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INCIDENTAL MORTALITY OF DOLPHINS IN THE EASTERN TROPICAL PACIFIC, 1959-72

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ABSTRACT

The estimates of the number of dolphins killed annually from the beginning of the U.S. tuna purse seine fishery in the eastern tropical Pacific are used by the National Marine Fisheries Service in developing management advice for the U.S. purse seine fleet. We estimated the annual number of dolphins killed incidentally in the tuna purse seine fishery for 1959-72. Kill data were available for only a few years prior to 1970. Because no obvious trend was shown with the existing data, kill rates were averaged over those years and stratified by various categories: large and small vessels, sets with large catch of tuna and small catch of tuna, sets which used backdown (a dolphin-releasing procedure), and sets which did not use backdown. These kill rates, combined with estimated number of sets, produced the estimated annual kills. Because data were available only for some of the years, they had to be pooled to obtain annual estimates. As a result, the annual estimates were highly correlated. Because the total as well as the annual estimates are of interest, it is necessary to compute the variance-covariance of the estimated annual kills. The annual kill from 1959 to 1972 varied from 55,000 in 1959 to 534,000 in 1961. There were three distinct maxima of 534,000, 460,000, and 467,000, corresponding to peaks in number of sets made on dolphins in 1961, 1965, and 1970. The total kill from 1959 to 1972 was estimated to be about 4.8 million, with a coefficient of variation of 17%.

The eastern tropical Pacific tuna purse seine fleet began to develop rapidly in the late 1950's and has grown to over 100 U.S.-registered vessels and a substantial number of non-U.S.-registered vessels in recent years. This fleet fishes primarily for yellowfin tuna, *Thunnus albacares*, and skipjack tuna, *Katsuwonus pelamis*. Majority of the yellowfin tuna are taken while the tunas are schooling with dolphins primarily of the species *Stenella attenuata* and *S. longirostris*. Birds and dolphins are frequently used as cues in finding the tuna. During the capture of the tuna, some of the dolphins are killed or drowned by becoming tangled in the net webbing (Perrin 1969). The number of dolphins killed has been estimated to have been greater than one-half million in some of the years in the 1960's (Smith 1983). Currently, fewer animals are killed each year due to improvements in the fishing gear and in procedures to release dolphins.

Estimates of the total number of dolphins killed each year in this fishery are used as a basis for management advice by the National Marine Fisheries Service (NMFS). In this paper we describe in detail the method used in Smith (1983), including estimation of the variances and covariances of the annual kill estimates so that the variance of the total kill for the period can be estimated. Additionally, we reexamine the data used in previous estimates (Perrin 1970; Perrin and Zweifel 1971[3]; Perrin et al. 1982; Smith 1983; Smith and Lo 1983), and we present revised estimates of the total numbers of dolphins killed.

MATERIALS AND METHODS

The model used to estimate the total annual incidental kill of dolphins (T_t) in the eastern tropical Pacific tuna purse seine fishery is

$$\hat{T}_t = \hat{R}_t \hat{X}_t \qquad (1)$$

where t denotes the year (1959 to 1972), R denotes the number of dolphins killed per set, and X denotes the number of sets made involving dolphins. The rate of kill (R) varies between larger and smaller vessels, and in dolphin sets where fewer and greater amounts of yellowfin tuna are caught (Lo et al. 1982). In addition, the rate of dolphin kills is generally less if

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[3]Perrin, W. F., and J. R. Zweifel. 1971. Porpoise mortality in the eastern tropical tuna fishery in 1971. Unpubl. manuscr., 22 p. Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service, NOAA, 8604 La Jolla Shores Drive, La Jolla, CA 92038.

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backdown, a dolphin-release procedure, is used (Green et al. 1971; Barham et al. 1977; Smith and Lo 1983). To account for these factors affecting rates of dolphin kill, Equation (1) can be reexpressed with the rates and numbers of sets stratified by vessel tuna carrying capacity, catch of fish, and use of backdown procedure:

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

where t = year
i = 1 for vessel capacity >600 tons; 2 for vessel capacity ≤600 tons
j = 1 for yellowfin tuna catch ≥¼ ton; 2 for yellowfin tuna catch <¼ ton
k = 1 backdown is used; 2 backdown is not used.

Data on the number of dolphins killed during fishing trips in the period from 1964 to 1968 are given in Smith and Lo (1983). Similar but more extensive data (e.g., backdown information) are available in NMFS records for 1971 and 1972. Estimates on the number of sets involving dolphins from 1959 to 1972 are given by Punsley (1983). These data sources have certain limitations which do not allow for the use of the complete stratification scheme in Equation (2). Assumptions are made based on sample sizes and on apparent lack of changes in rates over time to accommodate these limitations.

The mean numbers of dolphins killed (kill-per-set) are shown in Table 1 for each year in which data are available, stratified by vessel size and by catch of fish (successful, ≥¼ ton of yellowfin tuna; unsuccessful, <¼ ton of yellowfin tuna). The definition of successful set follows that of Perrin and Zweifel (fn. 3). The vessel class stratification was based on the vessel's fish carrying capacity. The 1964-74 kill data indicate that kill-per-set was different for vessels with ≤600 tons carrying capacity and vessels with >600 tons for unsuccessful sets. For successful sets the optimal vessel class stratification was not clear; either 400, 600, or 800 tons can be used as division points for stratification. For consistency, we adopted the same stratification used for unsuccessful sets. (The results were similar with alternative stratification schemes.) Other factors such as the age of the vessel and the experience of the captain could affect kill rates but were not considered in the stratification because these factors could not be isolated for analysis.

The mean number of dolphins killed varied markedly over the years but without any obvious trends (Table 1). A two-way analysis of variance with the data pooled over years showed statistically significant differences in kill rates in sets made by small and large vessels ($P < 0.01$) and in successful and unsuccessful sets ($P < 0.01$). Thus Equation (2) was simplified by eliminating the time stratification for kill rates, whereas the vessel size and catch strata were retained.

Few observations are available for sets where backdown was not used. In successful sets, backdown was used more than 90% of the time; thus, we have observations on kill rates in only 20 sets where backdown was not used. Thirteen of these sets were made by large vessels and seven by small vessels, and the mean kill rates within vessel size class are highly variable and not significantly different. The overall ratio of the kill rates, pooled over vessel size, when backdown was not used and when it was used is significantly greater than unity, and the annual

TABLE 1.—Average numbers of dolphins killed (M) in purse seine sets in the eastern tropical Pacific by year, for small and large vessels making successful (>¼ ton tuna) and unsuccessful (≤¼ ton tuna) net sets. Standard deviation (SD), number of sets (N), and number of trips are given.

Vessels and year	Successful sets				Unsuccessful sets				Data source
	M	SD	N	No. of trips	M	SD	N	No. of trips	
Small vessels (≤600 tons carrying capacity)									
1964	60	47	20	1	60	—	1	1	Smith and Lo (1983)[1]
1965	26	28	35	1	3	8	11	1	Smith and Lo (1983)
1968	130	114	13	1	4	4	2	1	Smith and Lo (1983)
1971	117	180	19	3	13	10	3	2	Unpubl. NMFS
1972	57	110	103	6	4	10	16	5	Unpubl. NMFS
Total	62	108	190	12	6	13	33	10	
Large vessels (>600 tons carrying capacity)									
1971	41	56	16	2	—	—	—	0	Unpubl. NMFS
1972	37	123	117	6	0.4	1.4	12	5	Unpubl. NMFS
Total	37	119	133	8	0.4	1.4	12	5	

[1]From table 5 of Smith and Lo (1983), omitting incomplete data collected in 1966.

ratios vary without a consistent trend over time (Table 2).

In unsuccessful sets the use of the backdown procedure was more variable because the conditions of the set are more diverse. For example, only a few or no dolphins may be captured, and the net may not be retrieved in the usual manner. Because of this diversity and because so few observations are available, we consider one kill rate for all unsuccessful sets.

Reexpressing Equation (2) to account for a constant ratio of kill rates for successful sets when backdown was used and when it was not used, and for no difference in kill rates for unsuccessful sets, yields

$$\hat{T}_t = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} \hat{R}_{\bullet ijk}\hat{X}_{tijk}$$

$$= \sum_{i=1}^{2} \{\hat{R}_{\bullet i11}(\hat{X}_{ti11} + C\hat{X}_{ti12}) + \hat{R}_{\bullet i2\bullet}\hat{X}_{ti2\bullet}\} \quad (3)$$

where $C = R_{\bullet\bullet 12}/R_{\bullet\bullet 11}$ and the subscript $\bullet$ is used when that stratifying variable is not considered. For example, $R_{\bullet ijk}$ is the kill-per-set not stratified by year t, and $X_{ti2\bullet}$ is the total number of sets not stratified by use of backdown.

Estimates of the total number of sets involving dolphins from 1959 to 1972, with approximate variances, are given by Punsly (1983). He also gives partial estimates of the numbers of successful and unsuccessful sets, but does not provide estimates of the numbers of sets by vessel size. Punsly's data did not indicate the use of the backdown procedure.

The coefficients of variation (CV) of Punsly's estimates are ≤1% in all years except 1959 and 1960, when it was 8%. The percentage of unidentified sets in 1959-61 was higher than subsequent years because set type was not recorded systematically (Hammond[4]). We assume these estimates are in fact constants, because in most years, and in the absence of additional information in 1959-61, the CVs are small compared with the CVs of the kill rates (0.13-1.0, Table 1).

By applying the proportions of successful and unsuccessful dolphin sets from Punsly's partial estimates to his totals, we obtained numbers of successful and unsuccessful dolphin sets. We further prorate these estimated numbers of successful and unsuccessful sets to large and small vessels by multiplying by the estimates of proportions from NMFS (Anonymous 1976[5]) of sets made by vessels of each size class (Table 3). The slight differences between the totals for each year given by Punsly are due to rounding.

The number of sets during which backdown was used can be estimated from the estimated total number of sets involving dolphins (Table 3) and the observed proportion of successful sets in which backdown was used (Table 2). The observed proportions increase from 0.79 in 1964-65 to almost unity (0.96) by 1972. The backdown procedure was reportedly

[4]P. S. Hammond, Sea Mammal Research Unit, British Antarctic Survey, Cambridge, England, pers. commun. 1983.

[5]Anonymous. 1976. Report of the workshop on stock assessment of porpoises involved in the eastern Pacific yellowfin tuna fishery (La Jolla, July 27-31, 1976). Southwest Fish. Cent., Admin. Rep. LJ-76-29, 54 p. + app.

TABLE 2.—Mean number of dolphins killed ($\hat{R}$) during purse seine sets in the eastern tropical Pacific Ocean when the backdown dolphin-release procedure was and was not used. Also given are the ratio of numbers killed with and without backdown ($\hat{C}$), the proportion of successful sets where backdown was used ($\hat{P}$), the number of sets (N), number of trips, and standard error in parentheses.

	Backdown used							
	Yes			No				
Year	$\hat{R}_{t\bullet 11}$	N	No. of trips	$\hat{R}_{t\bullet 12}$	N	No. of trips	$\hat{C}$	$\hat{P}$
1964[1]	44	16	1	128	4	1	3.0	0.79
1965[1]	48	6	1	24	2	1	0.50	
1966[1,2]	—	17	1	—	2	1	—	0.89
1968[1]	142	11	1	92	1	1	0.65	
1971[3]	81	30	5	111	4	3	1.40	
1972[3]	41	193	12	169	9	6	4.10	0.96
Total	50	256	21	131	20	12	2.62 [4](0.80)	0.93

[1]From Smith and Lo (1983).
[2]Kill rates for 1966 omitted because incomplete data were collected.
[3]NMFS records.
[4]$SE(\hat{C}) = \hat{C}\,[CV^2(\hat{R}_{\bullet\bullet 12}) + CV^2(\hat{R}_{\bullet\bullet 11}) - 2\,cor(\hat{R}_{\bullet\bullet 12}, \hat{R}_{\bullet\bullet 11})]^{1/2}$; where $\hat{C} = \hat{R}_{\bullet\bullet 12}/\hat{R}_{\bullet\bullet 11}$.

TABLE 3.—Numbers of purse seine sets involving dolphins in the eastern Pacific Ocean, from 1959 to 1972, for small (≤600 tons) and large (>600 tons) vessels, and for successful (>¼ tons tuna) and unsuccessful (≤¼ tons) sets, modified from Punsly (1983).

	Successful sets		Unsuccessful sets	
Year	small ($X_{t21\bullet}$)	large ($X_{t11\bullet}$)	small ($X_{t22\bullet}$)	large ($X_{t12\bullet}$)
1959	326	0	265	0
1960	3,170	0	2,303	0
1961	3,888	32	3,928	0
1962	1,773	5	1,942	19
1963	2,291	10	2,092	23
1964	4,444	45	3,089	64
1965	5,346	27	2,418	29
1966	4,948	44	1,835	25
1967	3,363	2	841	3
1968	2,956	175	982	41
1969	5,365	1,401	1,402	192
1970	4,936	2,313	957	412
1971	1,871	2,602	652	409
1972	2,704	4,982	855	846

developed on one vessel in 1959-60 (Barham et al. 1977) and used by at least three vessels in 1961 (Anonymous 1962). If 79% of the sets in 1964-65 were made using this procedure, as suggested by the very limited available data, a rather rapid increase in usage must have occurred in 1962 and 1963. This is possible because, if properly used, the procedure reduces the amount of handling time of dead dolphins, thus speeding up the fishing operation. As an approximation, we assume that usage increased from 0 to 0.79 linearly from 1959 to 1964-65, and was 0.89 for 1966-71 and 0.96 for 1972.

Denoting the interpolated and extrapolated estimates of the proportion of successful sets using the backdown dolphin release procedure by P_t gives

$$\hat{X}_{ti11} = \hat{P}_t \hat{X}_{ti1\bullet}$$

$$\hat{X}_{ti12} = (1 - \hat{P}_t)\, \hat{X}_{ti1\bullet}.$$

Substituting these relationships into Equation (3), with the assumption that the estimated numbers of sets given by Punsley (1983) are constants, the following equations result when the terms are rearranged:

$$\hat{T}_t = \sum_i \{\hat{R}_{\bullet i11}[X_{ti1\bullet}\hat{P}_t + C(1 - \hat{P}_t)X_{ti1\bullet}] + R_{\bullet i2\bullet}X_{ti2\bullet}\}$$

$$= \sum_i \{\hat{R}_{\bullet i11}X_{ti1\bullet}[\hat{P}_t + C(1 - \hat{P}_t)] + \hat{R}_{\bullet i2\bullet}\, X_{ti2\bullet}\}. \quad (4)$$

The time series of estimated annual kill ($\hat{T}_t$) from 1959 to 1972 was obtained by pooling the available data over years and strata, resulting in estimates that are not statistically independent. Thus in order to estimate the variance of the total kill of dolphins for the period in addition to the variances it is necessary to determine the covariances among the annual estimates.

We denote the estimates of the total kill of dolphins ($\hat{T}_t$) for each year from 1959 to 1972 by the vector $\hat{T}$, and denote the estimates of the variances of the elements of $\hat{T}$ by the symmetric matrix $\Sigma_{\hat{T}}$. The estimate of the kill in each year (Equation (4)) can be expressed in matrix form as the product of a vector of the numbers of sets in each of the four combinations of the vessel size and fishing success classifications (X_t), and a vector of the four corresponding kill rates (Q_t). Each element of $\hat{T}$ then can be expressed as a matrix product

$$\hat{T}_t = X'_t\, \hat{Q}_t \quad (5)$$

where $X'_t = (X_{t11\bullet}, X_{t21\bullet}, X_{t12\bullet}, X_{t22\bullet})$

$$\hat{Q}_t = \begin{bmatrix} \hat{Q}_{t1} \\ \hat{Q}_{t2} \\ \hat{Q}_{t3} \\ \hat{Q}_{t4} \end{bmatrix} = \begin{bmatrix} \hat{R}_{\bullet 111}[\hat{P}_t(1 - \hat{C}) + \hat{C}] \\ \hat{R}_{\bullet 211}[\hat{P}_t(1 - \hat{C}) + \hat{C}] \\ \hat{R}_{\bullet 12\bullet} \\ \hat{R}_{\bullet 22\bullet} \end{bmatrix} = \begin{bmatrix} \hat{R}_{\bullet 111} f_t \\ \hat{R}_{\bullet 211} f_t \\ \hat{R}_{\bullet 12\bullet} \\ \hat{R}_{\bullet 22\bullet} \end{bmatrix} \text{ and } f_t = \hat{P}_t(1 - \hat{C}) + \hat{C}.$$

Then the variance-covariance matrix of $\hat{T}$ is

$$\Sigma_{\hat{T}} = \begin{bmatrix} V(\hat{T}_{59}) & & & \\ Cov(\hat{T}_{59}, \hat{T}_{60}) & V(\hat{T}_{60}) & & \\ \cdot & \cdot & & \\ \cdot & \cdot & & \\ \cdot & \cdot & & \\ Cov(\hat{T}_{59}, \hat{T}_{72}) & Cov(\hat{T}_{60}, \hat{T}_{72}) & \ldots & V(\hat{T}_{72}) \end{bmatrix}$$

$$= \begin{bmatrix} V(X'_{59}\, Q_{59}) & & & \\ Cov(X'_{59}\, Q_{59}, X'_{60}\, Q_{60}) & V(X'_{60}\, Q_{60}) & & \\ \cdot & \cdot & & \\ \cdot & \cdot & & \\ \cdot & \cdot & & \\ Cov(X'_{59}\, Q_{59}, X'_{72}\, Q_{72}) & Cov(X'_{60}\, Q_{60}, X'_{72}\, Q_{72}) & \ldots & V(X'_{72}\, Q_{72}) \end{bmatrix}$$

with $V(\hat{T}_t) = X'_t\, \Sigma_{\hat{Q}_t} X_t$
as the diagonal elements of $\Sigma_{\hat{T}}$ (6)

$$\text{where } \Sigma_{\hat{Q}_t} = \begin{bmatrix} V(\hat{R}_{\bullet 111} f_t) & Cov(\hat{R}_{\bullet 111} f_t, \hat{R}_{\bullet 211} f_t) & 0 & 0 \\ & V(\hat{R}_{\bullet 211} f_t) & 0 & 0 \\ & & V(\hat{R}_{\bullet 21 \bullet}) & 0 \\ & & & V(\hat{R}_{\bullet 22 \bullet}) \end{bmatrix} . \quad (7)$$

The diagonal elements of $\Sigma_{\hat{T}}$ can be computed by noting that $\hat{R}_{\bullet i2 \bullet}$ is uncorrelated with $\hat{R}_{\bullet i11}$, $\hat{P}_t$, or $\hat{C}$, and the covariance of $\hat{P}_t$ and $\hat{C}$ is zero because one C value is used for all years in 1959-72 and $\hat{P}_t$ can be different between years.

The off-diagonal elements of $\Sigma_{\hat{T}}$ are

$$Cov(\hat{T}_u, \hat{T}_m) = Cov(X'_u \hat{Q}_u, X'_m \hat{Q}_m) \quad (8)$$

$$= \sum_{i=1}^{4} \sum_{j=1}^{4} X_{ui}\, Cov(\hat{Q}_{ui}, \hat{Q}_{mj})\, X_{mj}.$$

Expressions for each of the terms in $\Sigma_{\hat{T}}$ are given in the Appendix.

RESULTS AND DISCUSSION

The estimates of the total number of dolphins killed incidentally in the tuna purse seine fishery from 1959 to 1972 (Table 4, from Equation (4)) vary from a low of 55,000 in 1959 to a high of 534,000 in 1961. Three distinct maxima of 534,000, 460,000, and 467,000 are apparent (Fig. 1), corresponding to peaks in numbers of sets made on dolphins in 1961, 1965, and 1970 (Table 3). A total of about 4.8 million dolphins is estimated to have been killed in the whole period (Table 4).

The CVs of the annual estimates decline rapidly

TABLE 4.—Estimated number of dolphins killed by year (Equation (4)), with standard errors (SE) and coefficient of variations (CV).

Year	Number killed	SE	CV
1959	55,000	18	0.32
1960	478,000	146	0.31
1961	534,000	149	0.28
1962	216,000	54	0.25
1963	240,000	54	0.22
1964	390,000	77	0.20
1965	460,000	92	0.20
1966	374,000	58	0.15
1967	257,000	39	0.16
1968	229,000	35	0.15
1969	461,000	68	0.15
1970	467,000	70	0.15
1971	254,000	43	0.17
1972	380,000	61	0.16
1959-72	4,790,000	857	0.18

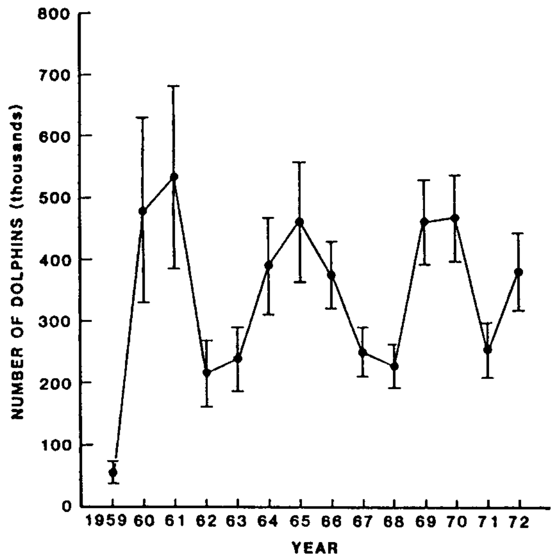

FIGURE 1.—Estimated numbers of dolphins killed in the eastern tropical Pacific tuna purse seine fishery from 1959 to 1972. Standard errors of the estimates shown as vertical bars. From Table 4.

from 32% in 1959 to 15% from 1966 to 1970, and then increase only slightly in 1971 and 1972. The covariances are large (upper triangular matrix, Table 5). They are all positives, and tend to be smaller for pairs of estimates widely spaced in time. The covariances can be examined more easily in terms of correlation coefficients (lower triangular matrix, Table 5). The correlations range from 0.31 to 0.99. The CV of the estimated total is 18%. This is substantially higher than the corresponding value of 6% obtained when the covariances are ignored. Because the total is the sum of 14 numbers, an approximate 95% confidence interval, obtained by adding and subtracting two standard errors, is 3.1-6.5 million dolphins.

The variation in the estimated numbers of dolphins killed over the period 1959-72 is due to several factors: 1) The number of sets made involving dolphins varied from year to year depending on the number of sets of tuna schooling in the absence of dolphins; such tuna are apparently preferred when available. 2) The use of the backdown dolphin-release procedure increased rapidly from 1959 to 1964. However, the development of the backdown dolphin-release procedure is not well known. The available data reflect the tendency of captains to use the technique once it was known. There is little information on how rapidly the procedure became known to other captains and no information on how rapidly they learned to use it effectively. Our assumption of a linear increase probably overestimates the use of backdown initially, but may or may not overestimate its subsequent use. 3) The proportion of successful sets made by small vessels increased from about 50% from 1959 to 1964, to >75% from 1965 to 1972 (Table 1). The higher dolphin kill rate for successful sets results in an increase in estimated dolphin kills as the proportion of successful sets increased. 4) The increase in the proportion of sets which were made by large vessels starting in 1968 results in a decrease in estimated dolphin kill rates due to the lower dolphin kill rate of these vessels.

Several factors which may have affected the numbers of dolphins killed in this period have not been accounted for because of the assumptions made by incomplete data. Chief among these assumptions were 1) the relatively small samples are representative of the fleet as a whole, 2) the kill rates on unsuccessful sets are not affected by the use of backdown, 3) the ratio of kill-per-set in successful sets without backdown to that with backdown is constant

TABLE 5.—Covariances (upper triangular matrix, $\times 10^{10}$) and correlation coefficients (lower triangular matrix) for the estimated total dolphins killed by year, from 1959 to 1972.

	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
1959		0.41	0.42	0.14	0.13	0.16	0.15	0.11	0.07	0.06	0.13	0.13	0.06	0.04
1960	0.99		3.49	1.24	1.15	1.37	1.32	0.92	0.62	0.56	1.10	1.08	0.54	0.40
1961	0.99	0.99		1.27	1.19	1.45	1.38	0.95	0.64	0.57	1.13	1.11	0.55	0.42
1962	0.97	0.98	0.99		0.44	0.55	0.52	0.34	0.23	0.21	0.41	0.40	0.19	0.15
1963	0.92	0.94	0.96	0.98		0.58	0.53	0.33	0.22	0.20	0.39	0.38	0.18	0.15
1964	0.76	0.79	0.83	0.88	0.95		0.75	0.43	0.29	0.26	0.50	0.49	0.23	0.20
1965	0.79	0.81	0.84	0.88	0.92	0.93		0.56	0.34	0.27	0.51	0.50	0.23	0.20
1966	0.65	0.66	0.67	0.67	0.67	0.62	0.86		0.30	0.21	0.39	0.38	0.17	0.16
1967	0.75	0.76	0.77	0.78	0.78	0.71	0.89	0.93		0.16	0.30	0.29	0.13	0.10
1968	0.74	0.75	0.76	0.77	0.76	0.70	0.77	0.69	0.90		0.31	0.30	0.14	0.10
1969	0.73	0.74	0.75	0.76	0.75	0.68	0.75	0.66	0.87	0.98		0.63	0.33	0.27
1970	0.71	0.72	0.73	0.73	0.72	0.65	0.70	0.62	0.83	0.94	0.98		0.36	0.38
1971	0.58	0.59	0.59	0.59	0.57	0.50	0.54	0.46	0.63	0.75	0.85	0.92		0.25
1972	0.34	0.35	0.36	0.36	0.36	0.34	0.37	0.34	0.39	0.43	0.55	0.65	0.83	

for both large and small vessels for all years, and 4) the kill rate itself for sets with backdown did not change over the years.

Although each of the unaccounted for factors could have an effect on the estimated numbers of dolphins killed, the magnitude of such effects is probably smaller than the magnitude of the effects of vessel size, set success, and use of backdown described in this study. For example, although the kill rate data available are few, there are some additional data which are not available to us, but which are reportedly similar (Smith and Lo 1983). The last three assumptions noted above deal with the dolphin kill rates with and without backdown, and would tend to both increase and decrease the estimates, if they could be taken into account.

Our estimates of the total number of dolphins killed (Table 4) are slightly lower than previous estimates made using the same method (Smith 1979[6], 1983). The previously estimated total number of dolphins killed from 1959 to 1972 was 5.1 million (total of Smith's [1983] table 4, divided by 0.96 for other species and by 1.048 for injured animals). The difference between the two estimates resulted from the revision of the estimated number of sets that capture tuna associated with dolphins (Punsly 1983) and of the numbers of dolphins killed per set (Smith and Lo 1983).

There are alternate approaches to estimating the numbers of dolphin killed. For example, estimates could be made from data on the numbers of fishing trips made (kill-per-trip), or the number of tons of tuna caught (kill-per-ton). These approaches make different assumptions about the fishing process (Lo et al. 1982; Hammond and Tsai 1983), and require data which are not as precise as are data on the total numbers of sets. For example, fishing trips are difficult to count consistently because they may not be completed within the calendar year and may be extended by partial unloading of the catch. There are fewer such problems with the data for kill-per-set estimators on the number of dolphins killed, and the problems that exist have already been resolved (Punsley 1983).

[6]Smith, T. D. (editor). 1979. Report of the Status of Porpoise Stocks Workshop, August 27-31, 1979, Southwest Fisheries Center, La Jolla, California. Southwest Fish. Cent., Admin. Rep. LJ-79-41, 120 p.

LITERATURE CITED

ANONYMOUS.
1962. How tuna seining paid off for the U.S. fleet in 1961. Fish Boat, Feb., p. 19-30.

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.

GREEN, R. E., W. F. PERRIN, AND B. P. PETRICH.
1971. The American tuna purse seine fishery. *In* Hilmar Kristjonsson (editor), Modern Fishing Gear of the World, Vol. 3, p. 182-194. Fish. News (Books) Ltd., Lond.

HAMMOND, P. S., AND K. T. TSAI.
1983. *Dolphin mortality incidental to purse-seining for tunas* in the eastern Pacific Ocean, 1979-81. Rep. Int. Whaling Comm. 33:589-597.

LO, N. C. H., J. POWERS, AND B. E. WAHLEN.
1982. Estimating and monitoring incidental dolphin mortality in the eastern tropical Pacific tuna purse seine fishery. Fish. Bull., U.S. 80:396-401.

PERRIN, W. F.
1969. Using porpoise to catch tuna. World Fishing 18(6): 42-45.
1969. The problem of porpoise mortality in the U.S. tropical tuna fishery. Proceedings of the 6th Annual Conference on Biology, Sonar, and Diving Mammals, p. 45-48. Stanford Research Institute.

PERRIN, W. F., T. D. SMITH, AND G. T. SAKAGAWA.
1982. Status of populations of spotted dolphin, *Stenella attenuata*, and spinner dolphin, *S. longirostris*, in the eastern tropical Pacific. *In* FAO, Mammals in the seas, Vol. IV. Small cetaceans, seals, sirenians, and otters, p. 67-83.

PUNSLY, R. G.
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., U.S. 81:1-14.

SMITH, T. D., AND N. C. H. LO.
1983. Some data on dolphin mortality in the eastern tropical Pacific tuna purse seine fishery prior to 1970. U.S. Dep. Commer., NOAA Tech. Memo. SWFC-TM-NMFS-34, 26 p.

APPENDIX

In Equation (7), the first and second terms on the main diagonal are

$$V(\hat{R}_{\bullet i11} f_t) = V(\hat{R}_{\bullet i11})V(f_t) + \hat{R}^2_{\bullet i11} V(f_t) + f_t^2 V(\hat{R}_{\bullet i11}) \quad \text{(A-1)}$$

for $i = 1$ and 2, noting that $\mathrm{Cov}(\hat{R}_{\bullet i11} f_t) = 0$.
The variance of f_t is given by

$$\begin{aligned} V(f_t) = {} & V(\hat{P}_t)(1 + V(\hat{C})) + \hat{P}_t^2 V(\hat{C}) \\ & + \hat{C}^2 V(\hat{P}_t) + V(\hat{C}) - 2V(\hat{P}_t)\hat{C} \\ & - 2V(\hat{C})\hat{P}_t^2 + 2\,\mathrm{Cov}(\hat{P}_t, \hat{C}). \end{aligned} \quad \text{(A-2)}$$

This last term is assumed to be zero, as noted above. The off-diagonal element in Equation (7) is

$$\mathrm{Cov}(\hat{R}_{\bullet i11} f_t, \hat{R}_{\bullet j11} f_t) \approx \hat{R}_{\bullet i11} \hat{R}_{\bullet j11} V(f_t) \quad \text{(A-3)}$$

for $i \neq j = 1$ and 2.

In Equation (8), based upon Equation (5)

$$\mathrm{Cov}(\hat{Q}_{ui}, \hat{Q}_{mj}) = \begin{cases} \mathrm{Cov}(\hat{R}_{\bullet i11} f_u, \hat{R}_{\bullet j11} f_m) & \text{for } i = 1,2 \\ & \text{and } j = 1,2 \\ 0 \qquad\qquad i \neq j & \text{for } i = 3,4 \\ V(\hat{R}_{\bullet i2\bullet}) \qquad i = j & \text{and } j = 3,4 \end{cases}$$

where $\mathrm{Cov}(\hat{R}_{\bullet i11} f_u, \hat{R}_{\bullet j11} f_m)$ (A-4)

$$= \begin{cases} [\hat{R}^2_{\bullet i11} + V(\hat{R}_{\bullet j11})]\mathrm{Cov}(f_u, f_m) + f_u f_m V(\hat{R}_{\bullet i11}) & i = j \\ \hat{R}_{\bullet i11}\hat{R}_{\bullet j11}\,\mathrm{Cov}(f_u, f_m) & i \neq j \end{cases}$$

assuming $\mathrm{Cov}(\hat{R}_{\bullet i11}, \hat{R}_{\bullet j11}) = 0$
and $\mathrm{Cov}(f_u, f_m) \approx \mathrm{Cov}(\hat{P}_u, \hat{P}_m)\,[V(\hat{C}) + \hat{C}^2] + V(\hat{C}) \bullet [1 + \hat{P}_u \hat{P}_m - \hat{P}_u - \hat{P}_m]$. (A-5)