Annual estimates of the unobserved incidental kill of pantropical spotted dolphin (*Stenella attenuata attenuata*) calves in the tuna purse-seine fishery of the eastern tropical Pacific

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Abstract—We estimated the total number of pantropical spotted dolphin (*Stenella attenuata)* mothers killed without their calves ("calf deficit") in all tuna purse-seine sets from 1973–90 and 1996–2000 in the eastern tropical Pacific. Estimates were based on a tally of the mothers killed as reported by color pattern and gender, several color-pattern-based frequency tables, and a weaning model. Over the time series, there was a decrease in the calf deficit from approximately 2800 for the western-southern stock and 5000 in the northeastern stock to about 60 missing calves per year. The mean deficit per set decreased from approximately 1.5 missing calves per set in the mid-1970s to 0.01 per set in the late-1990s. Over the time series examined, from 75% to 95% of the lactating females killed were killed without a calf. Under the assumption that these orphaned calves did not survive without their mothers, this calf deficit represents an approximately 14% increase in the reported kill of calves, which is relatively constant across the years examined. Because the calf deficit as we have defined it is based on the kill of mothers, the total number of missing calves that we estimate is potentially an underestimate of the actual number killed. Further research on the mechanism by which separation of mother and calf occurs is required to obtain better estimates of the unobserved kill of dolphin calves in this fishery.

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In the eastern tropical Pacific (ETP), yellowfin tuna (*Thunnus albacares*) are frequently found swimming under schools of pantropical spotted (*Stenella attenuata*) and spinner (*S. longirostris*) dolphins. For the past four decades, the ETP yellowfin tuna fishery has made use of this association by chasing the more visible dolphins at the surface and using purse-seines to encircle the schools "carrying" the tuna (NRC, 1992). The large bycatch of dolphins in this fishery has become widely known as the "tuna-dolphin issue" (Gerrodette, 2002). During the 1960s, the number of dolphins killed by the fishery was estimated to be 200,000–500,000 per year (Wade, 1995), and two stocks of spotted and spinner dolphins were reduced to fractions of their previous sizes (Smith, 1983; Wade et al.[1]). A long history of technological innovations by fishermen, laws and fishing regulations, dolphin quotas, eco-labeling of "dolphin-safe" tuna, and a comprehensive international observer program (Gosliner, 1999; Hall et al., 2000; Gerrodette, 2002) has reduced the dolphin bycatch to less than 1% of its former level. The reported bycatch in recent years is less than 2000 dolphins per year for all species combined (IATTC, 2002).

Although the reported kill has dramatically decreased, recent studies suggest that there is little evidence that the stocks are growing close to expected rates (Wade et al.[1]). One hypothesis for this lack of recovery has been that there are unobserved kills of dolphins during tuna purse-seine sets. Archer et al. (2001) presented evidence of an under-representation of suckling spotted and spinner dolphin calves in a sample of tuna purse-seine sets in the eastern tropical Pacific. Given that some of these missing calves are still dependent on their mothers for nutrition, it is likely that once separated they would die and this under-representation represents some degree of unobserved kill.

In Archer et al. (2001), the sample of sets examined was limited to those sets in which all of the animals killed had biological data collected by technicians aboard the tuna vessel. Calves still dependent on their mothers in the kill were identified by five intervals of body length, chosen to cover a range of

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[1] Wade, P. R., S. B. Reilly, and T. Gerrodette. 2002. Assessment of the population dynamics of the northeastern offshore spotted and the eastern spinner dolphin populations through 2002. National Oceanographic and Atmospheric Administration Administrative Report LJ-02-13, 58 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037.

calf sizes. Because of this approach, it was not possible to derive a single estimate of the number of missing calves or to extrapolate their estimate to sets not used in this analysis.

In the current study, we present a different method of estimating the number of missing calves in each set where offshore spotted dolphins (*S. attenuata attenuata*) were killed. For brevity, we call the shortage of calves in the kill in relation to the number of lactating females in the kill the "calf deficit." We examined the western-southern and northeastern offshore stocks separately according to the geographic boundaries described by Dizon et al. (1994). As they age, spotted dolphins change color through five color phases (Perrin, 1970). We used the color-phase frequency distribution of the kill in conjunction with age- and color-based frequency distributions from a sample of the kill to estimate the total number of missing calves in each stock, along with confidence intervals derived from bootstrap replications. This method also allowed us to examine the calf deficit from sets in recent years from which we did not have biological samples and to examine the time series of available years for evidence of a trend in the calf deficit.

Methods

Since 1973, observers have been randomly placed on tuna purse-seine vessels. For each spotted dolphin killed during an observed set, observers attempted to record the sex and the color phase of the dolphin (neonate, two-tone, speckled, mottled, and fused, see Perrin, 1970). From the National Marine Fisheries Service (NMFS) set log database, we obtained the number of northeastern and western-southern offshore spotted dolphins (by gender and color phase) killed in every observed set from 1973 to 1990. The Inter-American Tropical Tuna Commission (IATTC) provided the same data from 1996 to 2000.

Proration

In each set, color phase or gender (or both) may not have been recorded for some dolphins. Assuming that the distribution of the demographic composition of this missing data is equivalent to the overall demographic composition of the kill, we allocated the number of dolphins of unknown color phase (nu) to unknown gender in each color phase (ngu_c) according to the following formula,

$$ngu'_c = ngu_c + \left(nu \cdot \frac{N_c}{\sum_c N_c} \right), \tag{1}$$

where c = one of the five color phases (neonate to fused);
N_c = the total number of dolphins in each color phase in the entire data set; and
ngu'_c = the new number of dolphins in each color phase where gender is unknown, including the individuals of prorated unknown color phase

The number of male (nm'_c) or female (nf'_c) dolphins in a color phase was calculated as

$$nm'_c = nm_c + \left(ngu'_c \cdot \frac{Nm_c}{Nm_c + Nf_c} \right), \tag{2}$$

$$nf'_c = nf_c + \left(ngu'_c \cdot \frac{Nf_c}{Nm_c + Nf_c} \right), \tag{3}$$

where Nm_c and Nf_c are the total number of males and females, respectively, observed in that color phase in the entire data. Table 1 gives the sample size of sets for both stocks by year, as well as the fraction of the kill of unknown gender and color phase that were prorated as described above.

Number of suckling calves

As time permitted, NMFS observers would also collect biological data from a subset of the kill. For this study, we used ages estimated from teeth collected for a study of spotted dolphin growth and reproduction (Myrick et al., 1986). The specimens used were a random sample of all male and female spotted dolphins collected between 1973 and 1978 for which total body length was recorded and teeth were collected. However, additional specimens with lengths less than 150 cm were selected in order to match as closely as possible the length distribution of the aged sample to the underlying length distribution of the spotted dolphins in the kill. This was necessary because observers did not generally collect teeth from smaller, younger animals. Later, another sample of female spotted dolphins was selected from specimens collected in 1981. Specimens were aged as described in Myrick et al. (1986).

The final data set used in our analyses included age estimates for 1094 female spotted dolphin specimens and 798 male specimens. Of these, 649 females and 457 males belonged to the northeastern stock and had color phase recorded. These 1106 dolphins were used to generate the age frequency distribution for each color phase (F_{ac}, Table 2),

$$F_{ac} = \frac{S_{ac}}{\sum_a S_{ac}}, \tag{4}$$

where S_{ac} = the number of samples of age a in color phase c.

The oldest age recorded was 36 years.

To derive an age distribution for the dolphins killed in each tuna set, we estimated the number of dolphins in each age class (n_a) as

$$n_a = \sum_c (F_{ac} \cdot n'_c), \tag{5}$$

where n'_c = the sum of nm'_c and nf'_c (the number of males and females in each color phase after proration from Equations 2 and 3).

Table 1

Sample sizes of NMFS (1973–1990) and IATTC (1996–2000) observed sets with spotted dolphin kill made on two stocks of pantropical spotted dolphins (*Stenella attenuata*) by year.

	Northeastern stock				Western-southern stock			
Year	Number of sets with kill	Observed kill	Fraction of kill of unknown color phase	Fraction of kill of unknown gender	Number of sets with kill	Observed kill	Fraction of kill of unknown color phase	Fraction of kill of unknown gender
1973	332	5242	0.09	0.31	75	1199	0.17	0.34
1974	515	5864	0.16	0.23	92	1715	0.10	0.31
1975	554	8073	0.31	0.19	75	1702	0.30	0.20
1976	239	2376	0.24	0.25	356	6293	0.27	0.23
1977	467	2146	0.23	0.26	528	3358	0.18	0.32
1978	224	1016	0.18	0.41	329	3998	0.37	0.34
1979	218	1045	0.38	0.27	168	1262	0.40	0.14
1980	165	1132	0.45	0.28	106	1206	0.73	0.13
1981	121	815	0.46	0.13	112	1346	0.48	0.12
1982	171	1696	0.51	0.22	159	1966	0.37	0.38
1983	12	177	0.80	0.08	35	148	0.32	0.35
1984	43	294	0.37	0.25	71	961	0.48	0.15
1985	186	2625	0.39	0.40	54	381	0.49	0.13
1986	150	1816	0.48	0.28	132	1818	0.60	0.22
1987	630	3327	0.25	0.31	175	1768	0.62	0.14
1988	207	1142	0.18	0.27	107	479	0.36	0.34
1989	293	1096	0.29	0.25	323	2793	0.48	0.14
1990	157	515	0.16	0.31	121	829	0.35	0.13
1996	273	724	0.27	0.44	161	374	0.18	0.54
1997	163	393	0.15	0.42	274	738	0.24	0.48
1998	161	260	0.21	0.51	125	236	0.19	0.46
1999	189	317	0.18	0.58	88	159	0.11	0.56
2000	146	291	0.23	0.47	115	250	0.20	0.61

In Equation 4, an age distribution was generated for each color phase, and then the number of dolphins in each age class was summed across all color phases.

To estimate the number of calves in each set, we used this age distribution in conjunction with a weaning model developed from a study of the stomach contents and ages of calves (Archer and Robertson, in press). The model predicts the probability that an animal of a given age (a) will be suckling:

$$P(milk)_a = \frac{1}{1+e^{1.90-2.6 \cdot a}}. \tag{6}$$

The estimated number of calves (N_{calf}) in a set is then

$$N_{calf} = \sum_{a=0}^{3} \left(n_a \cdot P(milk)_a\right). \tag{7}$$

In our estimate of N_{calf} we chose to use only the first four age classes (0 to 3) because $P(milk)_4$ was extremely small (2×10^{-4}). These age classes allowed us to decrease computational time without significantly affecting the estimates.

Number of lactating females

Observers visually examined the mammaries of the 649 females used in the age distribution above (Eq. 4) for the presence of milk as part of the suite of biological data collected. Using these data in conjunction with the color phase of these females, we calculated the fraction of lactating females in each color phase ($Flac_c$),

$$Flac_c = \frac{Slac_c}{Sfem_c}, \tag{8}$$

where $Slac_c$ and $Sfem_c$ = the number of females that were lactating and the total number of females in color phase c of the samples examined.

$Flac_c$ was 0.00, 0.01, 0.04, 0.22, and 0.50 for neonate, two-tone, speckled, mottled, and fused specimens, respectively. The estimated number of lactating females (N_{lac}) in a set was then

$$N_{lac} = \sum_{c} \left(nf'_c \cdot Flac_c\right). \tag{9}$$

Calf deficit

As described in Archer et al. (2001), the calf deficit (D) in each set was calculated by subtracting the number of calves (N_{calf}) from the number of lactating females (N_{lac}). If this value was zero or less, then D was set to zero to indicate that there were enough calves to account for all lactating females killed (Fig. 1),

$$D = \left\langle \begin{array}{ll} N_{lac} - N_{calf} & \text{if } N_{lac} > N_{calf} \\ 0 & \text{if } N_{lac} \leq N_{calf} \end{array} \right. . \tag{10}$$

We calculated three deficit-based fractions: 1) the mean deficit per set (D_s); 2) the mean deficit per dolphin killed (D_k); and 3), the mean deficit per lactating female killed (D_l):

$$D_s = \frac{\sum D}{ObsSets}, \tag{11}$$

$$D_k = \frac{\sum D}{ObsKill}, \tag{12}$$

$$D_l = \frac{\sum D}{EstLacKill}, \tag{13}$$

where ΣD = the total observed calf deficit in each year;
$ObsSets$ = the number of observed sets used in the analysis, including those sets without a dolphin kill;
$ObsKill$ = the number of dolphins killed in the observed sets; and
$EstLacKill$ = the total estimated number of lactating females killed.

The above analysis was conducted each year. Estimation error was evaluated with 20,000 bootstrap replicates for each year. For each replicate, the sets within that year were randomly resampled. The frequency tables F_{ac} and $Flac_c$ were also recalculated by resampling the list of biological specimens. The parameters for the weaning model, $P(milk)_a$, were estimated again by resampling the 29 calves and by fitting the logistic model to the new data set as described in Archer and Robertson (in press). All resampling was done with replacement. N_{calf}, N_{lac}, and D were estimated as described above for each set, and D_s, D_k, and D_l were calculated for the replicate. The 95% confidence intervals for N_{calf}, N_{lac}, D, D_s, D_k, and D_l were estimated from the 2.5% and 97.5% quantiles of the distributions of the bootstrap replicate values.

The total calf deficit (D_{total}) was estimated as the deficit per dolphin killed (D_k) multiplied by the total number of dolphins killed (N_{killed}) by stock each year,

$$D_{total} = D_k \times N_{killed}. \tag{14}$$

Table 2

Age-class frequency distribution for each color phase (F_{ac}).

Age (yr)	Neonate	Two-tone	Speckled	Mottled	Fused
0	0.80	0.12	0	0	0
1	0.20	0.32	0	0	0
2	0	0.31	0.04	0	0
3	0	0.16	0.18	0.01	0
4	0	0.05	0.14	0.02	0
5	0	0.02	0.13	0.03	0
6	0	0	0.13	0.04	0.01
7	0	0	0.06	0.05	0
8	0	0	0.10	0.06	0
9	0	0	0.06	0.07	0.01
10	0	0	0.01	0.10	0.01
11	0	0	0.01	0.14	0.03
12	0	0	0.01	0.08	0.02
13	0	0	0.04	0.07	0.03
14	0	0	0.03	0.07	0.03
15	0	0	0	0.06	0.06
16	0	0.01	0.01	0.06	0.07
17	0	0	0.01	0.03	0.07
18	0	0	0	0.01	0.07
19	0	0	0	0.03	0.09
20	0	0	0	0.03	0.07
21	0	0	0	0.01	0.08
22	0	0	0	0	0.06
23	0	0	0.01	0	0.07
24	0	0	0	0.01	0.04
25	0	0	0	0.01	0.04
26	0	0	0	0	0.04
27	0	0	0	0.01	0.03
28	0	0	0	0.01	0.02
29	0	0	0	0	0.01
30	0	0	0	0.01	0.02
31	0	0	0	0	0.01
32	0	0	0	0	0
33	0	0	0	0	0.01
34	0	0	0	0	0
35	0	0	0	0	0
36	0	0	0	0	0.01

For the period 1973–84, annual values of N_{killed} for each stock were provided by the IATTC (Joseph[2]). For 1984–90 and 1996–2000, values were published by IATTC (2002). In the bootstrap estimation of the 95% CI around D_{total}, for the 1973–90 period, each replicate was randomly sampled from a normal distribution by using the estimated total kill standard error. For 1996–2000, the total kill was reported to be exact; therefore the total kill was used without variance in all replicates.

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[2] Joseph, J. 1994. Letter of September 6 to Michael Tillman, 2 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037.

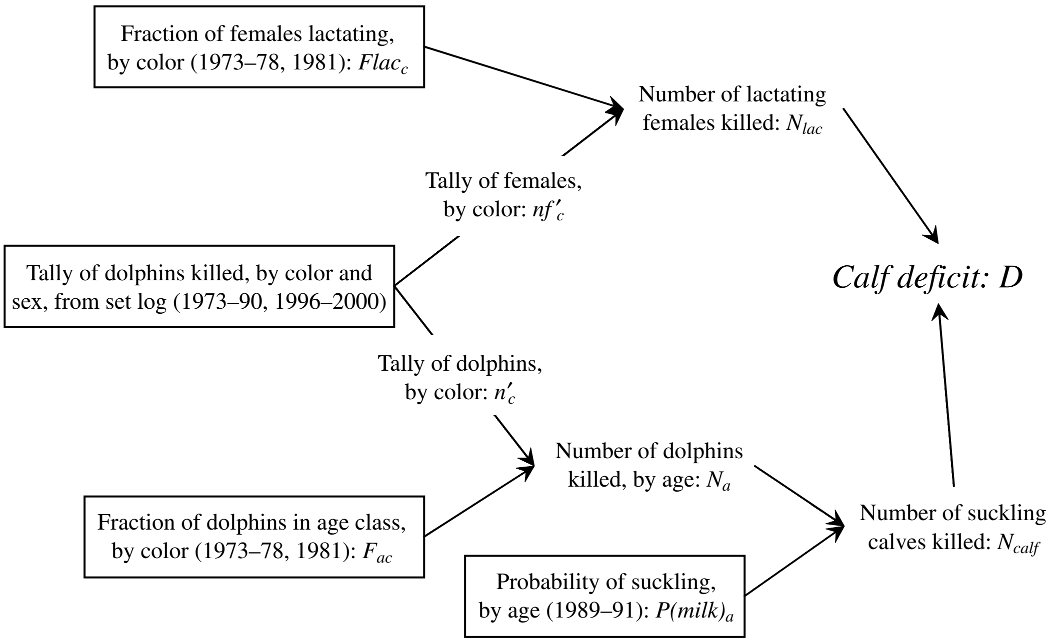

Figure 1

Diagram of the analytical method used to estimate the spotted dolphin (*Stenella attenuata attenuata)* calf deficit in each set as described in the text. Boxes identify original data that were bootstrapped to produce confidence intervals. Values in parentheses are years for which data were available.

In a subset of the sets that we examined, every individual killed had been examined and biological samples had been collected from it; therefore, we knew the actual number of lactating females killed. There were 1108 of these "100% sampled" sets on the northeastern stock, and 697 on the western-southern stock from 1973 to 1990. We evaluated the accuracy of our frequency-based method by conducting a paired *t*-test between our estimate of the number of lactating females and the number observed in each of these sets.

Stomach-content data were not available for every animal in these 100%-sampled sets; therefore, we did not know the actual number of suckling calves. However, we also used paired *t*-tests to compare our estimate of the number of suckling calves in each set with the number of animals smaller than 122 cm, which was the estimated length at which the probability of milk in the stomach was 0.5, given the weaning model of Archer and Robertson (in press). Likewise, our estimate of the calf deficit was compared with the deficit as estimated by using a cutoff length of 122 cm. These tests were done to determine if the method in the present study would produce significantly different results from the method used in the previous study. Paired *t*-tests were conducted for each year separately, as well as for all years combined. A power analysis was also performed for these paired *t*-tests to determine the minimum detectable difference at which we could reject the null hypothesis of no difference between methods given observed sample sizes and variability.

Results

The calf deficit as a fraction of the number of dolphins killed (D_k) increased slightly during the mid-1970s but remained relatively constant throughout the rest of the time series at approximately 0.14 missing calves per dolphin killed for both stocks (Fig. 2). The total calf deficit (D_{total}) as estimated from the annual kill decreased from highs of approximately 5000 in the mid-1970s down to 2000–3000 by the early 1980s (Fig. 3). In the late 1980s, this value increased to approximately 5000 in northeastern spotted dolphins (Table 3A) and approximately 2800 in the western-southern stock (Table 3B), reflecting an increase in the reported kills. In the last five years of the time series (1996–2000), the estimated total deficit was approximately 60 missing calves.

The mean deficit per set (D_s) for northeastern spotters over all years was 1.03 missing calves per set, and the median was 0.30 (Fig. 4). For western-southern spotted dolphins, the mean was 1.28 missing calves per set, and the median was 0.33. The estimated mean deficit per set was approximately 1.5 in the mid-1970s and decreased over time to 0.01–0.02 at the end of the time series (Fig. 4). For both stocks, 75– 95% of lactating females killed were not killed with their calf (Fig. 5).

In the sets that were 100%-sampled, for all years combined, there was no significant difference between the observed and the estimated number of lactating females killed in either stock (Table 4). The results of paired *t*-tests

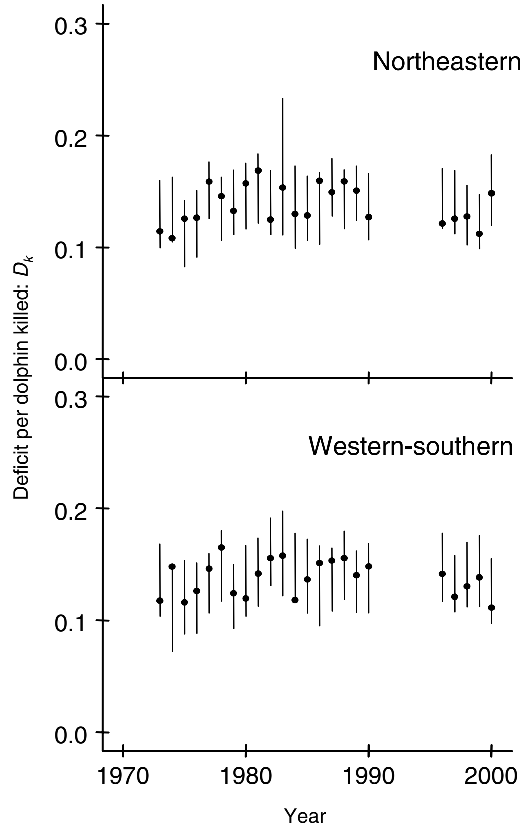

Figure 2

Calf deficit per spotted dolphin (*Stenella attenuata attenuata)* killed (D_k) by year. Vertical lines indicate 95% confidence intervals.

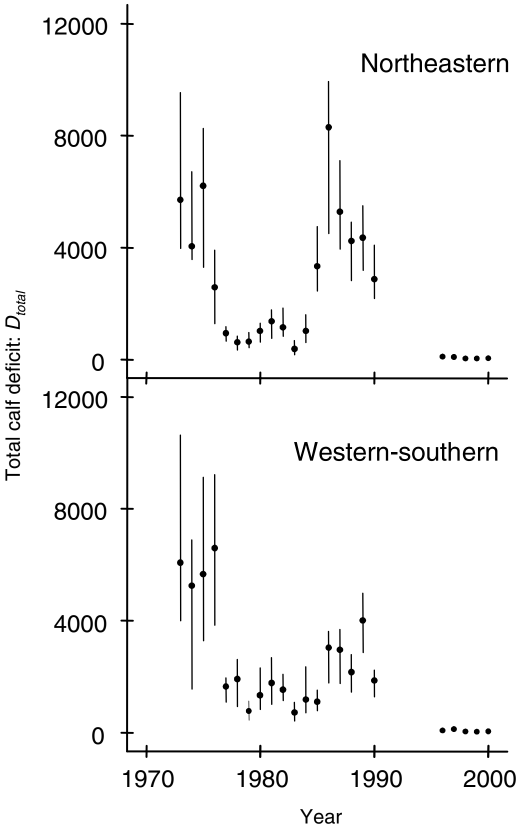

Figure 3

Total estimated calf deficit (D_{total}) by year. Vertical indicate 95% confidence intervals.

by year indicated that the observed number of lactating females in each set was significantly greater ($P \le 0.05$) than the estimated number in 1977 for the northeastern and the western-southern stocks and in 1979 for the western-southern stock. The difference was significantly less in 1984 for the western-southern stock. Using 0.1 as our type-2 error level, we determined through power analysis that the minimum detectable difference ($\alpha = 0.05$) between the mean observed and estimated number of lactating females per set across all years was approximately 0.08 and 0.09 in the northeastern and western-southern stocks respectively.

The observed number of calves per set, defined as the number of dolphins less than 122 cm, was significantly greater for both stocks, for all years combined, than the values estimated in this paper (Table 5). The overall mean difference was 0.17 calves per set for the northeastern stock and 0.12 for the western-southern stock. About half of the years showed a significant difference for each stock. In the comparison of the calf deficit by year, only a few years showed significant differences in either stock (Table 5). However, the estimated deficit tended to be larger than the observed deficit. The paired *t*-test for all years combined was significant for the northeastern stock, although the mean difference was only −0.06 missing calves per set. The minimum detectable difference from the power analysis for the mean number of calves per set and mean calf deficit per set across all years was 0.06 and 0.08 respectively for both stocks.

Discussion

In the present study, we present an estimate of the number of missing dependent northeastern and western-southern offshore spotted dolphin calves in the tuna purse-seine kill from 1973 to 1990 and from 1996 to 2000. The total number of missing calves decreased through the time series, which, because we estimated the calf deficit as a function of the size of the kill, was a direct result of the large reduction in the annual dolphin kill by the fishery. Between 1973 and 2000, the shortage of calves in the kill remained at a relatively constant fraction of the kill, about 14%, for both stocks of pantropical spotted dolphins (Fig. 2). On the assumption that suckling calves do not survive separation from their mother (Archer et al., 2001;

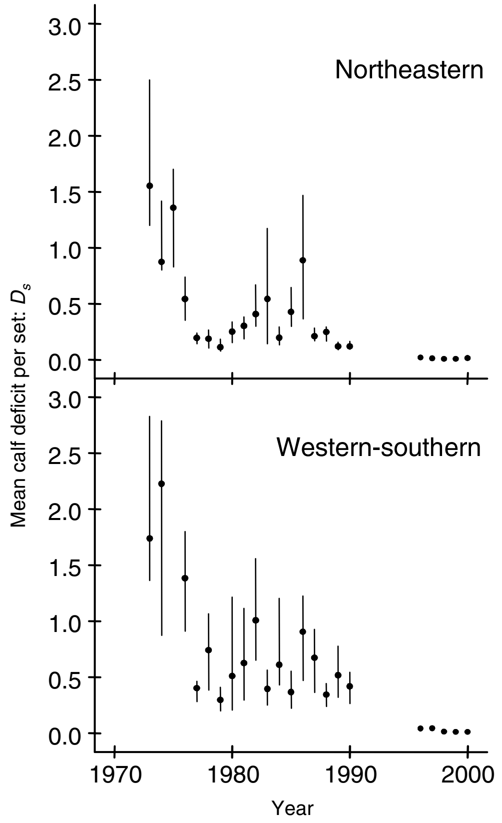

Figure 4

Mean calf deficit per set (D_s) by year. Vertical lines indicate 95% confidence intervals.

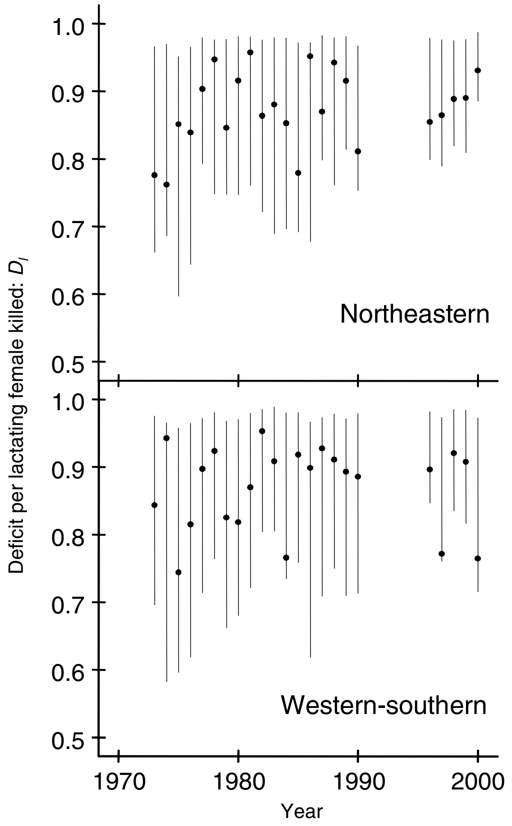

Figure 5

Calf deficit per lactating female killed (D_l) by year. Vertical lines indicate 95% confidence intervals.

Edwards[3]), the estimated calf deficit represents an approximately 14% underestimate of the reported kill.

The calf deficit in the present study was estimated from the number of dependent calves and lactating females killed by using age-color frequency tables and data on the stomach contents of weaning calves. Specimens used to derive the age and color table were collected from 1973 to 1978 and 1981, and specimens used for the weaning model were collected between 1989 and 1991. If the distributions of these samples were not representative of all years that we examined, then our results may be biased. However, the results of a study to construct the annual age distribution of the kill (Archer and Chivers[4]) indicated that there is no significant difference in the age-color frequency table across years. The sample size for the stomach data (29 calves) was too small to examine differences between years.

Our finding of no significant difference between our estimates of the number of lactating females and the observed tally of lactating females in sets where the entire kill was sampled validates this portion of our estimation procedure. However, because the number of suckling calves present in these 100%-sampled sets was not recorded, we were unable to validate the method used to generate these estimates in a similar manner.

The results of our paired *t*-tests indicated that the observed number of animals smaller than 122 cm tended to be greater than the number we estimated. This is most likely a result of the difference between how calves were counted in each method. Archer et al. (2001) considered all animals under a series of cutoff values to be calves that were dependent on suckling for survival. In the present study, the weaning model that we used (Archer and Rob-

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[3] Edwards, E. F. 2002. Behavioral contributions to separation and subsequent mortality of dolphin calves chased by tuna purse-seiners in the eastern tropical Pacific Ocean. National Oceanographic and Atmospheric Administration Administrative Report LJ-02-28, 34 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037.

[4] Archer, F., and S. J. Chivers. 2002. Age structure of the northeastern spotted dolphin incidental kill by year for 1971 to 1990 and 1996 to 2000. National Oceanographic and Atmospheric Administrative Report LJ-02-12, 18 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037.

Table 3

Estimated calf deficit per kill (D_k) and total calf deficit. Total number of spotted dolphins killed reported by the IATTC (2002) and Joseph (footnote 2 in the general text). Values in parentheses are 95% lower and upper confidence intervals.

Stock and year	Estimated calf deficit in observed sets	Observed dolphin kill	Mean calf deficit per kill (D_k)	Total number of NE spotted dolphins killed (±SE)	Estimated total calf deficit
A Northeastern (NE) stock					
1973	599	5242	0.11	49928 ±8899	5709
	(464,964)	(3947,6820)	(0.10,0.16)		(3972,9532)
1974	634	5864	0.11	37410 ±4222	4046
	(583,1027)	(4943,6916)	(0.10,0.16)		(3573,6708)
1975	1014	8073	0.13	49399 ±8809	6206
	(618,1269)	(6578,9965)	(0.08,0.14)		(3297,8254)
1976	300	2376	0.13	20443 ±4721	2583
	(196,408)	(1786,3079)	(0.09,0.15)		(1284,3903)
1977	341	2146	0.16	5937 ±690	943
	(249,416)	(1743,2622)	(0.13,0.18)		(656,1167)
1978	148	1016	0.15	4226 ±827	616
	(83,209)	(684,1431)	(0.11,0.16)		(336,836)
1979	138	1045	0.13	4828 ±817	640
	(96,226)	(680,1629)	(0.11,0.17)		(428,963)
1980	178	1132	0.16	6468 ±962	1016
	(107,239)	(724,1637)	(0.12,0.18)		(622,1300)
1981	137	815	0.17	8096 ±1508	1366
	(84,173)	(560,1122)	(0.12,0.18)		(753,1774)
1982	212	1696	0.12	9254 ±1529	1155
	(155,347)	(1126,2395)	(0.11,0.17)		(833,1840)
1983	27	177	0.15	2460 ±659	377
	(7,59)	(35,410)	(0.11,0.23)		(169,678)
1984	38	294	0.13	7836 ±1493	1017
	(26,57)	(191,417)	(0.10,0.17)		(608,1602)
1985	337	2625	0.13	25975 ±3210	3338
	(235,508)	(1839,3529)	(0.11,0.16)		(2447,4748)
1986	290	1816	0.16	52035 ±8134	8297
	(119,478)	(859,3440)	(0.10,0.17)		(4496,9935)
1987	497	3327	0.15	35366 ±4272	5280
	(397,667)	(2777,4002)	(0.13,0.18)		(3949,7106)
1988	182	1142	0.16	26625 ±2744	4234
	(122,215)	(880,1462)	(0.12,0.17)		(2825,4907)
1989	165	1096	0.15	28898 ±3108	4357
	(120,217)	(871,1371)	(0.12,0.17)		(3186,5492)
1990	65	515	0.13	22616 ±2575	2875
	(53,90)	(421,632)	(0.11,0.17)		(2176,4085)
1996	88	724	0.12	818	99
	(76,142)	(568,926)	(0.12,0.17)		(96,139)
1997	49	393	0.13	721	91
	(42,69)	(331,461)	(0.11,0.17)		(81,121)
1998	33	260	0.13	298	38
	(26,41)	(230,296)	(0.10,0.16)		(30,46)
1999	36	317	0.11	358	40
	(30,48)	(282,357)	(0.10,0.15)		(35,53)
2000	43	291	0.15	295	44
	(32,58)	(247,342)	(0.12,0.18)		(35,54)

continued

Table 3 (continued)

Stock and year	Estimated calf deficit in observed sets	Observed dolphin kill	Mean calf deficit per kill (D_k)	Total number of NE spotted dolphins killed (±SE)	Estimated total calf deficit
B Western-southern (WS) stock					
1973	141 (110,229)	1199 (836,1638)	0.12 (0.10,0.17)	51,712 ±10,721	6076 (3993–10,633)
1974	254 (100,318)	1715 (939,2733)	0.15 (0.07,0.15)	35,499 ±10,309	5254 (1554,6890)
1975	197 (123,322)	1702 (1104,2434)	0.12 (0.09,0.15)	48,837 ±10,055	5664 (3285,9121)
1976	795 (524,1036)	6293 (4925,7860)	0.13 (0.09,0.15)	52,206 ±8883	6595 (3833,9223)
1977	491 (345,563)	3358 (2860,3906)	0.15 (0.11,0.16)	11,260 ±1186	1647 (1098,1959)
1978	660 (342,949)	3998 (2508,5922)	0.17 (0.12,0.18)	11,610 ±2553	1917 (932,2614)
1979	157 (104,216)	1262 (939,1643)	0.12 (0.09,0.15)	6,254 ±1229	776 (438,1138)
1980	144 (59,344)	1206 (411,2542)	0.12 (0.10,0.17)	11,200 ±2430	1339 (831,2320)
1981	191 (90,340)	1346 (577,2416)	0.14 (0.11,0.17)	12,512 ±2629	1775 (1010,2682)
1982	306 (198,474)	1966 (1337,2734)	0.16 (0.13,0.19)	9869 ±1146	1536 (1156,2088)
1983	23 (15,33)	148 (99,206)	0.16 (0.12,0.20)	4587 ±928	724 (418,1087)
1984	114 (80,224)	961 (526,1513)	0.12 (0.12,0.18)	10,018 ±2614	1183 (712,2352)
1985	52 (32,79)	381 (225,570)	0.14 (0.11,0.17)	8089 ±951	1105 (781,1524)
1986	275 (143,373)	1818 (1065,2784)	0.15 (0.10,0.17)	20,074 ±2187	3037 (1776,3617)
1987	271 (147,374)	1768 (1068,2661)	0.15 (0.11,0.16)	19,298 ±2899	2959 (1754,3695)
1988	75 (51,96)	479 (368,605)	0.16 (0.12,0.18)	13,916 ±1741	2166 (1453,2785)
1989	392 (242,589)	2793 (1819,4277)	0.14 (0.11,0.16)	28,560 ±2675	4011 (2861,4977)
1990	123 (78,160)	829 (582,1128)	0.15 (0.11,0.17)	12,578 ±1015	1864 (1283,2236)
1996	53 (42,71)	374 (308,448)	0.14 (0.12,0.18)	545	77 (64,97)
1997	89 (72,132)	738 (598,931)	0.12 (0.11,0.16)	1044	126 (112,165)
1998	31 (25,42)	236 (192,288)	341 (0.11,0.17)	44	0.13 (38,58)
1999	22 (16,32)	159 (123,209)	0.14 (0.11,0.18)	253	35 (28,44)
2000	28 (22,44)	250 (189,330)	0.11 (0.10,0.15)	435	48 (42,67)

Table 4

Annual mean observed and mean estimated number of lactating females per set in 100% sampled sets. Values in parentheses are 95% lower and upper confidence intervals assuming a normal distribution of differences. Bold type indicates significant difference from zero ($P \leq 0.05$) in the paired *t*-tests.

	Northeastern stock				Western-southern stock			
Year	No. of sets	Observed	Estimated	Difference (95% CI)	No. of sets	Observed	Estimated	Difference (95% CI)
1973	116	0.55	0.61	−0.06 (−0.17,0.05)	21	1.19	1.30	−0.11 (−0.63,0.42)
1974	98	0.51	0.54	−0.03 (−0.13,0.07)	16	0.75	0.81	−0.06 (−0.36,0.24)
1975	99	0.57	0.48	0.09 (−0.05,0.22)	14	1.07	0.92	0.15 (−0.46,0.77)
1976	51	0.28	0.35	−0.08 (−0.18,0.02)	90	0.500	0.502	−0.002 (−0.119,0.115)
1977	167	0.55	0.46	**0.09 (0.01,0.15)**	163	0.49	0.37	**0.12 (0.03,0.21)**
1978	82	0.37	0.40	−0.03 (−0.14,0.08)	93	0.50	0.52	−0.02 (−0.19,0.13)
1979	75	0.47	0.46	0.01 (−0.13,0.14)	61	0.64	0.47	**0.17 (0.01,0.33)**
1980	54	0.39	0.38	0.01 (−0.11,0.13)	34	0.50	0.44	0.06 (−0.09,0.20)
1981	41	0.53	0.74	−0.21 (−0.81,0.38)	38	0.66	0.64	0.02 (−0.16,0.19)
1982	36	0.62	1.18	−0.56 (−1.40,0.27)	33	0.30	0.44	−0.14 (−0.37,0.10)
1983	33	1.33	2.14	−0.81 (−7.89,6.28)	6	0.17	0.57	−0.40 (−1.57,0.77)
1984	4	0.25	0.49	−0.24 (−0.67,0.18)	29	0.48	1.08	**−0.60 (−0.96, −0.23)**
1985	70	0.34	0.50	−0.16 (−0.36,0.06)	17	0.35	0.50	−0.15 (−0.49,0.20)
1986	45	0.71	0.47	0.24 (−0.04,0.51)	28	0.61	0.42	0.19 (−0.01,0.38)
1987	121	0.43	0.46	−0.03 (−0.18,0.11)	30	0.27	0.46	−0.19 (−0.44,0.06)
1988	6	0.44	0.57	−0.13 (−0.59,0.35)	—	—	—	—
1989	24	0.96	1.03	−0.07 (−0.59,0.44)	15	0.93	0.96	−0.03 (−0.68,0.64)
1990	16	0.56	0.47	0.09 (−0.25,0.44)	9	0.67	0.93	−0.26 (−0.94,0.42)
All	1108	0.50	0.53	−0.03 (−0.08,0.02)	697	0.545	0.546	−0.001 (−0.053,0.051)

ertson, in press) estimated the probability that a calf of a given age class was still suckling. Given that body length has a near linear relationship with age in these young age classes (Perrin, 1976), this meant that for any chosen length of independence, each individual smaller than that cutoff value would only be counted fractionally, in effect correcting for the probability that an animal of a given age is not suckling. This procedure caused the method in this paper to tally fewer "calves" in each set than in the previous study. A secondary result of this effect was that the mean deficit per set estimated in the present study tended to be slightly higher than that presented by Archer et al. in 2001.

We estimated the total number of missing calves as a function of the number of dolphins killed in each stock (Table 3). Prior to 1995, only a fraction of the purse-seine trips carried scientific observers. To estimate the number killed in each stock, kill rates from the observed trips were applied to unobserved trips, stratified by area and stock (IATTC, 2002; Joseph, 1994[2]). Since 1995 it has been reported that all dolphin sets have been observed, and that the number of dolphins killed is therefore known without error (IATTC, 2002).

The total calf deficit could also be estimated as a function of the number of sets by multiplying the total number of sets made on each stock by D_s (Fig. 4). In the only study to estimate the number of sets made on each stock annually, Archer et al.[5] used a relatively simple proration scheme of unobserved sets derived from ratios of the number of sets made on each stock in observed sets. However, because Archer et al.[5] did not stratify unobserved sets by area, basing the total calf deficit on these estimates would produce a different result from that presented in Table 3. Because the estimates of the kill by stock included stratification by area, estimates of the total calf deficit calculated by multiplying the kill estimates by D_k are likely to be more accurate. It is important to realize that the deficit that we present is directly related to the kill observed in the sets that we used. In other words, if proration schemes for unobserved sets were the same for the number of sets made and the number of dolphins killed, estimates of the total calf deficit with either D_s or D_k would be equivalent.

Wade et al.[1] explored the effects of 50% and 100% additional fisheries-related mortality on the assessment of the northeastern spotted dolphin stock. The assumption of additional mortality led to higher estimates of maximum

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[5] Archer, F., T. Gerrodette, and A. Jackson. 2002. Preliminary estimates of the annual number of sets, number of dolphins chased, and number of dolphins captured by stock in the tuna purse-seine fishery in the eastern tropical Pacific, 1971–2000. National Oceanographic and Atmospheric Administration Administrative Report LJ-02-10, 26 p. Southwest Fisheries Science Center, 8604 La Jolla Shores Dr., La Jolla, CA 92037.

Table 5

Annual mean number of dolphins killed ≤122 cm (calves killed based on length) and estimated number of suckling calves (calves based on weaning model) per set in 100% sampled sets (first line for each year). Mean deficit per set using 122 cm as cutoff length (calf deficit based on length) and calf deficit as estimated in this article (calf deficit based on weaning model) on second line for each year. Values in parentheses are 95% lower and upper confidence intervals assuming a normal distribution of differences. Differences in bold indicate significant difference from zero ($P \leq 0.05$) in the paired t-test.

	Northeastern stock				Western-southern stock			
		Calves killed based on length	Calves killed based on weaning model			Calves killed based on length	Calves killed based on weaning model	
Year	No. of sets	Calf deficit based on length	Calf deficit based on weaning model	Difference (95% CI)	No. of sets	Calf deficit based on length	Calf deficit based on weaning model	Difference (95% CI)
1973	116	0.54	0.21	**0.33 (0.18,0.50)**	21	0.33	0.06	**0.27 (0.01,0.55)**
		0.35	0.48	**–0.13 (–0.26,–0.03)**		1.00	1.25	–0.25 (–0.79,0.29)
1974	98	0.39	0.05	**0.34 (0.20,0.47)**	16	0.56	0.09	0.47 (–0.53,1.47)
		0.36	0.50	**–0.14 (–0.26,–0.03)**		0.56	0.74	–0.18 (–0.61,0.25)
1975	99	0.57	0.15	**0.42 (0.20,0.64)**	14	0.29	0.11	0.18 (–0.03,0.39)
		0.46	0.40	0.04 (–0.05,0.16)		0.93	0.83	0.10 (–0.45,0.66)
1976	51	0.18	0.11	0.07 (–0.01,0.15)	90	0.13	0.07	**0.06 (0.001,0.13)**
		0.28	0.31	–0.03 (–0.14,0.06)		0.49	0.47	0.02 (–0.10,0.15)
1977	167	0.10	0.03	**0.07 (0.02,0.12)**	163	0.17	0.06	**0.11 (0.06,0.16)**
		0.51	0.45	0.06 (–0.01,0.14)		0.46	0.35	0.11 (0.03,0.20)
1978	82	0.17	0.03	**0.14 (0.05,0.23)**	93	0.18	0.05	**0.13 (0.04,0.23)**
		0.35	0.39	–0.04 (–0.14,0.07)		0.43	0.50	–0.07 (–0.22,0.09)
1979	75	0.09	0.04	0.05 (–0.02,0.13)	61	0.31	0.13	**0.18 (0.04,0.32)**
		0.44	0.43	0.01 (–0.11,0.13)		0.51	0.37	0.14 (–0.03,0.31)
1980	54	0.16	0.03	**0.13 (0.02,0.25)**	34	0.00	0.01	**–0.01 (–0.02,–0.003)**
		0.373	0.371	0.002 –0.115,0.119)		0.50	0.44	0.06 (–0.08,0.21)
1981	41	0.105	0.110	–0.005 (–0.194,0.185)	38	0.05	0.04	0.01 (–0.04,0.07)
		0.53	0.65	–0.12 (–0.57,0.31)		0.63	0.62	0.01 (–0.17,0.20)
1982	36	0.44	0.21	0.23 (–0.10,0.55)	33	0.06	0.02	0.04 (–0.04,0.12)
		0.44	1.00	–0.56 (–1.27,0.14)		0.27	0.42	–0.15 (–0.37,0.08)
1983	33	0.00	0.14	0.14 (–0.64,0.36)	6	0.17	0.04	0.13 (–0.31,0.57)
		1.33	2.00	–0.67 (–7.25,5.91)		0.17	0.56	–0.39 (–1.56,0.76)
1984	4	0.00	0.02	–0.02 (–0.08,0.04)	29	0.14	0.04	0.10 (–0.01,0.21)
		0.25	0.49	–0.24 (–0.67,0.18)		0.35	1.04	–0.69 (–1.13,–0.26)
1985	70	0.13	0.04	**0.09 (0.02,0.15)**	17	0.06	0.04	0.02 (–0.06,0.10)
		0.29	0.47	–0.18 (–0.39,0.03)		0.35	0.49	–0.14 (–0.48,0.21)
1986	45	0.13	0.04	**0.09 (0.01,0.17)**	28	0.04	0.03	0.01 (–0.04,0.06)
		0.64	0.44	0.20 (–0.04,0.44)		0.57	0.39	0.18 (–0.02,0.38)
1987	121	0.14	0.02	**0.12 (0.05,0.20)**	30	0.23	0.08	**0.15 (0.02,0.30)**
		0.38	0.45	–0.07 (–0.22,0.07)		0.27	0.43	–0.16 (–0.41,0.09)
1988	6	0.11	0.12	–0.01 (–0.23,0.22)	—	—	—	—
		0.33	0.50	–0.17 (–0.62,0.28)				
1989	24	0.22	0.13	0.09 (–0.11,0.29)	15	0.47	0.20	**0.27 (0.05,0.49)**
		0.87	0.95	–0.08 (–0.60,0.43)		0.73	0.82	–0.09 (–0.66,0.48)
1990	16	0.31	0.21	0.10 (–0.18,0.38)	9	0.89	0.17	0.72 (–0.18,1.62)
		0.56	0.41	0.15 (–0.20,0.51)		0.33	0.77	–0.44 (–1.15,0.27)
All	1108	0.25	0.08	**0.17 (0.13,0.20)**	697	0.18	0.06	**0.12 (0.09,0.16)**
		0.42	0.48	**–0.06 (–0.10,–0.01)**		0.49	0.51	–0.02 (–0.08,0.03)

growth rates and lower estimates of the current size of the population in relation to carrying capacity. Wade et al.[1] did not model the calf deficit estimated in our present study, but the effect of 14% additional mortality would probably be less than the 50% additional mortality that was modeled. The 50% mortality was spread over all age classes, and additional mortality due to missing calves should be assigned to the first two year classes only. The important question is whether the calf deficit in the kill represents the main effect of mother-calf separation by the fishing process. As outlined in Archer et al. (2001), the mechanism by which suckling calves are separated from their mothers is unknown. If separation is simply a function of the number of lactating females killed, then the deficit presented here is an accurate representation of the number of "missing" calves.

However, there is some evidence that separation can occur without the mother being killed. In the early days of the backdown procedure, purse-seine skippers reported that "Babies swim around the outside of the net pushing to get back in probably because their mothers are still inside" (Gehres[6]). It is unclear whether these calves were separated prior to encirclement or were released early during backdown, prior to their mothers. Regardless, given that dolphins exhibit some of their fastest swimming during a set immediately upon release from the net (Chivers and Scott[7]), separated calves waiting immediately outside the net may risk separation if their mothers join the rest of the school rapidly swimming away from the net. If this, or any of the other scenarios regarding the manner in which permanent separation can occur without the mother being killed (Archer et al., 2001), then the calf deficit underestimates the actual number of orphaned calves. Future research should focus on the mechanism of calf separation because a better understanding of this process is the only way we will be able to estimate the magnitude of the unobserved calf mortality and its subsequent effects on the population.

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