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INCIDENTAL CATCH OF DOLPHINS IN TRAWLING FISHERIES OFF PATAGONIA, ARGENTINA: CAN POPULATIONS PERSIST?

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Abstract. The incidental mortality of dusky dolphins (*Lagenorhynchus obscurus*) in the Patagonian trawling fishery is a well-known problem, especially in mid-water trawl fisheries for shrimp and anchovy. Therefore, it is necessary to determine if recent levels of dolphin bycatch are compatible with the persistence of the dusky dolphin population. This was assessed by comparing annual bycatch rates with a sequence of critical values. These values were based on the maximum rate of increase (r_{max}) = $\lambda - 1$, where λ is the finite rate of increase. The finite rate of increase was estimated from a Leslie matrix where Monte Carlo procedures were employed to incorporate parameter uncertainties (age at first reproduction, survival rates, and fertility). Model life tables were used for survival, and reproductive parameters were estimated from available data on calving interval and age at sexual maturity. Uncertainties associated with annual bycatch rates were also included in the analysis through another randomization procedure that incorporated the variability in dolphin catch per unit effort, nominal fishing effort, and population size. This modeling approach rendered frequency distributions for the parameters of interest. Considering the critical values for incidental mortality rate as $(1/2)R = (1/2)r_{max}$ and $(1/4)R = (1/4)r_{max}$, and a 2-yr calving interval scenario, the probability that recent dolphin bycatch rates exceed the maximum annual removal rates were higher than 0.3. These results suggest that incidental mortality due to fishing could be, or may become, a threat for the dusky dolphin population off Patagonia. Therefore, a more accurate and intense monitoring program is needed to avoid the decline of this population. Also, this issue should be included in the fishery management strategies to be implemented in the near future.

Key words: Atlantic Ocean, South; bycatch; dusky dolphins; Lagenorhynchus obscurus; *Monte Carlo sampling; mortality; incidental; Patagonia; populations; rate of increase; sustainability; trawling fisheries; uncertainty analysis.*

Introduction

During the last 30 years, fisheries grew exponentially worldwide. This made clear the necessity of new strategies and approaches to properly manage fisheries, and consequently, to make them the basis for a sustainable development (Hilborn and Walters 1992). This fishery growth also brought to light new conflicts. Bycatch and incidental mortality of marine mammals are two of them.

Following this global trend, the Argentine fisheries operating in the southwestern South Atlantic also have been increasing for the last 20 years, playing an important role in the regional and national economy. In spite of the highly diverse and geographically extended coverage of Argentine fisheries, a large part of the fishing effort is concentrated in Patagonian waters. In this region, together with the jigging fishery directed to Argentine shortfin squid (*Illex argentinus*), an important trawling fishery operates for Argentine hake (*Merluccius hubbsi*) and Argentine red shrimp (*Pleoticus muelleri*). Several small cetaceans, such as dusky (*Lagenorhynchus obscurus*), Commerson's (*Cephalorhynchus commersonii*), and common (*Delphinus delphis*) dolphins die as bycatch in this trawling gear.

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Within the Patagonian trawling fishery a wide range of fishing types were identified considering the target species, mesh size, size of gear, and fishing hours (Crespo et al. 1997, Dans et al. 2003). These fishing types imply different impacts on the exploited community, mainly in relation to incidental catches of marine mammals (Crespo et al. 1997, Dans et al. 2003). Mid-water trawls for Argentine red shrimp showed the highest dolphin bycatch per unit effort (DPUE), leading to high dusky dolphin mortality during the 1980s (Crespo et al. 1997, Dans et al. 1997*a*).

The over exploitation of Argentine hake during the last decade (Bezzi et al. 1995, Aubone 2000) resulted in the collapse of this fishery. This collapse underscored the need for a change in harvest policies. During the decline of the Argentine hake, several measures were taken to reduce the catch levels of this species. One of them involved the reduction of mid-water trawls for Argentine red shrimp. This measure was implemented to reduce the bycatch of Argentine hake, and had the indirect benefit of reducing the incidental catch of dolphins. The collapse of the Argentine hake stock stimulated interest in alternative species. Experimental and commercial hauls targeting the underexploited Argentine anchovy (*Engraulis anchoita*) were carried out using mid-water trawls. Most of these trial operations reported incidental mortality of dusky and common dolphins (Crespo et al. 2000). In these cases, nominal fishing effort as number of trial hauls per day and per year, as well as DPUE, had not been properly estimated. Nevertheless, the frequency of entanglements suggests that the catch rates may be high.

The status of the affected dusky dolphin population will depend on its tolerance of current levels of incidental mortality. The evaluation of this tolerance requires knowledge of the vital parameters, and the development of demographic models to predict the impact of the removal of animals due to bycatch. In small cetaceans, the maximum rate of increase (r_{max}) is the parameter most commonly used for comparisons with the incidental mortality rate. If bycatch mortality rates exceed r_{max}, the population will always decline. Several international organizations and governmental agencies, such as the International Whaling Commission and the U.S. National Marine Fisheries Service, have established critical values for the maximum allowable incidental catches of marine mammals (International Whaling Commission 1991, 1996, Wade 1998).

For several endangered dolphin species, age-structured models were used to estimate maximum population growth rates and to evaluate management measures (Reilly and Barlow 1986, Barlow and Boveng 1991, Slooten and Lad 1991, Woodley and Read 1991). In most of these cases, the main constraint to implementation was the lack of vital rates. For this reason, reasonable sets of values for the rate of increase were obtained by considering different and plausible scenarios of survival and fecundity. Caswell et al. (1998) combined the use of model life tables and Monte Carlo techniques to incorporate the uncertainty in demographic vital rates of the harbor porpoise (*Phocoena phocoena*). In this way, they obtained the distribution of the finite rate of increase. A similar analysis was recently applied to Franciscana dolphins (*Pontoporia blainvillei*) in southern Brazil (Secchi 1999). More recently, Taylor et al. (2000) had shown how the United States management scheme for human-caused mortality of marine mammals was significantly improved by the explicit treatment of uncertainty.

The objective of this paper was to evaluate the impact of incidental catches of dusky dolphins in Patagonian waters, Argentina. The core element was to evaluate bycatch levels by comparing them with critical values based on the maximum population growth rate. This rate was estimated from a demographic model based on the available knowledge of the species in the region, and accounting for the uncertainty in some vital rates. Finally, uncertainty in maximum growth rate as well as population size and bycatch was explicitly considered for the comparison of bycatch levels with critical values.

Materials and Methods

Definition of critical values for incidental mortality

In population growth models with density dependence, the net recruitment rate (R_N), is defined as the annual per capita net growth rate resulting from reproduction and mortality. If we dismiss the Allee effect, this rate reaches its maximum value at low population sizes, and will be theoretically equal to the maximum rate of increase (r_{max}) when $N \to 0$. The net productivity rate of the population, defined as $R_N \times N$, will be lower at small population sizes and close to carrying capacity, reaching its maximum value, the maximum net productivity level (MNPL), at some fraction of the carrying capacity. For several marine mammal species, the MNPL would be reached between 50% and 85% of the carrying capacity depending on the degree of nonlinearity of the density dependence (Fowler 1981, DeMaster 1984, Taylor and DeMaster 1993).

Biological reference points or ''critical values'' for the incidental mortality rate can be defined on the basis of r_{max}. The assumption here is that bycatch rates should be less than or equal to the maximum quantity that the population would produce and replace. A sequence of three critical values was defined and then actual levels of mortality were compared to these values. These critical values were determined from r_{max} as follows:

1) R: the proportion of the population caught by the fishery equals r_{max}. This is the upper limit of mortality that a population may sustain, without any margin and without extinction.

2) (1/2)R: the proportion of the population caught by the fishery equals one-half r_{max}. This value considers that the population reaches the MNPL at 50% of its carrying capacity. Also at this point R_N is equal to one-half the maximum rate of increase (International Whaling Commission 1991).

3) (1/4)R: this value incorporates to the anterior value a factor ranging from 0 to 1 depending on the level of uncertainty, lack of knowledge, or population size. A factor of 0.5 is considered a more conservative figure and it was recommended at least for the harbor porpoise (International Whaling Commission 1996).

Demographic model and maximum rate of increase for dusky dolphins

Due to a lack of reliable information about demographic parameters for the dusky dolphin population off Patagonia, the maximum rate of increase (r_{max}) and its uncertainty were estimated by means of a Monte Carlo simulation (Caswell et al. 1998). This approach allowed consideration of the uncertainty in survival, age at first reproduction, and fertility.

The r_{max} was computed by an age-structured model based on a Leslie matrix (Caswell 1989). In this model

TABLE 1. Large mammal species for which reliable data were available. These species were used as reference species for survival pattern for dusky dolphins in this study.

Species	Age at first reproduction (yr) Mean	SD	CV	Reference
Dusky dolphin	6.93	0.398	0.058	this paper
African buffalo	4.00	0.203	0.051	Caswell et al. (1998)
Dall's sheep	2.00	0.207	0.104	Caswell et al. (1998)
Steller's sea lion	5.07	0.219	0.043	Calkins and Pitcher (1982)
Ringed seal	5.84	0.469	0.080	Smith (1975)
Northern fur seal	5.79	0.029	0.005	York (1983)
Pilot whale	8.99	0.155	0.017	Block et al. (1993)
Killer whale	15.14	0.759	0.050	Olesiuk et al. (1990)

Notes: Age at first reproduction for dusky dolphins and for each of the other species was estimated by considering the age at sexual maturity to be the age at which 50% of the females were mature. Standard deviation and coefficient of variation were obtained from bootstrap sampling procedures.

only females were considered and it was assumed that the first age class ($i = 1$) corresponds to newly born calves. The elements of the first row correspond to fertilities (F_i) and represent the number of female calves born per female of a given age class i. They were calculated as the annual pregnancy rate multiplied by the adult survival rate. The elements on the subdiagonal correspond to age-specific survival rates (P_i).

In theory, if survival and fertility rates remain constant over time, the population will reach a stable age distribution and will grow at the finite rate of increase (λ), which is the dominant eigenvalue of the matrix. The λ was estimated by solving

$$1 = \sum_{i=1}^{s} F_i \lambda^{-i} \prod_{j=1}^{i-1} P_j$$

which corresponds to the characteristic equation of the matrix and may be considered as a discrete version of Lotka's integral equation (Caswell 1989). In this model, the finite rate of increase represents the annual per capita rate of increase and relates to the maximum rate $r_{max} = \lambda - 1$, which can also be expressed as a percentage, $r_{max} = (\lambda - 1) \times 100$.

Survival

The survivorship pattern of the dusky dolphin population in Patagonia was based on published life tables for other species of large mammals that typically give birth to one offspring. The status of selected species represented a wide range of conditions. This was done due to the lack of knowledge about the survival pattern of dusky dolphins. Seven species were used, including two other delphinids (Table 1; Deevey 1947, Smith 1975, Calkins and Pitcher 1982, Olesiuk et al. 1990, Barlow and Boveng 1991, Block et al. 1993, Caughley and Sinclair 1995). These two delphinid populations were not harvested, and both showed positive rates of increase. Steller's sea lion population was harvested in previous years before the construction of the life table, but survival estimates produced a positive rate of increase, although low (Pascual and Adkinson 1994). Fur seals were also harvested, but catches can be considered negligible at the moment that survival estimates were obtained (Barlow and Boveng 1991). Among terrestrial mammals, a buffalo population was increasing at a rate of 7.7% per year (Caughley and Sinclair 1995).

Since the reference species and dusky dolphins have different lifespans, age was rescaled, correcting all age classes of each species by the age at first reproduction (AFR) as follows:

$$T_j^* = T_j \frac{\mathrm{AFR}_{\mathrm{dusky}}}{\mathrm{AFR}_j}$$

where T_j^* represents the corrected age for the species j, T_j represents the actual age for the species j, $\mathrm{AFR}_{\mathrm{dusky}}$ is the age at first reproduction of dusky dolphins, and AFR_j is the age at first reproduction of the species j. (Then if AFR is 6.93 and 15.14 for dusky dolphins and killer whales, respectively, 1 yr in the killer whale life table represents 0.46 yr for dusky dolphins.) Rescaled survivorship curves obtained by this method defined a space of possible survivorship patterns for the dusky dolphin (Fig. 1).

Following Caswell et al. (1998), available data from literature were used for estimating AFR for model species. For female dusky dolphins our own field data were used (Table 2). In most cases, AFR was estimated by adding the gestation period to the age at sexual maturity. In the case of the dusky dolphin, the gestation period was considered equal to 12 mo. Age at sexual maturity was defined as the age at which 50% of females are mature; then it was estimated by fitting a logistic regression to the proportion of mature females in each age class $p_{(x)}$:

$$\frac{p_{(x)}}{1 - p_{(x)}} = \exp(b_1 + b_2 x)$$

where x = age class, and b_1 and b_2 are parameters.

Then, the age at which $p_{(x)}$ is 0.5 (50% mature) is equal to $-b_1/b_2$. The AFR values obtained by this method are detailed in Table 1.

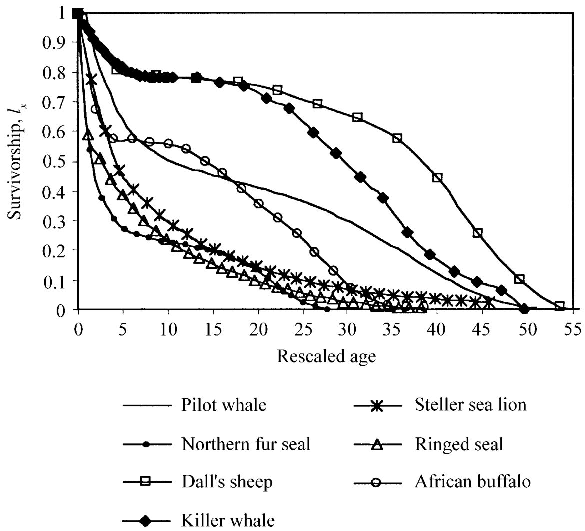

FIG. 1. Model survivorship curves from information available for other large mammals. The age was rescaled by using the age at first reproduction (AFR) as the correction factor.

Incorporation of uncertainty

The uncertainty in dusky dolphin survivorship was incorporated by a multiple step procedure. First, the uncertainty in AFR of the dusky dolphin as well as model species was taken into account. Then Monte Carlo techniques for sampling the space of survivorship curves were carried out.

Uncertainty in AFR.—A bootstrap sampling procedure was performed by which females in each age class x were resampled with replacement, taking a number of females equal to the number of females in the sample N_x. Then for each resampling event a new $p_{(x)}$ series was obtained, and age at sexual maturity was estimated again. This procedure was repeated 1000 times, calculating a mean value for AFR and its bootstrap generated distribution. For the dusky dolphin, data from a sample of 20 females were used (Table 2), and the bootstrap distribution of AFR is drawn in Fig. 2.

Monte Carlo sampling.—Model survivorship curves were combined to define the space of probable values of survival for each age. From this space, 1000 samples were taken following a Monte Carlo procedure as described by Caswell et al. (1998):

1) An AFR value was randomly chosen from the bootstrap generated distribution of this parameter for each model species as well as the dusky dolphin.

2) With the selected values, the scale was corrected and a new space of survivorship curves was defined.

3) From this new space of survivorship, only one curve for the dusky dolphin was constructed by averaging the survivorship values for each model species in each age, as follows:

TABLE 2. Reproductive status of female dusky dolphins from incidental catches in fisheries off Patagonia during 1990–1995.

Age, x (yr)	Immature	Mature	Total (N_x)†
3	3	0	3
4	2	0	2
5	4	0	4
6	1	2	3
7	1	3	4
8	0	3	3
9			0
10			0
11	0	1	1

† Sample size = 20 female dolphins.

$$l_x = \sum_j c_j l_{xj}$$

where l_{xj} is survivorship from birth to age x for species j and c_j is the weight of species j in the average. The weights were randomly assigned so that $c_j \geq 0$ and $\Sigma_j c_j = 1$. Then assuming that each curve has the same probability of describing the actual survivorship pattern of the dusky dolphin:

4) Steps 1–3 were performed 1000 times, thus obtaining a set of survivorship curves for the dusky dolphin. A subset of this Monte Carlo sample is shown in Fig. 3.

5) From each survivorship curve, age-specific survival rates (P_i) were calculated as

$$P_i = \frac{l_i}{l_{i-1}}.$$

Fertility

Age-specific fertility rates (F_i) were calculated as

$$F_i = \text{APR} \times P_i \times 0.5$$

where P_i is age-specific survival, 0.5 represents a sex

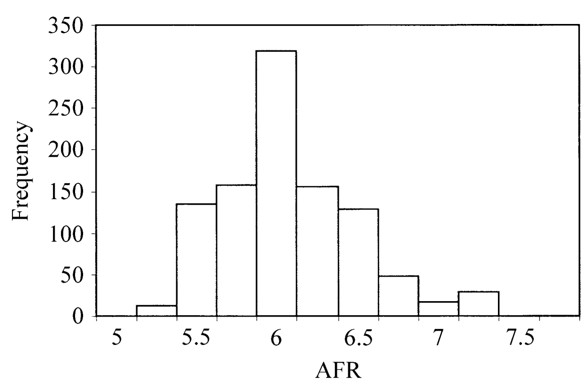

FIG. 2. Frequency distribution of the age at first reproduction (AFR) for the dusky dolphin. The distribution was obtained by bootstrap sampling the number of mature females in each age class, calculating the age at maturity, and adding the gestation period. Sample size = 1000 dolphins.

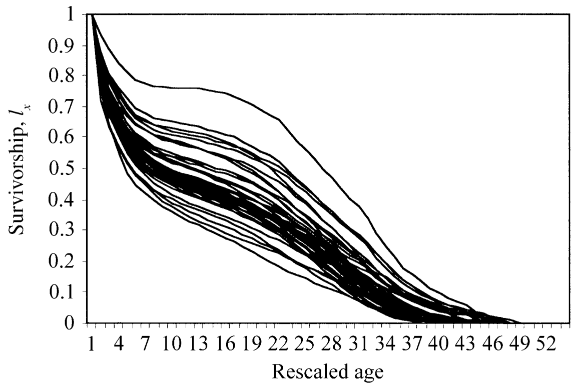

FIG. 3. Survivorship curves generated by Monte Carlo sampling of model life tables and rescaled age for the dusky dolphin. Each curve represents a weighted mean among survivorship values for each model species.

ratio of newborn calves of 1:1, and APR is the annual pregnancy rate. Annual pregnancy rate and calving interval (CI) are related by

$$\mathrm{APR} = \frac{1}{\mathrm{CI}}.$$

Then $F_i = 0.25 \times P_i$ if CI is 2 yr, and $F_i = 0.166667 \times P_i$ if CI is 3 yr.

Rate of increase and its uncertainty

Age-specific survival rates (P_i) obtained by Monte Carlo sampling, were introduced in the population matrix, and combined with fertility rates. Then the finite rate of increase was calculated by solving the characteristic equation of the matrix. This procedure was repeated 1000 times with each one of the survival patterns of the Monte Carlo sample, obtaining a distribution of the finite rate of increase.

The lack of age-specific pregnancy rates precluded the incorporation of the corresponding uncertainty in fertility rates. Nevertheless, on the basis of the available reproductive information of dusky dolphin populations, two different scenarios are plausible. In Patagonian waters, it was considered that the calving interval lasts at least two years (Dans et al. 1997*b*). In Peruvian and Chilean waters, it was estimated an annual pregnancy rate of 0.55 (Van Waerebeek 1992). Therefore, the two possible scenarios correspond to calving intervals of two or three years. A distribution of the finite rate of increase was obtained for each scenario. These calculations took into account the uncertainty of vital rates (survival and reproduction) of the dusky dolphin, but they did not include time trends. This assumption suggested that climate did not impact dolphin production.

Annual bycatch and its uncertainty

Obtaining reliable estimates of dolphin bycatch in the Patagonian trawling fishery is extremely difficult. The main reason is the low frequency of the entanglement events; this makes necessary a large sampling effort in order to get reasonable figures. The high diversity of fishing types within this fishery also contributes to these difficulties (Crespo et al. 1997). Putting together these two elements, it is clear that the annual number of incidentally caught dolphins will depend on the dolphin bycatch per unit effort (DPUE) of each fishing type, and the nominal fishing effort that they exert in a given year (Crespo et al. 1997, Dans et al. 2003). Therefore, the uncertainty associated with the annual bycatch implies both the variability of the DPUE itself, and the variability of the nominal fishing effort.

The uncertainty of the DPUE for each fishing type was incorporated by using a triangular distribution. The two extremes of these DPUE distributions were the mean catch rate and the maximum catch rate obtained for each fishing type (Crespo et al. 1997). The mean catch rate is the mean of all individual vessel DPUE, and the maximum catch rate is the maximum individual vessel DPUE within a given fishing type (Crespo et al. 1997).

The nominal fishing effort discriminated by fishing type was only available for 1995, 1998, and 2001 (Crespo et al. 1997, Dans et al. 2003).

Therefore, the total annual bycatch was obtained as follows:

1) For each fishing type, a value of DPUE was randomly selected from the corresponding triangular distribution.

2) One of the three available years with detailed information on nominal fishing effort was randomly selected (uniform distribution).

3) The annual bycatch of each fishing type was obtained by multiplying the corresponding nominal fishing effort and DPUE.

4) The annual bycatches of each fishing type were added up to obtain the total annual bycatch.

These steps were followed 1000 times to generate a distribution of the annual bycatch in recent years (Fig. 4). This procedure incorporates all known sources of variability that have enough information to allow modeling their contribution to the total uncertainty of the annual bycatch. One point that is not accounted for here is the possible trend of DPUE as a function of dolphin population size; it was assumed that it remained constant over the years.

Comparison of catch levels with critical values

A population size of 6628 dolphins (95% confidence interval = 4039, 10877) was estimated for the area subjected to the highest fishing effort (between Península Valdés and Puerto Deseado, 42° S to 46° S, and to the 100 m isobath; Schiavini et al. 1999). Using this information, the critical values for the incidental mortality rate, originally calculated as proportion of the population (number of dolphins/population size), were also expressed as absolute number of dolphins incidentally caught per year. These catch rates can be converted into a critical annual dolphin bycatch if one assumes a constant population level of 6628 dolphins. This abundance information was also employed to calculate the proportion of the population represented by the measured annual catches (Crespo et al. 1997, Dans et al. 1997*a*, 2003).

Punctual comparisons were made between the estimated annual catches for specific years and the critical values. However, these comparisons do not evaluate properly the risk that the annual catches could actually exceed the critical values. This risk evaluation requires a probabilistic approach that should incorporate the associated uncertainties.

For this evaluation, a value of λ was randomly chosen from the corresponding distribution, and converted to r_{max}. Using this last figure, the critical values were calculated.

On the other hand, a population size was randomly chosen from a lognormal distribution (Fig. 5) with parameters obtained from the abundance estimation analysis (Buckland et al. 1993, Schiavini et al. 1999). Also, a value of total annual bycatch was randomly selected from the previously generated distribution (Fig. 4). Then, a bycatch rate was calculated as the ratio between these two values and compared with each one of the critical values.

This procedure was repeated 1000 times for each reproductive scenario, and the number of times that the bycatch rate exceeded the critical values was computed. These data were used to calculate the corresponding probabilities.

Results

Maximum rate of increase

The distribution of the finite rate of increase (λ) for each fertility scenario is shown in Fig. 6. The percentiles of the distributions are given in Table 3. The uncertainty in the estimates of λ may be shown by the range between the 5th and 95th percentiles, as the 90% confidence intervals. Median values for λ are 1.0430 (1.0243–1.0600) and 1.0179 (0.9992–1.0348) for a calving interval of two or three years, respectively.

The highest possible value of the maximum rate of increase (r_{max}) for the dusky dolphin population may be close to 7%. Considering the most optimistic scenario of a calving interval of two years, the 99th percentile of this distribution corresponds to a value of 6.65% (Table 3). This value represents the largest plausible rate at which the population will increase in low abundance conditions and without resource restrictions.

Comparison of mortality rates with critical catch levels

The total annual catch in the Patagonian trawling fishery was estimated at 70–215 dusky dolphins in

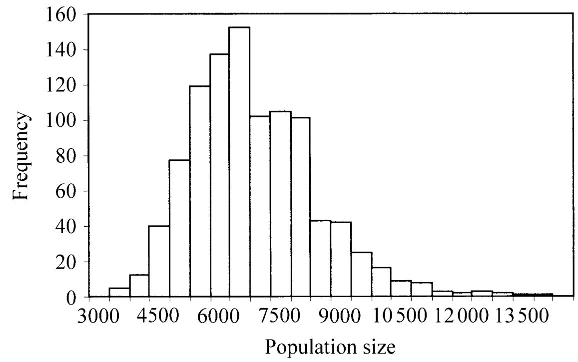

FIG. 5. Frequency distribution of the population size of dusky dolphin in the area subjected to the highest fishing effort, in central Patagonia. The frequencies were obtained from a lognormal distribution with a known mean of 6628 dolphins and a coefficient of variation of 0.2531 (Schiavini et al. 1999).

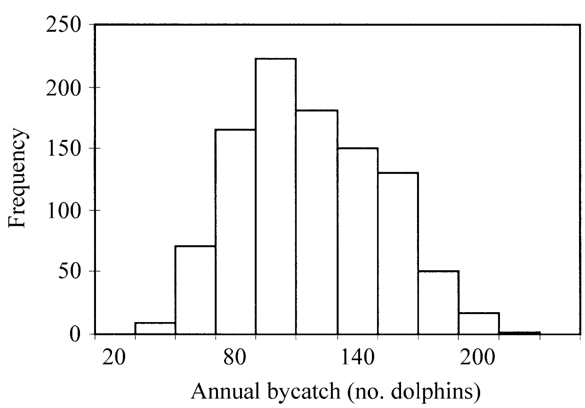

FIG. 4. Bootstrap distribution of the number of dusky dolphins incidentally caught per year in the Patagonian trawling fishery. The estimates were obtained from dolphin bycatch per unit effort (DPUE) and nominal fishing effort data for 1995 (Crespo et al. 1997), 1998, and 2001 (Dans et al. 2003).

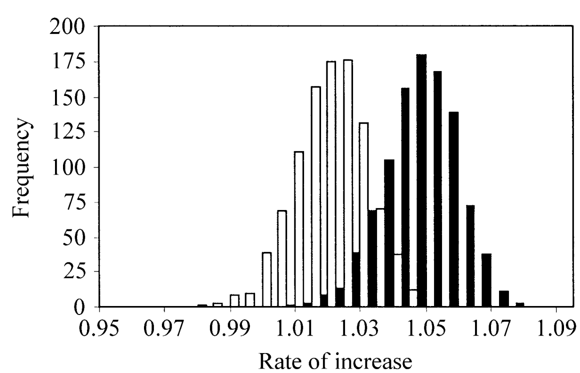

FIG. 6. Frequency distribution of the finite rate of increase (λ) obtained from 1000 projection matrices. Survival rates were obtained from Monte Carlo samples of model life tables; two scenarios were considered for fertility rates, corresponding to a calving interval of two years (solid columns) or three years (open columns).

TABLE 3. Percentiles of the Monte Carlo distribution of the finite rate of increase (λ) and maximum rate of increase (r_{max}) for dusky dolphin, from 1000 samples.

	CI = 2 yr		CI = 3 yr	
Percentile	λ	$r_{max} = (\lambda - 1)100$	λ	$r_{max} = (\lambda - 1)100$
0.01	1.0140	1.40	0.9895	−1.05
0.05	1.0243	2.43	0.9992	−0.08
0.1	1.0283	2.83	1.0033	0.33
0.2	1.0339	3.39	1.0088	0.88
0.3	1.0372	3.72	1.0124	1.24
0.4	1.0402	4.02	1.0151	1.51
0.5	1.0430	4.30	1.0179	1.79
0.6	1.0459	4.59	1.0207	2.07
0.7	1.0488	4.88	1.0238	2.38
0.8	1.0517	5.17	1.0266	2.66
0.9	1.0566	5.66	1.0310	3.10
0.95	1.0600	6.00	1.0348	3.48
0.99	1.0665	6.65	1.0403	4.03
Mean	1.0425	4.25	1.0174	1.74
SD	0.0110		0.0107	
CV	0.0105		0.0106	

Note: Results are shown for two scenarios of fertility corresponding to a calving interval (CI) of two and three years.

1994. Mid-water trawling for Argentine red shrimp produced the highest bycatch (Crespo et al. 1997, 2000) with a maximum of 560 dolphins in 1984, and 852–1377 dolphins killed in the period 1982–1995 (Dans et al. 1997*a*). Considering the randomization procedure described in this paper, the mean and median of the total annual bycatch in recent years were 107 and 103 dolphins/yr, respectively (Fig. 4), with a coefficient of variation of 0.33.

The estimated critical values, expressed as proportion of the population size and total number of dolphins, are given in Table 4. Catch levels estimated for 1984 (442–560 dusky dolphins) exceeded all critical values. The estimated figures for 1994 would be within the limits considering the best reproductive conditions (2-yr calving interval), but exceeded all critical values in the case of a calving interval of 3 yr.

From a probabilistic perspective and considering a calving interval of 3 yr, the catch level has a probability of 0.596 of exceeding all critical values, and of 0.993 of being higher than the most conservative figure of (1/4)*R* (Table 5). In a more optimistic scenario, considering a calving interval of 2 yr, the catch level has a probability lower than 0.05 of being higher than the less conservative critical value (*R*), but it is equal to 0.344 and 0.852 of exceeding the (1/2)*R* and (1/4)*R* critical values, respectively.

TABLE 5. Probabilities that the annual by-catch of dusky dolphins exceeds three different threshold values based on the maximum rate of increase (r_{max}).

Probabilities	CI = 2 yr	CI = 3 yr
Annual bycatch > *R*	0.037	0.596
Annual bycatch > (1/2)*R*	0.344	0.909
Annual bycatch > (1/4)*R*	0.852	0.993

Notes: Results are shown for two scenarios of fertility corresponding to a calving interval (CI) of two and three years. $r_{max} = \lambda - 1$.

DISCUSSION

Our results indicate that the population growth rate for the dusky dolphin off Patagonia could reach a maximum value close to 4%, as indicated by the mean values and considering the best reproductive conditions (i.e., 2-yr calving interval). Although the sampling distribution obtained for the growth rate included values as high as 7%, these represent only the upper limit of the distribution.

The comparisons between annual bycatch rates and critical values lead to the conclusion that dusky dolphin catches may be low in absolute numbers, but they are very close to allowable limits or they exceed the thresholds. Although the probability of exceeding the *R* criteria is low ($P < 0.05$), probabilities of exceeding (1/2)*R* and (1/4)*R* are all >0.30. Furthermore, the possibility that the potential population growth rate would reach low values, and the fact that population size would be lower than that of other pelagic dolphin species, turn this population into a vulnerable one. The vulnerability of the dusky dolphin population off Patagonia requires that monitoring of this population as well as the fishery must be continued and increased.

One assumption in the present analysis is that the survivorship pattern of the dusky dolphin can be found

TABLE 4. Critical values for annual dolphin by-catch, expressed as proportion of the population size and total number of dolphins per year.

	CI = 2 yr		CI = 3 yr	
Critical value	Percent of population	Dolphins/yr	Percent of population	Dolphins/yr
R	4.30	284.9	1.79	118.6
(1/2)*R*	2.15	142.4	0.89	59.3
(1/4)*R*	1.07	71.2	0.45	29.7

Notes: Results are shown for two scenarios of fertility corresponding to a calving interval (CI) of two and three years. These values are based on the rate of increase estimates (λ) for the dusky dolphin by model life tables. The maximum rate of increase (r_{max}; as a percentage) was calculated as (λ − 1)100, and the total number of dolphins was calculated considering the mean value of the population size (6628 dolphins).

in the space of survivorship curves defined by the model species. The reliability of the results obtained by this approach will depend on the validity of this assumption. In the case of the dusky dolphin, a relatively wide range of life tables was chosen, and this analysis may be improved as new information about the true survivorship pattern is gathered. The consequence of this improvement may lead to the use of a selected subset of the model life tables considered here. Furthermore, the uncertainty in the estimation would be reduced.

In the present work, two possible scenarios were considered for the calving interval. Several studies in other dolphin species showed calving intervals longer than two years, suggesting fecundity rates of 0.15, as in several populations of *Stenella* sp. (Barlow and Hohn 1984). Nevertheless, annual pregnancy rate for dusky dolphins in Peruvian waters was estimated at 0.55, suggesting a fecundity of 0.25 if the sex ratio at birth is assumed to be 1:1. This population has been subjected to a high extractive pressure (both incidental and direct captures) from the 1970s up to the present (Gaskin and Read 1987, Vidal 1992, Van Waerebeek et al. 1997). Then the apparent high pregnancy rate may represent a consequence of the high removal of animals and a decrease in population density. In Argentine waters, the proportion of resting females equal to 40% (Dans et al. 1997*b*) suggests the potential of a calving interval of two years. Available information is too scarce to enable the resampling procedure needed to generate a distribution for this parameter.

Even though a wide range of survivorship patterns was used, the coefficients of variation of the population growth rates were lower than the ones of population size estimates (25%) and annual catches (33%). In the present study, the uncertainty of the annual bycatch was essentially described by a triangular distribution because there was not enough information about potential temporal trends in dolphin bycatch per unit effort (DPUE) or nominal fishing effort by fishing type within the period 1995–2001. Therefore, the uncertainty in annual catches is one of the aspects to be improved in the future.

Time trends in abundance of dolphins or commercial fish stocks may influence the results. For example, as the dolphin population declines, the encounter rate with commercial fisheries may decline. Thus bycatch rates will be a function of effort by the fleet and the dolphin population size. Another possibility is the case where dolphins are attracted to locations commonly used by fisheries, so the encounter rate may remain high and DPUE constant although population size is declining. Also, dolphin abundance and bycatch may vary with area and season. At this moment, only one abundance estimate is available that included eight surveys carried out between 1994 and 1995, so time trend in the abundance of the dusky dolphin population is unknown. Likewise, if commercial fish stocks increase, fishing effort would also increase resulting in a higher mortality for dolphins.

The Patagonian trawling fishery is very heterogeneous, and the composition of the fleet may fluctuate rapidly during the year (Dans et al. 1997*a*). Larger vessels carry more than one type of gear so they can change the target species and the fishing area very rapidly (Crespo et al. 1997, Dans et al. 2003). Therefore, time trends in fishing effort are very difficult to predict, and particularly the effort of each strata and each fishing type.

The Argentine anchovy represents a potential alternative target, and this fact may lead to an increase in mid-water hauls, and the associated risk to dolphin populations. For this reason, monitoring programs of dolphin mortality, fishing effort, and variability in the use of fishing gear should be improved and/or developed. On board data gathering of dolphin bycatch must also be enhanced in the fishing observers' program. Furthermore, the Fishery Agency should address this issue, and the resulting impact on dolphin populations, as an integral part of the fishery management strategy.

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