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REVISED ESTIMATES OF FISHERIES KILL OF DOLPHIN STOCKS IN THE EASTERN TROPICAL PACIFIC, 1959-1972

By

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ABSTRACT

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 making management decisions about the population status of stocks killed in the fishery. A re-definition of the stock boundaries for offshore spotted dolphin makes it necessary to calculate estimates of annual kill for these new stock definitions for the years 1959 to 1992. Estimates of annual kill of offshore spotted dolphin stocks for the time period 1973 to 1992 were recently made by the Inter-American Tropical Tuna Commission. Estimates for the time period 1959 to 1972 were calculated in this paper, along with slightly revised estimates for the eastern and whitebelly stocks of spinner dolphin. To estimate kill for the spotted dolphin stocks, the mortality-per-set estimation method of previous estimates was duplicated, but multiplied by the number of sets stratified into the two new offshore spotted stock areas: northeastern and western/southern. The kill estimates for the 2 spinner dolphin stocks were calculated as before. Variances of the annual kill estimates for each stock were calculated using bootstrap methods, rather than by the analytical method previously used. This allowed the estimates to incorporate uncertainty in the species and stock proportions of the kill, which was not done previously. Nearly all of the fisheries kill of offshore spotted dolphin was of the northeastern stock during the 1959 to 1972 period. As expected, variances of the kill for each stock, expressed as coefficients of variation, were higher than the previously reported variances of the total kill.

INTRODUCTION

Dolphins have been killed in the eastern tropical Pacific since at least 1959 (Perrin 1969), when purse-seine fishing techniques began to dominate the yellowfin tuna fishery (McNeely 1961). The fishermen use the dolphins to locate schools of tuna, and often purposely capture the dolphins in their nets in order to maximize their catch of tuna. Although they often attempt to release the dolphins alive using a procedure called the backdown (Barham *et al.* 1977), some dolphin are killed when they become entangled in the net. Several species of dolphin are killed with the majority being either offshore spotted (*Stenella attenuata*) or spinner (*Stenella longirostris*) dolphins, with several stocks of each of those two species killed.

Estimates of the number of dolphins killed in each stock annually are used by the National Marine Fisheries Service (NMFS) in making management decisions about the population status of those stocks (e.g., Wade in press, Smith 1983). Recently, Dizon *et al.* (1992) established new stock boundaries for the offshore spotted dolphin (Fig. 1), based mostly on a re-examination of cranial morphology (Perrin *et al.* in press). Estimates of the number of offshore spotted dolphins killed from each stock must therefore be revised to reflect this changed view of the stock structure. Since 1979, the Inter-American Tropical Tuna Commission (IATTC) has been responsible for making estimates of the number of dolphins killed from each stock (IATTC 1989). Therefore the IATTC provided revised estimates of kill for the offshore spotted stocks for the years 1979 to 1992.[1] Additionally, they revised the estimates for 1973 to 1978 last calculated by Wahlen (1986). They chose to not revise estimates for the years 1959 to 1972, citing the scarcity of observer data on mortality-per-set (MPS) rates, the lack of a formal observer program prior to 1971, and potential biases in the data.[2] However, the number of purse-seine sets made on dolphins during that period is known with high precision from the fishing vessel's logbooks (Punsley 1983), and Lo and Smith (1986) presented a method of analysis that should provide accurate estimates of kill for the 1959-72 time period, given certain important but reasonable assumptions. Therefore, this paper uses that method to calculate estimates of the number of dolphins killed annually for the years 1959 to 1972 for the two stocks of offshore spotted dolphin, the northeastern stock and the western/southern stock. Additionally, minor corrections to the data and methods make it appropriate to report revised estimates for two spinner dolphin stocks, the eastern stock and the whitebelly stock, as well as for a pooled category consisting of all other stocks and species, referred to as "all other dolphin".

The most recent estimates of dolphin mortality for the 1959-1972 time period (Lo and Smith 1986) were total estimates of all dolphins killed in each year, and included estimates of the variances, but they were not apportioned to stocks. Earlier, Smith (1983) presented annual

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

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

estimates of dolphins killed in each stock for the same time period, but without estimates of the variance. Revised annual estimates of the number of dolphins killed in each stock could be calculated by applying the stock proportions of Smith (1983) to the annual estimates of total dolphin kill in Lo and Smith (1986). This was the method used by Wade (in press) to calculate kill estimates for the eastern stock of spinner dolphin for that time period in order to assess the population status of that stock. However, the revised stock boundaries for the offshore spotted dolphin require a re-analysis using a slightly modified version of Lo and Smith's (1986) method. Their stratified MPS rates were multiplied by geographically stratified totals of the number of sets on dolphin in each of the two offshore spotted stock areas, rather than to the total number of sets on dolphin.

An additional objective of this re-analysis was to provide variances for the kill estimates for each stock, rather than just for the total number of dolphins killed, so that these variances could be incorporated into population assessments of the stocks. Use of the bootstrap method (Efron 1982) allows for uncertainty in the species and stock proportions to be included in the variance estimate, something that was not done in the analytical variance calculations of Lo and Smith (1986). Although the kill estimates for the spinner dolphin stocks will not differ substantially from previous estimates, this paper provides variances for those stock kill estimates for the first time. Additionally, some minor corrections to the data and analysis methods will be documented.

METHODS

The overall method can be summarized as follows. Estimates of total dolphin MPS rates for strata defined by vessel size, catch of yellowfin tuna, and whether the backdown procedure was used or not, were calculated from pooled observer data from 1959-72. Those strata were chosen because they accounted for the most variation in the kill rates (Lo and Smith 1986). Those MPS rates were multiplied by the number of sets on dolphin in each stratum in each year to estimate the total number of dolphins killed in each year. Then that total kill was prorated by the observed stock proportions from the 1971-72 observer data to estimate the number of dolphins killed in each stock in each year. Bootstrap variances of those stock kill estimates were made by re-sampling fishing trips from the 1959-72 pooled observer data, and then re-calculating the MPS rates and species proportions as described above. The estimates of the number of sets on dolphins were very precise, having coefficients of variation of less than 1% in all years except for 1959 and 1960 (Punsley 1983), and were therefore treated as constants.

The methods of Lo and Smith (1986) used to estimate the total number of dolphins killed in each year were duplicated except for some minor modifications, as explained below. Their methods multiplied stratified MPS rates by estimates of the number of sets on dolphins in each stratum, for the entire eastern tropical Pacific. Since sets on dolphin prior to 1973 only occurred within the region of the now obsolete northern stock of offshore spotted dolphin, the total kill could be prorated to that stock by the observed proportion of spotted dolphin in the kill. With the re-definition of the stock boundaries, this procedure needs to be altered because the stocks of offshore spotted dolphin are not morphologically distinct, and could not therefore be noted as proportions in the observer data. Therefore, to estimate the number of northeastern offshore spotted dolphins killed, I multiplied the stratified MPS rates by the number of sets on dolphin in each stratum of vessel size, catch of yellowfin tuna, and whether the backdown procedure was used or not, but further stratified to just those totals that were in the northeastern stock area (Table 1). This provided an estimate of the total dolphin killed in that area, which was then prorated to spotted dolphins by the observed proportion of spotted dolphins in the 1971-72 observer data. The same procedure was used to estimate the kill of the western/southern stock of offshore spotted dolphin, using the stratified set totals from that area (Table 1). The 1959-72 observer data were all sets on dolphin that occurred in the northeastern stock area (Fig. 1). Therefore the estimates of kill for the western/southern stock have the implicit assumption that the MPS rates were the same there as in the northeastern stock area. Because the eastern spinner and whitebelly spinner dolphins are morphologically distinct, estimates of kill for those two stocks were made by prorating the estimated total dolphin kill (summed across the two geographic areas) by the observed proportions of the two stocks in the 1971-72 observer data. Similarly, the estimates of other dolphins killed in each year were made by prorating the estimated total dolphin kill by the observed proportion of other dolphins in the 1971-72 observer data. The same method as in Smith (1983) was used for prorating species proportions, and will be explained in more detail below.

For completeness, I will present the methods of Lo and Smith (1986) in some detail..Lo and Smith (1986, eq. 1) expressed the estimated number of dolphins killed in any year ($\hat{T}_t$) as:

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

where t = year
R = number of dolphins killed per set (mortality-per-set)
X = the number of sets on dolphins.

Lo *et al.* (1982) have shown, using the larger amount of data available in 1976, that MPS varied substantially between larger and smaller vessels, and in dolphin sets where fewer and greater amounts of yellowfin tuna are caught. Using a two-way analysis of variance, Lo and Smith (1986) found statistically significant differences in MPS for two strata in the 1959-1972 data: (1) small versus large vessels (>600 tons carrying capacity); and (2) successful versus unsuccessful (< 1/4 ton catch of yellowfin tuna) sets. Not surprisingly, using data pooled across all size vessels because of the small sample size, they found a statistically significant difference in MPS when backdown was used versus when it was not used. Therefore, they chose to stratify on all three of these variables, resulting in their eq. 2:

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

where t = year
i = 1 for vessel capacity > 600 tons; 2 for vessel capacity ≤ 600 tons
j = 1 for yellowfin tuna catch ≥ 1/4 ton; 2 for yellowfin tuna catch < 1/4 ton
k = 1 if backdown is used; 2 if backdown is not used.

Finding no significant trends in MPS over time, and that nine out of fourteen years between 1959 and 1972 had no observations of MPS, Lo and Smith (1986) chose to pool the MPS data across years. Due to few observations of sets where backdown was not used, and because there were no significant differences between vessel size categories, they assumed a constant ratio of kill rates for successful sets when backdown was used and when it was not used, regardless of the vessel size. Finally, they considered only one kill rate for unsuccessful sets, due to small sample sizes and because often these sets captured few dolphins, minimizing the influence of the backdown procedure. These assumptions and modifications led to Eq. 3:

$$\hat{T}_t=\sum_{i=1}^{2} [\hat{R}_{\bullet i11}(\hat{X}_{ti11}+C\hat{X}_{ti12})+\hat{R}_{\bullet i2\bullet}X_{ti2\bullet}] \qquad (3)$$

$$\text{where } C = \frac{\hat{R}_{\bullet\bullet 12}}{\hat{R}_{\bullet\bullet 11}}$$

and where the subscript • is used when data were pooled across that stratifying variable.

Lo and Smith (1986) used the number of sets on dolphin provided by Punsley (1983), which provided numbers stratified according to successful or unsuccessful sets, but not by vessel size or the use of backdown. They prorated Punsley's (1983) total sets to vessel size using NMFS data on proportions of sets made by vessels of each size class. To prorate the number of sets to the use of backdown or not, Lo and Smith (1986) used the observed proportions from the 1964-72 MPS observer data. They assumed that the proportion of backdowns used (1) increased linearly between the known use of 0.0 in 1959 and the observed proportion of 0.79 in 1964-1965; (2) was equal to the observed proportion of 0.89 for the years 1966-1971; and (3) was equal to the observed proportion of 0.96 in 1972. The increase may have been less than linear in the first few years, as there is some indication that the procedure was not demonstrated to a significant portion of the fleet until 1961 (Barham *et al.* 1977). Incorporating these assumptions and modifications lead to the final equation actually used by Lo and Smith (1986) to estimate dolphin kill:

$$\hat{T}_t=\sum_{i=1}^{2} [\hat{R}_{\bullet i11}X_{ti1\bullet}[\hat{P}_t+C(1-\hat{P}_t)]+\hat{R}_{\bullet i2\bullet}X_{ti2\bullet}] \qquad (4)$$

where $\hat{P}_t$ = the proportion of successful sets using the backdown dolphin release procedure.

The same methods were used in this paper with the following modifications. As discussed above, the estimates of kill for the offshore spotted dolphin stocks were made by stratifying the number of sets geographically according to the stock boundary, where the area north of 5° N and east of 120° W was the northeastern stock area, and where everything else was the western/southern stock area (Fig. 1). The number of sets made by the tuna purse seine fleet have been recorded by the IATTC from logbooks kept by the fisherman. The size of the vessel has been recorded, and therefore the IATTC was able to provide the number of sets by year stratified by area, set type (successful or unsuccessful), and vessel size (Table 1).[3] These estimates of the number of dolphin sets stratified by those three variables were made by multiplying Punsley's (1983) estimates of the total sets on dolphins by the proportions of known sets (from the IATTC logbook data base) that were in each (1) stock area, (2) set type, and (3) vessel size category. This is likely a substantial improvement in accuracy over the proration method based on less data used by Lo and Smith (1986).

Another modification to the Lo and Smith (1986) method was a change in the way that the variance was calculated. Their method presented equations for analytically calculating the variance of the estimated kill of all dolphins 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 the number of dolphins killed in each set from each stock were not collected until the formal observer program started in 1971 (Edwards 1989); therefore, Smith (1983) used the observed proportions from 1971-1972 for the entire 1959-1972 time period, with the exception that all spinner dolphins killed before 1969 were assumed to be from the eastern stock, with no whitebelly spinner dolphins killed until 1969. This assumption is supported by maps of dolphin sets by year in Punsley (1983), which showed that no sets on dolphins occurred in the whitebelly stock area before 1968, and only a very small number occurred in 1968. In this paper, 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 estimate the variance of the estimate of the number of dolphins killed in each stock in each year, I used the bootstrap method (Efron 1982), with fishing trip as the re-sampling unit, and 1000 bootstrap iterations. Thus, on each bootstrap iteration, 20 fishing trips were re-sampled with replacement from the 1959-72 pooled observer data, and the MPS rates were re-calculated and multiplied by the stratified set totals to estimate the total kill, which was then prorated to stock by the re-calculated species proportions. The variance of the kill of each stock in each year was then estimated as the variance of the 1000 bootstrap estimates of that stock. This method automatically incorporates into the variance uncertainty due to the observed proportions of each stock killed in the 1971-1972 MPS observer data.

[3] Data provided by M.G.Hinton, Senior Scientist, Inter-Am. Trop. Tuna Comm. c/o Scripps Inst. Oceanogr., La Jolla, CA 92093, June 24, 1993. A typographical error in Punsley (1983) let 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.

RESULTS AND DISCUSSION

Average MPS for each of the 20 observed trips between 1964-1972 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.

To confirm that I had correctly duplicated Lo and Smith's (1986) method, I re-calculated their estimates, using my estimates of MPS and the number of sets reported in their table 3. This resulted in slightly different estimates of the total number of dolphins killed than 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 they inadvertently used these values, versus $R_{\bullet 111}$ and $R_{\bullet 211}$ as they intended, because their equation is correct.[4] The estimates reported here (Table 4a) were calculated using Equation 4 and $R_{\bullet 111}$ and $R_{\bullet 211}$ of 29.9 and 65.8, respectively.

An inspection of the maps reported in Punsley (1983) showed that very few dolphin sets occurred outside of the northeastern offshore spotted stock area prior to 1969. As expected, nearly all of the sets on dolphins were in the northeastern stock area (Table 1). This resulted in nearly all of the fisheries kill of offshore spotted dolphin being from the northeastern stock (Table 4a). The few sets on dolphin that occurred outside of the northeastern spotted stock 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). Although this should have little effect on the kill estimates for the northeastern stock, it should be emphasized that the estimates of kill for the western/southern stock were based on no actual observations of kill of offshore spotted dolphins in the western/southern stock area except in the area north of the Galapagos but south of 5° N (Fig. 1). They were mostly based only on knowledge of the number of sets on dolphins within that stock area and on the implicit assumption that offshore spotted dolphins had similar MPS rates in that area as they did inshore in the northeastern area. The kill estimates for the western/southern stock, though relatively small, should therefore be used with some caution. Similarly, the kill estimates for the whitebelly stock of spinner dolphins suffer from the same problem, as observations of kill of whitebelly spinner dolphins came only from the region of overlap with the eastern spinner dolphin, with no observations of MPS from the outside region west of 120° W where whitebelly spinner dolphin are known to occur and where significant

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

fishing effort occurred in 1970, 1971, and 1972 (Punsley 1983). Therefore, the kill estimates for whitebelly spinner dolphins should also be used with some caution.

Lo and Smith (1986) did not allocate their estimates of total dolphin mortality to stocks. Smith (1983), using reported proportions from the 1971-72 MPS observer data, allocated 0.70, 0.23, 0.03, and 0.04 of the total mortality to the offshore spotted, eastern spinner, whitebelly spinner, and all other dolphins, respectively. Analogous results herein assign 0.694, 0.241, 0.034, and 0.029 of the mortality to the same categories.[5]

The estimated variances for the total number of dolphins killed in each year is higher here than those reported by Lo and Smith (1986), except for the years 1971 and 1972. Since the data in each case are the same, the difference must be due to the fact that the variances were calculated using the bootstrap method here, rather than using the analytical equations as in Lo and Smith (1986). These variances, when expressed as coefficients of variation (CV), are considerably higher than Lo and Smith (1986), particularly for the years 1959-65, which range from 0.24 to 0.48. For example, Lo and Smith (1986) report a CV of 0.31 for 1960, whereas here the estimate was 0.46. The CV's for the years 1966 to 1972 (from 0.13 to 0.20) are in the same range as CV's reported for later years (IATTC 1989) for which there were larger sample sizes of observed sets. This indicates 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, it may be that as MPS declined after 1972, the variance in MPS actually increased. One possible explanation could be that MPS declined for dolphin sets that went as planned, but did not for dolphin sets that experienced problems (so-called "disaster" or high-mortality sets). This could lead to a decrease in average MPS with an increase in the variance.

The three trips observed prior to 1971 were not part of an established data collection program. It can therefore be argued that they are potentially biased observations. The 1965 and 1968 trips were observed by scientists on board the tuna boats for the purpose of collecting dolphin specimens, but who also recorded MPS data on their own initiative (Smith and Lo 1983). There is no obvious reason why tuna vessels that agreed to allow scientists to collect specimens during their fishing operations would tend to have different mortality rates, but in a strict sense these were not random samples of fishing trips. However, it is not certain *a priori* in which direction bias would have occurred, if it did. Data from one fishing trip in 1964 were recorded and reported by a fisherman, who may have done so because of the magnitude of the kill, making those data biased (Smith and Lo 1983). The 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 unusual or biased (Table 2). To assess the impact of not using the data collected before the formal observer program began in 1971, I re-calculated kill for each stock using only

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[5]Differences are likely due to round off error. Additionally, they may be also due to revisions made to the NMFS observer database (pers. comm., Randall C. Rasmussen, Southwest Fisheries Science Center, NMFS, La Jolla, 92038).

the 17 sets that were observed in 1971 and 1972 (Table 4b). The resulting estimates of total dolphin kill were slightly higher than the estimates calculated using all 20 trips between 1964-72 (Table 4a) in all years except 1972. This was because of a slightly higher value for the ratio of MPS without backdown to MPS with backdown (C in Eq. 3). Due to the decrease in the quantity of data, the CV's were somewhat higher. This confirms that the kill estimates reported here (Table 4a) were not significantly biased by the use of the three pre-1971 observed trips.

It must be emphasized that accepting the assumption of constant MPS rates during 1959-72 is crucial to the accuracy of these kill estimates. The evidence that is available is consistent with this assumption. For example, it has already been noted that the three observed trips from 1964, 1965, and 1968 had MPS rates consistent with the data collected in 1971-72. There are additional observations prior to 1971 that are also consistent with this assumption. For example, dolphin were noted as being killed in all 28 dolphin sets observed on a trip in 1966, but 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; if one assumes one dolphin was killed on the other 23 sets, an average MPS for the 28 sets would be 45.5. Most of those sets were known to be successful sets using backdown, and a MPS rate of 45.5, which must be an underestimate, is consistent with other estimates for the small vessel stratum (Table 2). Verbal statements are available regarding a number of additional fishing trips prior to 1970 (Smith and Lo 1983). The scientist who observed the 1965 trip stated that he had accompanied several fishing trips that had killed dolphins in the 1960's, and had additional data that did not differ much from the 1965 trip. Also, R. Allen, cited as a personal communication in Smith and Lo (1983), noted that the IATTC held data from two fishing trips in that period that were similar in their MPS rates, but the data could not be released due to confidential agreements with the vessels' captains. Therefore, there are apparently at least four other observed fishing trips from the 1960's with kill rates similar to those reported here.

With the passage of the Marine Mammal Protection Act in 1972, fishermen had more motivation to kill fewer dolphins, and it would be expected that MPS rates would decline in 1973, which they did. I calculated stratified MPS rates for the 1973 data (with a total of 668 observed dolphin sets from 25 trips) and compared them with the 1964-72 data, with resulting values for $R_{\bullet 211}$, $R_{\bullet 22\bullet}$, $R_{\bullet 111}$, and $R_{\bullet 12\bullet}$ of 13.1, 7.9, 22.0, and 1.3, respectively, compared to analogous values of 65.8, 5.9, 29.9, and 0.4 (Table 2). The only dramatically different value is that of the MPS for small vessels, successful set, with backdown, 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 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, and by the end of 1972, 40-50% of the U.S. fleet was using it, with 60-70% using it by then end of 1973 (Barham *et al.* 1977). In summary, although the amount of data available from 1959-72 for this analysis is sparse, it is consistent with other information available from that time period, and with data available in 1973, which provides support for accepting the assumptions of this analysis and, therefore, accepting these estimates as being reasonably accurate.

It must also be emphasized that the variance estimates presented here are estimates of the sampling error given the assumptions that go into the analysis, such as MPS rates being constant from 1959-72. They do not provide a measure of truly how uncertain we are about how many dolphins were killed during this time period, because some assumptions were made that can probably never be tested. 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 is data available to test these kinds of assumptions.

MPS rates have historically decreased in the U.S. fleet since the beginning of the observer program in 1971. There is no evidence or logic to suggest that MPS rates prior to 1964 would have been substantially less than in later years. MPS rates may have declined somewhat during the time period 1959-64, as the fishermen became more proficient at the backdown procedure. Although no data are available from that early period before the backdown procedure was widely used, the proportion of dolphin killed that were captured in the net was acknowledged as being high relative to later years (Joseph and Greenough 1979). For that 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.

A total of nearly 5 million dolphins were estimated to have been killed by the yellowfin tuna fleet over the fourteen year period considered here, and average of 347,082 per year (Table 4a). As noted earlier, the passage of the MMPA in 1972 resulted in fewer dolphins killed in 1973, as Wahlen (1986) estimated a kill of 197,000 in that year. Although these estimates indicate that a large number of dolphins were killed in the early years of the fishery, as recently as 1986 the kill was estimated to be 133,174 (IATTC, 1989). However, the kill has dramatically declined in each year since to a level of 27,292 in 1991 (Hall and Lennert in press), with a preliminary estimate of 15,470 in 1992 (Hall and Lennert 1993).

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Table 1. Total dolphin sets by area, vessel capacity (Large vessel for >600 tons carrying capacity or Small vessels for ≤600 tons carrying capacity), and set type (Successful set for >1/4 ton yellowfin tuna or Unsuccessful set for ≤1/4 ton yellowfin tuna) for the years 1959-1972. Areas are: Northeastern (north of 5° N and east of 120° W, and Western/southern (all area outside of the northeastern area). Estimates are based on apportioning total dolphin sets estimated by Punsley (1983) to strata (data provided by M. G. Hinton, Senior Scientist, Inter-American Tropical Tuna Commission, La Jolla, CA).

Area:	Northeastern				Western/southern			
Size:	Large		Small		Large		Small	
Set:	Succ	Unsuc	Succ	Unsuc	Succ	Unsuc	Succ	Unsuc
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

Table 2. Average numbers of dolphins killed in purse seine sets in the eastern tropical Pacific by trip, for the 20 observed trips between 1964-1972. 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 ($>$600 tons carrying capacity) and 2 for small vessels ($\leq$600 tons carrying capacity), j equals 1 for successful set ($>$1/4 ton yellowfin tuna) and 2 for unsuccessful set ($\leq$1/4 ton yellowfin tuna), k equals 1 for backdown was used and 2 for 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 Backdown	Unsuccessful	Successful 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 (8)	1.0 (1)
1972	19	82.1 (15)	.5 (4)	.0 (0)
1972	11	44.5 (11)	.0 (0)	.0 (0)
1972	16	80.7 (14)	.0 (1)	179.0 (1)
1972	23	45.8 (22)	.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)	14.0 (1)
1971	2	2.0 (2)	.0 (0)	.0 (0)
1971	27	30.3 (24)	.0 (1)	643.5 (2)
1972	36	25.7 (28)	.0 (5)	16.0 (3)
1972	18	49.3 (17)	.0 (1)	.0 (0)
1972	16	16.8 (15)	.0 (0)	.0 (1)
1972	9	11.9 (8)	.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)

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 1964-1972, 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.

	Successful sets			Unsuccessful sets		
Vessels and Year	M	N	N_{tr}	M	N	N_{tr}
Small vessels						
1964	60.9	20	1	60.0	1	1
1965	25.9	35	1	2.6	11	1
1968	130.2	13	1	4.0	2	1
1971	116.6	19	3	12.7	3	2
1972	56.5	103	6	3.7	16	5
Total	62.4	190	12	5.9	33	10
Large vessels						
1971	41.1	16	2	0.0	1	1
1972	36.9	117	6	0.5	11	5
Total	37.4	133	8	0.4	12	5

Table 4. Annual estimates of dolphins killed in the eastern tropical Pacific tuna purse seine fishery, for each year between 1959-1972. Coefficients of variation are given in parentheses. The category of all dolphins is the sum of the four stock and other dolphins categories.

A.) Using mortality-per-set data from 1964-1972 (20 trips).

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)

B.) Using mortality-per-set data from 1971-1972 (17 trips).

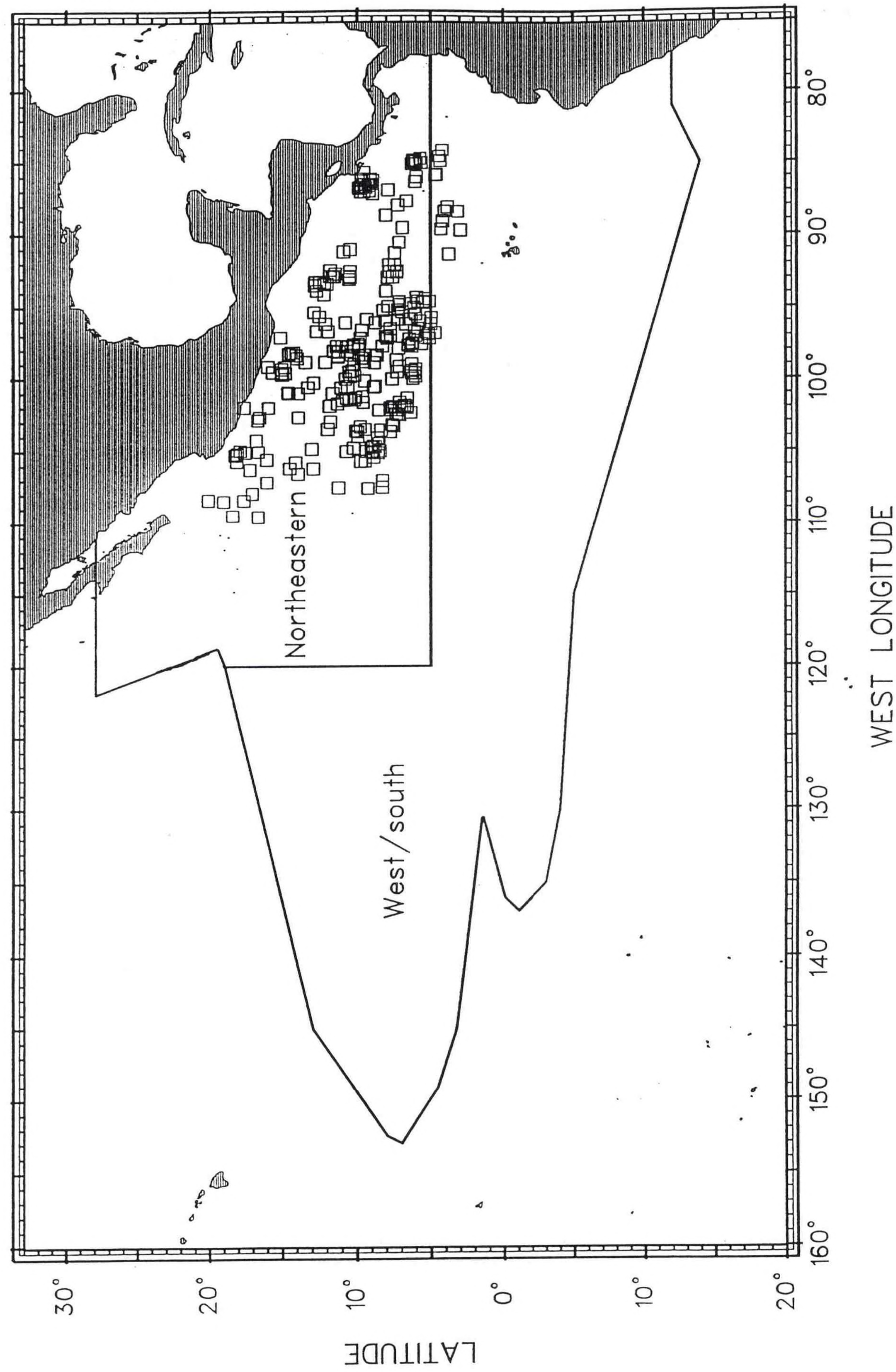
Year	All Dolphins		Northeastern Offshore Spotted		Western/southern Offshore Spotted		Eastern Spinner		Whitebelly Spinner		All other Dolphins	
1959	27461	(0.624)	18623	(0.684)	443	(0.690)	7544	(0.601)	0	(0.000)	851	(0.981)
1960	587526	(0.611)	401063	(0.670)	6846	(0.668)	161405	(0.591)	0	(0.000)	18212	(0.969)
1961	638396	(0.564)	418221	(0.621)	25006	(0.622)	175380	(0.553)	0	(0.000)	19789	(0.951)
1962	252469	(0.507)	157085	(0.560)	18199	(0.568)	69358	0.509)	0	(0.000)	7826	(0.936)
1963	273596	(0.436)	171310	(0.486)	18643	(0.485)	75162	(0.458)	0	(0.000)	8481	(0.922)
1964	426279	(0.334)	282929	(0.376)	13029	(0.376)	117107	(0.396)	0	(0.000)	13214	(0.917)
1965	502639	(0.339)	331833	(0.382)	17140	(0.373)	138085	(0.399)	0	(0.000)	15580	(0.914)
1966	393748	(0.252)	244821	(0.284)	28552	(0.284)	108170	(0.360)	0	(0.000)	12205	(0.929)
1967	264098	(0.256)	172437	(0.288)	10922	(0.279)	72553	(0.363)	0	(0.000)	8186	(0.928)
1968	240244	(0.251)	161951	(0.284)	4846	(0.273)	66000	(0.357)	0	(0.000)	7447	(0.925)
1969	463230	(0.239)	274157	(0.279)	47456	(0.274)	111717	(0.366)	15542	(0.585)	14359	(0.906)
1970	441511	(0.229)	222425	(0.275)	84109	(0.274)	106479	(0.348)	14813	(0.572)	13686	(0.886)
1971	255124	(0.221)	113383	(0.271)	63745	(0.275)	61528	(0.337)	8560	(0.563)	7908	(0.875)
1972	363571	(0.147)	165542	(0.188)	86880	(0.202)	87682	(0.331)	12198	(0.499)	11270	(0.897)

LIST OF FIGURES

Figure 1.

Offshore spotted dolphin stock areas. The outer line is the eastern tropical Pacific study area as defined by the National Marine Fisheries Service. The inside line represents the boundary between the northeastern and western/southern stocks of offshore spotted dolphin. All offshore spotted sightings to the north of 5° N and to the east of 120° W are assigned to the northeastern stock, and all offshore sightings outside of that area are assigned to the western/southern stock. The open squares represent the location of observed sets on dolphin 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.

Figure 1


Northeastern
West/south
WEST LONGITUDE
LATITUDE
80°
90°
100°
110°
120°
130°
140°
150°
160°
30°
20°
10°
0°
10°
20°