INCIDENTAL DOLPHIN MORTALITY IN THE EASTERN TROPICAL PACIFIC TUNA FISHERY, 1973 THROUGH 1978

BRUCE E. WAHLEN[1]

ABSTRACT

Since the late 1950's, large numbers of dolphins have been killed incidentally in the yellowfin tuna purse seine fishery in the eastern tropical Pacific. Estimates of numbers of dolphins killed incidentally in this fishery from 1973 through 1978 were made previously using a stratified ratio estimator. Previous estimates were revised by reducing the number of strata and incorporating revisions in the data. Revised estimates of total mortality, which are consistently more precise than previous estimates, declined from about 100,000 dolphins per year from 1973 through 1976 to about 25,000 and 15,000 during 1977 and 1978. The decline in estimated mortality between 1976 and 1977 was primarily the result of a decline in the kill rate which coincided with a significant management action in late 1976. Other examples during the 1964 through 1982 period of such a temporal correspondence between a change in the number or distribution of dolphins killed and legal or management actions are discussed.

Since the late 1950's, tuna purse seine fishermen operating in the eastern tropical Pacific Ocean (ETP) have exploited several dolphin species—primarily spotted dolphins, *Stenella attenuata*, and spinner dolphins, *S. longirostris*, and also striped dolphins, *S. coeruleoalba*, and common dolphins, *Delphinus delphis*—to locate and catch yellowfin tuna, *Thunnus albacares*. Perrin (1969) described the process of deploying, or setting, the net around the tuna and dolphins, and then releasing the dolphins while retaining the tuna. During this process, however, large numbers of dolphins have been killed incidentally by becoming entangled in the purse seines (Smith 1983).

The U.S. Marine Mammal Protection Act of 1972 mandated the Secretary of Commerce to make periodic assessments of the condition of dolphin populations involved in this ETP fishery. As a result of a 1976 ruling by a U.S. District Court regarding regulations promulgated under the Act, the Federal Government established annual dolphin mortality limits for the U.S. registered fleet (Fox 1978). Estimates of annual dolphin mortality have been an integral component of periodic assessments (Smith 1983).

Estimates of cumulative dolphin mortality made throughout the year are used to monitor mortalities relative to the annual limits (Lo et al. 1982). When a particular limit is reached, regulations prohibit U.S. registered vessels from fishing on the affected populations for the remainder of the year. In October 1976, the National Marine Fisheries Service (NMFS) issued a prohibition notice for the first time (Federal Register 1976), but because of litigation the notice did not become effective until November 1976.

In recent years, researchers have published several estimates and revisions of estimates of dolphin mortality incidental to this fishery. For the period 1959-78, estimates have been made by Smith (1979[2]), Lo et al. (1982), Smith (1983), and Lo and Smith (1986); for the years 1979-83, see Allen and Goldsmith (1981, 1982), Lo et al. (1982), Hammond and Tsai (1983), Hammond (1984), and Hammond and Hall (1985).

Lo et al. (1982) suggested that previous estimates of dolphin mortality incidental to this fishery were based on a stratification scheme with an unnecessarily large number of strata. In this paper, I revise the 1973-78 estimates for U.S. registered purse seiners by reducing the number of strata and by incorporating revisions in the data.

DATA

Sample data were obtained from recorded observations of scientific observers who had been placed by the NMFS aboard selected U.S. registered tuna purse seine vessels fishing in the ETP. Data recorded by these observers included the type, date,

[1]Southwest Fisheries Center La Jolla Laboratory, National Marine Fisheries Service, P.O. Box 271, La Jolla, CA 92038.

[2]Smith, T. D. (editor). 1979. Report of the status of porpoise stocks workshop, La Jolla, Calif., 27-31 August 1979. Southwest Fish. Cent. La Jolla Lab., Natl. Mar. Fish. Serv., NOAA, Admin. Rep. LJ-79-41, 120 p.

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location, and estimated tuna catch of each set, and other information describing the fishing operation. For sets involving dolphins (dolphin sets), the observers collected additional data, including the number of dolphins killed by species.

In 1973, all sampled trips were arranged with vessel captains under a voluntary sampling program. Beginning in 1974, trips to be sampled were determined from a randomly ordered list of vessels. Which trips were actually sampled during 1974 and 1975 depended on several factors, including the cooperation of the captains. Because of uncertainties about the cooperation of the captains and the number of fishing trips that would be made in a year, observers were placed on vessels as soon as possible. Thus, before 1976, the planned number of sampled trips was frequently obtained in the first half of the year. The sampling process became more random starting in 1976, when participation in the sampling program became mandatory for captains making sets on dolphins.

I extracted independent information for the population of all fishing trips by U.S. registered tuna purse seiners in the ETP from the Inter-American Tropical Tuna Commission (IATTC) logbook data base. This data base contains abstracts of vessels' logbooks obtained by IATTC personnel. An individual entry in the logbook data base provides information about one or more sets, including number of sets, set type, date and location, estimated tuna catch by species, but not numbers of dolphins killed.

The logbook data are incomplete in that number of sets may be missing, set type may not be recorded, and information for some sets of a trip and for all sets of some trips may be omitted (Punsly 1983). To compensate for these omissions from the logbook data, Punsly (1983) estimated the total number of dolphin sets made by all U.S. and non-U.S. seiners in the ETP. He then modified this procedure to estimate the total number of dolphin sets made by U.S. seiners only (Table 1).

METHODS

I stratified the data to allow for potential differences in dolphin kills. If kills do indeed differ among strata, then a stratified estimator may be superior to an unstratified estimator in two respects. First, a stratified estimator will have a smaller standard error and thus be more precise. Second, if the sample data are unrepresentative of the population with respect to these strata, a stratified estimator will be less biased.

Therefore, estimates of incidental dolphin mortality by species or species grouping were computed using a stratified kill-per-set ratio estimator, following the general approach described by Lo et al. (1982). I excluded trips which made no dolphin sets and experimental-gear trips from the sample and the population. However, I added dolphin kills incidental to the experimental-gear trips as constants to the mortality estimates.

I stratified the dolphin set data by four factors used in previously published estimates: 1) year of the set, 2) fish-carrying capacity of the vessel, or simply vessel capacity, 3) period within year of the set, and 4) geographic location of the set. Vessel capacity was divided into two categories—small and large. The breakpoint between categories was determined by examining the cumulative distribution of sampled trips by capacity. Periods were defined to be quarters of the year, considering the results of Wahlen and Smith (1985). The ETP was divided into three geographic areas—North Inside, North Outside, and South (Fig. 1)—because mean kill (per set) after 1978 has been shown to differ among these areas.[3]

In previous estimates, the amount of tuna caught in the set was included as a stratification factor. However, Hammond and Tsai (1983) found that stratification by this factor made very little difference in their estimates. For that reason and to avoid possible overstratification, I omitted amount of tuna caught as a stratification factor.

I pooled dolphin set data over strata when it was determined that between-strata differences in mean kill were not statistically significant or that sample sizes were otherwise too small. I prorated the estimated numbers of dolphin sets made by U.S. seiners (Table 1) among the pooled strata according to pro-

[3]K.-T. Tsai, Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92093, pers. commun. December 1983.

TABLE 1.—Estimated number of dolphin sets made by U.S. purse seiners fishing in the eastern tropical Pacific, by year.[1]

Year	Number of dolphin sets
1973	8,341
1974	7,475
1975	7,902
1976	7,126
1977	7,239
1978	4,214

[1]Peterson, C. L. (editor). 1984. The quarterly report October-December 1983 of the Inter-American Tropical Tuna Commission. Inter-Am. Trop. Tuna Comm., c/o Scripps Inst. Oceanogr., La Jolla, CA 92093.

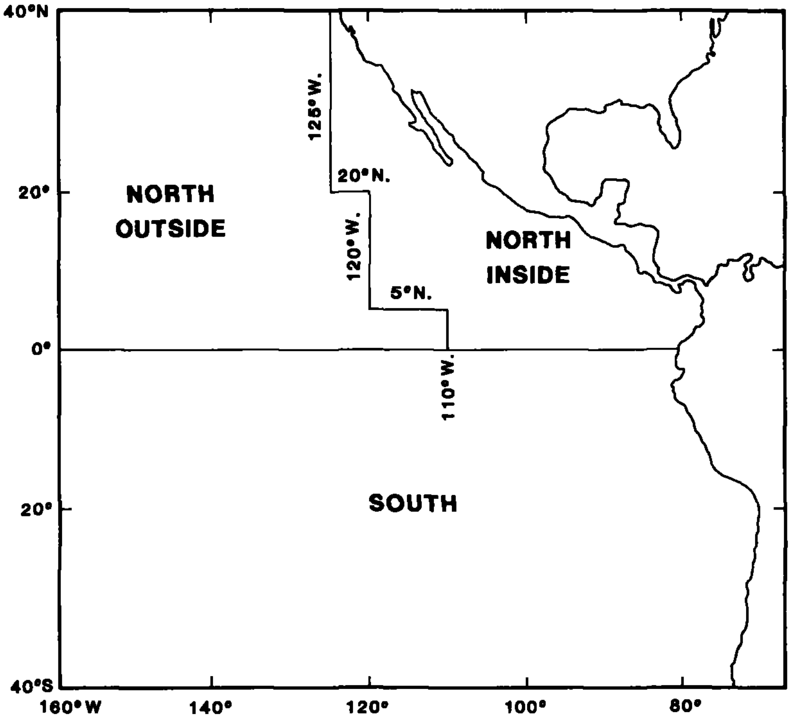

FIGURE 1.—The three areas of the eastern tropical Pacific used to stratify the data, bounded by lat. 40°N, long. 160°W, lat. 40°S, and the western coastline of the North and South American continents.

portions of known dolphin sets which were calculated from logbook data.

I tested for significant between-strata differences in mean total kill using analysis of variance (ANOVA) methods of BMDP programs P7D and P2V (Dixon 1983). Violation of the ANOVA assumption of equal cell variances may seriously distort significance probabilities in unbalanced models such as in this study (Glass et al. 1972). Because such distortion could be great, test results were considered to be inconclusive when significance probabilities were close to 0.05.

I was unable to test for the combined effect of all four stratification factors using the whole data set because data were sparse or unavailable in many of the 144 cells of the proposed four-factor stratification. Thus, ANOVA results for restricted subsets of the data containing adequate sample sizes were assumed to hold for subsets with inadequate sample sizes. To eliminate significant between-factor interactions, I tried logarithmic and power transformations of the dependent variable, total number of dolphins killed. When these transformations failed to eliminate the interactions, I partitioned the analysis into individual levels of the interacting variables.

When it was necessary to determine where the within-factor differences occurred, t-tests for differences between all pairs of cell means were made. Since I tested for differences between all pairs rather than between a few preselected pairs, a difference was considered significant if its significance probability was less than the quotient of 0.05 and the number of pairs. This Bonferroni adjustment to the significance level of each test assured a level of 0.05 simultaneously across all tests (Snedecor and Cochran 1980).

I computed t-values for pairwise differences using separate rather than pooled variance estimates because the cell variances were unequal according to Levene's test; this test was selected because it is more robust under nonnormality than either the common F-ratio or Bartlett's test (Brown and Forsythe 1974). Degrees of freedom were calculated with Satterthwaite's approximation, so that significance probabilities could be obtained from an ordinary t-distribution (Snedecor and Cochran 1980).

TABLE 2.—Cumulative distributions of number of sampled U.S. purse seine trips, by vessel capacity (tons) for the years 1973-78, with relative frequencies (percents) in parentheses.

Vessel capacity (tons)	Year					
	1973	1974	1975	1976	1977	1978
<200	0	0	0	0	0	0
	(0)	(0)	(0)	(0)	(0)	(0)
<300	0	1	1	0	0	0
	(0)	(3)	(3)	(0)	(0)	(0)
<400	1	3	2	3	0	0
	(4)	(8)	(7)	(7)	(0)	(0)
<600	5	9	5	11	15	8
	(22)	(24)	(17)	(24)	(15)	(8)
<800	15	15	8	20	34	27
	(65)	(41)	(28)	(43)	(35)	(26)
<1,000	16	20	16	24	39	33
	(70)	(54)	(55)	(52)	(40)	(32)
<1,200	20	30	26	34	70	67
	(87)	(81)	(90)	(74)	(71)	(66)
Total	23	37	29	46	98	102
	(100)	(100)	(100)	(100)	(100)	(100)

RESULTS

Setting the breakpoint between small and large vessel capacities at 600 tons (or lower) or at 1,200 tons would, in each case, create small and large vessel categories with severely unbalanced sample sizes (Table 2). The percent of sampled vessels with capacity <1,000 tons was more stable over years than the percent of sampled vessels <800 tons, especially from 1973 through 1976. Therefore, the breakpoint between vessel categories was set at 1,000 tons.

Because of data sparseness, particularly in the North Outside and South areas (Table 3), I made three multiway ANOVA tests restricted to subsets of the whole data set: 1) two-way test of year and vessel capacity, restricted to the North Inside area and the second quarter, 2) three-way test of year, quarter, and vessel capacity, restricted to the North Inside area and the first two quarters during 1973 through 1976, and 3) four-way test, restricted to the North Inside and North Outside areas, and the

TABLE 3.—Number of dolphin sets made during sampled trips, by year, vessel capacity (tons), quarter of the year, and area.

Year	Vessel capacity (tons)	Quarter	Area			Total
			North Inside	North Outside	South	
1973	<1,000	1	325	0	9	334
		2	167	47	0	214
		3	0	0	0	0
		4	0	0	0	0
		Total	492	47	9	548
	≥1,000	1	116	0	5	121
		2	43	2	0	45
		3	0	0	0	0
		4	0	0	0	0
		Total	159	2	5	166
1974	<1,000	1	459	0	0	459
		2	88	0	0	88
		3	0	6	0	6
		4	0	0	0	0
		Total	547	6	0	553
	≥1,000	1	362	0	0	362
		2	57	0	0	57
		3	31	12	0	43
		4	0	0	0	0
		Total	450	12	0	462
1975	<1,000	1	404	0	3	407
		2	106	0	4	110
		3	0	0	0	0
		4	0	0	0	0
		Total	510	0	7	517
	≥1,000	1	268	0	0	268
		2	111	0	5	116
		3	47	0	0	47
		4	0	0	0	0
		Total	426	0	5	431
1976	<1,000	1	155	0	0	155
		2	41	27	0	68
		3	18	71	0	89
		4	20	13	4	37
		Total	234	111	4	349
	≥1,000	1	129	0	118	247
		2	42	0	0	42
		3	17	80	1	98
		4	16	6	0	22
		Total	204	86	119	409
1977	<1,000	1	3	0	1	4
		2	239	67	0	306
		3	433	134	0	567
		4	53	0	0	53
		Total	728	201	1	930
	≥1,000	1	0	0	2	2
		2	563	86	16	665
		3	1,034	218	23	1,275
		4	356	30	31	417
		Total	1,953	334	72	2,359
1978	<1,000	1	170	0	13	183
		2	75	50	0	125
		3	86	138	0	224
		4	59	6	0	65
		Total	390	194	13	597
	≥1,000	1	320	0	52	372
		2	117	77	1	195
		3	104	255	2	361
		4	165	8	15	188
		Total	706	340	70	1,116
Total			6,799	1,333	305	8,437

second and third quarters during 1977 and 1978. Additionally, pairwise t-tests were made to isolate annual and quarter differences detected by the above tests.

Tests for Year Differences

Sample statistics of mean kill by year and vessel capacity (Test 1) revealed an unbalanced design and suggested that cell variances were related to cell means (Table 4). For each of several transformations of total kill, neither the interaction between vessel capacity and year nor the difference between vessel capacities was significant, but the difference among years was significant.

To determine where the yearly differences occurred, the data were pooled over vessel capacity so that t-tests for differences between each pair of yearly means could be made. The resulting one-way classification by year was unbalanced and characterized by significantly different cell variances ($P < 0.001$), and suggested that the means from 1973 through 1976 were larger than the means from 1977 and 1978 (Table 4).

Results from pairwise t-tests indicated that means were not significantly different within each of the two periods from 1973 through 1976 and from 1977 through 1978 (Table 5). However, each of the means from 1973 through 1976 was significantly different (or nearly so) from each of the means from 1977 and 1978 (Table 5). Based on these results, I divided the data into two periods, 1973 through 1976 and 1977 through 1978, for further tests within each period.

TABLE 4.—Mean of total number of dolphins killed ($\bar{k}$), standard deviation (s), and number of dolphin sets (d) for sampled trips, by year and vessel capacity (tons) for all sets made in the North Inside area during quarter two. Significance probabilities (P) obtained for 2-way ANOVA's on transformed values of total kill: interaction ($P \geq 0.1180$), year ($P < 0.001$), and vessel capacity ($P \geq 0.7851$).

Vessel capacity (tons)	Statistic	Year					
		1973	1974	1975	1976	1977	1978
<1,000	$\bar{k}$	8.62	6.20	16.33	8.58	3.08	2.35
	s	18.84	10.94	40.73	20.08	11.64	7.34
	d	167	88	106	41	239	75
≥1,000	$\bar{k}$	11.49	5.25	8.79	14.57	2.53	1.18
	s	25.96	14.08	17.43	32.44	7.84	3.31
	d	43	57	111	42	563	117
Pooled	$\bar{k}$	9.21	5.83	12.47	11.61	2.69	1.64
	s	20.46	12.23	31.23	27.05	9.13	5.28
	d	210	145	217	83	802	192

TABLE 5.—Matrix of significance probabilities associated with t-tests for differences between pairs of annual means of total number of dolphins killed. Significant values, required by the Bonferroni adjustment to be <0.0033, are indicated by "*", and nearly significant values are indicated by "+". Data are from sampled dolphin sets made during quarter two in the North Inside area.

Year	1974	1975	1976	1977	1978
1973	0.0526	0.2007	0.4659	0.0000*	0.0000*
1974		0.0050	0.0681	0.0037+	0.0002*
1975			0.8139	0.0000*	0.0000*
1976				0.0037+	0.0013*
1977					0.0344

Tests for Differences Within the 1973-76 Period

The three-way ANOVA table by year, quarter, and vessel capacity (Test 2) was unbalanced and suggested that cell variances were unequal (Table 6). Furthermore, no between-factor interactions were significant. The test for year differences was inconclusive; however, there is evidence for a year effect within only one cell (1976, quarter 1, small vessels), and there is no consistent yearly pattern of means within rows of the table. Therefore, I concluded that annual means during 1973-76 were not significantly different and, hence, I pooled over years within this period. I also pooled over vessel capacity since it was not a significant effect during these years.

Before 1976, sample data were unrepresentative of quarter and area, since nearly all data were obtained from trips made during the first half of the year and, thus, within the North Inside area. Data sparseness in the North Outside and South areas,

TABLE 6.—Mean of total number of dolphins killed ($\bar{k}$), standard deviation (s), and number of dolphin sets (d) for sampled trips, by year, quarter, and vessel capacity (tons) for all sets made in the North Inside area during the first two quarters of 1973-76. Significance probabilities (P) obtained for a 3-way ANOVA on total kill: interactions ($P \geq 0.1374$), year ($P = 0.0534$), quarter ($P = 0.0501$), and vessel capacity ($P = 0.8219$).

Vessel capacity (tons)	Quarter	Statistic	Year			
			1973	1974	1975	1976
<1,000	1	$\bar{k}$	23.15	14.10	16.45	3.47
		s	69.70	40.39	47.31	8.12
		d	325	459	404	155
	2	$\bar{k}$	8.62	6.20	16.33	8.59
		s	18.84	10.94	40.73	20.08
		d	167	88	106	41
≥1,000	1	$\bar{k}$	15.75	11.23	15.45	10.86
		s	27.64	24.85	34.37	24.35
		d	116	362	268	129
	2	$\bar{k}$	11.49	5.25	8.79	14.57
		s	25.95	14.08	17.43	32.44
		d	43	57	111	42

resulting from the unrepresentative areal sample, precluded testing for an area effect during the 1973-76 period (Table 3); however, after 1978 mean kills were shown to differ among the three areas, as noted earlier. Therefore, to minimize the amount of bias which might be introduced into the estimates from a sample which was unrepresentative of area, I retained the three-area stratification.

Small sample sizes during 1973-76 dictated pooling over all quarters within both the North Outside and South areas and over quarters 3 and 4 within the North Inside area (Table 3). The test result for quarter 1 and 2 differences in the North Inside area was inconclusive (Table 6). Based on bias considerations similar to those above, I did not pool data from quarters 1 and 2 in the North Inside area in case their means did indeed differ.

After pooling over year, vessel capacity, and quarter as indicated above, five strata remained for the 1973-76 data: 1) North Inside, quarter 1, 2) North Inside, quarter 2, 3) North Inside, quarters 3 and 4 pooled, 4) North Outside, all quarters pooled, and 5) South, all quarters pooled.

Tests for Differences Within the 1977-78 Period

Interpretation of the four-way ANOVA (Test 3), restricted by data sparseness to the North Inside and North Outside areas during the second and third quarters of 1977-78 (Table 3), was complicated by significant interaction between quarters and each of the other three factors ($P \leq 0.0159$, for total kill and all transformations of total kill). Therefore, the four-way table was partitioned into two, three-way tables, one for each level of quarter (Tables 7, 8), and decisions about between-strata differences during these years were based on results obtained separately for each quarter.

For second quarter data, interactions were not significant (Table 7). However, for third quarter data, interaction between year and vessel capacity was significant ($P < 0.001$) primarily because of the two large means recorded in the North Inside and North Outside areas by small vessels during 1978 (Table 8). Omitting the data from one extraordinarily large kill set in each of these two cells reduces their means from 11.27 to 4.68 for the North Inside and from 9.77 to 5.46 for the North Outside.

Results from the second and third quarter data were inconsistent for both year and vessel capacity. Neither effect was significant during the second quarter (Table 7), but during the third quarter (Table 8) the large means in the two cells noted above provided some evidence of both a year and vessel capacity effect. Since the evidence for both a year and vessel capacity effect was confined to two, third quarter cells whose means were each strongly influenced by only one set, I concluded that year and vessel capacity were not significant effects during 1977-78. Hence, I pooled over year and vessel capacity within this period. The evidence regarding an area effect during 1977-78 was also inconsistent between quarters (Tables 7, 8); however, I retained area as a stratification factor since it was shown to be significant after 1978.

Beginning in 1976 when the sampling program became mandatory the sample data became more representative of quarter. Thus, for the 1977-78 data, bias considerations were of lesser importance

TABLE 7.—Mean of total number of dolphins killed ($\bar{k}$), standard deviation (s), and number of dolphin sets (d) for sampled trips, by area, vessel capacity (tons), and year for all sets made in the North Inside and North Outside areas during quarter two of 1977-78. Significance probabilities (P) obtained for a 3-way ANOVA on total kill: interactions ($P \geq 0.2095$), area ($P = 0.0060$), vessel capacity ($P = 0.8857$), and year ($P = 0.6050$).

Year	Vessel capacity (tons)	Statistic	Area: North Inside	Area: North Outside
1977	<1,000	$\bar{k}$	3.08	2.94
		s	11.64	8.68
		d	239	67
	≥1,000	$\bar{k}$	2.53	5.66
		s	7.84	13.82
		d	563	86
1978	<1,000	$\bar{k}$	2.35	4.82
		s	7.34	16.00
		d	75	50
	≥1,000	$\bar{k}$	1.18	4.26
		s	3.31	21.19
		d	117	77

TABLE 8.—Mean of total number of dolphins killed ($\bar{k}$), standard deviation (s), and number of dolphin sets (d) for sampled trips, by area, vessel capacity (tons), and year for all sets made in the North Inside and North Outside areas during quarter three of 1977-78.

Year	Vessel capacity (tons)	Statistic	Area: North Inside	Area: North Outside
1977	<1,000	$\bar{k}$	2.08	2.33
		s	5.72	7.92
		d	433	134
	≥1,000	$\bar{k}$	2.85	2.89
		s	9.81	6.45
		d	1034	218
1978	<1,000	$\bar{k}$	11.27	9.77
		s	61.74	52.52
		d	86	138
	≥1,000	$\bar{k}$	2.00	2.81
		s	4.34	10.97
		d	104	255

in stratification decisions than for the 1973-76 data. The four-way test on 1977-78 data (Test 3) was not helpful in resolving the question of quarter differences because of the interactions between quarter and each of the other three factors. However, pairwise t-tests for differences between quarterly means in the North Inside area during 1977-78, pooled over year and vessel capacity, detected no significant quarter differences (Table 9). Based on that result, I pooled over all quarters in the North Inside and North Outside areas. Finally, I pooled over all quarters in the South area because of the small sample sizes (Table 3).

Thus, after pooling over year, vessel capacity, and quarter as indicated above, only three strata remained for the 1977-78 data: 1) North Inside, 2) North Outside, and 3) South.

TABLE 9.—Matrix of significance probabilities associated with t-tests for differences between pairs of quarterly means of total number of dolphins killed. No significant values, required by the Bonferroni adjustment to be <0.0083, were attained. Data are from sampled dolphin sets made in the North Inside area from 1977 through 1978.

	Quarter		
Quarter	2	3	4
1	0.7062	0.2417	0.0684
2		0.2623	0.0730
3			0.2831

Estimates

I obtained annual estimates of the total number of dolphins killed by summing estimates for each of three or five strata, depending on the year. Estimates for a stratum were computed as the product of (a) total number of dolphin sets (Table 10) and (b) the corresponding total kill-per-set ratio (Table 11), increased by (c) the observed total number of dolphins killed during experimental-gear trips (Table

TABLE 10.—Estimated number of dolphin sets (D) and number of trips (N) for the population of trips, by year within strata.

		North Inside						
Year	Statistic	Quarter 1	Quarter 2	Quarters 3 & 4	Total	North Outside	South	Total
1973	D	3,203	1,670	501		2,591	330	8,295
	N	172	104	69		117	34	
1974	D	3,486	1,176	242		2,453	12	7,369
	N	126	92	38		93	4	
1975	D	3,069	1,749	434		2,495	53	7,800
	N	119	96	40		96	23	
1976	D	1,618	1,520	716		2,001	729	6,584
	N	127	98	92		90	76	
1977	D				5,722	1,128	252	7,102
	N				186	76	37	
1978	D				2,811	1,153	162	4,126
	N				206	58	27	

TABLE 11.—By-trip means of total number of dolphins killed ($\bar{k}$) and of number of dolphin sets ($\bar{d}$), total kill-per-set ratio ($\hat{R}$), estimated standard error of the total kill-per-set ratio (s), and number of sampled trips (n), by strata.

		North Inside					
Years	Statistic	Quarter 1	Quarter 2	Quarters 3 & 4	Total	North Outside	South
1973-76	$\bar{k}$	354.51	157.32	155.50		265.06	239.85
	$\bar{d}$	24.11	15.98	9.31		16.50	7.45
	$\hat{R}$	14.70	9.85	16.70		16.06	32.19
	s	1.19	1.15	4.38		4.21	4.17
	n	92	41	16		16	20
1977-78	$\bar{k}$				58.66	57.55	22.12
	$\bar{d}$				19.88	13.71	4.73
	$\hat{R}$				2.95	4.20	4.68
	s				0.23	0.51	1.03
	n				190	78	33

12). For example, the total estimated kill for 1977 (Table 13) was obtained as a sum of estimates of the total for three strata as [(5,722)(2.95) + 175] + [(1,128)(4.20) + 15] + [(252)(4.68) + 0]. Estimates for each species or species grouping were obtained in the same manner as estimates of the total, except that values for the species or species grouping were substituted for the totals in (b) and (c) above.

Similarly, I estimated the variance of the number of dolphins killed during any year by summing variance estimates for each stratum. The estimated variance of total kill for a stratum was computed

TABLE 12.—Total number of dolphins killed (*k*), number of dolphin sets (*d*), and number of experimental-gear trips (*n*), by year within strata. These data were excluded from all sample and population statistics.

		North Inside						
Year	Statistic	Quarter 1	Quarter 2	Quarters 3 & 4	Total	North Outside	South	Total
1973	*k*	0	0	513		0	0	513
	d	0	0	46		0	0	46
	n	0	0	2		0	0	
1974	*k*	0	0	497		192	0	689
	d	0	0	70		36	0	106
	n	0	0	2		1	0	
1975	*k*	0	0	512		271	0	783
	d	0	0	76		26	0	102
	n	0	0	2		1	0	
1976	*k*	139	1,400	111		1,886	547	4,083
	d	35	256	92		153	6	542
	n	2	16	7		5	2	
1977	*k*				175	15	0	190
	d				129	8	0	137
	n				4	2	0	
1978	*k*				226	27	0	253
	d				77	11	0	88
	n				6	2	0	

TABLE 13.—Estimates of dolphin mortality incidental to U.S. purse seiners, by species grouping and year, with coefficients of variation in parentheses.

	Year					
Species grouping	1973	1974	1975	1976	1977	1978
Spotted	70,000	61,000	63,000	61,000	14,000	9,000
	(0.12)	(0.13)	(0.13)	(0.11)	(0.08)	(0.08)
Spinner						
Eastern[1]	12,000	11,000	11,600	9,500	1,300	700
	(0.16)	(0.11)	(0.11)	(0.12)	(0.12)	(0.11)
Whitebelly	20,000	16,000	17,000	19,000	3,600	2,300
	(0.17)	(0.19)	(0.19)	(0.15)	(0.11)	(0.10)
Unidentified	8,700	7,600	7,700	7,500	60	40
	(0.24)	(0.26)	(0.25)	(0.25)	(0.18)	(0.17)
Total	41,000	35,000	36,000	36,000	5,000	3,000
Common	8,500	7,000	8,300	6,600	3,000	1,500
	(0.22)	(0.25)	(0.22)	(0.20)	(0.23)	(0.24)
Striped	640	380	500	800	200	130
	(0.30)	(0.34)	(0.35)	(0.33)	(0.26)	(0.24)
Unidentified	5,000	3,700	4,000	5,400	450	300
	(0.19)	(0.20)	(0.19)	(0.26)	(0.12)	(0.12)
Other	180	90	100	280	180	100
	(0.45)	(0.26)	(0.26)	(0.64)	(0.22)	(0.26)
Total[2]	125,000	107,000	112,000	110,000	23,000	14,000
	(0.10)	(0.10)	(0.10)	(0.09)	(0.06)	(0.06)

[1]May include small number of Costa Rican spinner dolphins.
[2]Sum of estimated kills over species grouping not exactly equal to total estimated kill because of rounding error.

as the square of the product of (a) the number of dolphin sets[4] (Table 10) and (b) the corresponding estimated standard error of the total kill-per-set ratio (Table 11). I computed the estimated stratum variance for each species or species grouping, substituting values for the species or species grouping for the total in (b) above. I estimated the standard errors (Table 11) using mean number of dolphin sets per trip calculated from the sample rather than from the population (Lo et al. 1982).

My annual estimates of the total number of dolphins killed incidentally in the U.S. purse seine fishery of the ETP ranged from a maximum of 125,000 dolphins in 1973 to a minimum of 14,000 dolphins in 1978, with coefficients of variation (CV) no greater than 10% (Table 13). The estimated mortalities of the two species most often exploited, spotted and spinner dolphins, together accounted for about 80-90% of each annual total.

DISCUSSION AND CONCLUSIONS

The kill-per-set ratio, or mean kill, declined from 15 dolphins/set during the 1973-76 period to 3 dolphins/set during the 1977-78 period (Table 11, pooled over quarter and area). Many changes affecting dolphin kill were made during these periods, including improvements in fishing gear and dolphin-release procedures and introduction of federal regulations. The change in mean kill between 1973-76 and 1977-78 coincided with the first NMFS notice in late 1976 prohibiting fishing on dolphins for the remainder of the year. This one example of a correspondence between a change in the number or distribution of dolphins killed during purse seine sets and an identifiable legal or management action is not necessarily indicative of a cause and effect relationship. There are, however, two other examples of such a temporal correspondence present in the data from 1964 through 1982.

In the second example, the data prior to 1973, while sparse, suggest that the mean kill was substantially higher than during the 1973-76 period. Lo and Smith (1986) reported a mean kill of 46 dolphins/set based on 1964 through 1972 data, pooled over vessel capacity and catch of tuna. They found no consistent differences in annual mean kill during that period. The decline in the mean from 46 dolphins/set during the 1964-72 period to 15 dolphins/set during the 1973-76 period coincided with the passage of the Marine Mammal Protection Act in late 1972.

In the third example, Wahlen and Smith (1985) demonstrated a difference between the two periods from 1979 through March 1981 and from April 1981 through 1982 in the frequency distributions of number of dolphins killed during purse seine sets. While the difference in mean kill during these two periods was not significant, the percent of dolphin sets in which no dolphins were killed (zero-kill sets) decreased significantly. This decrease coincided with a court order in March 1981 which prohibited using data collected by NMFS observers to monitor compliance of vessel captains with dolphin-release procedures.

These three examples suggest that significant legal or management actions can affect kill rates, measured by the kill-per-set ratio or by the percent of zero-kill sets. Furthermore, such effects on the kill-per-set rate are reflected in the series of estimates of total numbers of dolphins killed presented here. For example, between 1976 and 1977 the number of dolphin sets increased slightly (Table 10), yet total estimated mortality decreased by nearly 80% (Table 13), due primarily to the significantly lower kill rate after 1976. The further decline in estimated mortality to 14,000 dolphins in 1978 reflects both the lower kill rate and a decline in the number of dolphin sets. Thus, the decrease in the kill rate following the first enforcement of dolphin kill limits in 1976 is reflected in the decrease in the estimates of total mortality after 1976.

My estimates of total annual dolphin mortality in U.S. purse seine fishing from 1973 through 1978 (Table 13) are lower, except for 1976, and more precise than those in the Status of Porpoise Stocks Workshop Report (SOPS) (Table 14). However, for each year except 1973, my estimated total is contained inside an approximate 95% confidence interval around the estimated total ($\hat{T}$) in SOPS, where the confidence interval is computed as $\hat{T} \pm 2 \cdot \text{CV} \cdot \hat{T}$. Thus, the differences between my point estimates and those in SOPS are small when the imprecision (large CV) of the SOPS estimates is considered.

The lower precision of the SOPS estimates may be due to overstratification because of a concern that the sample might not be representative of the population, particularly during the 1973-75 period. Thus, in order to minimize bias, a large number of strata (32 per year) were defined. Tests for between-strata differences in mean kill were not made, but strata were pooled to the degree that each pooled stratum contained some sample data. However, even after pooling, some strata during the years 1973-76

[4]Numbers of dolphin sets were treated as constants since no variances were provided for these estimated quantities. Therefore, my variances of estimated mortality are underestimated to an unknown, though likely small, degree.

TABLE 14.—Estimates of dolphin mortality incidental to U.S. purse seiners, by species and year, from Status of Porpoise Stocks Workshop Report (Smith text footnote 2). Coefficients of variation of totals in parentheses.

	Year					
Species	1973	1974	1975	1976	1977	1978
Spotted	114,000	75,000	84,000	57,000	12,000	13,000
Spinner	65,000	62,000	70,000	39,000	5,000	4,400
Common	18,000	3,000	2,300	5,400	6,600	1,000
Striped	40	140	900	2,000	100	250
Unidentified[1]	0	0	0	0	0	0
Other	0	80	160	690	80	50
Total[2]	197,000 (0.17)	140,000 (0.41)	157,000 (0.17)	104,000 (0.13)	24,000 (0.15)	19,000 (0.20)

[1]Kills of unidentified dolphins prorated among known species.
[2]Sum of estimated kills over species not exactly equal to total estimated kill because of rounding error.

contained only one dolphin set. Such small sample sizes within some strata account for the lower precision of the SOPS estimates relative to my estimates.

While the differences between my point estimates and those in SOPS are small in a statistical sense, my estimates are consistently lower except for 1976. However, these new estimates are to be preferred on methodological grounds. I tested for statistically significant between-strata differences in mean kill and pooled over strata when significant differences were not detected or when sample sizes were otherwise too small. Pooling of the data produced estimates which were more precise than the SOPS estimates because it resulted in fewer strata with larger sample sizes. However, to minimize the possibility of introducing bias into the estimates during the 1973-76 period, when the sample was unrepresentative of area and quarter, I did not pool over area and I pooled over quarter only in the event of small sample sizes.

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