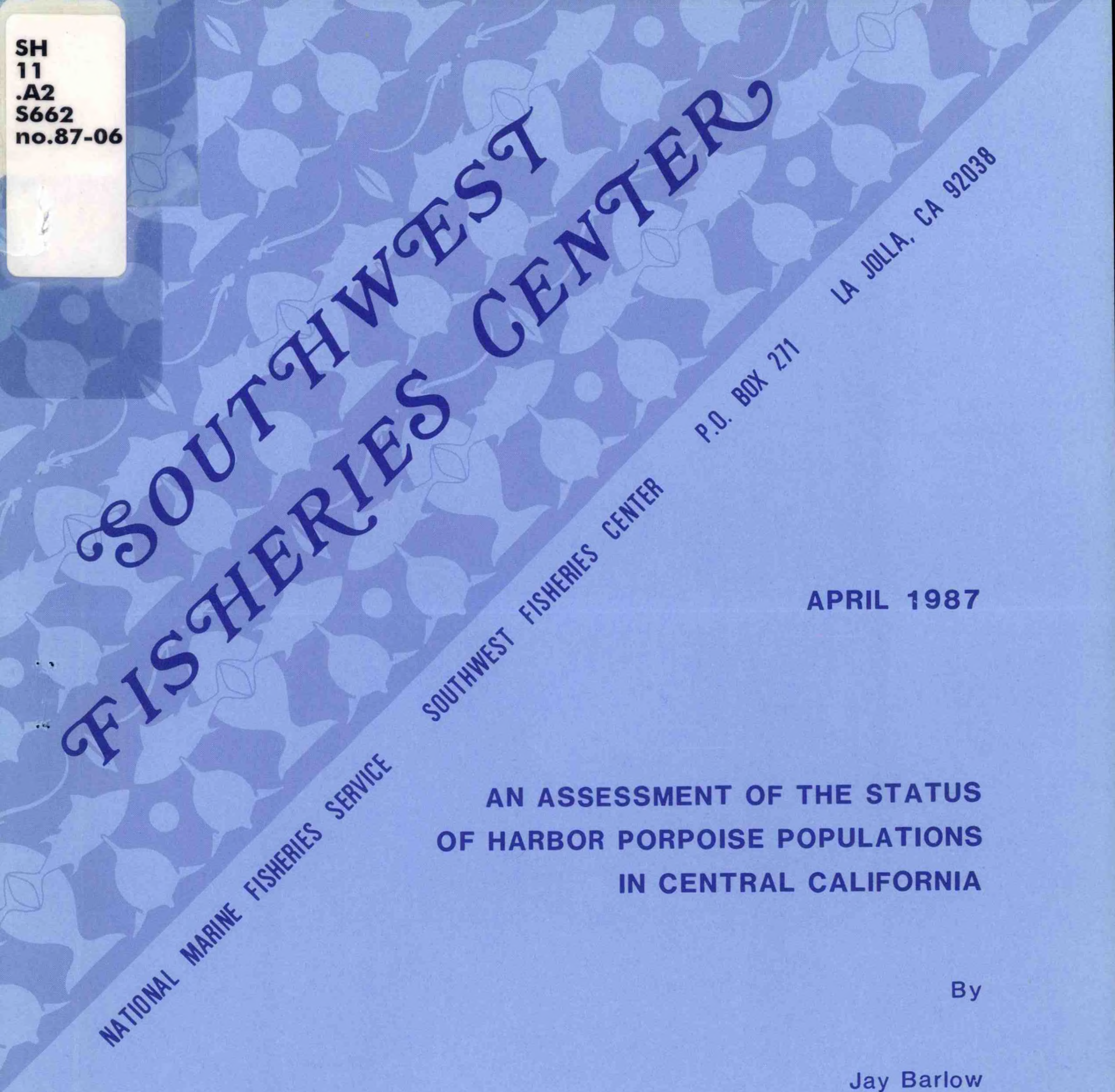

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AN ASSESSMENT OF THE STATUS OF HARBOR PORPOISE POPULATIONS IN CENTRAL CALIFORNIA

By

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AN ASSESSMENT OF THE STATUS OF HARBOR PORPOISE POPULATIONS IN CENTRAL CALIFORNIA

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I. INTRODUCTION

Harbor porpoise (Phocoena phocoena) are small cetaceans which occur commonly along north-temperate coastlines of the Pacific and Atlantic Oceans (Gaskin 1984; Barnes 1985). Harbor porpoise in central California are killed incidentally in a halibut set-net fishery which developed rapidly circa 1979 (Diamond and Hanan 1986). In this paper I review information regarding harbor porpoise abundance and population dynamics on the west coast of the U.S. and assess the potential impact of incidental fishing mortality on central California porpoise populations.

There have been few previous reports that examine the status of harbor porpoise populations. Harbor porpoise were given little consideration in the last National Marine Fisheries Service (NMFS) assessment of marine mammals involved in commercial fishing operations (NMFS 1980). Fishery mortality was mentioned as occurring in several areas, included California, but insufficient information was available at that time to assess the impact of this mortality on porpoise stocks. As evidence of fishery mortality in California became more apparent, the Center for Environmental Education commissioned a report on the status of harbor porpoise in the eastern Pacific, with an emphasis on California (Szczepaniak and Webber 1985). Their report serves as a good review of the information on harbor porpoise and on potential factors that could affect the species. That report did not determine, however, whether fisheries were having a significant impact on porpoise stocks in California.

Most studies of the effect of humans on harbor porpoise have focused on situations where porpoise have abandoned or have been eliminated from areas where they were previously found. Harbor porpoise were once abundant in southern Puget Sound (Scheffer and Slipp 1948), but are now rarely seen there (Calambokidis et al. 1978; Everitt et al. 1979). Calambokidis et al. (1985) raise the possibility that the disappearance of harbor porpoise in Puget Sound was related to high concentrations of polychlorinated biphenyls (PCBs). Similarly, harbor porpoise were reported as common in San Francisco Bay but are rare today (Szczepaniak and Webber 1985), possibly due to pollution or vessel traffic

(Brownell 1964). In Europe, harbor porpoise declines have been linked to pollutants along the west coast of Sweden (Otterlind 1976) and to pollutants and incidental fishing mortality in the Wadden Sea (Verwey and Wolff 1981). Given this history of harbor porpoise disappearance, caution should be exercised in the management of porpoise populations.

II. MANAGEMENT FRAMEWORK

The incidental take of harbor porpoise is regulated under the purview of the Marine Mammal Protection Act of 1972 (and subsequent re-authorizations). Under this Act, management authority for cetacean species has been delegated to the National Marine Fisheries Service (NMFS) within the U.S. Department of Commerce. The Secretary of the Department of Commerce can issue permits authorizing the take of marine mammals incidental to commercial fishing operations. Although the Act was written to incorporate ecological concepts, it is not worded in terms that are familiar to most ecologists. In order to understand what information is needed for this permitting process, it is necessary to examine and interpret the wording in the Act.

The primary requirements for authorizing an incidental **take** under the Act are: 1) the species or **population stock** must be at their **optimum sustainable population level**, and 2) the authorized **take** must not be to the **disadvantage** of the stock. Within the Act, **take** means to harass, hunt, capture, or kill any marine mammal or to try to do any of these. A **population stock** or **stock** is defined as a group of the same species (or smaller taxon) in a common spatial arrangement, that interbreed when mature. **Optimum sustainable population** (OSP) was not defined in the Act, but has been subsequently defined in the U.S. Federal Register (41:55536) as being a population size which falls within a range from the population level of a given species or stock which is the largest supportable within the ecosystem to the population level that results in maximum net productivity (or net population growth rate). The Act defines a **depleted** species or stock as being one which is below its OSP level or one which is listed as endangered or threatened under the Endangered Species Act of 1973. A **disadvantaged** stock (in the context of number 2 above) was not defined in the Act, but implicitly includes a stock which is depleted.

Interpretation of the MMPA has developed in the process of issuing permits for the incidental take of other species of marine mammals. The population size resulting in the maximum net productivity has been estimated as being between 50 and 80% of the maximum supportable population for several stocks of tropical dolphins (Smith 1983). Using this example, a population is within the OSP range if abundance is above 80% of its maximum, <u>may</u> be within the OSP range if abundance is between 50 and 80% of its maximum, or is below OSP if abundance is less than 50% of its maximum. The maximum size of a population has been previously estimated as the size of the population before it was affected by any fisheries (Smith 1983).

Within the above regulatory structure, several questions must be answered in order to issue a permit for continued harbor porpoise take by commercial fisheries: What are the stocks that are affected by the fishery? Are these stocks above a critical percentage of their abundance prior to the fishery? If so, what level of take can be authorized without reducing the stock below its OSP level? The remainder of this document addresses these questions.

The following format will be used in addressing these questions. First, the number of harbor porpoise killed in California set-net fisheries from 1969/70 to present is estimated from California Department of Fish and Game (CDFG) data. Next, harbor porpoise abundance estimates are presented for central California and for the entire coast. The justification and uncertainty in defining a separate stock of harbor porpoise in central California is then discussed. Next, maximum population growth rate is estimated, and a model is presented for calculating current growth rate. All the preceding information is then used to calculate the ratio of current abundance to pre-fishery abundance using a population back-projection model. Finally, replacement rate is estimated, and suggestions are made for allowable take quotas.

III. INCIDENTAL FISHERY MORTALITY

For harbor porpoise in California, incidental fishery mortality is largely limited to large-mesh, bottom-set entangling nets (gill nets, suspendered gill nets, and trammel nets) (Diamond and Hanan 1986). Currently, such nets are used primarily in a fishery for California halibut (which also takes flounder and sharks). Historically such nets have also been used for white seabass. Incidental porpoise mortality is examined below for both of these fisheries, and past mortality level are estimated for the more recent halibut fishery. One porpoise death has also been observed in a small-mesh set-net in the white croaker fishery near San Francisco. Information regarding this fishery is also presented.

White Seabass Fishery

White seabass (<u>Cynoscion</u> <u>nobilis</u>) is a large (up to 83 pounds) member of the croaker family (Thomas 1968). A valuable fishery for this species has existed in California since the early 1900s, with total landing reaching a maximum of approximately 3 million pounds in 1922 (Fitch 1949). The fishery has declined since that time; currently, commercial catches are very small, and the stock is considered badly depleted (Methot 1983). Fish were taken primarily by purse seines in the early 1900s, but this method was prohibited in 1939 (Methot 1983). Since that time, large-mesh (6.0 to 7.5 inch) gill nets have been used as the primary fishing method (Thomas 1968; Methot 1983). In California, white seabass is generally considered a southern species. Landings north of Point Conception have been variable but are typically small (Fig. 1). However, northern landings were very high circa 1959, when the seabass distribution shifted to the north (Methot 1983), possibly associated with a strong el Niño event.

Norris and Prescott (1961) report that 6 harbor porpoise were drowned in a seabass gill net in Morro Bay, California. All were caught on December 6, 1958 in water depth of approximately 15 fathoms. A few days earlier, the captain of the same fishing vessel reportedly caught four porpoise off Pismo Beach, California (Norris and Prescott 1961). Other than these two incidents, no quantitative data exist from which to estimate rates of porpoise mortality in white seabass nets.

California Halibut Fishery

California halibut (<u>Paralichthys</u> <u>californicus</u>) are also caught in large-mesh gill nets. Information regarding this fishery is given by Diamond and Hanan (1986), Hanan, Diamond and Scholl (1986) and Hanan, Diamond, and Scholl (in prep.). This information is summarized as follows: Nets are set on the bottom at 3 to 15 fathoms (5 to 28 meters) depth and are retrieved after 12 to 48 hours (typically 24 hours). Monofilament nylon and multi-strand nets are used with stretched mesh sizes of 8 inches or greater. Nets are from 100-400 fathoms (185-740 meters) in length with an average of 200 fathoms (370 meters). Peak fishing activity occurs in July-August. In this report, the fishing year is taken as the period between April 1 and March 31.

In California, harbor porpoise are rare south of Point Conception (Norris and McFarland 1958; Gaskin 1984). California fishing regulations prevent halibut set nets north of the Russian River. Harbor porpoise mortality in set nets is therefore limited to central California (Fig. 2).

California halibut have been fished many years in central California (Fig. 3). Total halibut landings in the state appear to be highly variable and, perhaps, cyclic (Methot 1983). Fishing methods have changed from being predominantly bottom trawling to predominantly entangling set nets (Methot 1983). The number of dead harbor porpoise which have been found on beaches in central California appears to have increased in recent years (Szczepaniak and Webber 1985), which may be the result of a general increase in the halibut fishery and the change in fishing methods.

The CDFG (under contract to the NMFS Southwest Regional Office) has estimated the number of harbor porpoise killed in halibut set nets for the fishing years 1983/84, 1984/85, and 1985/86. Kill estimates were made by calculating the average number of porpoise that die per net-haul and extrapolating to the total number of halibut net-hauls. The average kill rate per net-haul is estimated by observing a sample of net-hauls using CDFG observers either aboard cooperating fishing vessels or on shore with high powered telescopes. Estimates of the total number of halibut net-hauls is made from set-logs and landing records (Diamond and Hanan 1986).

Three methods were used to estimate annual porpoise mortality in recent years (a straight ratio, a negative binomial model, and a bootstrap estimate), and all gave very similar results (Diamond and Hanan 1986; Hanan et al. 1986; Hanan et al., in prep.). Here I use bootstrap estimates which have been stratified by geographic areas. These estimates are 303, 226, and 226 porpoise killed in the 1983/84, 1984/85, and 1985/86 fishing seasons, respectively (Diamond and Hanan 1986; Hanan et al. 1986; Hanan et al., in prep.). Central California is divided into 3 statistical areas for reporting these kills: Point Arguello to Point Sur, Point Sur to Half Moon Bay, and Half Moon Bay to Bodega Bay (Regions 1, 2, and 3; Fig. 2). Kill estimates for each fishing season and each of these areas are given in Table 1.

Porpoise mortality from 1969/70 to 1982/83 was first estimated using a measure of set-net fishing effort during that time and using the more recent estimates of the number of porpoise killed per unit of fishing effort. This estimate is later modified to account for the higher abundance of porpoise in the earlier years (see section VII).

Fishing effort was measured as the number of halibut landings (ie. the number of CDFG "pink tickets" for California halibut) that could be attributed to set nets. This measure of fishing effort is less accurate than the measure used to estimate kill in 1983/84 from 1985/86 (Diamond and Hanan 1986); however, it is the only measure of effort available for the period prior to 1983/84. I stratified halibut landings into three catagories of gear type: set nets (entangling gear, gill nets, and trammel nets), unidentified gear (including unspecified "nets"), and other gear (primarily trawl nets). The proportion of central California halibut landings attributed to these gear types are shown in Figure 4.

A gradual increase can be seen in the proportion of landings attributed to entangling nets from a low in 1974/75 to a high in

1985/86. A general improvement in reporting can also be seen in the decreasing fraction of unidentified gear during the same time period (with the exception of 1983/84 and 1984/85). The large increase in unidentified gear in these two fishing years was accompanied by a large decrease in the reported catch attributed to set-nets. The timing of this change in reporting corresponds with a time period when gill nets were coming under increasing criticism by conservationists. Therefore, in 1983/84 and 1984/85, the majority of landings with unspecified gear type may have been from set nets.

The total number of halibut landings attributed to set nets was estimated as the sum of known set-net landings plus a fraction of the landings for which gear type was not specified. Landings attributed to unidentified gear types were prorated based on the fraction of set-net and other-gear landings. For the years 1983/84 and 1984/85, when unidentified gear may have been predominantly set-nets, the unidentified landings were prorated based on the fraction of set-net and other-gear landings in the adjacent years (1982/83 and 1985/86, respectively). Total landings attributed to set-nets are given in Table 2.

The rate of porpoise mortality per halibut landing was estimated by regression (Fig. 5) using the CDFG mortality estimates for 1983/84, 1984/85, and 1985/86 and the estimated set-net landings for the same time periods (Table 2) (forcing the regression through the origin). The resulting rate (0.125 porpoise killed per landing) was applied to the set-net landings (Table 2) to estimate porpoise mortality from 1969/70 to 1982/83 (Table 2).

White Croaker Fishery

White croaker (Genyonemus lineatus) is currently caught in small-mesh gill nets in central California. This fishery is centered around San Francisco and Monterey Bay. The fishery developed rapidly since 1979, and in 1985 the landings of white croaker in central California (860,000 pounds) exceeded the maximum historical landings of white seabass and California halibut in this area (CDFG 1985).

Since 1980, the retrieval of approximately 200 white croaker nets have been observed by CDFG employees working in central California (Hanan et al., in prep.). Of these, only one resulted in the death of a harbor porpoise. This rate (0.005 porpoise per net) is considerably less than the rate observed for halibut nets (0.024 to 0.030) (Diamond and Hanan 1986; Hanan, Diamond, and Scholl 1986). Insufficient information exists to estimate the total porpoise mortality attributable to white croaker nets.

IV. ABUNDANCE

Three sources of information exist pertaining to harbor porpoise abundance in California: 1) a series of aerial surveys contracted by the U.S. Minerals Management Service (MMS) from 1980 to 1983, 2) a series of 4 ship surveys conducted by NMFS from 1984 to 1986, and 3) two aerial surveys conducted cooperatively by NMFS and CDFG in 1984 and 1985. Each of these is considered in detail below.

Aerial Line Transects

The results of aerial surveys sponsored by the MMS are described by Dohl, Guess, Duman, and Helm (1983). Line transect methods were used to estimate harbor porpoise abundance. Their results indicate that porpoise density is higher in northern California than in central California. Estimates of abundance ranged from 1,600 (summer) to 3,000 (autumn) animals in central and northern California combined. These estimates are, however, almost certainly too low because no correction was made for approximately 75% of animals that would be diving (and hence invisible to aerial observers) at any given instant (Barlow, Oliver, Jackson, and Taylor, in prep.). Adjusting for diving animals (multiplying by a factor of 4.0), yields a rough estimate of 6,400 to 12,000 harbor porpoise in California.

Ship Line Transects

Harbor porpoise abundance was also estimated from 4 ship surveys which were conducted by NMFS and which covered the entire coast between Point Conception, California and Cape Flattery, Washington (Barlow 1987). Line transect methods were used on all 4 surveys, with slight improvements in methods being made between surveys. Abundance estimates were based only on two of these surveys (September 1984 and September 1985). Abundance estimates from the two surveys were pooled, and the pooled estimate is treated as population size for April 1, 1985 (to coincide with the end of a fishing year). The other two cruises were used to investigate seasonal changes in porpoise distribution, changes in porpoise distribution with water depth, and applicability of line transect assumptions. Corrections were made for violations of line transect assumptions, and the resulting abundance estimates are more soundly based than the adjusted estimates from aerial surveys (Barlow 1987).

The September ship surveys were largely limited to transects which followed the 18m isobath. The method used to estimate abundance involved: 1) estimating the density of animals (per km^2) along this 18m isobath using line transect methods, 2) using this density estimate and information on depth distribution to create a continuous model of porpoise density as a function of water depth, 3) calculating the average density in 3 isobath intervals (0-50m, 50-100m, and 100-300m), and 4) multiplying these average densities by the area within these depth intervals. Errors may have been introduced at any of these 4 steps. Random error can, in some cases, be estimated statistically, but errors due to bias are more difficult to estimate. Sources of error in these abundance estimates are considered below.

In step 1 above, line transect estimates of density are subject to both statistical error and bias. Estimating statistical error has been given much attention in the literature; although some debate continues, most researchers favor empirical variance estimators (Buckland 1982). Barlow (1987) uses a combination of two empirical variance estimators: jackknife and bootstrap. Estimating error due to bias has been given less attention. Bias can be introduced by violations in the assumptions of line transect sampling. The primary assumption is that 100% of all porpoise located directly on the trackline are detected by observers (and do not move from the trackline before detection). Using two independent teams of observers, Barlow (1987) estimates that 23% of all porpoise which surface within 100m of the trackline are missed by the principal team of 5 observers. Other biases that he addresses include the possibility that some trackline porpoise may never surface within the visual range of the observers during the transit of the ship and that some of the trackline porpoise may move away from the trackline before being detected by observers. The magnitude of these biases cannot be measured with available data; however, limited observations from a helicopter indicate that the effects of both appear to be minor (Barlow 1987). In this assessment, I use Barlow's estimates of density with the adjustment for missed trackline animals. Statistical errors are assumed to be normally distributed, and 67% confidence limits are estimated as plus and minus 1 standard error. Although this assumption may be poor for individual areas, porpoise abundance is estimated by adding estimates from many areas, and (by the central limit theorem) the sum should be more normally distributed than the parts.

Step 2 involved creation of a continuous model of porpoise density as a function of water depth. This was based on the relative number of porpoise encountered on transects along several different isobaths (Barlow 1987). These transect were limited to a few sites along the coastline and were limited to only 2 to 4 different depths at each site. Insufficient information was gathered to mathematically fit a model to these data; hence, a simple heuristic model was proposed that was consistent with these data. The model of depth distribution is thus the weakest element of Barlow's abundance estimates. Because the model was heuristic, it is not possible to estimate statistical error. Because it was based on a limited sample of locations and depths, biases may be significant. To account for these problems, Barlow (1987) proposed two alternative models which encompass a very wide range of possible depth distributions. In this assessment, the two alternative models will be treated as confidence limits for the depth distribution model.

The third step in Barlow's abundance estimation was to estimate the mean porpoise density within the 0-50, 50-100, and 100-300m depth contours. He used his model of porpoise depth distribution and assumed that depths were uniformly distributed within the above depth contours. No direct information was presented for the validity of this assumption. This is not believed to be a significant source of error and is not considered further.

The fourth step in abundance estimation was to multiply the average density within each depth contour by the area encompassed. Areas were calculated from digitized bathymetric data used by NOAA to construct navigational charts. Errors in this step are also considered minimal and are not discussed further in this assessment.

Resulting abundance estimates (Barlow 1987) indicate that the greatest number of porpoise are outside the range of the halibut set-net fishery. The southern three strata used by Barlow correspond to the three geographic strata in which fishery take is reported (Diamond and Hanan 1986). Adjusting for missed animals, Barlow's estimate of abundance in this region (henceforth referred to as central California) is 1,854 porpoise (s.e. = 991) for both surveys pooled. Barlow (1987) did not use a stratum bounded by the California/Oregon border, so his estimates are not directly comparable to those of Dohl et al. (1983). His adjusted estimate for Point Conception to Cape Mendocino (150km south of the California/Oregon border) is 11,457 porpoise. His adjusted estimate for the entire coast from Point Conception to Cape Flattery is 49,862 animals. A summary of Barlow's estimates from the two surveys, and his pooled estimates, are given in Table 3, stratified by geographic region.

Aerial Strip Transects

Two aerial surveys were also conducted by NMFS in September of 1984 and 1985 using strip transect methods (Barlow et al., in prep.). Because sampling requirements for strip transects of harbor porpoise are stringent, many of the data that were collected were not useful for estimating abundance, and geographic coverage with the remaining data was insufficient to estimate porpoise abundance reliably. It was concluded that density estimates should be multiplied by approximately 4.0 to account for submerged individuals that were missed. Uncertainty in estimating this large adjustment factor introduces considerable uncertainty in estimating porpoise density from aerial surveys. The aerial survey results can be useful, however, in corroborating density estimates from ship surveys. Based on the limited areas surveyed under good sighting conditions, mean density was estimated as 2.23km^{-2} (with adjustment for 75% missed animals). This corresponds to an estimate of 1.75km^{-2} (adjusted for 23% missed trackline animals) from the ship survey (Barlow 1987).

V. POPULATION STOCK STRUCTURE

The concept of a stock is commonly used in management of populations of wild animals. It does not have a single accepted definition, but, in general, it is used to describe a collection of animals that can be sensibly managed as a single unit (Larkin 1972; MacCall 1984). The definition of a stock in the MMPA (a group of the same species which inhabit a common spatial arrangement and which interbreed when mature) is ambiguous. Can individuals which live their entire lives 1000 kilometers apart be said to belong to the same stock? Clearly those individuals do not interbreed, but the only impediment may be distance. What about the individuals found between these extremes. Some will be close enough to interbreed and others will not. The problem is analogous to applying discrete categories to a continuous variable. Historically, the criteria for identifying discrete stocks have been 1) physical discontinuities in distribution of individuals, 2) habitat discontinuities, 3) evidence of restricted movement from tagging studies, or 4) demonstration of genetic or morphological difference between two groups. Although these may be sufficient conditions for defining sensible management units, they are not necessary conditions.

Gaskin (1984) proposed subdivision of harbor porpoise populations in the Pacific Ocean based on discontinuities in habitat type. He grouped the animals along the coasts of California, Oregon, and Washington together in a unit which is separate from the porpoises found in the inland waters of Puget Sound and those found in British Columbia and southeastern Alaska. No evidence exists for discontinuities in harbor porpoise distribution along the coasts of California, Oregon, and Washington (Barlow 1987). No attempt has been made to examine genetic differences within this range. Radio-tagging studies are planned (Silber, pers. comm.), but no data on individual movement patterns are presently available.

Indirect evidence of restricted movement is available from studies of pollutant residues in harbor porpoise tissues (Calambokidis 1986). Harbor porpoise concentrate environmental contaminants such as DDT, DDE (a break-down product of DDT), PCB, and HCB (hexachlorobenzine). Accumulation is believed to occur slowly over the life of an individual. Because pollutants accumulate slowly, tissue concentrations cannot change rapidly when environmental concentrations change. If concentrations of environmental contaminants differ between two areas and if porpoise movement between those areas is restricted, the concentration of contaminant in porpoise tissue may differ between those areas. If, on the other hand, porpoise moved freely between two areas, no difference would be expected in porpoise tissues.

Calambokidis (1986) found significant differences in concentrations of pollutants in tissue samples of harbor porpoise collected along the coasts of California, Oregon, and Washington. He examined the ratio of DDE to PCB and the ratio of HCB to DDE, and for both he found significant differences between states ($p < 0.001$). Within central California, samples came from three regions (separated by less than 225km); ratios of DDE to PCB did not overlap between these regions. These results suggest that a strong gradient exists in environmental contaminants and that porpoise movement is restricted to some degree. Such large differences (no overlap) over such short distances (225km) is evidence that porpoise movement may be restricted to local regions.

If harbor porpoise movement is restricted within central California and if harbor porpoise in California, Oregon, and Washington are managed as a single stock, local depletion of stocks could result. Because sample sizes are small and because samples do not include all age and sex classes, it is not possible to say definitively that porpoise do not move more than 225km in their lives. Current evidence does, however, support the hypothesis that harbor porpoise movement is very restricted. In the remainder of this paper, the harbor porpoise stock that is affected by the central California set-net fishery is assumed to include only those animals in central California (Point Conception to the Russian River). Because considerable uncertainty exists in this assumption, I also calculate stock size based on all animals in California, Oregon, and Washington.

VI. POPULATION GROWTH RATES

Maximum Growth Rates

Limits can be placed on the maximum rate of population growth based on constraints imposed by the biology of the animal. Reilly and Barlow (1987) used this approach to estimate maximum growth rates for delphinid cetaceans. Below, maximum values are estimated for birth rates and survival rates based on what is known of harbor porpoise. These are used to estimate maximum population growth rates by solving Lotka's characteristic equation. Computer programs used by Reilly and Barlow (1986) are used in the present study, with input ranges corresponding to those expected for harbor porpoise.

Little is known of the reproductive life history of harbor porpoise in California, but estimates can be made from studies that have been made elsewhere. Harbor porpoise are believed to mature at approximately 3 to 5 years (Gaskin et al. 1984). Most estimates of gestation time range from 10 to 11 months for all porpoise species (Gaskin et al. 1984). Therefore, a female maturing at age 3 could first give birth at approximately age 4. Reproduction is strongly seasonal with mating occurring in middle to late summer and with parturition occurring in late spring and early summer (Gaskin et al. 1984). Except in very rare cases, the litter size for delphinids is one (Perrin and Reilly 1984); this appears to hold for phocoenids as well. Lactation continues after birth for a period up to 8 months (Gaskin et al. 1984). Simultaneously pregnant and lactating females have been found in samples from several populations (Gaskin et al. 1984), indicating that mature females may give birth every year. This is verified by cases where individually recognizable females were accompanied by different calves in consecutive years (Watson 1976; Taylor and Dawson, manuscript). In most studies, however, the percentage of mature females that were simultaneously pregnant and lactating was less than 100% (Gaskin et al. 1984), indicating an average calving interval greater than 1 year.

Also, little is known of natural mortality patterns for harbor porpoise in California. Again, estimates are made from studies of other populations. Mortality rates have not been measured directly, so rates must be inferred from what is known of longevity. Most researchers have agreed that porpoises are relatively short lived for cetaceans and probably live to a maximum of 13-15 years, with few individuals living longer than 7-8 years (Gaskin et al. 1984). In order to estimate survival rates for harbor porpoise, survivorship curves of other mammals are scaled to yield a longevity of approximately 15 years.

The expected mortality pattern for mammals is low initial survival rates during a juvenile period, high survival rates in young adulthood, and steadily decreasing survival rates in senescence (Caughley 1966; Siler 1979). Following the justification given by Reilly and Barlow (1986), I assume that the calf survival rate equals (at most) the square of the mean survival rate of reproductive adults. Three different models of non-calf survival are used (Fig. 6) each resulting in 1% survivorship to age 15: 1) constant survival rate with age, 2) a model with senescence patterned after data on the Himalayan thar (Caughley 1966), and 3) a model with senescence patterned after data on human females circa 1900 (Fruehling 1982). For the latter two, the Siler (1979) model was used to fit published data in order to obtain smoothed survivorship curves.

To summarize what are reasonably assumed to be the biological constraints on population growth in harbor porpoise: the minimum calving interval is greater than 1 year, the youngest age at first birth is 4 years, the maximum longevity is 15 years, and the maximum calf survival rate is less than the square of the adult rate. Using these values, population growth rates are 0.897, 1.068, and 1.146, respectively for survivorship models 1, 2, and 3. These range from a decrease of 10.3% per year to an increase of 14.6% per year. Because the first model does not allow population growth, it is not given further consideration. Both of the other models are considered plausible, and maximum population growth rates of 7 and 15% are included in calculating current growth rates.

Current Growth Rates

The maximum growth rates calculated above indicate the how rapidly a population might grow given the best conditions that could occur. These conditions are likely to occur only when population size is relatively small and individuals are not competing or having other detrimental influences on each other. As populations increase, growth rates decrease, until at some point growth stops entirely and the population reaches an equilibrium. This equilibrium population size is called carrying capacity, K. Due to fishery mortality, current populations are likely to be less than K; hence, current growth rates are likely to be positive, but less than the maximum rate calculated above.

The expected relationship between growth rate and population size has been termed density dependence. Recruitment rates are often substituted for population growth rates in expressing density dependent relationships. The net recruitment rate, R, is directly related to the finite rate of population growth, λ, by the following relationship: $R = \lambda - 1$. The maximum net recruitment rate, R_m, was thus estimated above as 0.07 or 0.15. In this report I use a model of density dependence (Allen 1981):

$$R(N) = R_m \left(1 - (N / K)^z \right) \qquad (1),$$

where N = population size, and
z = shape parameter.

The shape parameter, z, adds considerable flexibility in determining the shape of the density dependent response. This model of recruitment rate has been used previously in studies of small cetaceans (Smith 1983) and whales (Allen 1981).

The parameter z is extremely difficult to estimate. Empirical evidence indicates that z is typically greater than 1.0

for long lived mammals, including all marine mammals (Eberhardt and Siniff 1977; Fowler 1981). Also, theoretical arguments indicate that z is expected to be greater than 1.0 for mammals. Gilpin, Case, and Ayala (1976) show that selection favors higher values of their parameter, Θ, (hence z > 1.0) for animals which (like mammals) are less sensitive to environmental fluctuations. In previous estimates of current growth rate for dolphins, values of 1.0, 3.5, and 11.5 have been used for z (Smith 1983). Lacking any new information, the same range will be used here.

VII. PRE-FISHERY ABUNDANCE

The ratio of current abundance (taken as April 1, 1986) to carrying capacity, N/K, is estimated by assuming populations were at carrying capacity at the time when use of set nets for halibut became common (1969). Population size at April 1, 1969 is estimated using the Smith and Polacheck (1979) back-projection model:

$$N_T = \frac{N_{T+1} + \frac{H_T}{2}}{1 + R(N_T)} + \frac{H_T}{2} ,$$

where N_T = abundance at time T

N_{T+1} = abundance at time T + 1

H_T = number killed during time period T

$R(N_T)$ = population growth rate as a function of abundance

The back-projection model was applied to the abundance estimate for April 1985 to estimate abundance in April 1984. This process was repeated for each year, back to 1969. The population in 1969 was assumed to be at carrying capacity for the purpose of estimating population growth rate, R(N), in subsequent years. In order to account for the greater number of animals at risk in earlier years, the preliminary estimates of the number of porpoise killed from 1969/70 to 1982/83 (Section III, above) were multiplied by the ratio of porpoise abundance in 1985/86 to abundance in the given year. Because of the dependence of the model on its resulting estimate of population size in 1969 and on estimates of abundance in intervening years, the model must be applied recursively. The back-projection was repeated until estimates of population size in 1969 converged. Population size in April 1986 was estimated from abundance in April 1985 by reversing the back-projection model (Smith and Polacheck 1979, Eq. 1).

Input parameters for the back-projection model include estimates of current population size (Table 2), fishery mortality from 1974 to present (Table 3), the maximum rate of population growth (R_m), and the shape parameter for population growth (z). Because of uncertainty in estimates, ranges of values were used for each of the above parameters. The choice of these ranges are described below.

Six different values were used for current population size (out of the 18 values given in Table 2). The best estimates are believed to those based on the Primary Model for depth distribution. Maximum and minimum estimates of population size were based on Alternate Model 1 plus one standard error and Alternate Model 2 minus one standard error (respectively). These three values are more analogous to a mean and upper and lower confidence limits rather than three equally plausible values. Because of the heuristic manner in which the models of depth distribution were chosen, it is not possible to assign probability values to these confidence limits (eg. 95% or 99%). The six values that were used for back-projection were mean size and confidence limits based on the assumption that a) the population in central California constitutes a separate stock, and b) the porpoise in central California belong to a stock which extends to northern Washington.

Three alternative values were used to represent the maximum population growth rate of harbor porpoise in California. The first value, $R_m = 0.07$, was based on a survivorship curve patterned after Himalayan thar. The second value, $R_m = 0.15$ was based on a human survivorship curve. The third estimate, $R_m = 0.0$, was based on the possibility that growth in harbor porpoise populations may be affected by pollutants, vessel traffic, other fisheries, or other human encroachments aside from direct mortality in the halibut fishery. Indirect human affects were also considered in a previous assessment of dolphin stocks affected by the yellowfin tuna fishery, and a maximum growth rate of zero was considered possible (Smith 1983). Given the history of harbor porpoise disappearance in other areas (Introduction), the possibility of a zero growth rate was explored.

Three alternative values were used for the shape parameter, z, in the population growth equation. The values used (1.0, 3.5, and 11.5) correspond to maximum net productivity levels at 50, 65, and 80% of carrying capacity (respectively) (Smith 1983). Based on information presented above, the value of 50% (k = 1.0) is a reasonable lower limit. The values of 50, 65, and 80% were chosen on the basis of their previous use in dolphin population assessments (Smith 1983), and no basis exists for choosing a best estimate among these three. An example of back projected population sizes are given in Table 2 for the central estimates of population size (1854 animals), the parameter z (3.5), and R_m (0.07).

Estimates of the ratio of current abundance to abundance in 1969 are given in Table 4 for the above range of input parameters. It is difficult to assess the status of harbor porpoise in 1969 with certainty, but in the following discussion I will assume populations were at carrying capacity. Assuming that the population in central California is a separate stock, and using the central estimate of porpoise abundance (1,854 animals), the current population is estimated to be at or below its maximum net productivity level. If porpoise in central California are assumed to belong to a stock which extends to northern Washington, populations are estimated to be above 90% of their carrying capacity regardless of the range of input parameters that were used (Table 4). Population sizes in April 1986 were projected from the census period (taken as April 1985) and are given in Table 5 for the same range of input parameters.

VIII. MAXIMUM ALLOWABLE TAKE

If a population of marine mammals is not considered depleted under the definitions in the MMPA, the Act specifies that continued take can be permitted, subject to certain limitations. The most important of these is that the population cannot be allowed to fall below their OSP level during a permit period. Maximum allowable take should therefore be set to maintain populations within the OSP range.

Maximum allowable take may be based either on a numerical quota or on a constant percentage of a population. I define a numerical quota as an allowable take that is set at the beginning of a permit period that is constant throughout that period. I define a percentage quota as an allowable take that varies as a constant percentage of the current population size. The difference between these management strategies may seem subtle, but numerical quotas tend to de-stabilize population size and percentage quotas can act to stabilize population size. Furthermore, numerical quotas are more sensitive to errors in assessing the status of a population. A numerical quota can, if applied for several years, result in a population declining below their OSP level, and, if that happens, the rate of that decline will increase with time. Percentage quotas are therefore recommended.

An example of a percentage quota is the "2 percent rule" which has been recommended by the Marine Mammal Commission for the management of live-captured bottlenose dolphins, Tursiops truncatus, along the Gulf of Mexico (Powers 1984). Such percentage quotas are much less sensitive to errors is assessing the status of a population. If a population is judged to be within its OSP level when it is, in fact, below that level, a properly chosen percentage quota will still allow population growth and recovery. If a percentage quota is to be applied effectively, there must be an additional requirement to determine population size on a regular basis and to adjust levels of annual take to reflect any changes in estimates of population size.

Insufficient information exists to accurately estimate the maximum allowable take as a percentage of harbor porpoise populations in California. The "2 percent rule" was first proposed for a species (the bottlenose dolphin) which has roughly a 3-year calving period and which attains sexual maturity at approximately 12 years (Reilly and Barlow 1986). Because harbor porpoise may have a 1-year calving period and may mature at 3 to 5 years, the maximum allowable take of this species may exceed 2%. Other marine mammal species (with life history parameters which are similar to harbor porpoise) have shown population growth rates that are greater than 2%. The population of northern elephant seals (Mirounga angustirostris) in Mexico and California has grown at an estimated annual rate of 8.3% (Cooper and Stewart 1983). The California population of sea otters (Enhydra lutris) has grown at a maximum of approximately 5% per year (G. VanBlaricom, pers. comm.), and in Alaska, sea otters have grown at an estimated rate of 10-12% per year (Kenyon 1969). California sea lions (Zalophus californianus) are estimated to grow at an annual rate of 4-6% (DeMaster et al. 1982). Southern fur seals (Arctocephalus gazella) may have achieved growth rates as high as 14.1-16.8% annually (Payne 1977). For large whales, an annual population growth of 7.2% has been observed for right whales (Balaena glacialis) (Best 1985) and 3.7% has been observed for gray whales (Eschrichtius robustus) (Reilly 1984).

There are, however, no examples of harbor porpoise populations growing in the presence of an incidental fishing mortality. The 2-percent rule was originally proposed as a conservative guideline to be used in the absence of known growth rates. Given the lack of evidence for growth in harbor porpoise populations, a conservative value is recommended for maximum allowable take. The 2-percent rule might be reasonable.

IX. CONCLUSION

Using the central estimate of abundance (1,854 animals in April 1985) and assuming no net emigration of animals from the north, harbor porpoise abundance in central California is approximately 29-81% of that in 1969. If abundance were at equilibrium (carrying capacity) in 1969, harbor porpoise in central California are currently near or below the depleted level as defined in the MMPA. Most of the parameter combinations (MNPL and R_m) result in the conclusion that harbor porpoise are a depleted stock in central California. Using median estimates for MNPL and R_m (0.65 and 0.07, respectively), central California porpoise would be at 46% of their previous abundance, 19 percentage points under the level at which they would be considered depleted under the MMPA. The determination of depleted status is dependent, however, on the value used for harbor porpoise abundance. Using the upper confidence limit for population size would result in a determination that harbor porpoise populations are not depleted in central California. Given this, it is difficult to determine definitively whether the stock is depleted.

Violations of several assumptions could cause the above estimates to be high, and thus the relative status of harbor porpoise could be worse than predicted. First, and most important, is the assumption that porpoise were at carrying capacity in 1969. Harbor porpoise are known to have been taken in white seabass gill nets in the late 1950s. Set nets for halibut were reported as being used in 1969 (Fig. 4) and presumably were used prior to that time. Evidence is cited above for the disappearance of harbor porpoise from San Francisco Bay long before 1969. Pollution, vessel traffic, and fishing mortality may have reduced the abundance in all of central California prior to 1969. Second, set-net mortality since 1983 was based on estimates of the number of sets made. Because some sets are not reported, mortality may be underestimated (Diamond and Hanan 1986). Finally, the estimate of porpoise abundance were for April 1, 1986, and fishing mortality has likely reduced the population since that time.

Violation of several other assumptions could, however, cause the above estimates to be low, and thus the relative status of harbor porpoise could be better than predicted. First, if submerged animals were missed during ship surveys, the population size would have been underestimated. Secondly, if emigration has occurred from the north, porpoise in central California would be at a higher fraction of carrying capacity. How much higher would depend on the emigration rate. More importantly, however, if the emigration rate is high enough, the designation of a separate management stock in central California is invalid. Currently the only information on movement rates are those based on pollutant residues which indicate restricted movement patterns within central California. Sample sizes in that study are small and may not be representative of all segments of the population.

Additional research may reduce some of the uncertainty in assessing the status of harbor porpoise in central California. Clearly one of the more important fields of future research should be the question of stock structure. The possibility of emigration from northern to central California is clearly very important. Unfortunately the pollutant study (on which stock differentiation was based) did not include any porpoise samples from northern California. Considerable uncertainty also exists in estimates of population size in central California. Much of the variability in population size estimates results from lack of information on changes in distribution of porpoise with water depth. Additional survey effort covering the entire offshore range of harbor porpoise would eliminate the need for a model of depth distribution and could greatly improve abundance estimates for central California.

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Table 1. CDFG estimates of harbor porpoise mortality in halibut set nets for fishing years 1983/84, 1984/85, and 1985/86. Estimates are based on the bootstrap method with area stratification (Diamond and Hanan 1986; Hanan et al. 1986; and Hanan et al., in prep.). Areas refer to regions shown in Fig. 2. Confidence limits (95%) are based on a bootstrap method.

Year	Area	Porpoise Mortality	Upper C.L.	Lower C.L.
1983/84	1	78	11	145
	2	47	0	108
	3	173	20	326
	Total	303	124	482
1984/85	1	27	3	57
	2	26	0	64
	3	192	86	298
	Total	226	108	334
1985/86	1	37	1	73
	2	55	0	129
	3	134	68	200
	Total	226	120	332

Table 2. Estimated number of California halibut landings attributed to set nets, estimated harbor porpoise mortality due to set-nets, and estimated harbor porpoise population sizes for the fishing years 1969/70 to 1985/86. Samples of CDFG landing records are limited to ports from Point Conception to Crescent City. California halibut landings attributed to set nets are based on known set-net landings plus a prorated fraction of landings attributed to unspecified gear. Porpoise mortality for 1983/84, 1984/85, and 1985/86 are from Table 1. The preliminary estimates of porpoise mortality are based on regression of porpoise mortality to halibut landings using data from 1983/84 to 1985/86. The back projection estimates of porpoise mortality are based on the preliminary estimates and on the ratio of abundance in the given year to that of 1985/86. Porpoise population sizes are for the start of each fishing year and were calculated from the back projection model using an initial population size of 1854 animals and input parameters of $z= 3.5$ and $R_m= 0.07$.

Fishing Year	Number of Set-Net Halibut Landings	Set-Net Porpoise Mortality		Back-projected Porpoise Population Size
		Preliminary	Back-projected	
1969/70	256	32	64	3749
1970/71	190	24	47	3686
1971/72	419	52	100	3654
1972/73	565	71	133	3575
1973/74	178	22	41	3480
1974/75	353	44	82	3494
1975/76	696	87	158	3464
1976/77	869	109	191	3364
1977/78	676	85	146	3245
1978/79	1131	141	232	3187
1979/80	1629	204	232	3048
1980/81	2053	257	360	2840
1981/82	2573	322	402	2596
1982/83	2015	252	292	2315
1983/84	1884	(303)		2147
1984/85	2267	(226)		1964
1985/86	1788	(226)		1854
			April 1986	1739

Table 3. Estimates of harbor porpoise abundance based on ship surveys: a) from Pt. Conception to Bodega Head and b) from Pt. Conception to Cape Flattery. Three models of porpoise depth distribution and three estimates of porpoise trackline density are used (Barlow 1987); all estimates are adjusted for the estimated 23% of trackline animals that were not detected by observers.

Area Covered	Depth Distribution Model	Porpoise Abundance Estimate -1 s.e.	mean	+1 s.e.
a.	Alternate model 1	1324	2855	4386
	Principal model	863	1854	2845
	Alternate model 2	544	1166	1788
b.	Alternate model 1	65445	79425	93405
	Principal model	40971	49862	58753
	Alternate model 2	25801	31456	37111

Table 4. Estimates of the ratio of forward-projected abundance (April 1986) to back-projected abundance (April 1969) based on estimates of R_m, z, historical set-net mortality (Table 2), and population size in April 1985. Population size estimates are for a) central California and b) California, Oregon, and Washington combined. Upper and lower confidence limits for population estimates are in parentheses.

Population Size	MNPL	Maximum Net Recruitment Rate, R_m		
		0.00	0.07	0.15
a) (544) Lower C.L.	50% K	0.02	0.03	0.05
	65% K	0.02	0.04	0.08
	80% K	0.02	0.05	0.10
1854	50% K	0.29	0.37	0.46
	65% K	0.29	0.46	0.64
	80% K	0.29	0.55	0.81
(4386) Upper C.L.	50% K	0.58	0.66	0.73
	65% K	0.58	0.77	0.87
	80% K	0.58	0.88	0.96
b) (25801) Lower C.L.	50% K	0.91	0.93	0.95
	65% K	0.91	0.96	0.98
	80% K	0.91	0.99	0.99
49862	50% K	0.95	0.96	0.97
	65% K	0.95	0.98	0.99
	80% K	0.95	0.99	1.00
(92882) Upper C.L.	50% K	0.97	0.98	0.99
	65% K	0.97	0.99	1.00
	80% K	0.97	1.00	1.00

Table 5. Estimates of current abundance (April 1986) based on a forward projection from the census period (taken as April 1985), using estimates of R_m, z, and 1985/86 set net mortality. Population size estimates are for a) central California and b) California, Oregon, and Washington combined. Upper and lower confidence limits for population estimates are in parentheses.

		Maximum Net Recruitment Rate, R_m		
Population Size	MNPL	0.00	0.07	0.15
a) (544)	50% K	318	347	378
Lower C.L.	65% K	318	348	383
	80% K	318	348	383
1854	50% K	1628	1701	1763
	65% K	1628	1739	1831
	80% K	1628	1750	1869
(4386)	50% K	4160	4255	4324
Upper C.L.	65% K	4160	4337	4407
	80% K	4160	4395	4410
b) (25801)	50% K	25575	25687	25759
Lower C.L.	65% K	25575	25796	25827
	80% K	25575	25828	25806
49862	50% K	49636	49750	49821
	65% K	49636	49862	49888
	80% K	49636	49887	49865
(93405)	50% K	93179	93294	93366
Upper C.L.	65% K	93179	93406	93430
	80% K	93179	93429	93408

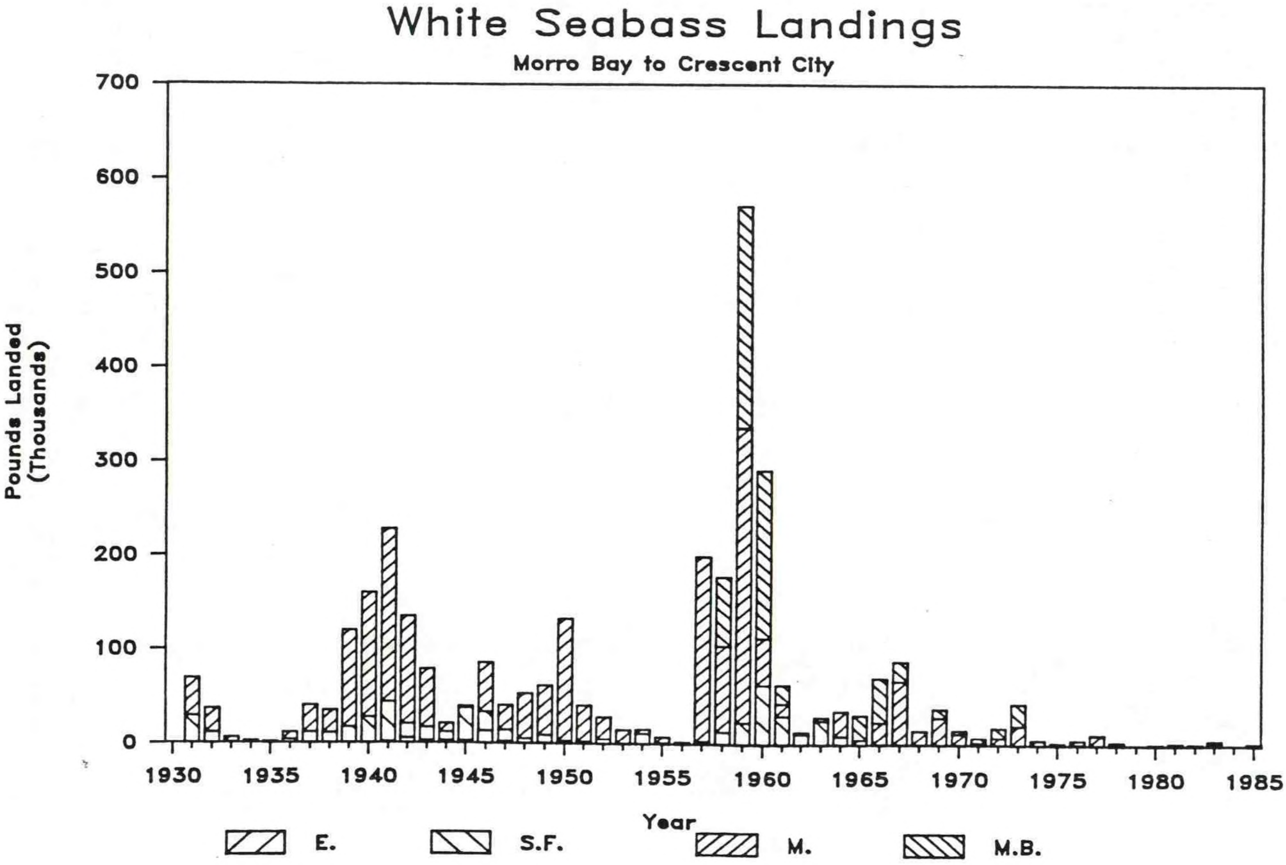

Figure 1. Total pounds of white sea bass landed from Morro Bay to San Francisco in 1931-85 (CDFG 1931-85) . Statistical areas include San Francisco (S.F.), Monterey (M.), and the port of Morro Bay (M.B.). CDFG landing records for Morro Bay are not reported for all years. Values for 1977 to 1985 are based on preliminary estimates.

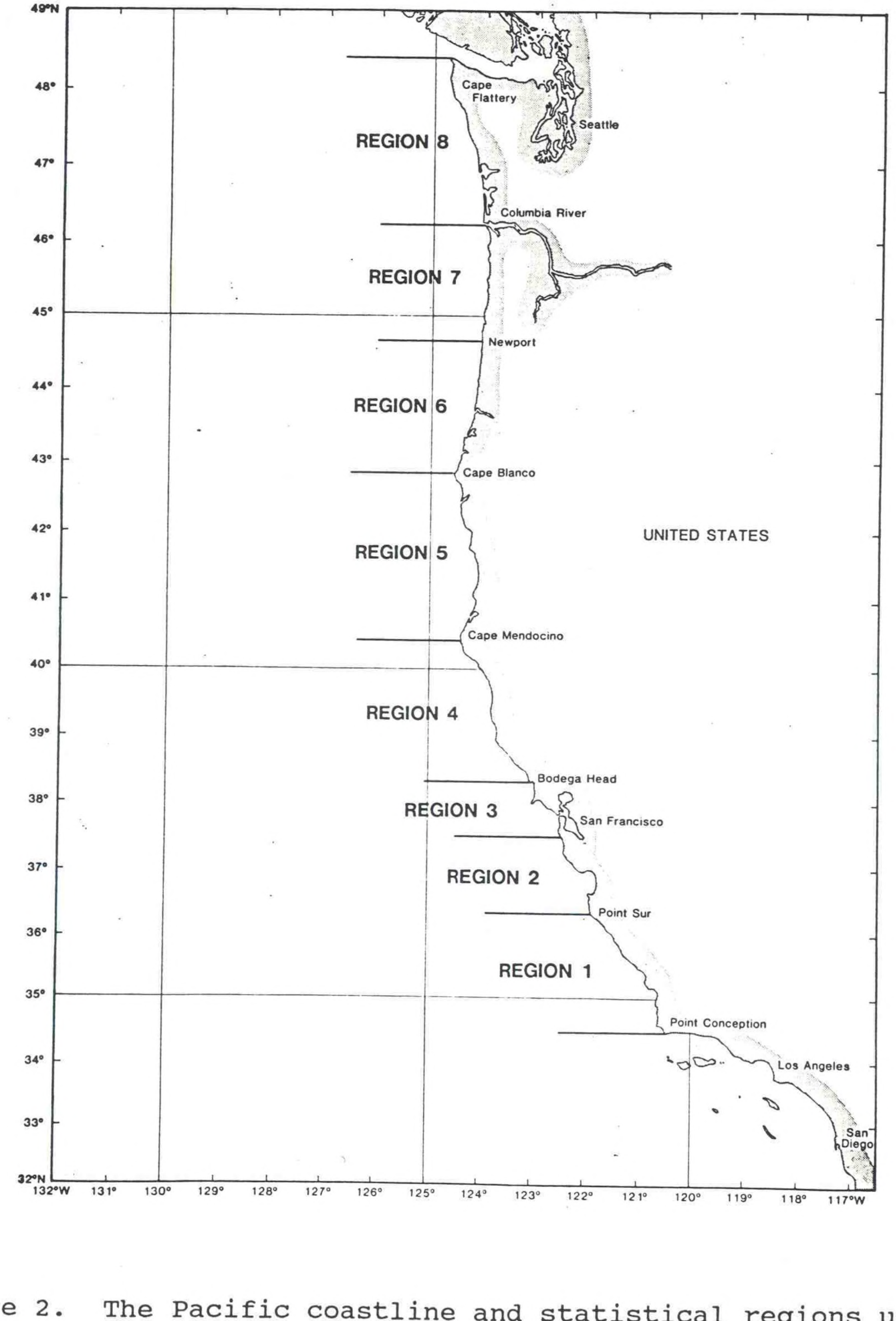

Figure 2. The Pacific coastline and statistical regions used for abundance estimation and fishery mortality estimation. Central California includes Regions 1, 2, and 3.

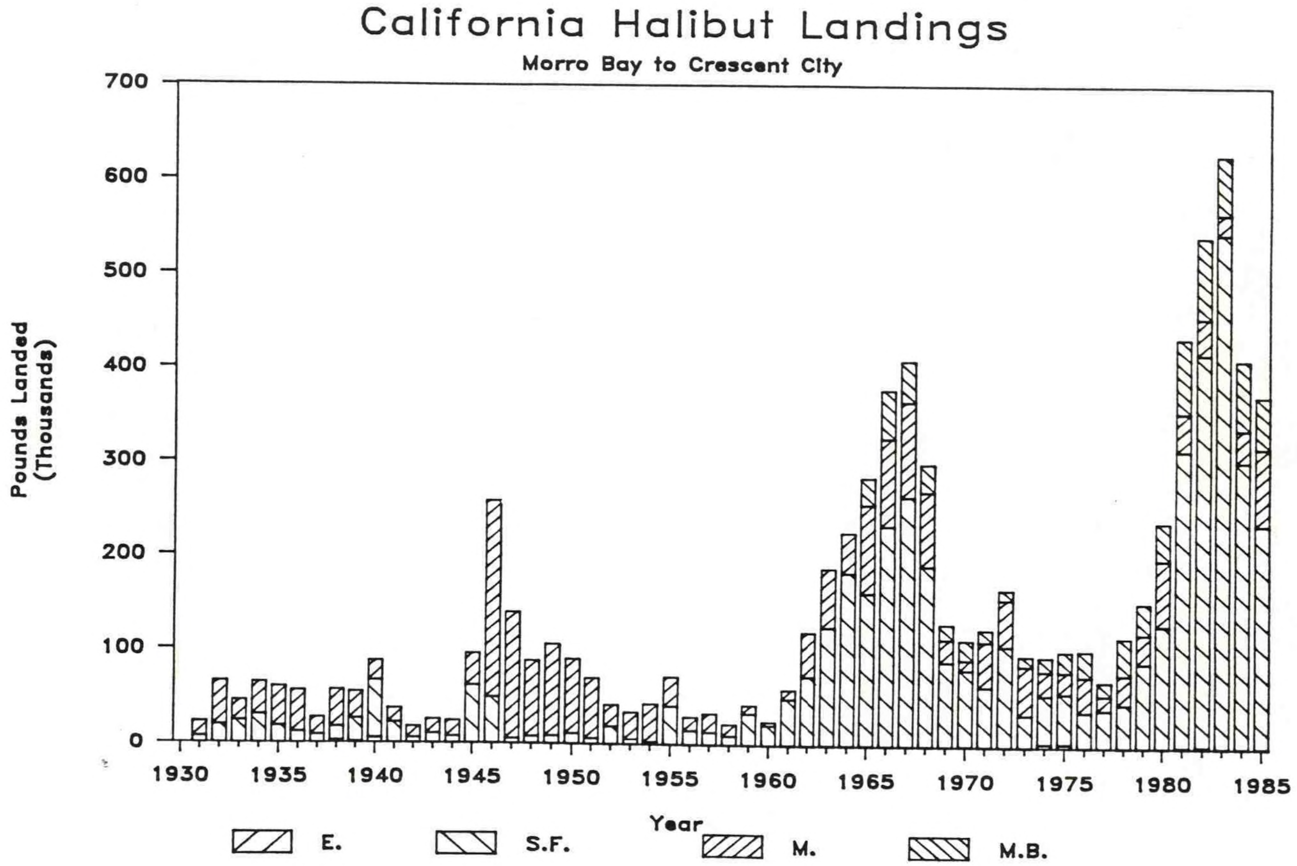

Figure 3. Total pounds of halibut landed from Morro Bay to Crescent City in 1931-85 (CDFG 1931-85). Statistical areas include Eureka (E.), San Francisco (S.F.), Monterey (M.), and the port of Morro Bay (M.B.). CDFG landing records for Morro Bay are not reported for all years. Values for 1977 to 1985 are based on preliminary estimates.

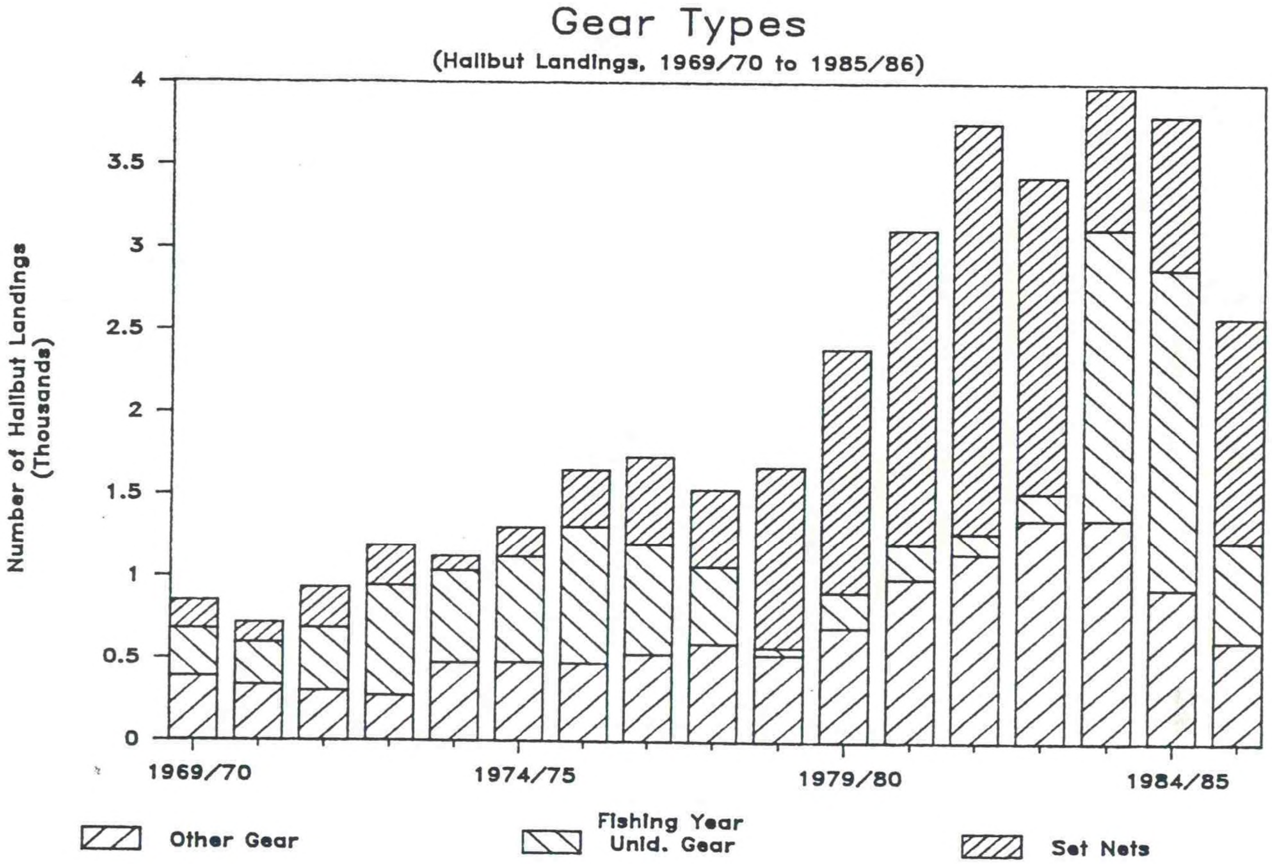

Figure 4. Proportion of total number of halibut landings attributed to the indicated gear types during the fishing seasons from 1969/70 to 1985/86. Data include ports from Point Conception to Crescent City.

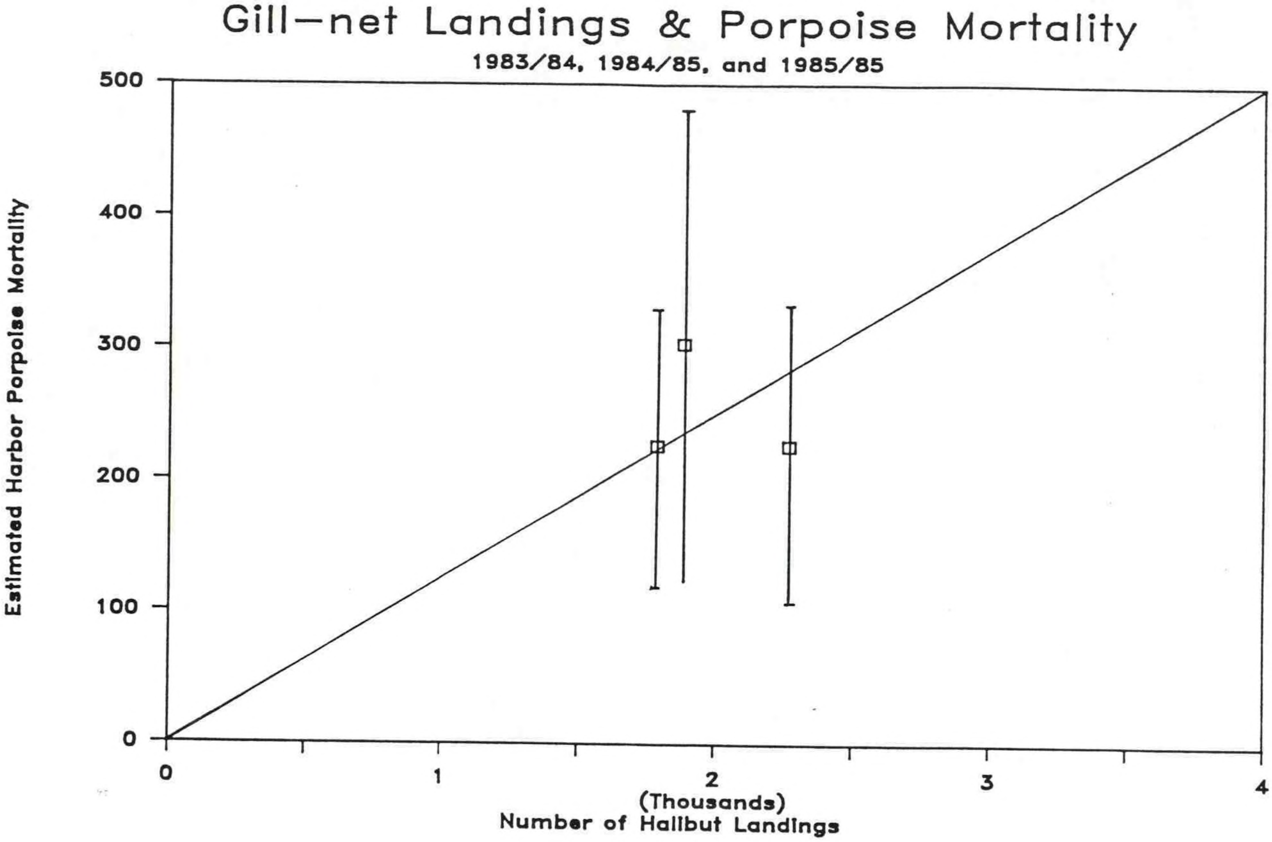

Figure 5. Relationship between porpoise mortality in set nets and number of halibut set-net landings for 1983/84, 1984/85, and 1985/86. Landings are limited to north of Point Conception. Error bars indicate 95% confidence limits for estimates of porpoise mortality (Table 1). Line indicates least-squares regression which was constrained to pass through the origin.

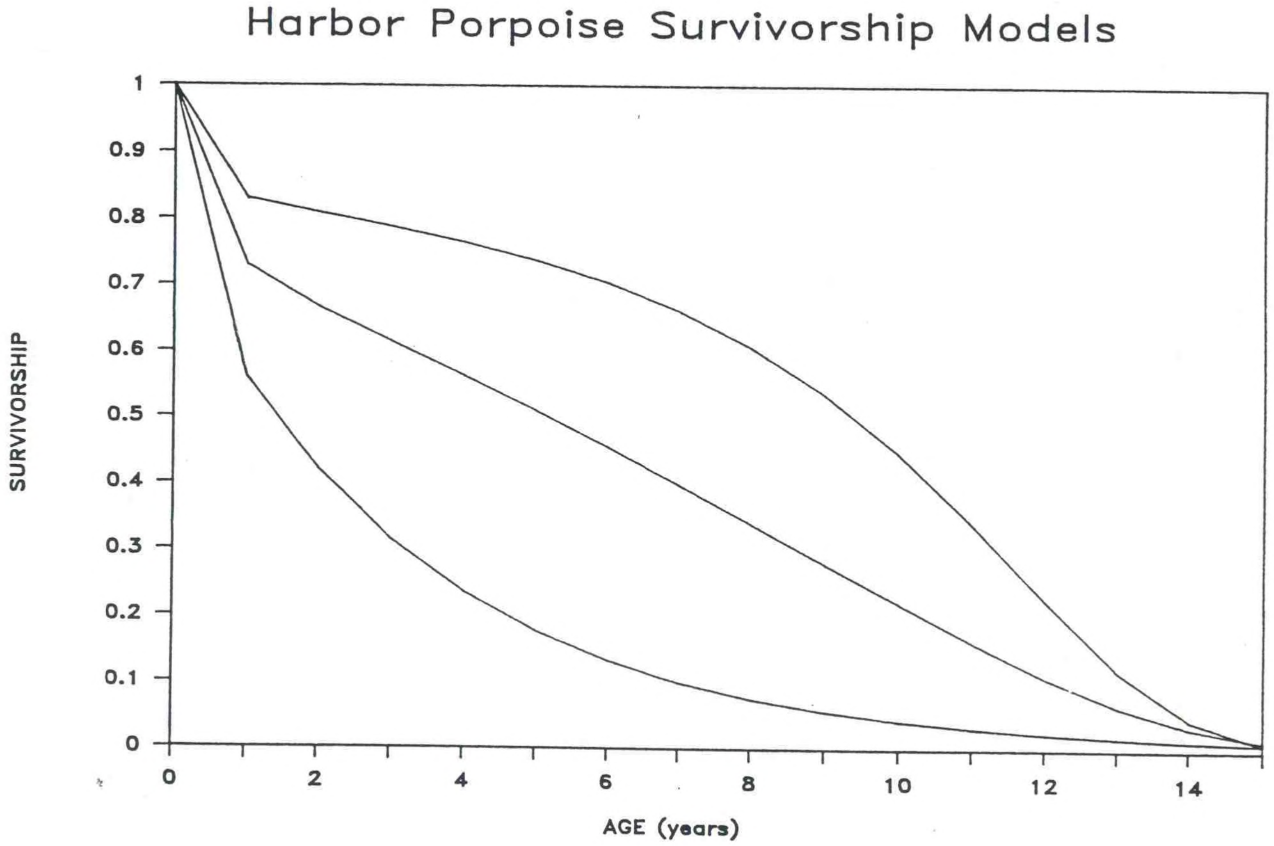

Figure 6. Survivorship curves used to estimate maximum rates of population growth. All are scaled to give a survivorship of 1% at age 15 yr. Curves are based on a) constant survivorship with age, b) the survivorship curve of the Himalayan thar (Caughley 1966), and c) the survivorship curve of human females circa 1900 (Fruehling 1982). For all, survivorship for the first year is estimated as the square of the mean survival rate of the reproductive age classes.