Revised estimates of incidental kill of dolphins (Delphinidae) by the purse-seine tuna fishery in the eastern tropical Pacific, 1959–1972

Paul R. Wade

Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093

Southwest Fisheries Science Center*
National Marine Fisheries Service, NOAA
P.O. Box 271, La Jolla, CA 92038

Abstract.—Dolphins (Delphinidae) have been killed incidentally by the purse-seine fishery for yellowfin tuna, *Thunnus albacares,* in the eastern tropical Pacific since at least 1959. Annual estimates of the number of dolphins killed from each stock are used by the National Marine Fisheries Service in making management decisions about the population status of affected stocks. Mortality estimates from the period with the greatest kill of dolphins, 1959–72, are important for estimates of the level of depletion of these stocks from their unexploited population sizes. A redefinition of the geographical boundaries of offshore stocks of pantropical spotted dolphins, *Stenella attenuata,* makes it necessary to estimate annual kill for these newly defined stocks for 1959–72. I estimated the number of dolphins killed annually from 1959 to 1972 for the northeastern and western/southern stocks of spotted dolphins, using the methods of Lo and Smith (1986). I also revised the estimates of annual kill for the eastern and whitebelly stocks of spinner dolphins, *S. longirostris,* by correcting minor problems in previous data and analyses. Additionally, I estimated a coefficient of variation (CV) for each stock-specific estimate of incidental kill, which had not previously been done. Estimates of total kill were similar to previous estimates: 4.9 million dolphins are estimated to have been killed by the purse-seine fishery over the fourteen year period considered here, an average of 347,082 per year. Nearly all of the fisheries kill of pantropical spotted dolphins was of the northeastern stock, totaling 3.0 million (211,612 per year). Estimates of kill for the eastern stock of spinner dolphins were similar to previous estimates, totaling 1.3 million (91,739 per year). As expected, CV's of the kill for each stock were higher than those previously reported for the total kill.

Manuscript accepted 22 September 1994.
Fishery Bulletin 93:345–354 (1995).

Dolphins (Delphinidae) have been killed incidentally by the purse-seine fishery for yellowfin tuna, *Thunnus albacares,* in the eastern tropical Pacific (McNeely, 1961) since at least 1959 (Perrin, 1969). Purse seiners catch tuna by locating and capturing dolphin schools, taking advantage of an association between these species (Au, 1991). In spite of attempts to release dolphins alive using a procedure called the backdown (Barham et al., 1977), dolphins are killed when they become entangled in the net. Dolphins from several species are killed; the majority represent either pantropical spotted dolphins, *Stenella attenuata,* or spinner dolphins, *Stenella longirostris.* Several stocks of each species are impacted.

Annual estimates of the number of dolphins killed from each stock are used by the National Marine Fisheries Service (NMFS) in making management decisions about the population status of affected stocks. For example, Wade (1993) used annual estimates of mortality and variance in mortality to conclude that eastern spinner dolphins, *Stenella longirostris orientalis,* were likely below 60% of their unexploited population size in 1959. This led to the listing of eastern spinner dolphins as a depleted species under the U.S. Marine Mammal Protection Act.[1] During the period of greatest dolphin mortality, 1959–72, the kill of spotted dolphins was estimated to be twice that of spinner dolphins (Smith, 1983). Therefore, it is also important to investigate the management status of stocks of spotted dolphins. Wade (1993) showed that the estimated decline of the eastern spinner dolphin was mostly due to the early period of high mortality. Thus, estimates of incidental kill from 1959 to 1972, along with a measure of their uncertainty, are crucial for assessing whether spotted dolphin stocks are also depleted.

Recently, Dizon et al. (1994) established new geographical boundaries for the offshore stocks of pantropical spotted dolphins (Fig. 1) on the basis of a reexamination of cranial morphology (Perrin et al., 1994). Estimates of the number of spotted dolphins killed from each stock must be revised to reflect this stock structure. Therefore, my first objective was to estimate annual kill of the northeastern and west-

* Address for correspondence.

[1] Federal Register Vol. 58, No. 164, August 26, 1993 (58 FR 45066).

ern/southern stocks of offshore spotted dolphins for 1959–72, by using the methods of Lo and Smith (1986). My second objective was to revise estimates of annual kill for the eastern and whitebelly stocks of spinner dolphin by correcting minor problems in previous data and analyses. My final objective was to estimate variances for these stock-specific mortality estimates, which has not previously been done.

Background

The number of purse-seine sets capturing dolphins ("dolphin sets" or "sets") is known from fishing vessel logbooks for every year since 1959 (Punsley, 1983). Data on mortality per set (MPS) of dolphins have been collected by scientists on tuna purse seiners since 1964 (Smith and Lo, 1983). A formal observer program to collect MPS data was started by NMFS in 1971 (Edwards, 1989). Estimates of incidental dolphin mortality were first presented during workshops[2,3] to assess the status of impacted dolphin stocks and were first published by Smith (1983). The most recent estimates of dolphin mortality for 1959–72 are from Lo and Smith (1986).

Since 1979, the Inter-American Tropical Tuna Commission (IATTC) has been responsible for estimating the number of dolphins killed from each stock (IATTC, 1989). At the request of NMFS, IATTC provided revised estimates of kill for the northeastern stock of spotted dolphin for the years 1979 to 1992.[4] Additionally, they revised the estimates for 1973 to 1978, last calculated by Wahlen (1986).

IATTC chose not to revise estimates for 1959 to 1972, citing the scarcity of observer data on MPS, the lack of a formal observer program prior to 1971, and potential biases in the data.[5] However, the numbers of sets made during that period are known with high precision (Punsley, 1983). Lo and Smith (1986) presented a method of analysis that should provide accurate estimates of kill for 1959–72, given certain important but reasonable assumptions. Therefore, I used that method to estimate the number of dolphins killed in each stock annually for the years 1959 to 1972.

Lo and Smith (1986) estimated the variance of the total kill of dolphins in each year, but uncertainty in prorating that total to individual stocks has not previously been accounted for. In this study, I include uncertainty of the species and stock proportions by bootstrapping the variance estimates (Efron, 1982) instead of using the analytical estimates of Lo and Smith (1986). This procedure allows this source of variance to be correctly included for the first time in assessments of the status of these dolphin stocks.

Methods

Lo and Smith (1986) formulated a model of total dolphin kill, $\hat{T}_t$, as:

$$\hat{T}_t = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} \hat{R}_{tijk}\, X_{tijk}, \qquad (1)$$

where

$\hat{R}_{tijk}$ = estimated mortality-per-set of dolphins in year t and stratum ijk;

X_{tijk} = the number of dolphin sets in year t and stratum ijk,

and where strata were defined as

i = 1 for large vessels (capacity >600 tons), 2 for small (capacity ≤600 tons);

j = 1 for successful yellowfin tuna catch (≥1/4 ton); 2 for unsuccessful catch (<1/4 ton);

k = 1 if the backdown procedure was used to release dolphins; 2 if the backdown was not used.

Lo and Smith (1986) chose these strata because they accounted for significant differences in dolphin kill: MPS was higher for small vessels with successful tuna catches and with sets without backdown (Lo et al., 1982). Lo and Smith (1986) modified Equation 1 to estimate total dolphin kill as:

$$\hat{T}_t = \sum_{i=1}^{2}\left[\hat{R}_{\bullet i11}\, X_{ti1\bullet}\left[\hat{P}_t + C(1-\hat{P}_t)\right] + \hat{R}_{\bullet i2\bullet}\, X_{ti2\bullet}\right], \qquad (2)$$

where

$\bullet$ = data were pooled across that stratum;

$\hat{P}_t$ = the proportion of successful sets using the backdown procedure to release dolphins,

C = $\hat{R}_{\bullet\bullet 12}/\hat{R}_{\bullet\bullet 11}$, the ratio during successful sets of MPS without backdown to MPS with backdown, pooled across large and small vessels.

---

[2] Anonymous, 1976. Report of the Workshop on stock assessment of porpoises involved in the eastern Pacific yellowfin tuna fishery. NOAA, Natl. Mar. Fish. Serv., SWFC Admin. Rep. LJ-76-29.

[3] Smith, T. (ed.). 1979. Report of the status of porpoise stocks workshop (August 27–31, 1979, La Jolla, Ca.). NOAA, Natl. Mar. Fish. Serv., SWFC Admin. Rep. LJ-79-41, 120 p.

[4] Estimates provided to National Marine Fisheries Service by J. Joseph, Director, IATTC, La Jolla, CA, 18 May 1993.

[5] Joseph, J., director, IATTC, La Jolla, CA, 17 February 1993, in a letter addressed to Michael Payne at the NMFS Office of Protected Resources, Silver Spring, MD.

Lo and Smith (1986) solved for Equation 2 from Equation 1 for the following reasons:

- MPS was assumed to be constant within a stratum during this period because they found no significant differences in MPS by year, and some years had no data on MPS available.
- The vessel logbooks did not show use or not of the backdown procedure, so the number of sets could not be stratified on this variable. Instead, the proportion of use of backdown procedure, $\hat{P}_t$, was estimated from the MPS data where it was assumed that backdown 1) increased linearly between the known use of 0.0 in 1959 and the observed proportion of 0.79 in 1964–65; 2) equaled the proportion of 0.89 observed in 1966–71; and 3) equaled the proportion of 0.93 observed in 1972.
- Unsuccessful sets were not frequent and usually captured few or no dolphins. Backdown was thus not often used during these sets, which killed relatively few dolphins. Therefore, MPS was pooled across stratum k, the use or not of backdown, for unsuccessful sets.
- The use or not of the backdown procedure was assumed to have the same magnitude of effect on small and large vessels. Therefore, the ratio of MPS with no backdown to MPS with backdown, C, was pooled across vessel stratum to increase the sample size.

To confirm that I was correctly duplicating Lo and Smith's (1986) method, I recalculated their kill estimates using my calculations of MPS and the number of sets reported in their Table 3.

I modified their method in the following ways. The first modification was to account for the revised stocks of offshore spotted dolphin. IATTC provided the number of sets by year previously reported by Punsley (1983) but stratified geographically into separate totals for the northeastern and western/southern areas (Fig. 1).[6]

[6] Data provided by M. G. Hinton, Senior Scientist, Inter-Am. Trop. Tuna Comm. c/o Scripps Inst. Oceanogr., La Jolla, CA 92093, 24 June 1993. A typographical error in Punsley (1983) led to the inadvertent use of an incorrect value for the total number of dolphin sets in 1959 in Lo and Smith (1986). The correct value of 391 has been used here in place of 591.

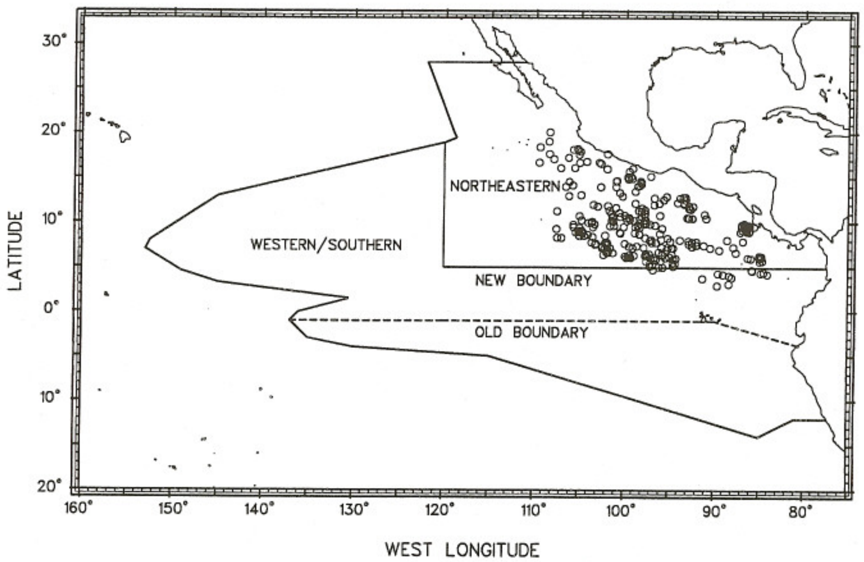

Figure 1

Newly defined areas for offshore stocks of pantropical spotted dolphins, *Stenella attenuata*. The outer line is the eastern tropical Pacific study area as defined by the National Marine Fisheries Service. The inside solid line represents the new boundary between the northeastern and western/southern stocks of spotted dolphins. Sightings of offshore spotted dolphins to the north of 5°N and to the east of 120°W are assigned to the northeastern stock, and sightings outside of that area are assigned to the western/southern stock. The dashed line represents the old boundary between the previously defined northern and southern stocks. The circles represent the location of observed dolphin sets used to estimate mortality per set in this paper, consisting of one fishing trip in 1968, five trips in 1971, and 12 trips in 1972. The exact location of sets from the 1964 and 1965 trips were not available, but the 1964 trip was stated to be 200 miles off the coast of Acapulco, Mexico.

The stocks of offshore spotted dolphins are not distinct in external morphology and therefore could not be noted as proportions in the observer data. Therefore, I estimated kill for each stock by using these stratified numbers of sets to estimate total dolphin kill in each stock area, then prorated the total kill by the observed proportion of offshore spotted dolphins in the kill. The same method as in Smith (1983) was used for prorating species proportions and will be explained in more detail below.

Because eastern spinner and whitebelly spinner dolphins are morphologically distinct, estimates of kill for those two stocks were prorated from the estimated total dolphin kill (summed across the two geographic areas) by observed proportions of the two stocks in the kill. Observed proportions of dolphins killed from species other than spotted and spinner were reported as "other dolphins." Therefore, estimates were made for this pooled category in the same way as for the stocks of spinner dolphins. Dolphins in this category were primarily common dolphins, *Delphinus delphis* (Smith, 1983).

A second modification was possible because IATTC provided the number of sets additionally stratified by tuna catch and vessel size (Table 1). Estimates of the number of sets in each stratum were made by multiplying Punsley's (1983) estimates of total dolphin sets by the proportions of known sets (from the IATTC logbook database) that were in each stock area, set type, and vessel size category.[6] This is likely a substantial improvement in accuracy over the proration method based on less data used by Lo and Smith (1986).

A third modification to the Lo and Smith (1986) method was a change in the way that the variance was calculated. They derived analytical equations for estimating the variance of total dolphin mortality in each year. More important for management is the variance of the estimate of dolphins killed in each stock in each year, which cannot be obtained from the equations in Lo and Smith (1986). Observations of stock and species proportions of the kill were not systematically collected until the observer program started in 1971 (Edwards, 1989). Therefore, Smith (1983) used the observed proportions from 1971 to 1972 for the entire 1959–72 time period, with the exception that all spinner dolphins killed before 1969 were assumed to be from the eastern stock and that no whitebelly spinner dolphins were killed until 1969. This was assumed because no dolphin sets occurred in the whitebelly stock area before 1968, and only a very small number occurred in 1968 (Punsley, 1983).

Table 1

Total dolphin sets for the years 1959–72 stratified by geographical area, by vessel capacity (large is >600 tons, small is ≤600 tons), and by catch of yellowfin tuna (successful is >1/4 ton, unsuccessful ≤1/4 ton). Areas are northeastern (north of 5°N and east of 120°W and western/southern (all areas outside of the northeastern area). Estimates are based on apportioning total dolphin sets estimated by Punsley (1983) to strata (data provided by the Inter-American Tropical Tuna Commission, La Jolla, CA).

	Northeastern				Western/southern			
	Large		Small		Large		Small	
Year	Successful	Unsuccessful	Successful	Unsuccessful	Successful	Unsuccessful	Successful	Unsuccessful
1959	0	0	125	259	0	0	3	5
1960	0	0	3117	2258	0	0	53	46
1961	59	79	3637	3652	17	7	212	187
1962	5	15	1583	1812	10	6	182	126
1963	7	13	2068	1876	7	19	222	204
1964	44	54	4238	2968	17	17	189	117
1965	21	10	5055	2226	78	75	223	131
1966	56	26	4385	1702	65	20	489	111
1967	3	1	3133	788	57	20	172	36
1968	152	50	2857	949	64	12	58	12
1969	1161	165	4424	1281	599	66	584	80
1970	2003	342	3097	769	1166	117	985	142
1971	1296	219	1430	646	1106	104	641	90
1972	2226	452	2364	935	2432	241	666	73

In this study, I duplicated the method of Smith (1983), using the observed proportions of dolphins killed in each stock from the 1971–72 MPS data, with the same assumption about whitebelly spinner kill. However, to calculate the variance of the estimate of the number of dolphins killed in each stock in each year, I used the bootstrap method (Efron, 1982): each fishing trip was a resampling unit and there were 1,000 iterations. Thus, on each bootstrap iteration, 20 fishing trips were resampled with replacement from the 1959–72 pooled observer data, and the MPS rates were recalculated and multiplied by the stratified set totals to estimate the total kill, which was then prorated to stock by the recalculated species proportions. The variance of the kill of each stock in each year was then estimated as the variance of the 1,000 bootstrap estimates of that stock. This method automatically incorporates into the variance uncertainty due to the observed proportions of each stock killed in the 1971–72 MPS observer data. Estimates of number of dolphin sets were precise, having coefficients of variation less than 1% in all years except 1959 and 1960 (Punsley, 1983) and were therefore treated as constants.

For comparative purposes, I made two additional calculations. First, I investigated the effect of the 1964, 1965, and 1968 trips by recalculating the kill of dolphins using only the MPS data collected during the observer program in 1971 and 1972. Second, I calculated stratified MPS rates from the 1973 observer data to compare to MPS rates used here from 1964 to 1972.

Results

Average MPS for each of the 20 observed trips between 1964 and 1972 showed that most of the trips had similar kill rates (Table 2). Calculated estimates of the MPS for each category of year, vessel size, and set type (Table 3) were, as expected, equivalent to the values reported by Lo and Smith (1986). The six R_{tijk} values used in Equation 4 are also shown in Table 2.

Estimating total dolphin mortality with my MPS rates (Tables 2 and 3) and the number of sets from Lo and Smith (1986, their Table 3) resulted in slightly different estimates of the total number of dolphins killed than those they reported in their Table 4. However, when I used the six MPS values reported in their Tables 1 and 2, I obtained their estimates. Of six MPS values in their Tables 1 and 2, two were not the same as the MPS values required by their Equation 4. Their Table 1 reports MPS for both large and small vessels by category of successful set, but pooled over backdown or no backdown ($R_{\bullet 11 \bullet}$ and $R_{\bullet 21 \bullet}$, respectively), whereas Equation 4 requires the MPS for both large and small vessels by category of successful set and by backdown status ($R_{\bullet 111}$ and $R_{\bullet 211}$, respectively). I duplicated the results of Lo and Smith (1986) exactly using $R_{\bullet 11 \bullet}$ and $R_{\bullet 21 \bullet}$ and conclude that they inadvertently used these values, versus $R_{\bullet 111}$ and $R_{\bullet 211}$ as they intended, because their equation is correct.[7] The estimates reported here (Table 4) were calculated by using Equation 4 and $R_{\bullet 111}$ and $R_{\bullet 211}$ of 29.9 and 65.8, respectively.

Lo and Smith (1986) did not prorate their estimates of total dolphin mortality to stocks. Using reported proportions from the 1971–72 MPS observer data, Smith (1983) prorated 0.70, 0.23, 0.03, and 0.04 of the total mortality to offshore spotted, eastern spinner, whitebelly spinner, and other dolphins, respectively. My results assign 0.694, 0.241, 0.034, and 0.029 of the mortality to the same categories.[8]

Annual estimates of incidental mortality of dolphins ranged from a low of 23,485 in 1959 to a high of 558,572 in 1961; CV's ranged from 0.13 to 0.48 (Table 4). Nearly 5 million dolphins were estimated to have been killed by the purse-seine fishery over the fourteen-year period considered here, an average of 347,082 per year. More northeastern spotted dolphins were killed than from any other stock; a total estimate for the period was 3.0 million (211,612 per year). Totals for other stocks were 0.4 million (29,361 per year) western/southern spotted dolphins, 1.3 million (91,739 per year) eastern spinner dolphins, 0.05 million whitebelly spinner dolphins, and 0.15 million dolphins from other species. CV's of the annual kill estimates ranged from 0.17 to 0.53 for the northeastern spotted, 0.19 to 0.54 for the western/southern spotted, 0.32 to 0.47 for the eastern spinner, 0.45 to 0.50 for the whitebelly spinner, and from 0.84 to 0.89 for other dolphins.

When I recalculated dolphin mortality using only MPS data from the 17 trips for 1971–72, total dolphin kill for 1959–72 was estimated to be 5.1 million. In all years except 1972 the estimates were slightly higher than those in Table 4 that were calculated by using all 20 1964–72 trips. The higher value in 1972 was due to a slightly higher value for the ratio of MPS without backdown to MPS with backdown (C in Eq. 3). Owing to the decrease in the

[7] Original records were not available to confirm which values were used (Lo, N. C. H., Southwest Fisheries Science Center, NMFS, La Jolla, CA, 92038, and T. D. Smith, Northeast Fisheries Science Center, NMFS, Woods Hole, MA, 02543. Pers. commun., 1993).

[8] Differences are likely due to round-off error. Additionally, they may be also due to revisions made to the NMFS observer database (Rasmussen, R. C., Southwest Fisheries Science Center, NMFS, La Jolla, 92038. Pers. commun., 1993).

Table 2

Average numbers of dolphins killed in purse-seine sets in the eastern tropical Pacific by trip, for the 20 observed trips between 1964 and 1972. n equals the total number of observed dolphin sets during the trip. Also given are the six mean mortality per sets ($R_{\bullet ijk}$) used in Equation 4, where i equals 1 for large vessels (>600 tons carrying capacity) and 2 for small vessels (≤600 tons carrying capacity), j equals 1 for successful set (≥1/4 ton yellowfin tuna) and 2 for unsuccessful set (≤1/4 ton yellowfin tuna), k equals 1 for when backdown was used and 2 for when backdown was not used, and where the subscript $\bullet$ indicates pooling across that variable. Sample sizes of number of observed sets in each stratum are in parentheses. The data used are from 1) Smith and Lo (1983) for the years 1964, 1965, and 1968, and 2) unpublished National Marine Fisheries Service tuna vessel observer data for the years 1971 and 1972.

Year	n	Successful set, backdown	Unsuccessful set, pooled	Successful set, no backdown
Small vessels				
1964	21	44.2 (16)	60.0 (1)	127.8 (4)
1965	19	48.0 (6)	2.6 (11)	24.0 (2)
1968	14	142.5 (11)	4.0 (2)	92.0 (1)
1971	11	89.1 (11)	.0 (0)	.0 (0)
1971	7	258.0 (3)	11.0 (2)	214.5 (2)
1971	3	33.0 (1)	16.0 (1)	.0 (1)
1972	24	57.9 (15)	0.0 (8)	1.0 (1)
1972	19	82.1 (15)	0.5 (4)	.0 (0)
1972	11	44.5 (11)	0.0 (0)	.0 (0)
1972	16	80.7 (14)	0.0 (1)	179.0 (1)
1972	23	45.8 (22)	0.0 (1)	.0 (0)
1972	23	23.6 (20)	28.5 (2)	7.0 (1)
Total	191	($R_{\bullet 211}$) 65.8 (145)	($R_{\bullet 22\bullet}$) 5.9 (33)	
Large vessels				
1971	14	49.2 (13)	0.0 (0)	14.0 (1)
1971	2	2.0 (2)	0.0 (0)	.0 (0)
1972	27	30.3 (24)	0.0 (1)	643.5 (2)
1972	36	25.7 (28)	0.0 (5)	16.0 (3)
1972	18	49.3 (17)	0.0 (1)	.0 (0)
1972	16	16.8 (15)	0.0 (0)	.0 (1)
1972	9	11.9 (8)	0.0 (1)	.0 (0)
1972	8	11.5 (4)	1.3 (4)	.0 (0)
Total	130	($R_{\bullet 111}$) 29.9 (111)	($R_{\bullet 12\bullet}$) 0.4 (12)	
Small and large vessels				
Total	321	($R_{\bullet\bullet 11}$) 50.3 (256)		($R_{\bullet\bullet 12}$) 130.8 (20)

quantity of data, the CV's using just 17 trips were somewhat higher.

The 1973 observer data include 668 observed dolphin sets from 25 trips. My calculations of MPS from those data resulted in values of 13.1, 7.9, 22.0, and 1.3 for the strata $R_{\bullet 211}$, $R_{\bullet 22\bullet}$, $R_{\bullet 111}$, and $R_{\bullet 12\bullet}$, respectively.

Discussion

Nearly all the mortality of spotted dolphins was observed in the northeastern stock (Table 4) because very few dolphin sets were located outside the northeastern area prior to 1969 (Punsley, 1983). The few sets that occurred outside this area prior to 1968 were sets that were not far offshore but were south of the southern boundary of the stock area at 5°N (Punsley, 1983). Consequently, there were few observations of MPS in western/southern area except in the area south of 5°N and north of the Galapagos (Fig. 1). Although this should have little effect on the estimates for the northeastern stock, estimates of mortality for the western/southern stock were not based on many actual observations of MPS of spotted dolphins in the western/southern area. There was complete knowledge of the number of dolphin sets within the western/southern area, but the estimates of mortality for that stock are based on the assumption that MPS was the same in both stock areas. Annual mortality estimates for the western/southern stock, though relatively small, may therefore be biased. In areas corresponding to the western/southern area, MPS rates were as much as 100% greater than those in the area corresponding to the northeastern area during 1973–76 and 1977–78; significant areal differences were found in 1977–78 (Wahlen, 1986). If similar differences in MPS by area existed during 1959–72, my estimates of mortality for western/southern spotted dolphins are negatively biased.

For the same reason, my mortality estimates for whitebelly spinner dolphins may also have a negative bias. Observations of MPS of whitebelly spinner dolphins came only from the region of overlap with eastern spinner dolphins; no observations of MPS were from the outside region west of 120°W where whitebelly spinner dolphins are known to occur and where significant fishing effort occurred in 1970, 1971, and 1972 (Punsley, 1983).

The three trips observed prior to 1971 were not part of an established data collection program and, therefore, may have been biased observations. In 1965 and 1968, two trips with tuna boats were observed by scientists, who collected dolphin specimens and also recorded MPS data (Smith and Lo, 1983). These data were not based on random samples, but there is no obvious reason why the data from tuna vessels on which scientists were allowed to collect specimens would tend to have different mortality rates. However, it is not certain a priori in which direction bias would have occurred. Data from the third

Table 3

Average numbers of dolphins killed (M) in purse seine sets in the eastern tropical Pacific by year for the 20 observed trips between 1964 and 1972, for small (≤600 tons carrying capacity) and large (>600 tons carrying capacity) vessels making successful (>1/4 ton yellowfin tuna) and unsuccessful (≤1/4 ton yellowfin tuna) sets on dolphin, pooled over whether the backdown dolphin release procedure was used or not. The number of observed sets (n) and the number of trips (n_{tr}) are given. Numbers of successful sets here are greater than yearly totals calculated from Table 2 because that table excludes sets for which the use or not of backdown was not recorded.

		Successful sets		Unsuccessful sets	
Vessels and year	n_{tr}	M	n	M	n
Small vessels					
1964	1	60.9	20	60.0	1
1965	1	25.9	35	2.6	11
1968	1	130.2	13	4.0	2
1971	3	116.6	19	12.7	3
1972	6	56.5	103	3.7	16
Total	12	62.4	190	5.9	33
Large vessels					
1971	2	41.1	16	0.0	0
1972	6	36.9	117	0.4	12
Total	8	37.4	133	0.4	12

Table 4

Annual estimates of dolphins killed in the eastern tropical Pacific tuna purse-seine fishery, for each year between 1959 and 1972. Coefficients of variation are given in parentheses. The category of all dolphins is the sum of the four stock and other dolphins categories. Estimates were made using mortality-per-set data from 1964 to 1972 (20 trips). See text for scientific names.

Year	All dolphins	Northeastern offshore spotted	Western/southern offshore spotted	Eastern spinner	Whitebelly spinner	All other dolphins
1959	23485 (0.476)	15928 (0.534)	377 (0.540)	6452 (0.472)	0 (0.000)	728 (0.853)
1960	503879 (0.464)	343955 (0.522)	5880 (0.519)	138426 (0.465)	0 (0.000)	15619 (0.842)
1961	558572 (0.421)	365988 (0.476)	21819 (0.478)	153451 (0.433)	0 (0.000)	17314 (0.839)
1962	226396 (0.371)	140952 (0.423)	16231 (0.431)	62196 (0.401)	0 (0.000)	7018 (0.841)
1963	252607 (0.313)	158178 (0.362)	17202 (0.362)	69396 (0.369)	0 (0.000)	7830 (0.847)
1964	410195 (0.240)	272289 (0.282)	12502 (0.282)	112689 (0.338)	0 (0.000)	12715 (0.867)
1965	482331 (0.244)	318528 (0.286)	16346 (0.281)	132506 (0.341)	0 (0.000)	14951 (0.863)
1966	392441 (0.192)	244123 (0.224)	28342 (0.224)	107812 (0.331)	0 (0.000)	12165 (0.893)
1967	262947 (0.195)	171765 (0.227)	10794 (0.221)	72237 (0.333)	0 (0.000)	8151 (0.892)
1968	239051 (0.191)	161234 (0.224)	4735 (0.219)	65672 (0.328)	0 (0.000)	7410 (0.889)
1969	457903 (0.181)	271533 (0.221)	46381 (0.220)	110432 (0.348)	15363 (0.497)	14194 (0.875)
1970	433201 (0.172)	218702 (0.219)	82062 (0.220)	104475 (0.332)	14534 (0.487)	13428 (0.859)
1971	249373 (0.166)	111253 (0.216)	61882 (0.223)	60141 (0.321)	8367 (0.480)	7730 (0.851)
1972	366771 (0.129)	168136 (0.172)	86506 (0.189)	88454 (0.324)	12306 (0.450)	11369 (0.877)

fishing trip in 1964 were recorded and reported by a fisherman who may have reported his observation because of the magnitude of the kill, biasing those data (Smith and Lo, 1983). However, mean MPS's from these three trips were mostly within the range of values from the other observed trips in 1971–72 and therefore do not appear biased (Table 2).

Removing the data from the three trips observed prior to 1971 resulted in minimal changes to the mortality estimates. Annual mortality was higher in each year except 1972. This resulted in an estimate of total dolphin kill for 1959–72 of 5.1 million versus an estimate of 4.9 million when those trips were included. This confirms that my kill estimates were not significantly biased by the three pre-1971 observed trips.

Accepting the assumption of constant MPS rates during 1959–72 is crucial to the accuracy of these kill estimates. Available evidence is consistent with this assumption. For example, the three observed trips from 1964, 1965, and 1968 had MPS rates in the same range as the data collected in 1971–72. There are additional observations prior to 1971 that are also consistent with this assumption. For example, dolphins were noted as being killed in all 28 sets observed on a trip in 1966, but precise counts were made for only the five sets on which the greatest number of dolphins were killed (Smith and Lo, 1983). The average MPS for those five sets was 250.0; thus a minimum estimate of the average MPS for that trip is 45.5, if one assumes that only one dolphin was killed during each of the other 23 sets. Perrin (1969) reported a "rough count" of the total number killed on the trip as 2,000, resulting in an average MPS of 71.4. Most of those sets were known to be successful sets using backdown procedure, and values of 45.5 or 71.4 are within the range (44.2 to 142.5) reported for the small vessel stratum on the 1964–68 trips (Table 2). During the same period of 1964–68, another scientist reported observing two trips with similar MPS rates (Allen[9]). Therefore, there are apparently at least four other observed fishing trips from the 1960's with kill rates similar to those reported here. Finally, fishermen on the 1965 trip and the 1966 and 1968 trips reported to observing scientists that the MPS rates on those trips were the usual rates experienced by the crew of those vessels and others in the fleet at that time[10,11].

Perhaps the greatest uncertainty is due to the lack of MPS data prior to 1964. Historically, MPS rates have decreased in the U.S. fleet because of improvements in the equipment and in the skill and motivation of the fishermen. Use of the backdown procedure was developed on one boat in 1959–60, and its use spread quickly through the majority of the fleet only after 1961 (Barham et al., 1977). Because the procedure saved them time in retrieving the net (Barham et al., 1977), the fishermen likely improved their backdown performance during these first few years. Therefore, the average MPS during backdown sets prior to 1964 may have been higher than in later years. This is consistent with the observation that the proportion of dolphins killed in the net was high during these early years relative to later years (Joseph and Greenough, 1979). For this reason, any substantial bias in these kill estimates is likely a negative bias; the actual kill of dolphins may have been higher, particularly prior to 1964.

Passage of the Marine Mammal Protection Act in 1972 motivated fishermen to kill fewer dolphins, and I expected MPS to decline in 1973, which it did. My calculations of MPS in 1973 for $R_{\bullet 211}$, $R_{\bullet 22\bullet}$, $R_{\bullet 111}$, and $R_{\bullet 12\bullet}$ were 13.1, 7.9, 22.0, and 1.3, respectively, compared with analogous values of 65.8, 5.9, 29.9, and 0.4 in 1959–72 (Table 2). The only dramatically different value was that of the MPS for small vessels with successful set and with backdown procedure, which declined from a value of 65.8 to 13.1. The other values are fairly similar. Kill rates on small vessels prior to 1973 were apparently more than twice as high as those on large vessels. Therefore, it seems reasonable that the most dramatic improvement in MPS rates would have occurred in this category. One technological reason for a decline in kill rates at that time was the increasing use of the Medina panel, an area of finer mesh net in the backdown channel that helped prevent entanglement of dolphins. It was first used experimentally in 1971; by the end of 1972, 40–50% of the U.S. fleet were using it, and 60–70% were using it by the end of 1973 (Barham et al., 1977). In summary, although data available from 1959–72 are sparse, they are consistent with other information available from that period and 1973, which provides support for accepting the assumptions of this analysis and, therefore, accepting these estimates as being reasonably accurate.

Except for the years 1971 and 1972, the coefficients of variation (CV) for the total number of dolphins killed in each year were considerably higher than those reported by Lo and Smith (1986). Since the data in each case are the same, the differences must be due to the use of the bootstrap method versus the analytical equations used in Lo and Smith (1986). The differences in CV's were largest for years 1959–65. For example, they report a CV of 0.31 for 1960

[9] Allen, R., pers. commun., cited in Smith and Lo, 1983.

[10] 1965 trip, David W. Waller, Dept. of Biol. Sci., Kent State Univ., Kent, Ohio. Pers. commun., 1994.

[11] 1966 and 1968 trips, William F. Perrin, Southwest Fish. Sci. Cent., La Jolla, CA. Pers. commun., 1994.

versus my estimate of 0.46. My CV's from 1966 to 1972 (from 0.13 to 0.20) are in the same range as bootstrap CV's reported for 1979–87 (IATTC, 1989) for which there were larger sample sizes of observed sets. These data indicate that there was less variation in MPS between trips in the data set used here than was usual in succeeding years. This may have been an artifact of a relatively small sample size. Alternatively, as MPS declined after 1972, the variance in MPS may have actually increased. One possible explanation for increased variance may be that MPS declined for sets that went as planned but did not decline for high-mortality sets. This could lead to a decrease in average MPS and an increase in the variance.

As expected, CV's of the kill for each stock were higher than those for the total kill because they included additional uncertainty in species proportions. CV's for northeastern spotted dolphins were on average 0.05 more than CV's for total dolphin mortality. CV's were even greater for eastern spinner dolphins, averaging 0.10 more than for total dolphin mortality.

Variance estimates presented here are estimates of the precision given the assumptions of the analysis, such as constant MPS rates in 1959–72. They cannot provide a complete measure of uncertainty of how many dolphins were killed during this period, because some untestable assumptions were made which could lead to bias. However, this is always the case for statistical variance estimates, unless one can be assured that all assumptions have been met or unless one accepts subjective beliefs and incorporates them into a Bayesian statistical analysis (Press, 1989). For example, the assumed linear increase in the use of the backdown procedure between 1959 and 1964 (Lo and Smith, 1986) is probably open to question, but it is unlikely that there are data available to test these kinds of assumptions.

Although my estimates of the numbers of dolphins killed in the early years of the fishery come from a limited set of data on MPS and seem quite large, these estimates are consistent with statements from scientists involved in the fishery then (e.g. "in the early years of the fishery these incidental mortalities were very high," Joseph, 1994). Additionally, my estimates are reasonable when compared with estimates from later years that had substantially more data on MPS. Even after expected declines in MPS due to the passage of the MMPA in 1972 and the increased use of the Medina panel, Wahlen (1986) estimated a kill of 197,000 in 1973, a reduction of about one-third from the average kill of 308,072 per year in the two previous years (Table 4). As recently as 1986, the mortality of dolphin was estimated to be 133,174 (IATTC, 1989). Of those, 52,000 were estimated to be northeastern spotted dolphins, representing 7.1% of the population's estimated abundance in 1986–90 (Wade and Gerrodette, 1993), a level of mortality that is probably not sustainable.

Events in recent years have shown how quickly MPS can change. A variety of efforts to decrease MPS in the fishery (Joseph, 1994) have caused the total kill to decline dramatically to levels of 27,292 in 1991 (Hall and Lennert, 1993), 15,539 in 1992 (Hall and Lennert, 1994), and 3,601 in 1993 (Hall and Lennert, in press). The 1993 mortality of northeastern spotted dolphins was 1,139 or 0.16% of the 1986–90 abundance estimate, and all other stocks had even lower percent mortality levels. The low 1993 levels of mortality (if continued) should allow future growth and recovery of these populations, even if they are currently depleted.

Acknowledgments

I would like to thank the observers on the tuna vessels who collected the mortality-per-set data and Randall C. Rasmussen and Ken Wallace for helping to guide me through the NMFS tuna vessel observer databases. I would especially like to thank Michael G. Hinton for so efficiently providing the set effort data. This manuscript was improved considerably by comments from Robert Brownell, Tim Gerrodette, Michael G. Hinton, Keith Mullin, Joyce E. Sisson, and Steve Reilly. I thank them for their contribution and note that the author is solely responsible for the contents.

Literature cited

Au, D. W.
1991. Polyspecific nature of tuna schools: shark, dolphin, and seabird associates. Fish. Bull. 89:343–354.

Barham, E. G., W. K. Taguchi, and S. B. Reilly.
1977. Porpoise rescue methods in the yellowfin purse seine fishery and the importance of Medina panel mesh size. Mar. Fish. Rev. 39(5):1–10.

Dizon, A. E., W. F. Perrin, and P. A. Akin.
1994. Stocks of dolphins (*Stenella* spp. and *Delphinus delphis*) in the eastern tropical Pacific: a phylogeographic classification. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 119, 20 p.

Edwards, E. F.
1989. Using tuna-vessel observer data to detect trends in abundance of dolphin populations: history and research to date (1988). U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFC-122, 123 p.

Efron, B.
1982. The jackknife, the bootstrap, and other resampling methods. SIAM, monograph 38, CBMS-NSF, 92 p.

Hall, M. A., and C. Lennert.
1993. Estimates of incidental mortality in the eastern Pacific ocean tuna fishery in 1991. Rep. Int. Whal. Comm. 43:397–399.
1994. Incidental mortality of dolphins in the eastern Pacific ocean tuna fishery in 1992. Rep. Int. Whal. Comm. 44:349–351.
In press. Estimates of incidental mortality of dolphins in the eastern Pacific Ocean tuna fishery in 1993. Rep. Int. Whal. Comm. 45.

IATTC (Inter-American Tropical Tuna Commission).
1989. Annual Report, 1988. Inter-Am. Trop. Tuna Comm., Scripps Inst. of Ocean., La Jolla, 288 p.

Joseph, J.
1994. The tuna-dolphin controversy in the eastern Pacific Ocean: biological, economic, and political impacts. Ocean Development and International Law. 25:1–30.

Joseph, J., and J. W. Greenough.
1979. International management of tuna, porpoise, and billfish. Univ. Wash. Press, Seattle and London. 253 p.

Lo, N. C. H., and T. D. Smith.
1986. Incidental mortality of dolphins in the eastern tropical Pacific, 1959–72. Fish. Bull. 84:27–33.

Lo, N. C. H., J. E. Powers, and B. E. Wahlen.
1982. Estimating and monitoring incidental dolphin mortality in the eastern tropical Pacific tuna purse seine fishery. Fish. Bull. 80:396–401.

McNeely, R. L.
1961. Purse seine revolution in tuna fishing. Pacific Fisherman, June, p. 27–58.

Perrin, W. F.
1969. Using porpoise to catch tuna. World Fishing 18: 42–45.

Perrin, W. F., G. D. Schnell, D. J. Hough, J. W. Gilpatrick, and J. V. Kashiwada.
1994. Reexamination of geographical variation in cranial morphology of the pantropical spotted dolphin, *Stenella attenuata*, in the eastern Pacific. Fish. Bull. 92:324–346.

Press, S. J.
1989. Bayesian statistics: principles, models, and applications. John Wiley, NY, 237 p.

Punsley, R.
1983. Estimation of the number of purse-seiner sets on tuna associated with dolphins in the eastern Pacific Ocean during 1959–1980. Inter-Am. Trop. Tuna Comm. Bull. 18:229–299.

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

Smith, T. D., and N. C. H. Lo.
1983. Some data on dolphin mortality in eastern tropical Pacific tuna purse seine fishery prior to 1970. U.S. Dep. Commer. NOAA Tech. Memo. SWFC 34, 26 p.

Wade, P. R.
1993. Estimation of historical population size of the eastern spinner dolphin (*Stenella longirostris orientalis*). Fish. Bull. 91:775–787.

Wade, P. R., and T. Gerrodette.
1993. Estimates of cetacean abundance and distribution in the eastern tropical Pacific. Rep. Int. Whal. Comm. 43:477–493.

Wahlen, B. E.
1986. Incidental dolphin mortality in the eastern tropical Pacific tuna fishery, 1973 through 1978. Fish. Bull. 84:559–569.