# HISTORIC POPULATION LEVELS OF DALL'S PORPOISE IN THE NORTH PACIFIC

by

J. M. Breiwick

**National Marine Mammal Laboratory**
Northwest and Alaska Fisheries Center
National Marine Fisheries Service, NOAA
7600 Sand Point Way N.E., Bldg. 4
Seattle, Washington 98115

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## INTRODUCTION

In order to determine the current status of cetacean stocks, scientists, managers, and administrators have usually adopted a procedure based largely on the International Whaling Commission's (IWC) "new management procedure" (NMP), which was adopted in principle by the Commission at its 1974 meeting (International Whaling Commission, 1975) and took effect during the 1975-76 and subsequent seasons. The NMP consists of classifying the stock in question (defined as the total, mature, or exploitable population, as appropriate) as Initial Management Stock (IMS), Sustained Management Stock (SMS), or Protection Stock (PS), according to whether the current stock is equal to or greater than 20% above the maximum sustainable yield level (MSYL), between 10% below MSYL and 20% above MSYL, or less than 10% below the MSYL, respectively. The IWC further specifies quotas (as a fraction of MSY) for each stock classification.

In order to apply the above procedure the following information is needed: 1) the size of the current population, 2) the size of the "initial" or pre-exploitation population, and 3) the relationship between population density and productivity, i.e. the "production" curve (MSY is also required in order to set quotas). The usual practice is to estimate the current stock size using models based on catch and effort, or sighting data, assume a particular form for the relationship between recruitment rate and stock density, and back calculate this current size to some starting year, based on a projection model. The parameters of the density-recruitment function determines the level at which maximum net productivity (MNP) of the stock occurs. As such, the procedure is simple to apply once the various relationships and parameter values are specified.

This paper presents an analysis of the pre-exploitation population size (in 1952) of Dall's porpoise in the North Pacific based on a simple population model.

**POPULATION MODEL**

The population model adopted was based on the following relationship:

$$N_{t+1} = N_t - K_t + R_t, \quad [1]$$

where $N_t$ is the population size at the start of fishing season t, $K_t$ is the total removals during season t, and $R_t$ is the number of animals recruited to the population between time t and t+1. This is the same model used by Smith (1983) to model changes in several *Stenella* populations in the eastern tropical Pacific Ocean. Recruitment ($R_t$) is modeled as a density-dependent net recruitment rate ($r_t$) times the approximate average population size during the fishing season (neglecting natural mortality, which is small during the fishing season):

$$R_t = r_t(N_t - K_t/2). \quad [2]$$

The relationship between population density and net recruitment rate is based on Allen (1980):

$$r_t = r_m(1-[N_t/N_o])^z. \quad [3]$$

Here, $r_m$ is the maximum net recruitment rate, $N_o$ is the pre-exploitation population size, and z is the density-dependent exponent.

At equilibrium $N_{t+1} = N_t = N$ and $K = R$. By differentiating K with respect to N and setting this equal to 0 ($dK/dN = 0$) the MNPL (relative to $N_o$) can be solved for (Polacheck, 1982):

$$MNPL = (\{r_m+z+1 - [(r_m+z+1)^2-r_m(r_m+2)]^{1/2}\}/r_m)^{1/z} \qquad [4]$$

If $R_t=r_tN_t$ then the MNPL (relative to $N_o$) simplifies to

$$\text{relative MNPL} = (1+z)^{-1/z}. \qquad [5]$$

If $z=1$, then the MNPL is $0.5N_o$ and if $z=2.39$ the MNPL is $0.6N_o$. The exact relationship (based on [4]) is a function of $r_m$ as well as z. It can be shown, using L'Hospital's rule for finding the limit of the quotient of two functions, that [5] is the limit of [4] as $r_m$  0. Equations [4] and [5] can also be solved iteratively for z for a given MNPL.

By solving the population model for K under equilibrium conditions, the sustainable yield at relative population level p is given by

$$\begin{aligned} SY_p &= N_o p r_p/[1+(r_p/2)] \\ &= N_o r_m(1-p^z)p/[1+(r_m/2)(1-p^z)], \end{aligned}$$

where $p=N/N_o$ is the relative population size.

The estimation scheme involves specifying a current population size, a vector of removals ($K_t$), and the parameters $r_m$ and z. Due to the nonlinearity in the coupled equations [1-3], the initial population size ($N_o$) is estimated via an iterative process. This has been implemented using an algorithm for finding the roots of a polynomial.

**INCIDENTAL KILL ESTIMATES**

Initial population size estimates were made for two populations of Dall's porpoise: the western central North Pacific population and the Bering Sea population. The existence of a Bering Sea population is supported by electrophoretic analysis, parasite levels and differences in biological parameters, particularly calving period. There are insufficient data available to determine whether there are separate populations in the western and eastern North Pacific. Electrophoretic analysis indicates that the area of $50^o$ N to $52^o$ N latitude and $170^o$ E to $175^o$ E longitude may have a mixed population that does not include animals from the Bering Sea (Winans and Jones, 1987). The mixture could be of animals from the west and east areas but no samples were available from the eastern Pacific to test this hypothesis. Separate populations in the North Pacific were assumed for this assessment. Only the western North Pacific stock which is involved in the take by salmon and squid fisheries is considered in this assessment.

The Japanese high seas salmon mothership fishery has been operating in the North Pacific since 1952. Although there was some fishing effort before World War II the effect this effort might have had on the population of Dall's porpoise would have been offset by the lack of effort (and likely recovery of the population) during the war years.

Effort data (in tans) were compiled for geographical ranges of the two populations considered: the Bering Sea (Limited) stock and the Western-Central North Pacific (Limited) Stock (Bouchet, Ferrero, and Turnock, 1986). The boundary between the two stocks is given by 53° N. latitude (Jones, Bouchet, and Turnock, 1986). Mothership fishing effort (in tans) by 2° x 5° squares by year were provided by M. Dahlberg, Auke Bay Fisheries Laboratory, NMFS, from data obtained from the Japan Fishery Agency. Fishing effort in squares which included 53° N. was prorated to the two stocks according to the relative area in each square (0.5). Fishing effort effort for the land-based salmon fishery was also used for analyses involving the Western-Central North Pacific porpoise stock. These data were taken from Table 3 of Ohsumi (1981 MS). Tans were converted to gillnet operations (sets) based on the relation 330 tans/gillnet operation. Effort data, for the period 1952 to 1979, are presented in Table 1.

The mean observed take rate for observed gillnet operations in the western North Pacific mothership fishery area within the U.S. EEZ from 1981 to 1985 was 0.47 porpoise per set. The mean observed incidental take rate in the Bering Sea area north of the U.S. EEZ from 1981 to 1985 was 0.28 porpoise per set. For assessment purposes the mean kill rates for the western central North Pacific and Bering Sea stock were rounded to the nearest tenth (0.5 and 0.3, respectively). To investigate the sensitivity of the model to the kill rate the values 1.0 and 0.6 (twice the rounded estimates) were used for the western central North Pacific and Bering Sea stock, respectively.

It is reasonable to assume that the number of porpoise killed per gillnet operation is proportional to porpoise density. Therefore, back calculations were also performed based on this assumption. It is recognized, however, that historic effort in this fishery was more widely distributed than at present. In addition, it is not clear that porpoise density with respect to the fishing effort has changed during the course of the fishery. Nevertheless, back calculations were also made based on the assumption of a kill rate proportional to porpoise density in order to investigate the sensitivity of the model to a departure from a constant kill rate.

**CURRENT POPULATION SIZE**

Population estimates for Dall's porpoise in the North Pacific have been made for each year for the period 1978-1984 using line transect as well as strip transect methodology (Bouchet *et al.*, 1986). Owing to greater uncertainties and bias in strip transect estimates (Burnham, Anderson, and Laake, 1985) only estimates based on line transect theory were considered (Bouchet *et al.*, 1986.). The estimates based on the 1980-1984 pooled data were used since there were few data in the U.S.

Fishery Conservation Zone (FCZ) in 1978 and 1979. Previously, abundance estimates were made using both a negative exponential and half-normal detection models, the former giving higher population estimates owing to a higher estimate of f(0) - the detection model evaluated at 0 distance (i.e. on the trackline) (Bouchet *et al.*, 1986). Recently, the more robust Fourier series model was fit to the sighting data and the resulting estimate corrected for both movement and visibility biases (Turnock, 1987). The results of fitting the three sighting models to the pooled 1980-1984 data are given in Table 2. Only results based on the Fourier series model, however, were used in back calculations since this model is less sensitive to departures from the assumptions of line transect theory than either the half-normal or negative exponential model.

The yearly abundance estimates from Tables 1-14 of Bouchet *et al.* (1986) (summarized in Jones *et al.*, 1986; Table 13) vary due to a number of factors (sampling variability, amount of coverage etc.). These yearly estimates do not differ significantly and therefore it is assumed that the population has not changed dramatically over the period 1980-1984. As a result, combined estimates for 1980-1984 have been used in the model as an estimate of the 1980 population size.

**MODEL PARAMETERS**

In addition to estimates of removals from the population, the other parameters required in the model [1-3] are the maximum net recruitment rate ($r_m$) and the density dependent exponent (z).

The net recruitment rate is the difference between the gross recruitment rate and the natural mortality rate. However, since the natural mortality rate is very difficult to estimate directly for cetacean populations (de la Mare, 1985; Mizroch, 1985) the approach taken here, as elsewhere (e.g. Breiwick and Mitchell, 1983) is to provide a range of values of $r_m$ (0.02-0.06) that are likely to encompass the true value. Given that Dall's porpoise have an apparent 1 yr breeding cycle and mature at about 2 to 4 years (Jones *et al.*, 1986) it is unlikely that the maximum net recruitment is as low as 0.02. This lower value has been included to provide a upper bound on the calculation of the pre-exploitation stock size.

Although there are no cetacean populations for which z has been directly estimated, based on life history and other information, large mammals are assumed to have maximum net productivity at levels greater than $N_o/2$ (Fowler, 1981). Dall's porpoise, with an apparent breeding cycle of 1 yr might be expected to have an MNPL no greater that of large baleen whales, for which a value of z=2.39 (MNPL=$0.6N_o$) has usually been used by the IWC. Smith (1983) employed a range for MNPL of 50-80%. I have adopted values of z such that relative MNPL = 0.60 and note the direction of change in the estimates of $N_t/N_o$ as the MNPL departs from $0.60N_o$.

**RESULTS**

The initial population size estimates corresponding to kill rates of 0.3 and 0.6 are given for the Bering Sea stock in

Table 3. For the constant kill rate of 0.3 the ratio of current to initial stock size varies from 0.90 to 0.95 for maximum net recruitment rates varying from 0.02 to 0.06. The ratios vary from 0.81 to 0.90 for a constant kill rate of 0.6.. The effect of using a density dependent kill rate is a slight increase in the initial population size estimates and a corresponding slight decrease in the ratio of current to initial population size. The Bering Sea stock has been less affected by the fishery than the Western-Central North Pacific stock. Even with the higher kill rate of 0.6 and a maximum net recruitment rate of 0.02 the current population is still greater than 80% of the pre-exploitation size. A feature apparent from the tables is that the difference between ratios based on a constant kill rate and a density dependent kill rate becomes smaller as the maximum net recruitment rate increases.

Estimates corresponding to kill rates of 0.5 and 1.0 are given for the Western Central North Pacific stock in Table 4. The results indicate that the fishery in the Western Central North Pacific has had more of an impact than the fishery in the Bering Sea. Ratios of current to initial population size are greater than 60% except for a maximum net recruitment rate of 0.02 with a kill rate of 1.0. The higher the nominal kill rate (1980 rate) is, however, the greater the difference between results based on a constant kill rate and results based on a density dependent kill rate.

For the density dependent kill rate assumption the kill rate in 1952 can be calculated from the table by dividing the nominal kill rate by the ratio of current to initial population size. This follows from the fact that the kill rate in each year was made proportional to the estimated population size. Thus, if the population has been reduced to 50% of the initial level the 1952 kill rate would be twice the nominal (1980) kill rate.

Figures 1 and 2 show the back calculated initial population sizes projected forward to the 1980 level for maximum net recruitment rates of 0.02, 0.04, and 0.06, for the two stocks. Figures 3 and 4 give the sustainable yields for the two stocks for the three maximum net recruitment rates (constant kill rate only). Maximum sustainable yields for the Bering Sea stock vary from 1,970 to 5,460 for maximum net recruitment rates of 0.02 to 0.06. For the western-central North Pacific stock the maximum sustainable yields vary from 8,138 to 20,655. Actual sustainable yields are lower, depending on how much greater than the MNPL the current stock is. In addition, if these sustainable yield curves are to applied to the present stocks consideration must be given to natural variability in population processes and the catch history must be considered (i.e. it must be borne in mind that the current population is unlikely to be an equilibrium population since annual removals are not constant).

**DISCUSSION**

The above analysis is a deterministic one and as such does not take into account variability in parameters such as net recruitment and kill rate. To avoid having to introduce another parameter (natural mortality rate) a rather simple model has been employed. The strategy has been to use a model whose complexity is compatible with the amount of information available (Ludwig and Walters, 1985).

Three main sources of error are identified: 1) error in the correct form of the population projection model, 2) errors in model parameters (vital rate parameters, historic effort and kill rates etc.), and 3) errors in defining the stock in question.

While the above procedure is rather simple in its assumptions (e.g. equal sex ratio in historic kills, MNPL equal to 60%, etc.) it does attempt to account for the basic life history features of the Dall's porpoise populations in the North Pacific and Bering Sea.

A density dependent exponent such that the MNPL is 60% of the initial population size has been used in this analysis based on its historical use by the IWC. If it is assumed that the MNPL is greater that 60% then the estimates of initial population size decrease and the corresponding ratio of current to initial increases. If lower values for current population size are adopted then the ratios in Tables 3 and 4 will be lower. There are also a number of other models based on different assumptions about population processes that could be used. However, since little is know about historic population parameters, assumptions must be kept to a minimum; more complicated models (i.e. age and sex structured models) are not possible at present.

A stochastic approach to estimating initial population sizes, which has its own drawbacks, is to assume a probability distribution for representing the uncertainty in the value of maximum net recruitment rate and current population size (and possibly other parameters, such as kill rate, MNP level, etc.) and use a Monte Carlo approach. Thus for each trial (consisting of an estimate of the initial population size) these two parameters would be chosen from an appropriate probability distribution and after a large number of trials the fraction of the ratios of current to initial population size that are above 60% could be calculated. A similar technique has been used to assess eastern spinner dolphins (Sebenius, 1981). This approach, however, requires a number of additional assumptions and is not warranted at present.

**LITERATURE CITED**

Allen, K. R. 1980.
Conservation and management of whales. Washington Sea Grant Publication (University of Washington Press), Seattle. 107 p.

Bouchet, G. C., R. C. Ferrero, and B. J. Turnock. 1986.
Estimation of abundance of Dall's porpoise (*Phocoenoides dalli)* by shipboard sighting surveys. Document submitted to the meeting of the Scientific Subcommittee of the Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, Tokyo, Japan. March 10-15, 1986. 50 pp.

Breiwick, J. M. and E. D. Mitchell. 1983.
Estimated initial population size of the Bering Sea stock of bowhead whale (*Balaena mysticetus*) from logbook and other catch data. Rep. int. Whal. Commn (Special Issue 5) :147-151.

Burnham, K. P., D. R. Anderson, and J. L. Laake. 1985.
Efficiency and bias in strip and line transect sampling. J. Wildl. Manage. 49(4):1012-1018.

de la Mare, W. K. 1985
On the estimation of mortality rates from whale age data, with particular reference to minke whales (*Balaenoptera acutorostrata*) in the Southern Hemisphere. Rep. int. Whal. Commn 35:239-250.

Fowler, C. W. 1981.
Density dependence as related to life history strategy. Ecology 62:602-610.

International Whaling Commission, 1975.
Annex F. Classification of Whale Stocks. Rep. int. Whal. Commn 26:39-42.

Jones, L. L., G. C. Bouchet, and B. J. Turnock. 1986.
Comprehensive report on the incidental take, biology and status of Dall's porpoise. Document submitted to the Scientific Subcommittee, Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, March 10-14, 1987, Tokyo, Japan.

Ludwig, D. and C. J. Walters. 1985.
Are age-structured models appropriate for catch-effort data? Can. J. Fish. Aquat. Sci. 42:1066-1072.

Mizroch, S. A. 1985
On the relationship between mortality rate and length in baleen whales. Rep. int. Whal. Commn 35:505-510.

Ohsumi, S. 1981 MS.
An assessment of the population of Dall porpoise. Exhibit FJS-4. Statement of Seiji Ohsumi at Public Hearings Before the National Marine Fisheries Service on Proposed Regulations Governing the Take of Marine Mammals Incidental to Commercial Salmon Fishing Operations. MMPAH #1981-1. 28 p. + 3 suppl. pp.

Polacheck, T. 1982.
Local stability and maximum net productivity levels for a simple model of porpoise population sizes. U.S. Dept. Commerce, NOAA-TM-NMFS-SWFC-17, 14 p.

Sebenius, J. K. 1981.
Marine resource management under uncertainty: the case of Eastern Spinner dolphin depletion. Mar. Fish. Rev. 43(10): 1-4.

Smith, T. D. 1983
Changes in size of three dolphin (*Stenella* spp.) populations in the Eastern Tropical Pacific. Fish. Bull. 81(1):1-13.

Turnock, B. J. 1987. Analysis of experiments to assess movement of Dall's porpoise in relation to survey vessels and population estimates corrected for movement and visibility bias for the North Pacific Ocean. Document submitted to the Scientific Subcommittee, Ad Hoc Committee on Marine Mammals, International North Pacific Fisheries Commission, March 10-14, 1987, Tokyo, Japan.

Winans, G. A. and L. L. Jones. 1987. Electrophoretic variability in the Dall's porpoise (*Phocoenoides dalli*) in the North Pacific Ocean and Bering Sea. (submitted to J. Mammal.).

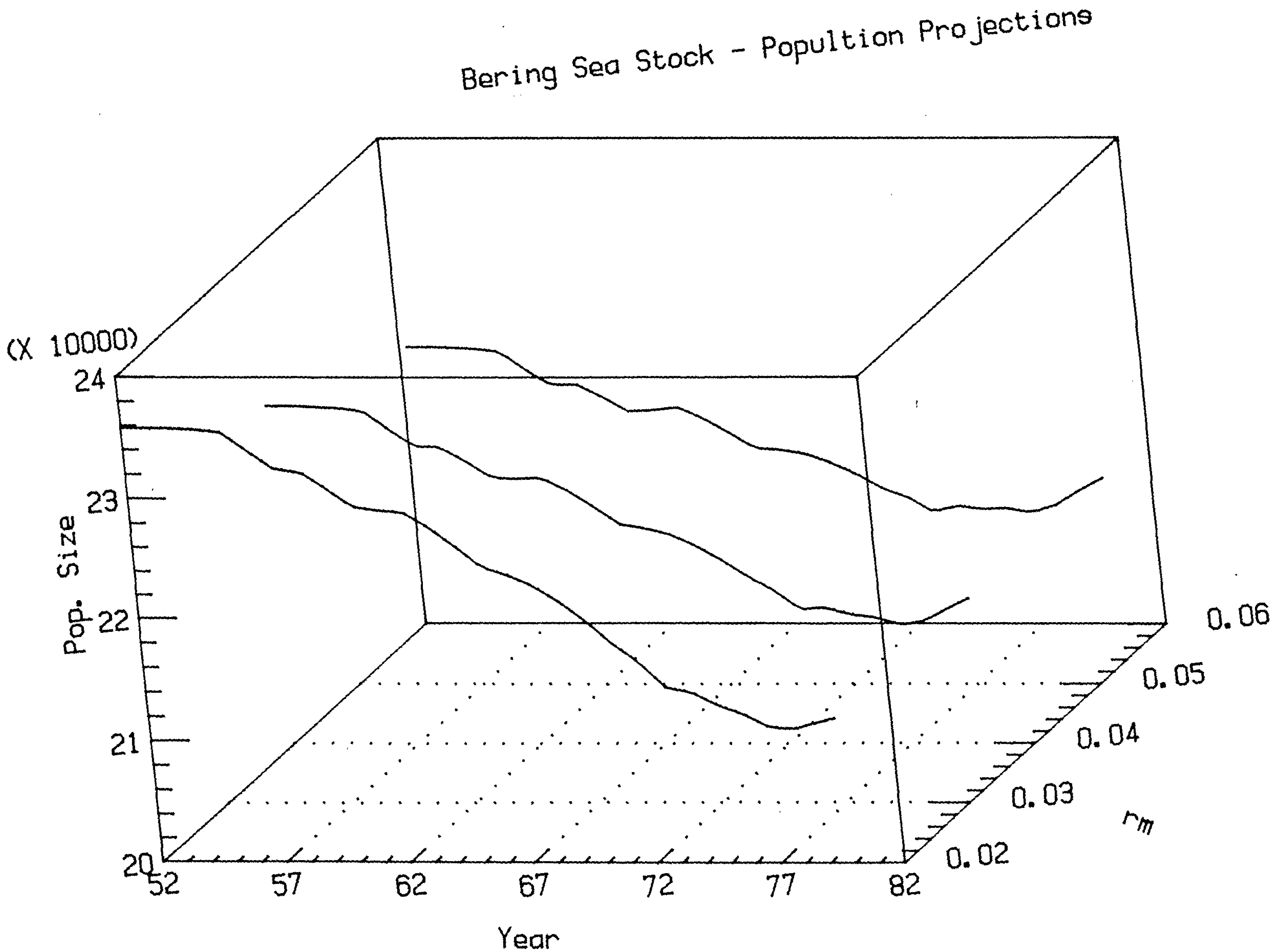


Fig. 1. Population trajectories for the Bering Sea stock of Dall's porpoise for $r_m$ = 0.02, 0.04, and 0.06. $N_{1980}$ = 212,000.

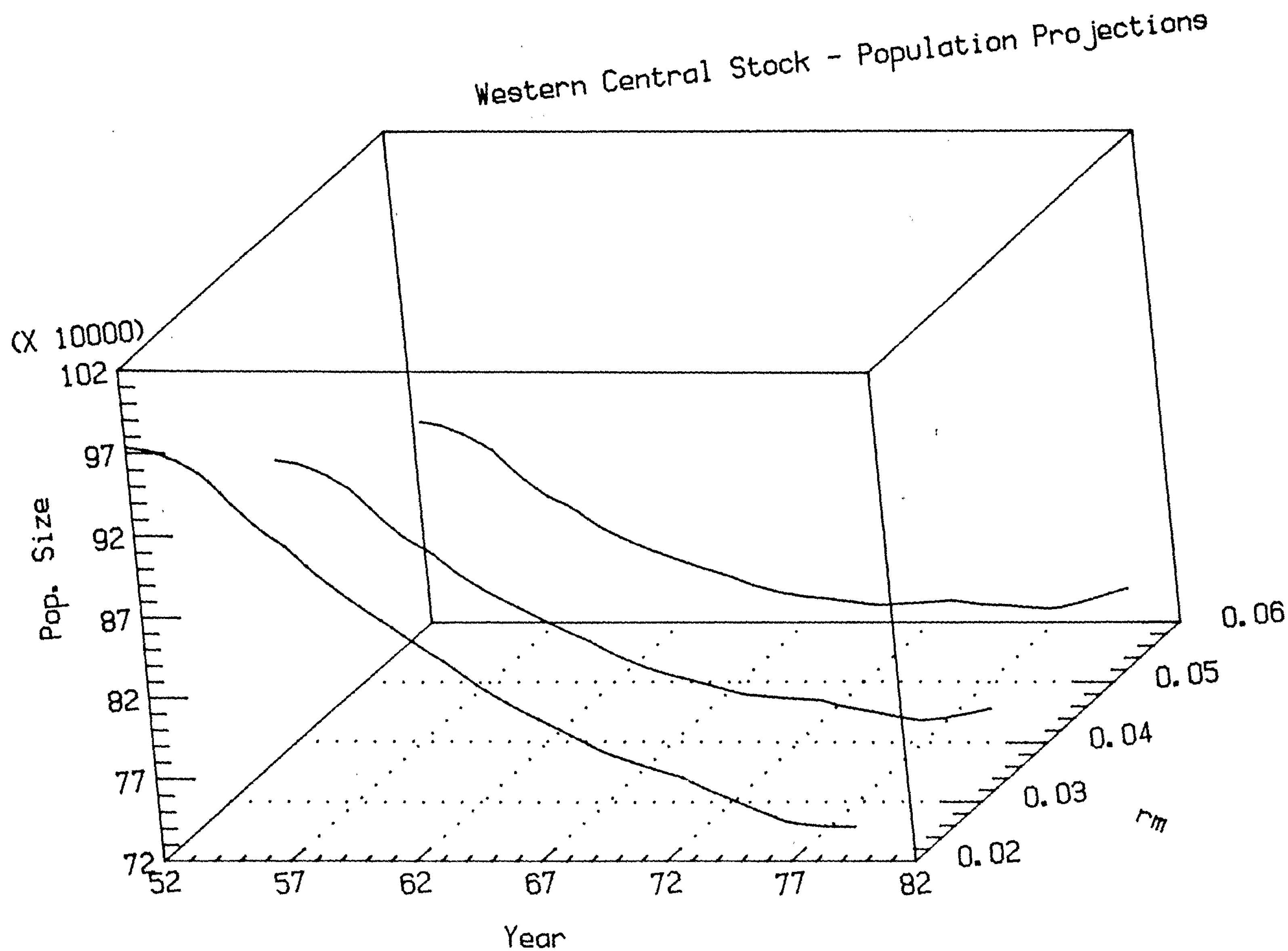


Fig. 2. Population trajectories for the Western Central North Pacific stock of Dall's porpoise for $r_m = 0.02, 0.04$, and $0.06$. $N_{1980} = 741,000$.

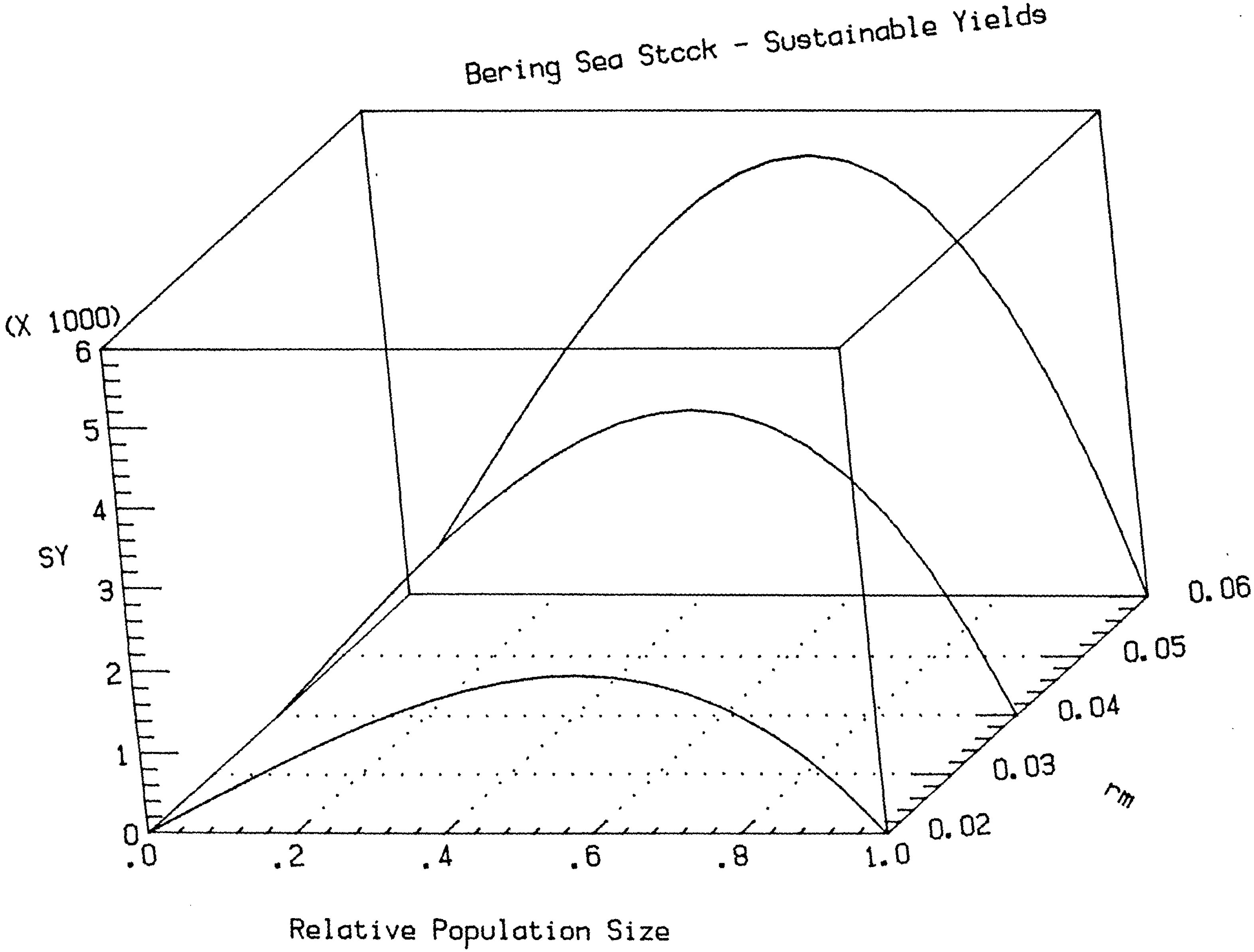


Fig. 3. Sustainable yield curves for the Bering Sea stock of Dall's porpoise for kill rate = 0.3 and $r_m$ = 0.02, 0.04, and 0.06. $N_{1980}$ = 212,000.

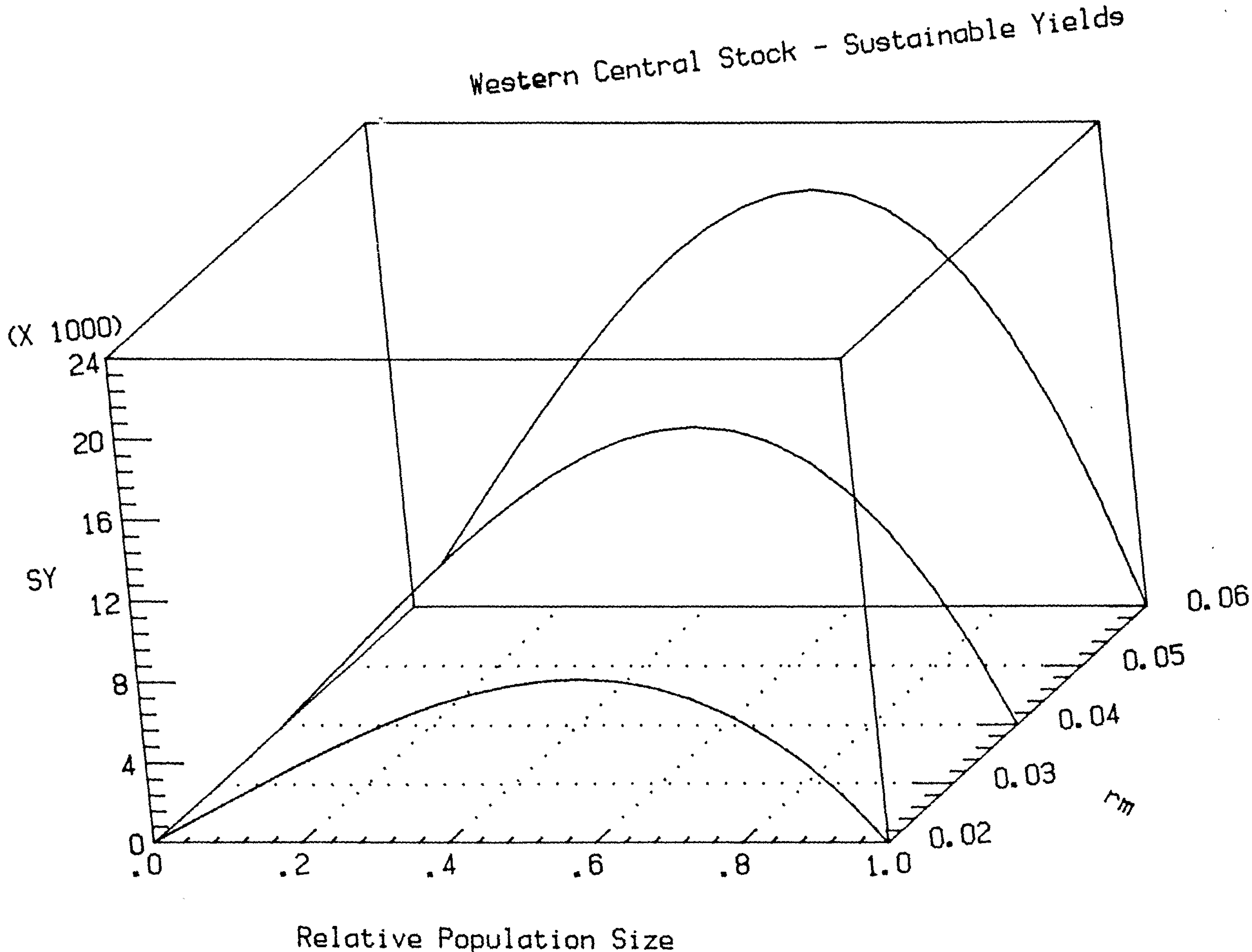


Fig. 4. Sustainable yield curves for the Western Central North Pacific stock of Dall's porpoise for kill rate = 0.5 and $r_m$ = 0.02, 0.04, and 0.06. $N_{1980}$ = 741,000.

Table 1. Total gillnet operations (sets) for 1952-1979. Mothership data from M. Dahlberg (pers. comm.); Land-base data from Ohsumi (1981 MS).

| | Western-Central North Pacific | | | Bering Sea (North of 53° N.) |
|---|---|---|---|---|
| Season | Mothership | Land-Base | Total | Mothership |
| 1952 | 1395 | 2668 | 4063 | 33 |
| 1953 | 3932 | 8786 | 12718 | 144 |
| 1954 | 9704 | 9476 | 19180 | 322 |
| 1955 | 20290 | 14950 | 35240 | 893 |
| 1956 | 23058 | 10166 | 33224 | 5158 |
| 1957 | 14863 | 10626 | 25489 | 5175 |
| 1958 | 24834 | 11086 | 35920 | 1210 |
| 1959 | 16558 | 14880 | 31438 | 4946 |
| 1960 | 14038 | 15840 | 29878 | 5716 |
| 1961 | 13023 | 16620 | 29643 | 2110 |
| 1962 | 16259 | 14520 | 30779 | 1473 |
| 1963 | 12822 | 16980 | 29802 | 5221 |
| 1964 | 16289 | 17580 | 33869 | 6497 |
| 1965 | 11210 | 19762 | 30972 | 7306 |
| 1966 | 11711 | 16818 | 28529 | 4032 |
| 1967 | 11094 | 15616 | 26710 | 4760 |
| 1968 | 11747 | 16394 | 28141 | 6204 |
| 1969 | 1508 | 16503 | 28011 | 7331 |
| 1970 | 9955 | 12988 | 22943 | 8315 |
| 1971 | 10083 | 12525 | 22608 | 7613 |
| 1972 | 8484 | 13517 | 22001 | 9447 |
| 1973 | 13653 | 15087 | 28740 | 4075 |
| 1974 | 10039 | 15784 | 25823 | 6427 |
| 1975 | 11581 | 15709 | 27290 | 5489 |
| 1976 | 10874 | 15590 | 26464 | 6735 |
| 1977 | 8225 | 9751 | 17976 | 3849 |
| 1978 | 6788 | 8841 | 15629 | 1459 |
| 1979 | 6973 | 7545 | 14518 | 1507 |

Table 2. Population size (1980-1984) based on three sighting distance models for Dall's porpoise in the Bering Sea and Western-Central North Pacific. HN = half-normal model, FS = Fourier series model, NE = negative exponential model. Numbers are in thousands. From Bouchet et al., 1986) and Turnock (1987).

| Bering Sea (North of 53° N.) | | | Western-Central North Pacific | | |
|---|---|---|---|---|---|
| HN | FS | NE | HN | FS | NE |
| 148 | 212 | 270 | 483 | 741 | 955 |

Table 3. Initial population size estimate for the Bering Sea stock (north of 53° N.) of Dall's porpoise (in thousands). Lower numbers are the current population size as a percentage of the initial population size.

| | | Maximum Net Recruitment Rate | | |
|---|---|---|---|---|
| | | 0.02 | 0.04 | 0.06 |
| Current Population Size | Kill Rate | Density dependent exponent | | |
| | | 2.367 | 2.344 | 2.322 |
| 212.0 | 0.3 | 235.8 | 227.8 | 222.9 |
| | | 0.899 | 0.931 | 0.951 |
| | 0.3* | 236.8 | 228.0 | 222.9 |
| | | 0.895 | 0.930 | 0.951 |
| | 0.6 | 262.1 | 246.4 | 236.1 |
| | | 0.809 | 0.861 | 0.898 |
| | 0.6* | 267.4 | 247.7 | 236.2 |
| | | 0.793 | 0.856 | 0.898 |

* Density dependent kill rate (= 1980 rate)

Table 4. Initial population size estimate for the Western-Central North Pacific stock of Dall's porpoise (in thousands). Lower numbers are the current population size as a percentage of the initial population size.

| | | Maximum Net Recruitment Rate | | |
|---|---|---|---|---|
| | | 0.02 | 0.04 | 0.06 |
| Current Population Size | Kill Rate | Density dependent exponent | | |
| | | 2.367 | 2.344 | 2.322 |
| 741.0 | 0.5 | 973.5 | 892.8 | 843.2 |
| | | 0.761 | 0.830 | 0.879 |
| | 0.5* | 1006.1 | 899.5 | 843.1 |
| | | 0.736 | 0.824 | 0.879 |
| | 1.0 | 1251.9 | 1102.8 | 997.1 |
| | | 0.592 | 0.672 | 0.743 |
| | 1.0* | 1471.5 | 1177.0 | 1012.9 |
| | | 0.504 | 0.630 | 0.732 |

* Density dependent kill rate (= 1980 rate)