INTERNATIONAL DOLPHIN CONSERVATION PROGRAM

SCIENTIFIC ADVISORY BOARD

7TH MEETING

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UPDATED ESTIMATES OF N_{MIN} AND STOCK MORTALITY LIMITS

1. Background

The current Stock Mortality Limits (SMLs) for spotted and spinner dolphins are based on a series of surveys conducted during 1986-1990 by the U.S. National Marine Fisheries Service (NMFS). The abundance estimates generated during these surveys (Wade and Gerrodette 1993) were to be used to calculate SMLs "until the Parties agreed on an updated set of figures. Such updates could result from the analysis of data from future research cruises and indices of abundance and other relevant scientific data from the Parties, the IATTC and other scientific organizations" (AIDCP Annex III).

SMLs are calculated as 0.1% of the minimum abundance estimates of the stocks (N_{min}; Barlow *et al*. 1995), a conservative measure of abundance that incorporates both the abundance and the variability of the estimate:

$$N_{min} = N/\exp(z(\ln(1+CV(N)^2))^{1/2})$$

where N is the abundance estimate, CV(N) is the coefficient of variation of the abundance estimate, and z = 0.842. N_{min} is the 20th percentile of a log-normal distribution based on an estimate of the number of animals in a stock (which is equivalent to the lower limit of a 60% 2-tailed confidence interval). The SMLs adopted in 1999 (to begin application in 2000), and currently used by the AIDCP, are listed in Table 1.

TABLE 1. Abundance estimates (N), minimum abundance estimates (N_{min}), and per-stock mortality limits (SML = 0.1% of N_{min}) based on the 1986-1993 NMFS surveys (Wade and Gerrodette, 1993; unpub. data for northern and central common dolphins).

Species and stock	N	N_{min}	SML
Spotted dolphin (*Stenella attenuata*)			
Northeastern	730,900	648,920	648
Western/Southern	1,298,400	1,145,149	1,145
Spinner dolphin (*Stenella longirostris*)			
Eastern	631,800	518,495	518
Whitebelly	1,019,300	871,982	871
Common dolphins (*Delphinus delphis* and *D. capensis*)			
Northern	713,700	562,719	562
Central	239,400	207,298	207
Southern	2,210,900	1,845,561	1,845

Since 1990, surveys have been conducted by NMFS in 1992-1993 (upon which current common dolphin abundance estimates and SMLs are based), 1998-2000, 2003, and 2006. In addition to now having more extensive and recent data available, recent information indicates that the original 1986-1990 estimates were biased low for eastern spinner dolphins (Gerrodette *et al*. 2008). The IATTC convened a Technical Workshop on Calculating N_{min} in 2005 to recommend methods for using these additional data. For the stocks of spotted and spinner dolphins, the Workshop recommended to the SAB that a logistic approach be used with all data available since 1986. The SAB agreed that the logistic population model used by the Workshop was appropriate, and recommended its adoption for the calculation of SMLs. The SAB recommended at its 6th meeting that these analyses be updated to include 2006 abundance estimates (Gerrodette *et al*. 2008) and that new SMLs be calculated and presented to the Meeting of the Parties.

2. Updated estimates of N and N_{min}

The IATTC staff has computed new model-based estimates of N, and has updated the values of N_{min} and SMLs for spotted and spinner dolphin stocks. New abundance estimates were calculated for only these stocks because revising common dolphin stock estimates will take more effort, as the effect of migration beyond the survey areas still must be addressed (see [Technical Workshop on Calculating N_{min}]).

The new estimates of N were obtained for each stock from a generalized logistic model using the most recent information from NMFS abundance estimates (Gerrodette *et al*. 2008) and mortality estimates for 1959-2008 (Letter from Joseph to Tillman 1994; Wade 1994, 1995; Wade *et al*. 2007; IATTC 2009; IATTC preliminary estimate of mortality for 2008). In addition, a sensitivity analysis was performed for the northeastern spotted dolphin. The details of the generalized logistic model and the various scenarios used in the sensitivity analysis are presented in the Appendix. The "standard scenario" upon which the new estimates of N_{min} are based assumed a maximum net productivity level (MNPL) of 0.65, included error on the estimates of total bycatch (but no bias), and estimated the growth rate (r) and carrying capacities from the model. The western/southern spotted and whitebelly spinner dolphin assessments also included a prior on r (r~U[0,0.08]) because the maximum likelihood estimates of r were higher than 0.08. Both maximum likelihood and Bayesian analysis were performed. The new estimates of N_{min} are based on the Bayesian analysis because this method makes more realistic assumptions in order to compute percentiles of the distribution of N. In addition, although generalized logistic models are often preferred for marine mammal population modeling and have been used previously for dolphins in the eastern Pacific (Wade *et al*. 2007), for comparison to the specific methods used in the N_{min} Workshop, a logistic model was also used for calculating N_{min}. When the MNPL is set at 0.5, the generalized logistic model is equivalent to a logistic model. To note is that Wade *et al*. (2007) set a uniform prior distribution on the MNPL, over values from 0.5 to 0.8; the logistic model is equivalent to using the lower bound on this prior which is not necessarily a best choice. The MNPL of 0.65 that we chose is the center point of the interval 0.5-0.8.

A time series of model estimates of abundance from 1959 to 2010 are shown in Figures 1-4, and the projected estimates of N and N_{min} for 2010 are shown in Table 2 (estimates were not projected beyond 2010 because new data should be available after the NMFS conducts the new abundance surveys scheduled for that year). The time series of abundance estimates show substantial declines since 1959 for the northeastern spotted and eastern spinner dolphin populations, while those for the western/southern spotted and whitebelly spinner show little decline. This difference in the apparent status is probably an artifact of the modeling due to variability and high uncertainty in the survey abundance estimates for the western/southern spotted and whitebelly spinner populations. This is similar to the finding in the N_{min} Workshop. The estimates of N_{min} are higher for all four species compared to those estimated in the N_{min} Workshop (Table 1). This is true even if the values of abundance for 2006 were to be used in the calculation of N_{min} since N (and hence N_{min}) only changes slightly in consecutive years. N_{min} estimates for 2003 to 2010 are shown in Table 3. The maximum likelihood estimates of N_{min} differ from the Bayesian estimates by only a few percent (Table 4). Parameter estimates and derived quantities for the standard scenario for each stock are shown in Table 4. Results from using a logistic model for each of the four stocks are shown in Table 5. For the northeastern spotted and eastern spinner, the two stocks with the most reliable data, estimates of N_{min} are similar to those of the standard scenario from the generalized logistic model.

TABLE 2. Abundance estimates (N) for 2010, minimum abundance estimates (N_{min}), and per-stock mortality limits (SML = 0.1% of N_{min}), based on the standard scenario.

Species and stock	N	N_{min}	SML
Spotted dolphin			
Northeastern	911,177	793,466	793
Western/Southern	911,830	881,256	881
Spinner dolphin			
Eastern	790,613	655,562	655
Whitebelly	711,883	666,852	666

TABLE 3. Annual estimates of N_{min} for each of the four stocks, in thousands of animals, 2003-2010,.

Species and stock	2003	2004	2005	2006	2007	2008	2009	2010
Spotted dolphin								
Northeastern	721	732	743	753	764	774	785	793
Western/Southern	876	877	878	879	880	880	881	881
Spinner dolphin								
Eastern	602	610	618	626	634	643	649	656
Whitebelly	655	656	659	661	662	664	665	667

TABLE 4. Parameter and derived quantity estimates from the standard scenario of the generalized logistic model for each of the four stocks. The N_{min} 2010 Bayesian estimates are presented as the new estimates of N_{min} in Table 2. r = growth rate; K = carrying capacity; sd = standard deviation. Values of N and N_{min} are in thousands of animals.

	Northeastern spotted dolphin	Western/Southern spotted dolphin	Eastern spinner dolphin	Whitebelly spinner dolphin
Negative log likelihood	5.83	7.99	4.80	5.60
K	3519	913	1638	713
R	0.02	0.08	0.02	0.08
N_{2010}	911	912	791	712
sd_{2010}	135	72	245	80
CV_{2010}	0.15	0.08	0.18	0.11
$N_{min\ 2010}$	805	853	680	647
$N_{min\ 2010}$ Bayesian	793	881	656	667

TABLE 5. Parameter and derived quantity estimates from the logistic model for each of the four stocks. r = growth rate; K = carrying capacity; sd = standard deviation. Values of N and N_{min} are in thousands of animals.

	Northeastern spotted dolphin	Western/Southern spotted dolphin	Eastern spinner dolphin	Whitebelly spinner dolphin
Negative log likelihood	5.85	6.46	4.88	5.51
K	3650	1622	1700	925
R	0.03	0.00	0.03	0.00
N_{2010}	904	8.08	768	682
sd_{2010}	127	88	247	216
CV_{2010}	0.14	0.10	0.16	0.31
$N_{min\ 2010}$	803	745	671	529
$N_{min\ 2010}$ Bayesian	788	751	671	674

3. Stock Mortality Limits (SMLs)

Stock Mortality Limits are calculated as 0.1% of N_{min}. Should the Parties adopt new SMLs for 2010, revised SMLs based on the 2010 estimates of N_{min} have been calculated and are presented in Table 2.

If these revised SMLs were to be adopted by the Parties, this would result in greater SMLs for the northeastern spotted dolphin (+145) and eastern spinner dolphin (+137), the two major stocks of dolphins associated with the tuna purse-seine fishery. The SMLs would be lower for the western/southern spotted dolphin (-264) and the whitebelly spinner dolphin (-205). Differences between the current and revised SMLs are partially attributable to the addition of survey estimates from 1998-2000, 2003, and 2006, and to the fact that a different approach is being used (a generalized logistic model versus simple averaging). In addition, for the western/southern spotted dolphin and whitebelly spinner dolphin stocks, model parameters are not well determined due to variability and high uncertainty in the survey estimates, and this leads to instability in the estimates of N_{min}. Figure 5 shows a comparison of the mortalities from 1998-2008 with both the current and revised SMLs. During this period, the current SMLs have not been exceeded, nor would they have been exceeded with the revised SMLs. Even for the two stocks for which the revised SMLs were lower than the current SMLs, the mortalities from this time period would not have been close to exceeding the revised SML.

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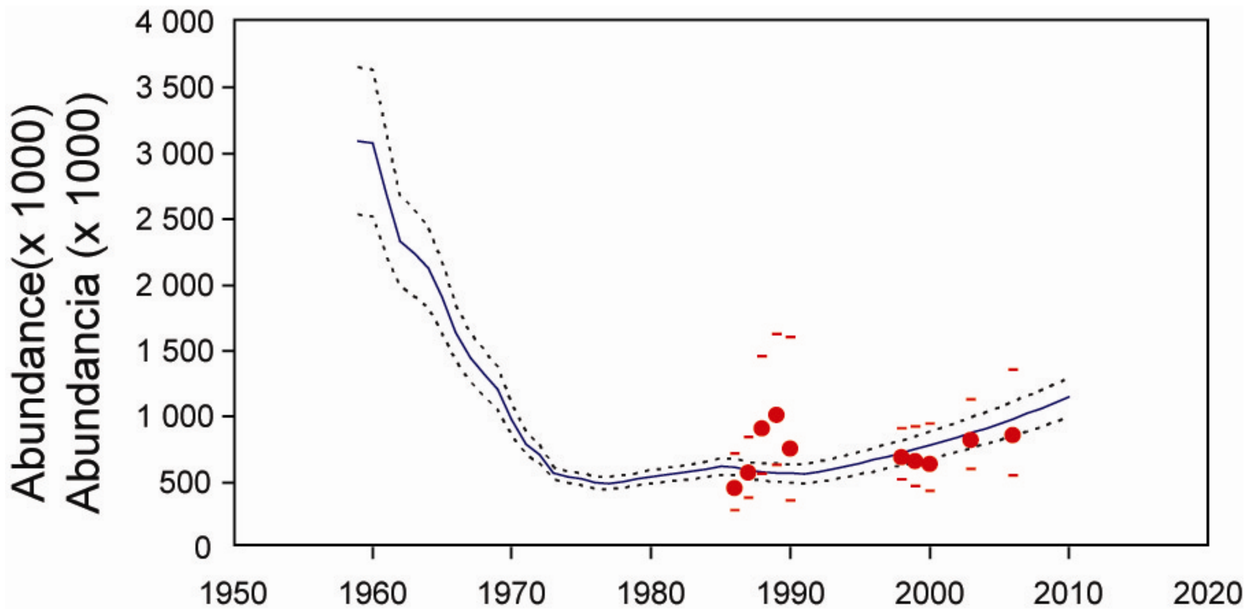

FIGURE 1. Abundance estimates for the northeastern spotted dolphin, based on the generalized logistic model. The solid line is the stock assessment abundance estimate. The dashed lines are the normal approximation 95% confidence intervals on the stock assessment abundance estimate. The solid circles are the survey abundance estimates and the bars are the 95% confidence intervals.

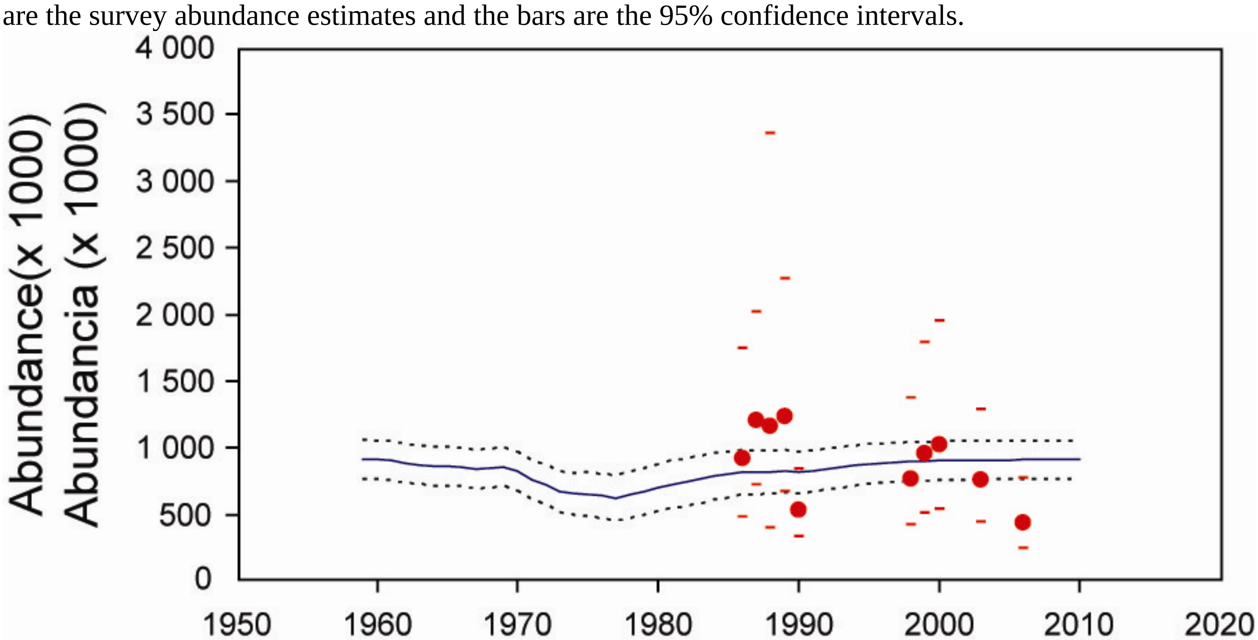

FIGURE 2. Abundance estimates for the western/southern spotted dolphin, based on the generalized logistic model. The solid line is the stock assessment abundance estimate. The dashed lines are the normal approximation 95% confidence intervals on the stock assessment abundance estimate. The solid circles are the survey abundance estimates and the bars are the 95% confidence intervals.

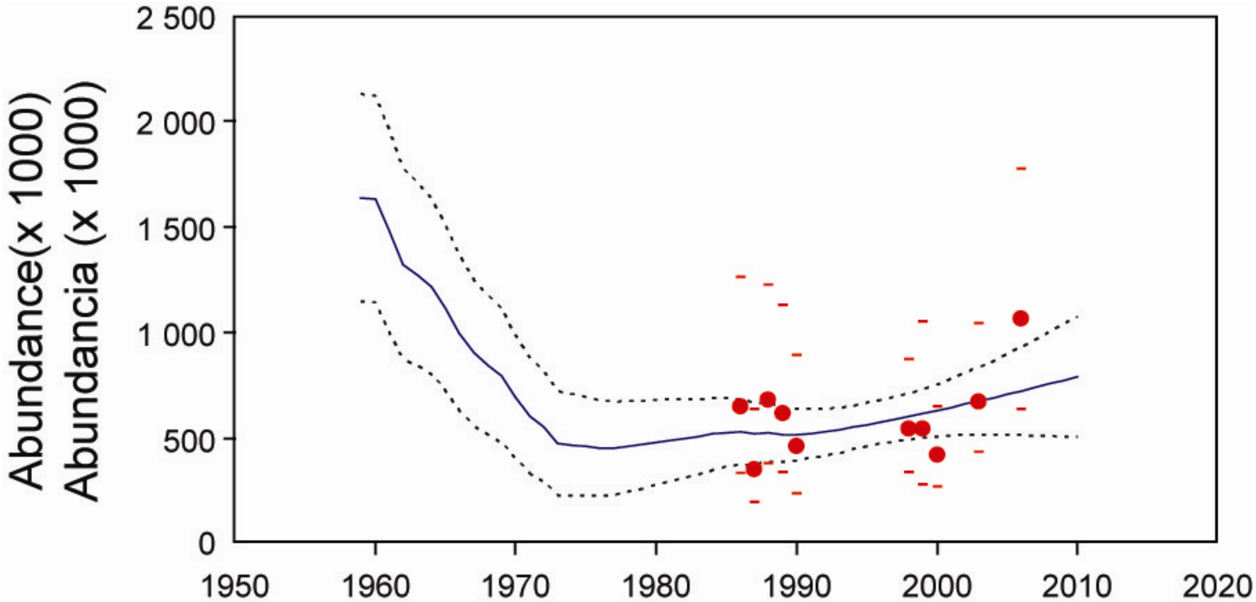

FIGURE 3. Abundance estimates for the eastern spinner dolphin, based on the generalized logistic model. The solid line is the stock assessment abundance estimate. The dashed lines are the normal approximation 95% confidence intervals on the stock assessment abundance estimate. The solid circles are the survey abundance estimates and the bars are the 95% confidence intervals.

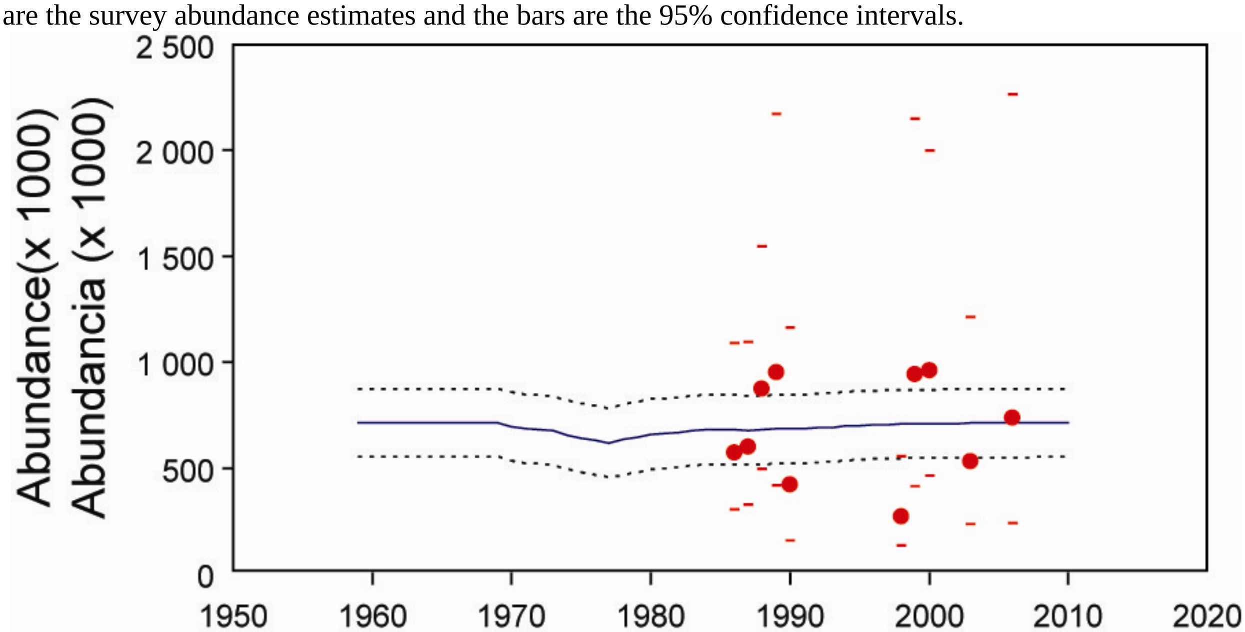

FIGURE 4. Abundance estimates for the whitebelly spinner dolphin, based on the generalized logistic model. The solid line is the stock assessment abundance estimate. The dashed lines are the normal approximation 95% confidence intervals on the stock assessment abundance estimate. The solid circles are the survey abundance estimates and the bars are the 95% confidence intervals.

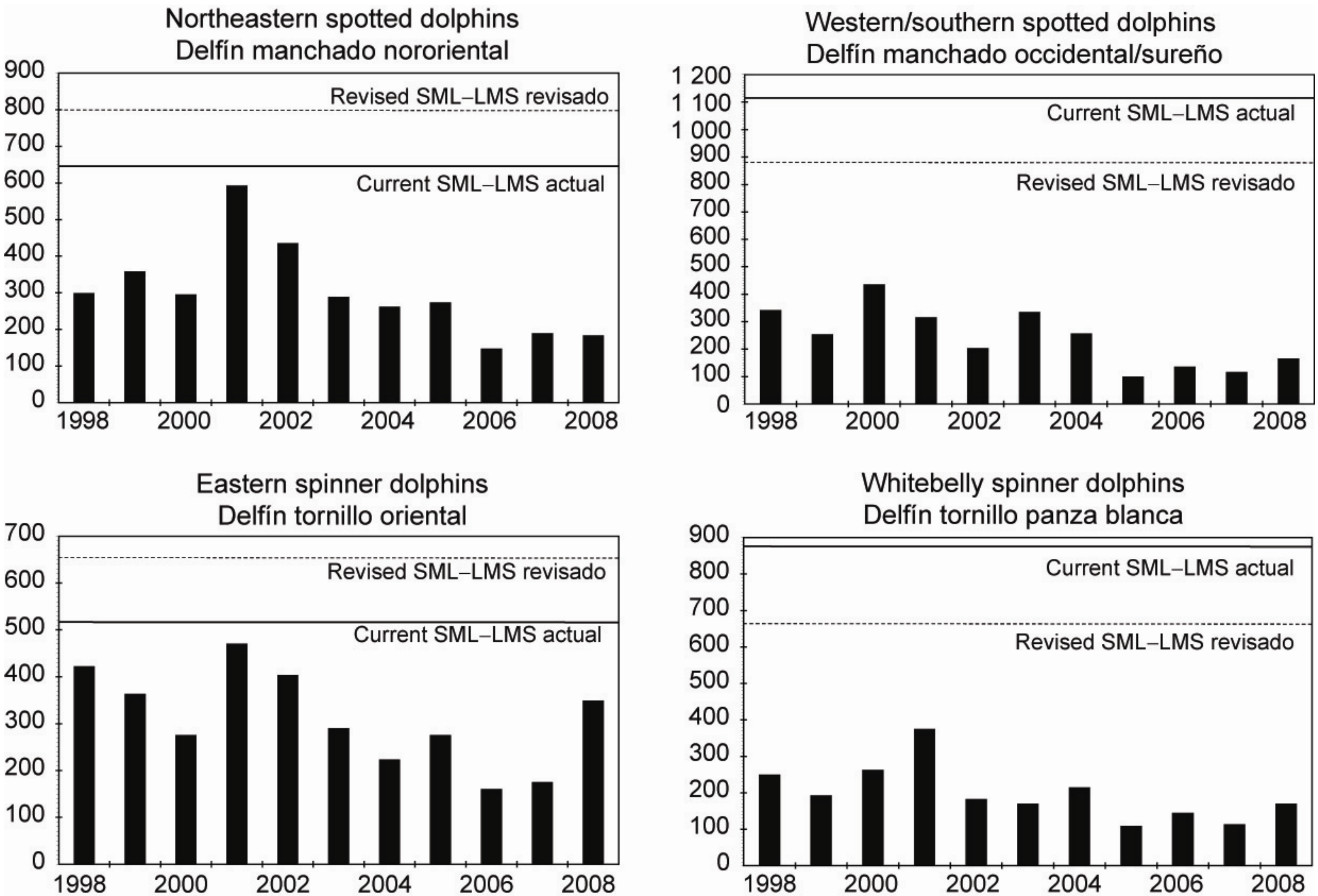

FIGURE 5. Comparison of 1998-2008 mortality estimates with current and revised SMLs for northeastern and western/southern spotted dolphins and eastern and whitebelly spinner dolphins.

APPENDIX A: Descriptions of the generalized logistic model and the sensitivity analysis conducted for the northeastern spotted dolphin, and results from the sensitivity analysis.

Population dynamics

A generalized logistic model was used to model the population size (N) from the start of 1959 to the start of 2010. The formula for N at year y+1 is given by:

$$N_{y+1} = N_y + rN_y\left(1-\left(\frac{N_y}{K}\right)^z\right) - C_y$$

where C_y is the bycatch in year y, r is the growth rate, and K is the carrying capacity.

The shape parameter (z) determines the maximum net production level (MNPL).

$$MNPL = (z+1)^{-1/z}$$

The abundance at the start of the modeling time frame is assumed to be at the carrying capacity:

$$N_{y=1959} = K$$

Process error

In the scenario that includes process error in the productivity (see below), the formula for abundance at year y+1 becomes:

$$N_{y+1} = N_y + rN_y\left(1-\left(\frac{N_y}{K}\right)^z\right)\exp\left[\sigma_p\varepsilon_y - 0.5\sigma_p^2\right] - C_y$$

where

σ_p is the standard deviation of the process error distribution and $\varepsilon \sim N(0,1)$

Fit to abundance index

The abundance estimates are assumed to be log-normally distributed.

$$-\ln[L(I)] = \sum_i \frac{\left(\ln[I_y] - \left(\ln[N_y] - 0.5\sigma_{I,y}^2\right)\right)^2}{2\sigma_{I,y}^2}$$

$$\sigma_{I,y} = \sqrt{\ln\left[CV_{I,y}^2 + 1\right]}$$

Modeling uncertainty in catch

Two types of uncertainty in bycatch are modeled, bias and precision. The bycatch estimates are treated as data (or priors), which may be biased. Bycatch for each year is modeled as a parameter (C_y) and the estimated bycatch is used as a data point (prior). The observed bycatch is assumed to be log-normally distributed mean unbiased after adjusting for bias. (Note that treating the observed bycatch as a prior would result in a different term added to the objective function.) These conditions are made explicit with the following formulas:

$$C^{adjust} = \begin{cases} C_y^{obs} & y \notin \{\text{specific years}\} \\ \delta C_y^{obs} & y \in \{\text{specific years}\} \end{cases}$$

$$-\ln\left[L(C)\right]=\sum_i \frac{\left(\ln\left[C_y^{adjust}\right]-\left(\ln\left[C_y\right]-0.5\sigma_{C,y}^2\right)\right)^2}{2\sigma_{C,y}^2}$$

$$\sigma_{C,y}=\sqrt{\ln\left[CV_{C,y}^2+1\right]}$$

Model scenarios

The standard scenarios for each of the four stocks assume that the maximum net productivity level (MNPL) is 0.65, include error but no bias in the bycatch data, and growth rate (r) and carrying capacity (K) are estimated. The western-southern spotted and whitebelly spinner assessments also included a prior on r~U[0,0.08] because the maximum likelihood estimates of r were higher than 0.08. Both maximum likelihood and Bayesian analysis were performed.

To investigate the sensitivity of the assessment to model assumptions, several scenarios were conducted using the northeastern spotted dolphin. All scenarios were modifications of the standard scenario. To investigate the differences between this assessment and those conducted at the N_{min} workshop, the following scenarios were conducted:

1. No error in the bycatch data
2. Error in the bycatch data (standard scenario)
3. Using the logistic model (MNPL = 0.5)
4. Adding process error with sd = 0.2
5. Using the abundance data from the N_{min} workshop, which did not have the 2006 data point available.
6. Including a prior on r~U[0, 0.08].

To investigate the influence of bias in the mortality data the following scenarios were conducted:

1. Estimating the bias in dolphin mortality for the years 1959-1972
2. Estimating the bias in dolphin mortality for the years 1992-present
3. Fixing the bias in dolphin mortality for the years 1992-present to 2, as in Wade *et al*. (2007)
4. Repeating the standard scenario and scenarios (1) to (3) with r = 0.04.

To investigate the sensitivity of the assessment results to changes in the population growth rate or the carrying capacity, we performed the following scenarios, following Wade *et al*. (2007):

1. Include a change in r in 1993
2. Include a change in K in 1990

Results of sensitivity analysis

Using a logistic model, putting a prior on r, and adding process error had very little influence on the estimate of N_{min} (Table A-1). The biggest differences between the estimates in this report and those given in the N_{min} Workshop appear to be in the revised abundance estimates and the addition of the abundance estimate for 2006. Using the abundance estimates from the N_{min} Workshop, which did not have the 2006 estimate available, provides an estimate of N_{min} in 2006 (685) which is similar to that estimated in the N_{min} Workshop (678).

There is no information in the data about the bias in bycatch in 1959-1972 and it has little influence on the estimate of N_{min} (Table A-2). The estimate of the scaling factor for the bias in bycatch in 1992-2009 provides a statistically significant improvement of the fit to the data, but the estimate of the bycatch scaling parameter is unrealistically high and it results in a much larger estimate of N_{min} (Table A-2). Fixing the scaling factor to 2 as done by Wade *et al*. (2007) does not provide a significant improvement in the fit and the estimate of N_{min} only changes slightly (Table A-2) (note that the Bayesian analysis was problematic for this scenario and results could not be obtained). Fixing r = 0.04 degrades the fit to the data (see the negative log likelihood in Table A-2, but the fit is visually similar, see Figure A-1) and increases the estimate of N_{min}, however it does reduce the scaling factor on the bycatch bias for 1992-2009 (Table A-2).

Estimating a change in carrying capacity starting in 1990 causes convergence problems in the assessment model. However, the fit to the data is significantly better (Table A-3) although the abundance trajectory is unrealistic (Figure A-2). Estimating a change in the population growth rate parameter starting in 1993 does not significantly improve the fit to the data, but the estimate of N_{min} is smaller (Table A-3).

TABLE A-1. Parameter and derived quantity estimates from the scenarios investigating the current model sensitivity to options used in the N_{min} Workshop for the northeastern spotted dolphin.

	Bycatch known	**Standard (error in bycatch)**	**Logistic**	**Process error sd = 0.2**	**Old data**	**Prior on *r*~U[0,0.08]**
Negative log likelihood	6.07	5.83	5.85	5.83	5.27	5.83
Relative parameters		0	0			
Difference in AIC		0.00	0.03			
K	3370	3519	3650	3518	3543	3519
r	0.021	0.021	0.026	0.022	0.020	0.021
MNPL	0.65	0.65	0.50	0.65	0.65	0.65
N_{2010}	911	911	904	912	836	911
sd_{2010}	135	135	127	136	137	135
CV_{2010}	0.15	0.15	0.14	0.15	0.16	0.15
$N_{min\ 2010}$	805	805	803	805	729	805
$N_{min\ 2010}$ Bayesian	773	793	788	796	715	793

TABLE A-2. Parameter and derived quantity estimates from the scenarios investigating the bias in the bycatch data for the northeastern spotted dolphin.

					r = 0.4			
	Base case (error in bycatch)	**Bias 1959-1972**	**Bias 1992-2009**	**Bias 1992-2009 = 2**	**Error in catch**	**Bias 1959-1972**	**Bias 1992-2009**	**Bias 1992-2009 = 2**
Negative log likelihood	5.83	5.83	3.57	5.78	7.33	6.02	4.97	7.10
Relative parameters	0	1	1	1	-1	0	0	1
Difference in AIC	0.00	2.00	-2.52	1.90	0.99	0.38	-1.73	4.53
K	3519	3095	2116	3494	3095	882	3151	3098
r	0.021	0.022	0.129	0.023	0.040	0.040	0.040	0.040
Bycatch scale	1	0.85	108.29	2	1	0.09	22.31	2
N_{2010}	911	911	1532	917	1144	841	987	1136
sd_{2010}	135	136	313	136	74	108	97	74
CV_{2010}	0.15	0.15	0.20	0.15	0.06	0.13	0.10	0.07
$N_{min\ 2010}$	805	804	1292	810	1084	755	908	1075
$N_{min\ 2010}$ Bayesian	793	790	1400		1085	780	938	

TABLE A-3. Parameter and derived quantity estimates from the scenarios investigating temporal changes in carrying capacity (*K*) or population growth rate (*r*) for the northeastern spotted dolphin.

	Base case (error in bycatch)	***r* changes in 1993**	***K* changes in 1990**
Negative log likelihood	5.83	5.58	1.30
Relative parameters	0	1	1
Difference in AIC	0.00	1.49	-7.06
K 1959-1989	3519	2951	1016
r 1959-1992w	0.021	0.051	0.502
K 1990-2009	3519	2951	731
*r*2 1993-2009	0.021	0.004	0.502
N_{2010}	911	781	730
sd_{2010}	135	205	
CV_{2010}	0.15	0.26	
$N_{min\ 2010}$	805	629	
$N_{min\ 2010}$ Bayesian	793	699	

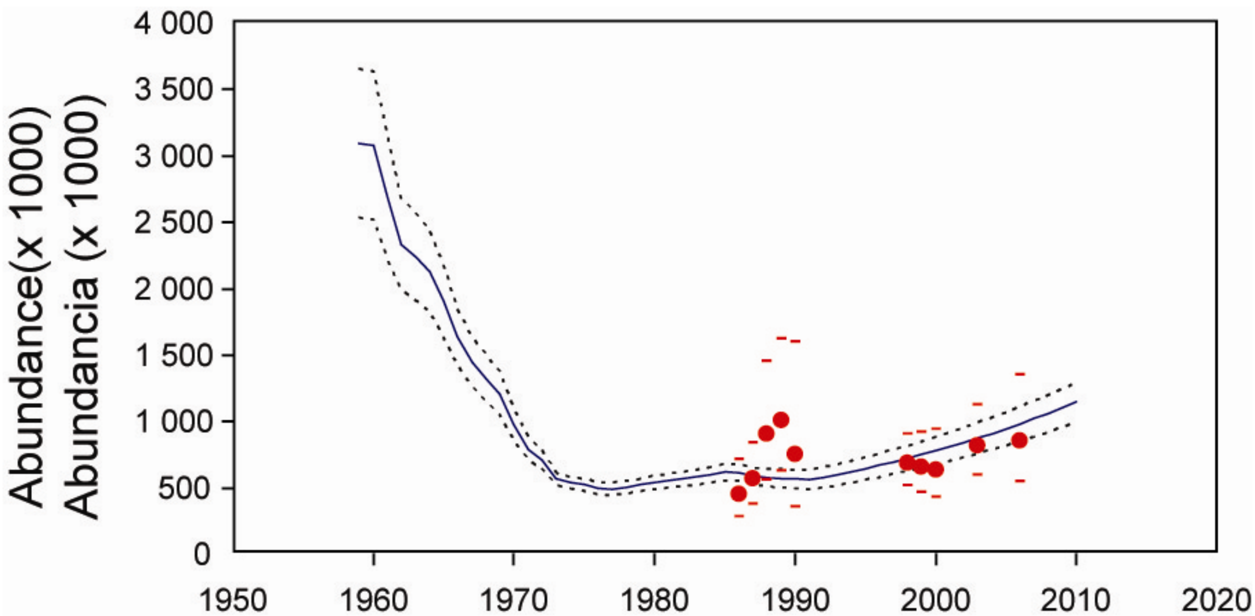

FIGURE A-1. Fit to the abundance estimates for the northeastern spotted stock when *r* = 0.4. The solid line is the stock assessment abundance estimate. The dashed lines are the normal approximation 95% confidence intervals on the stock assessment abundance estimate. The solid circles are the survey abundance estimates and the bars are the 95% confidence intervals.

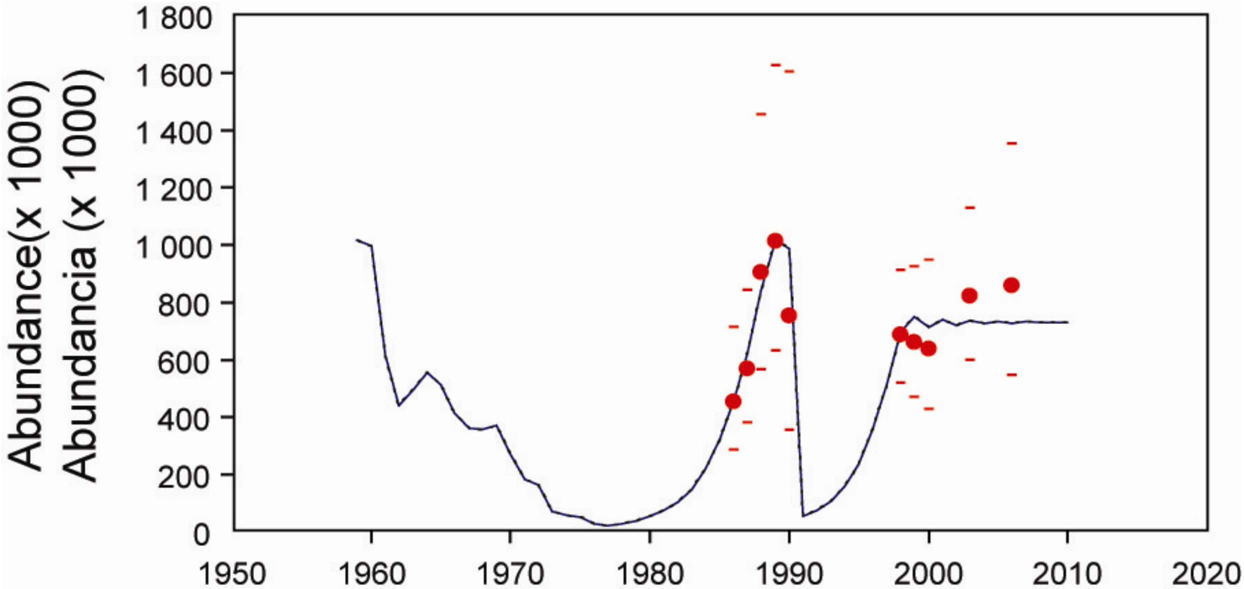

FIGURE A-2. Fit to the abundance estimates for the northeastern spotted stock when estimating a change in carrying capacity starting in 1990. The solid line is the stock assessment abundance estimate. The dashed lines are the normal approximation 95% confidence intervals on the stock assessment abundance estimate. The solid circles are the survey abundance estimates and the bars are the 95% confidence intervals.