Estimated tuna discard from dolphin, school, and log sets in the eastern tropical Pacific Ocean, 1989–1992

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Abstract.–Pressure to reduce fishery-related dolphin mortality in the tuna purse-seine fishery of the eastern tropical Pacific Ocean (ETP) may alter fishing patterns from the current situation, in which most tuna is caught in association with dolphins, to a situation in which these "dolphin sets" are replaced by sets on unassociated schools of tuna (school sets) or on floating objects (log sets). Although not likely to effect any substantial change in dolphin population dynamics, owing to current low levels of dolphin mortality, such a change in fishing pattern could damage the commercial stock of yellowfin tuna and perhaps stocks of other tuna species because, unlike dolphin sets which generate almost no unwanted catch, school and log sets capture moderate to large amounts of undersized or otherwise undesirable tuna that are subsequently discarded at sea.

In this study, we examined the differences between set types (in short tons of tuna discarded per set by U.S. vessels fishing in the ETP during 1989–92) and then predicted the increase in short tons of tuna discarded per set (all tuna species combined) that would likely result from replacing the dolphin sets with an equivalent number of school or log sets (or both).

Expected discard weight of tuna was 100 times higher for log sets and 10 times higher for school sets than for dolphin sets. Average expected tuna discard per set was 0.06 short tons for dolphin sets, 1.15 short tons for school sets, and 10.5 short tons for log sets. Hypothetically, redistributing all dolphin sets to log sets increased estimated average discard of tuna by the international fleet in the ETP by about 337%.

A hypothetical replacement of all dolphin sets with log sets would lead to estimated discards of 10–25% of the estimated average number of yellowfin recruits to the fishery each year. If this discard is combined with an estimated 25% reduction in tons of yellowfin tuna caught that would result from concommitant changes in size structure of the landed fish (Punsley et al., 1994), the fishery could lose 30–50% of the approximately 98 million individual yellowfin tuna estimated to recruit to the fishery each year. Sustained removals of this magnitude, combined with environmental variability, could pose problems for long-term sustainability of the ETP yellowfin tuna stock; moreover, the change in fishing-effort patterns leading to this effect on yellowfin tuna would likely contribute little to recovery or sustainability of ETP dolphin stocks.

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Tuna purse-seiners fishing in the eastern tropical Pacific Ocean (ETP) conduct three different types of sets on tuna schools: dolphin sets, school sets, and log sets (IATTC[1,2]). Set types differ only in the technique used to capture the fish; the net used is the same in all cases. Dolphin sets include all sets in which the tuna were captured in association with dolphins. School sets include all sets on tuna schools not associated with either floating objects or with dolphins. "Log" sets as defined in our study include all sets on any floating object encountered by the purse seiner, including natural objects such as trees and tree limbs, dead whales, and other large animals, or other natural debris, as well as human-generated objects such as rafts and discarded trash.

The overwhelming majority of dolphins caught during purse-seining activities in the ETP are caught during dolphin sets, the only set type during which dolphins are captured intentionally. A few dolphins (generally fewer than 25–50) are captured accidentally each year in a few school or log sets or both (generally fewer than 5–10 dolphins), usually because the dolphins were not observed prior to making the set. School sets tend to catch free-swimming schools of moderately small yellowfin tuna, *Thunnus albacares* (about 7–8 kg, 60 cm total length, and not associated with dolphins and with other, unwanted fish), or mixed schools of yellowfin and skipjack tuna (*Katsuwonus pelamis)*, and little else. Dolphin sets catch relatively large yellowfin tuna (15–25 kg and 75–125 cm) associated with dolphins (Punsley[3]), some or (rarely) all of the associated dolphins, and very little else. Log sets have tended historically to catch small, prereproductive yellowfin tuna smaller than about 5 kg and less than about 50 cm fork length or skipjack tuna (or a mixture of both tuna), together with a wide variety and large quantity of other biota including sharks, billfish, other large and small sportfish, and a variety of other small noncommercial tunas.

Dolphin sets traditionally have been preferred by tuna fishermen because the associated yellowfin tuna are abundant, large, relatively easy to locate and capture, not associated with unwanted (nontarget)

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[1] IATTC (Inter-American Tropical Tuna Commission) Annual Report. 1988. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92038, 288 p.

[2] IATTC Annual Report. 1990. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92038, 261 p.

[3] More recently (1995 onward), some log sets have begun to capture some bigeye tuna and larger yellowfin although the majority of logs still capture mostly smaller fish. Punsley, R. 1995. Inter-American Tropical Tuna Commission, La Jolla, CA 92038. Personal commun.

fish, and generally have been more valuable per pound than the smaller school- or log-associated tuna. Dolphin sets traditionally have been opposed by conservationists because large numbers of dolphins have died annually as a result of net entanglement during these sets. Fishery-related dolphin mortalities began occurring in the ETP with the advent in the late 1950's and early 1960's of the tuna purse-seine fishery. At that time, new net-hauling equipment and net materials made large-scale purse seining practical for the first time. Within a few years, the earlier practice of catching tuna by pole and line was replaced almost entirely by purse seining. Estimates of dolphin mortality during the 1960's and early 1970's were on the order of 300,000–400,000 dolphins annually. Mortality estimates exceeded 100,000 per year until 1977, when the effects of dolphin mortality limits and improvements in fishing practices finally brought mortality below 50,000 per year. Mortality estimates decreased through 1983 to about 12,000 per year but increased significantly again to over 130,000 in 1986 when U.S. vessels left the ETP to move to the western Pacific and were replaced by vessels from countries with less experience in purse-seining techniques. Following a number of new restrictions on fishing methods and limits on allowable species composition of dolphin mortality, enacted by the U.S. congress in the late 1980's and early 1990's, mortality decreased again to about 25,000 per year in 1991.

Obviously, eliminating dolphin sets would virtually eliminate dolphin captures and associated dolphin mortality in the fishery. Recognizing this simple fact, the U.S. congress in 1992 passed legislation designed to eliminate fishing on dolphins by eliminating the U.S. market for tuna caught in association with dolphins while leaving the market open to tuna caught by other methods in the ETP, i.e. by school and log fishing. It was assumed that all effort previously directed to sets involving dolphins would simply be transferred to sets on schools and logs.

It is probably fortunate for the commercial stock of yellowfin tuna in the ETP, as well as for a host of other species, that the legislation did not affect the fishery in the manner expected. More or less concurrent with the changes in U.S. laws, the majority of the countries practicing purse-seining in the ETP, with the help and leadership of the Inter-American Tropical Tuna Commission, formed in 1992 a voluntary agreement (the Panama Declaration) to limit dolphin mortality dramatically in the tuna fishery. A major factor influencing the remarkable success of this program was the introduction of dolphin mortality limits on a per-vessel basis. Under this system, the total mortality quota for a given year is divided equally among all the vessels fishing that year. In addition, annual quotas were adopted that decreased annually to zero mortality by the year 2005.

Results during the first year that this system was fully operational (1993) far exceeded the stated limits of the Panama Declaration (annual mortality quota of 15,000 dolphins). Annual dolphin mortality during 1993 dropped to about 3,600 animals. Annual dolphin mortality has continued to decrease since then, to less than 2,600 animals during 1996. This decrease in mortality was not accomplished by decreasing the number of sets on dolphins, but rather by significantly decreasing dolphin mortality per set, from about 5 animals per set in 1986 to about 0.3 per set in 1996. The number of dolphin sets remains around 8,000 per year, down only about 20% from the approximately 10,000 sets per year that were practiced from the early 1970's through the early 1990's. At the current time, annual dolphin mortality is between 0.1% and 0.2% of estimated abundances of all dolphin stocks affected by the fishery, compared with annual net reproductive rates of 2–4% per year. Thus, fishery-related dolphin mortality at present is negligible compared with estimated current abundances and replacement rates.

This decrease in dolphin mortality, achieved by decreasing kill-per-set rather than decreasing the number of dolphin sets, has probably been fortunate for the commercial stock of yellowfin tuna and other biota in the ETP because it has apparently forestalled any major shift of fishing effort from dolphin sets to school or log sets.

The remainder of this paper focuses on the potential changes in tuna bycatch (discard) that could have been expected had dolphin set effort actually been transferred to school and log sets. We focus on tuna discard because bycatch data for tuna were the only available data to us when this study began.[4] Provided that the currently low levels of dolphin mortality are maintained, so that maintaining effort on dolphin sets does not appear to endanger dolphin population status or dynamics, the results presented here imply that encouraging such a change in effort patterns would be ecologically unsound.

This study presents the first report characterizing patterns and extent of tuna discard from the U.S. tuna purse-seine fishery in the ETP. We describe here general characteristics of the discard data available to us and apply statistical methods described elsewhere (Perkins and Edwards, 1996) to estimate average discard per set for each set type. We use these estimates of discard per set to estimate average an-

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[4] The Inter-American Tropical Tuna Commission initiated in 1993 a large-scale bycatch monitoring program in the ETP, but those data are still being collected and analyzed by that agency.

nual discard by the U.S. fleet during the study period (1989–92) for observed patterns and to predict discards that would have resulted if sets on dolphins were redirected to school or log sets. We then predict annual average discard from the international fleet (of which the U.S. was only a small part) under the same redistributions of effort and discard rates assumed for the U.S. fleet.

Although providing the ultimate impetus for the current study, we consider here only briefly the change in dolphin bycatch that would result from replacing dolphin sets with school and log sets because the effect is quite easy to estimate and is currently almost irrelevant in terms of dolphin population dynamics. The effect is easy to estimate because dolphin mortality is almost nonexistent in school and log sets. Thus replacing dolphin sets with school or log sets (or both) will virtually eliminate fishery-related dolphin deaths. This result is irrelevant in a population dynamics sense because annual fishery-related dolphin mortality is currently less than 5% of estimated annual replacement rates (compared with dolphin mortality rates approaching 100% of annual replacement rates during most years prior to 1993). Current mortality levels are about 2,600 dolphins per year from a variety of stocks composing an overall abundance of about 9.5 million dolphins in the ETP. Even for the stock most commonly affected by the fishery, the northeastern spotted dolphin (*Stenella attenuata*), current kill levels are about 800/year from a stock of about 700,000 animals with an estimated replacement rate of 14,000–28,000 animals/year.

Thus, replacing all dolphin sets with school or log sets would likely have little effect on dolphin stock dynamics, given current levels of fishery-related mortality. However, it appears very likely from our analysis that such a replacement could substantially reduce the abundance and biomass of the commercial tuna stock by substantially increasing the bycatch of yellowfin tuna that are too small for market sale. Discarding these small fish affects both current catch and future size composition. Thus we focus here on the potentially detrimental effects on the commercial stock of ETP yellowfin tuna that could result from redirecting dolphin sets to school and log sets, rather than on the negligible effects such effort changes are likely to have on ETP dolphin stock dynamics.

Methods

Data collection

As part of a bycatch study initiated in 1989 by the Inter-American Tropical Tuna Commission (IATTC), data were collected by scientific observers from either the National Marine Fisheries Service (NMFS) or IATTC, placed aboard U.S. tuna purse seiners during routine fishing trips to the ETP. Observed purse seiners included only those with greater than 400 short-t holding capacity. Those with a smaller capacity do operate in the ETP and are numerous for some countries but are not included in the ETP observer program (IATTC[1,2,5,6]).

Each agency contributed about 50% of the observers. Agencies alternated sending observers on departing trips. Observers recorded time, position, and set type of all sets made by U.S. vessels during the 31-month "study period" from 1 September 1989 through 30 March 1992. Position data were used to allocate each set to one of three geographic areas of fishing effort, as explained below.

Short tons of tuna discarded per set was calculated by subtracting the reported "total tons tuna loaded" from the reported " total tons tuna captured." After completing the original analysis of these data (Perkins and Edwards, 1996), we were informed that the data set we had been provided for analysis did not distinguish between true discard and those cases in which the calculated discard also included some tuna that were transferred to another vessel rather than loaded by the capture vessel because the capture vessel had reached capacity during that set. Thus in our original analysis we missed a small number of sets in which some of the captured fish were transferred to another vessel and became part of the commercial catch rather than discard. We recalculated the discard estimates for this paper using the corrected data; therefore the estimated average discard (and associated parameters) reported here differ slightly from our earlier paper. Because the problem occurred in only a few sets, it led to very little change between the estimated model parameters presented in Perkins and Edwards (1996) and those presented here. The largest change (approximately 10%) occurred in the parameter μ for estimating discard from dolphin sets, but this change has almost no effect on subsequent analyses or conclusions because so little discard overall occurs from dolphin sets.

Observers recorded discard data for only 50% of the sets made during the period 1 September 1989 through 30 July 1990 because only IATTC observers were collecting discard data during this period. During the remaining period, 1 August 1990 through 30

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[5] IATTC Annual Rep. 1991. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92038, 271 p.

[6] IATTC Annual Rep. 1992. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92038, 315 p.

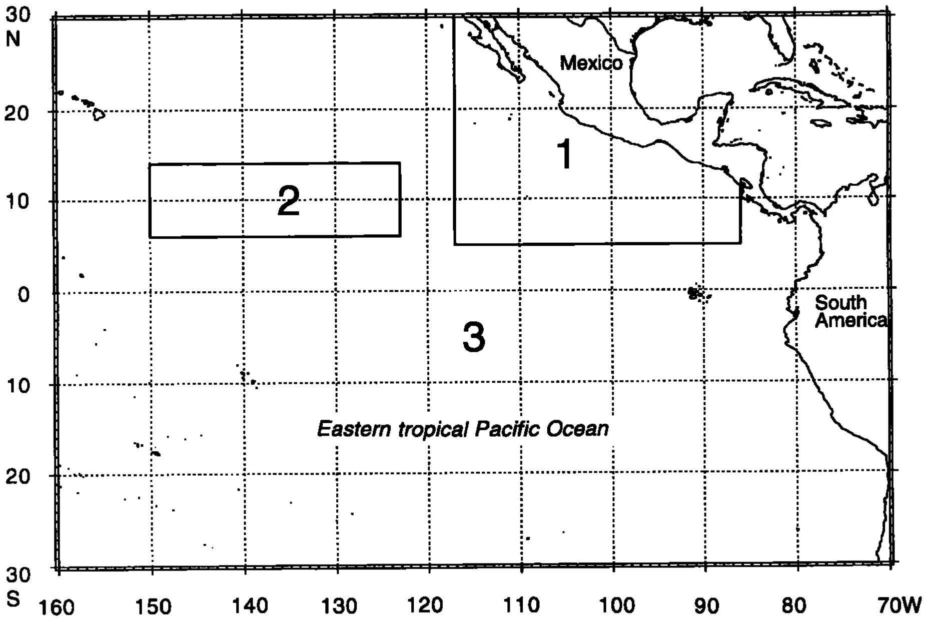

Figure 1

Geographic strata used in estimating average annual discard per set by the U.S. tuna purse-seine fleet fishing in the eastern tropical Pacific Ocean, 1989–92.

March 1992, observers from both agencies collected discard data for all observed sets. Because complete records of discard were missing for the early part of the study period, it was necessary to estimate discard during the study period rather than to measure it directly.

Complete details of data collection and statistical modeling methods and rationale appear in Perkins and Edwards (1996). In summary, we chose to model the data using a modified negative binomial (NB) distribution (the negative binomial with added zeros, Johnson and Kotz, 1969) because this distribution was sufficiently flexible to describe with a single form the disparate catch per set distributions for the three set types. The modified NB was able to accommodate the preponderance of zeros and the long tails (extreme skewness) in the dolphin-set and school-set discard data as well as the more strictly negative binomial distribution of the discard data from log sets.

Readily apparent differences in tuna discard per set type in different areas contributed to our stratification of the data into three geographic areas (Fig. 1), the same areas used currently to determine comparability of U.S. and non-U.S. dolphin mortality rates (Federal Register, 1989). For the purposes of estimating overall discard rates, we ignored school and log fishing in area 2 because no school sets and only ten log sets occurred there (Table 1).

Table 1

Effort data (number of sets on logs, schools, and dolphins) for the U.S. tuna purse-seine fishery in the eastern tropical Pacific Ocean 1989–92. Geographic areas as defined in Federal Register (1989). N = number of sets in a given area, n = number of sets examined for discard, and n^+ = number of sets examined for discard in which discard actually occurred.

Set type	Area		N	n	n+
Dolphin	1		2,496	1,445	10
	2		498	272	5
	3		596	393	4
		Total	3,590	2,110	19
School	1		399	279	32
	2		0	0	0
	3		867	681	48
		Total	1,266	960	80
Log	1		537	326	257
	2		10	4	4
	3		791	672	393
		Total	1,338	1,002	654

There was no distinct difference in discard rates among months for any of the three set types, and we did not include a monthly or seasonal effect in our analyses. Although the sample of sets was unbalanced with respect to months (i.e. the period September through March occurred three times during the study period, whereas the period April through August occurred only twice), the magnitude of the imbalance during the study period was not large. Data were too few to examine any annual effects.

We used maximum-likelihood estimates of model parameters from the best-fit models to estimate expected discard per set for each set type. We calculated estimates for individual geographic areas where model fits indicated significant areal effects on parameter values (i.e. for school and log sets), then calculated a "pooled" estimate of expected discard per set from the area-specific estimates. Where no areal stratification was appropriate (i.e. for dolphin sets), we calculated only one "pooled" estimate using the maximum-likelihood estimates of parameter values for the unstratified model.

We estimated standard errors for expected discard per set by bootstrapping rather than by using analytic formulae because only bootstrap methods could be efficiently applied to all three set types. Analytic methods could be easily applied only in the case where no areal stratification was appropriate (i.e. dolphin sets, where we fitted a single model for all areas) and in the case where complete areal stratification was appropriate (i.e. log sets, where we fit separate models in each of the geographic areas).

We estimated annual discard and standard errors of those estimates for the U.S. fleet as observed during the study period by multiplying the estimated overall discard rate for each set type by the corresponding average annual number of sets.

To investigate the effect of entirely eliminating dolphin sets, we predicted potential discard after redirecting all dolphin sets to school or log sets (or both). We used three hypothetical redistributions: 1) all dolphin sets were reassigned to school sets; 2) half of dolphin sets were reassigned to school sets, the remaining half were reassigned to log sets; and 3) all dolphin sets were reassigned to log sets. Sets were reassigned in proportion to the observed proportions of set types by the U.S. fleet in each geographic area; therefore the pooled estimates of expected discard per set could be used for each set type.[7]

We predicted total redistributed discard during the study period by multiplying pooled estimates of expected discard per set for school and log sets by the redistributed number of sets for each type. This procedure assumes that the redirected effort did not change the fishing habits, geographic patterns of the fleet, or the discard per set realized during the redirected effort.

Results

Patterns in set-type distributions

Several patterns are evident in the number of sets of each type. During the study period, about half the sets by U.S. boats were made on dolphins, about one quarter were made on school sets, and one quarter on log sets (Table 1). Sets were most common in the relatively nearshore area 1, rare in the offshore equatorial area 2, and moderate in the remaining area 3. Only dolphin sets were made with any frequency in area 2 (Table 1; Fig. 2). All three set types were common in areas 1 and 3.

About 70% of school sets were observed in area 3 (Table 1: Fig. 2). Of those sets, most occurred during April and May (59% of sets), between the hours of 8 am and 4 pm local time (68% of sets). Observed school sets in area 1 also occurred primarily between 8 am and 4 pm (76% of sets) but were distributed more homogeneously throughout the year and were much less common than in area 3. No school sets were observed in area 2.

Log sets were also observed primarily in area 3 (58% of sets, Table 1), although fewer sets were observed here during the period June–September (Fig. 2). Observed log sets decreased during summer and winter months in area 1. Log sets usually occurred early in the day in all areas (80% before noon, 56% before 8 am, Fig. 2). Less than 1% of observed log-set effort occurred in area 2.

Contrary to school-set and log-set effort, dolphin sets were observed primarily in area 1 (66% of sets, Table 1) with a small but important number of sets observed in area 2 (17% of sets). Effort in area 2 obviously replaced effort in area 1 during the months of June and July (Fig. 2). Only 1.6% of effort in area 1 but 78% of effort in area 2 occurred during these two months, and all effort in area 2 occurred between June and October. In all three areas, dolphin sets were observed primarily (79%) between the hours of 8 am and 4 pm during which greater effort was evident before noon.

Discard patterns

Estimated tuna discard from U.S. vessels was recorded for 59% (Table 1) of observed dolphin sets,

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[7] The geographic distribution of set types by U.S. vessels tends to differ from the geographic distribution with international fleet as a whole because U.S. vessels are largely restricted from the nearshore Exclusive Economic Zones (EEZ's) of coastal nations. If data for the geographic distribution of effort by the international fleet had been available, it would have been more appropriate to use that. However, the general results of the present study would likely remain unchanged (see "Caveats" in "Discussion" section).

76% of observed school sets, and 75% of observed log sets. The set data reported 134, 1,098, and 9,819 tons of observed discard, respectively. A nonzero amount of discard was reported in 65% (Table 1) of log sets where discard was recorded, but in only 8% of school sets and only 0.7% of dolphin sets where discard was recorded. Frequency distributions for tons of tuna discarded per set were clustered near zero for dolphin sets, were somewhat wider for school sets, and were much wider for log sets (Fig. 3), indicating the increasing frequency and increasing tonnage of tuna discard from dolphin, school, and log sets, respectively.

Geographic patterns in discard reflected geographic patterns in effort devoted to the three different set types. Both effort and positive discard occurred most frequently in area 1 for dolphin sets and in area 3 for school and log sets (Table 1).

Expected discard per set

Expected discard per set for log sets was 10.5 short tons of tuna (all tuna species combined; SE= 0.83, *n*=998, means range 7.1–15.4 short-t depending on geographic area; Fig. 4). Expected discard per set for school sets was 1.15 short tons of tuna (SE=0.24, *n*=960, means range 0.97–1.57 short-t) depending on geographic area). Expected discard per set for dolphin sets was 0.06 short tons of tuna (SE=0.2, *n*=2,110 fishery wide).

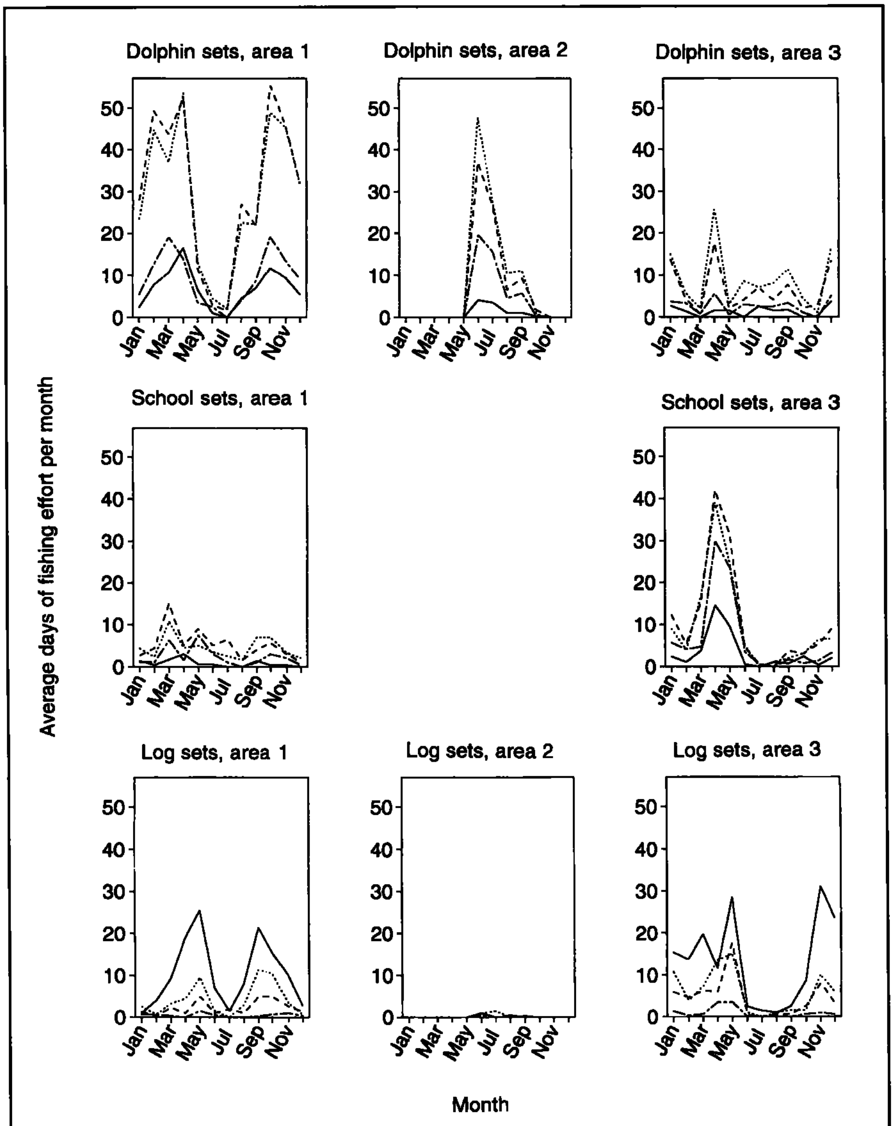

Figure 2

Daily, monthly, and geographic (areas 1, 2, and 3) patterns in fishing effort (number of sets) made on dolphin, school, and log sets by the U.S. tuna purse-seine fleet fishing in the eastern tropical Pacific Ocean, 1989–92. Solid line = before 0800 hours, dotted line = 0800–1200 hours, dashed line = 1200–1600 hours, and dot-dashed line = after 1600 hours.

Estimated average annual discard

Despite the much larger number of sets (greater fishing effort) on dolphins than on school or logs (Table 1), estimated average annual discard was much greater for log sets than for school or dolphin sets, reflecting the enormous difference between set types in expected discard per set. Estimated average annual discard for the entire U.S. fleet during the study period was 88 short tons per year (SE=29, *n*=2,110) from dolphin sets, 595 short tons per year (SE=125, *n*=960) from school sets, and 5,400 short tons of tuna (all species combined) per year (SE=426, *n*=998) from log sets, based on observed patterns of effort (Fig. 5).

Redistributing the great number of dolphin sets to either of the other set types considerably increased predicted annual discard of tuna from school or log sets (or both), and from the U.S. fleet as a whole.

Redistributing all dolphins sets to school sets increased predicted annual discard of tuna from school sets by the U.S. fleet from 595 to 2,190 short tons per year. Redistributing all dolphin sets to log sets had by far the greatest effect, increasing predicted annual discard of tuna from log sets by the U.S. fleet from 5,400 to 19,900 short tons.

Predicted total annual discards of tuna from the U.S. fleet for all set types combined were 7,500, 14,000, and 20,500 short tons for redistribution of dolphin sets to all school sets, combined school and log sets, and all log sets, respectively (Fig. 5), representing increases of 1.25 (7,580/6,080), 2.31 (14,000/ 6,080), and 3.34 (20,500/6,080) times, respectively.

Discussion

Comparison with other discard data

Although the data used in this report consist of estimates made "by eye" (i.e. estimated by visually noting the volume of discarded tuna and mentally comparing that volume to the volume of tuna in some container of known size, e.g. the vessel's brailer) and could not be analyzed in hindsight for inter-observer reliability, our results are reasonably similar in magnitude, especially in relative magnitude (expressed as tonnages) between set types, to data collected during 1993 and 1994 by the IATTC as part of a greatly expanded bycatch sampling program in the ETP. Average short tons of tuna discarded per set during these 2 years for dolphin, school, and log sets was 0.17 (no difference between years), 0.58 (0.5 in 1993, 0.9 in 1994), and 8.3 (5 in 1993, 11 in 1994), respectively (Hall[8]). These values are reasonably comparable to our estimates of 0.06, 1.2, and 10.5 short tons of tuna discard per set for dolphin, school, and log sets, respectively. The apparently large differences between the IATTC and NMFS estimates for dolphin sets, and to some extent for school sets, are relatively unimportant because the overall discards for these set types are so low. In addition, annual differences can be substantial although still low in relation to log sets.

Implications for the ETP yellowfin fishery

Our results imply that historically, tuna discard from the U.S. tuna

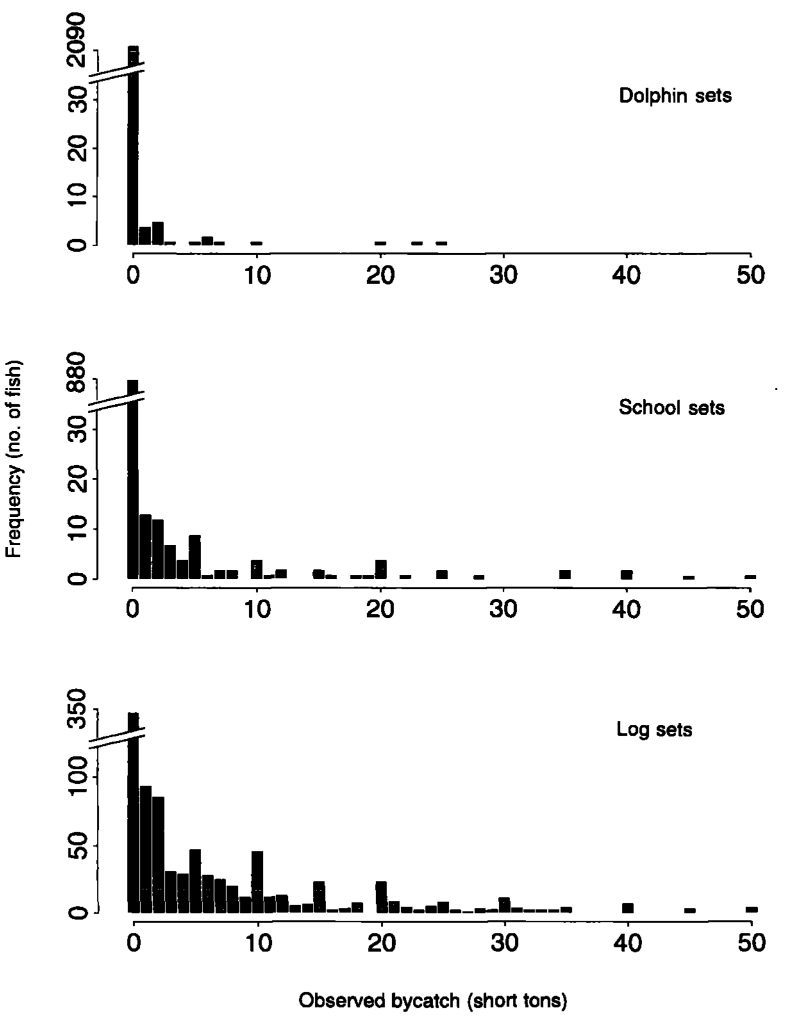

Figure 3

Frequency distributions of observed discard per set for dolphin, school, and log sets by the U.S. tuna purse-seine fleet fishing in the eastern tropical Pacific Ocean, 1989–92. The scale for school sets does not show 3 school sets exceeding 50 short tons per set, totaling 310 short tons, and representing 30% of total catch on school sets, with maximum catch per school set = 150 short tons. The scale for log sets does not show 25 sets exceeding 50 tons per set, totaling 3,221 short tons, and representing 33% of the total catch on log sets, with maximum catch per log set = 325 short tons.

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[8] Hall, M. 1995. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92038. Personal commun.

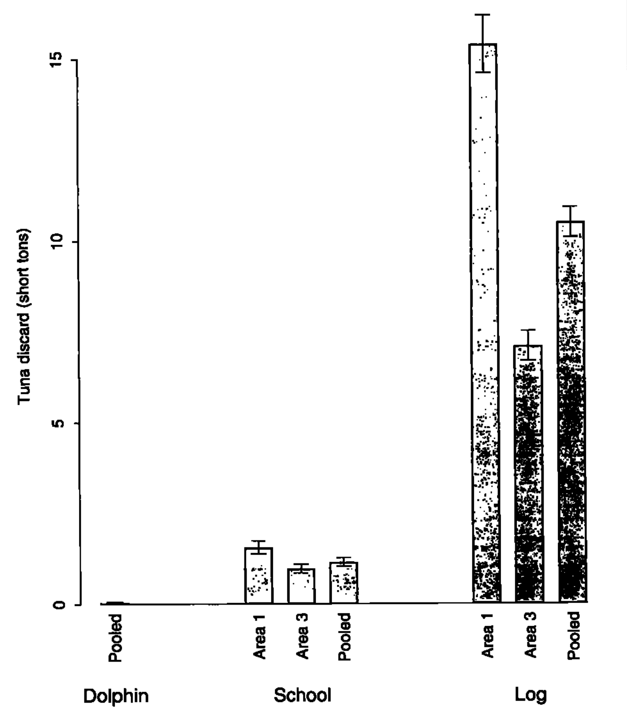

Figure 4

Estimated expected tuna discard per set by the U.S. tuna purse-seine fleet fishing in the eastern tropical Pacific Ocean, 1989–92, in specified geographic strata (Federal Register, 1989) and in all areas pooled. Standard errors indicated by vertical bars.

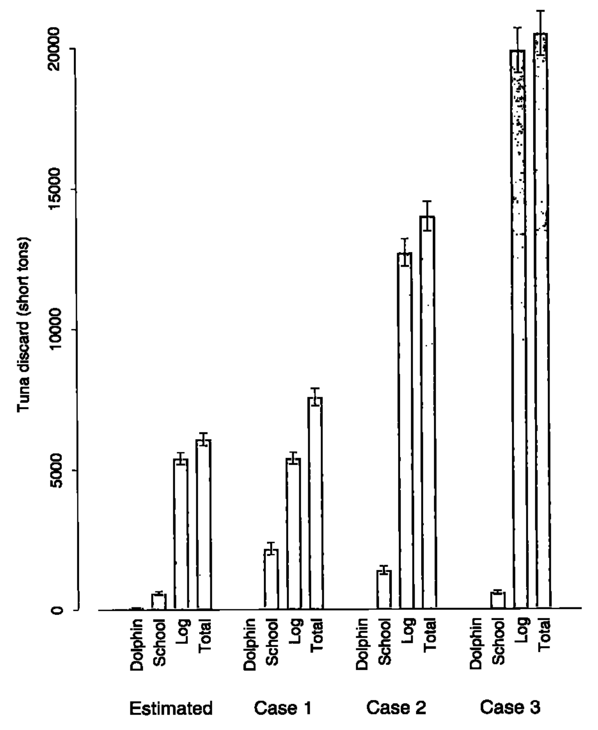

Figure 5

Estimated annual tuna discard by the US tuna purse-seine fleet fishing in the eastern tropical Pacific Ocean, 1989–92, under observed effort patterns and redistributed effort patterns where all dolphin sets were redistributed exclusively to school sets (case 1), equally to school and log sets (case 2), and exclusively to log sets (case 3).

purse-seine fleet in the ETP was probably relatively minor (although local effects might have been large at some times). From the fishery's inception in the early 1960's through the mid-1980's, the majority of U.S. vessels (which during that period represented over 90% of the international fleet) targeted tuna associated with dolphins, a strategy that generates very little tuna discard.

The situation has changed dramatically in the past few years, in particular since 1) passage, in 1988, of stringent new amendments to the Marine Mammal Protection Act, 2) the decision by U.S. canneries in April 1990 to buy only "dolphin-safe" tuna, and 3) the passage of the International Dolphin Conservation Act of 1992 (IDCA). The 1988 amendments required non-U.S. fleets to meet strict comparability criteria related to dolphin mortality rates in order to export tuna to the U.S. The cannery decision for dolphin-safe tuna (adopted also by European Community nations in 1993) means that the canneries involved will now buy only tuna that is certified not to have been caught either in association with dolphins or by drift gill nets on the high seas. The IDCA places increasing pressure on both U.S. and non-U.S. fleets to reduce dolphin mortality and to eliminate it altogether by 1999.

Largely in response to these events, most U.S. vessels have left the ETP, either to change flags, retire from fishing altogether, or to fish in the western Pacific Ocean under license from various island nations. Of those U.S. vessels remaining (4 vessels in 1994), all fish on school and floating logs. This change to school and log fishing will have greatly increased the U.S. discard of small immature tuna, although the overall effect on the tuna stocks due to changes in fishing practices by the U.S. fleet is probably small because very few U.S. vessels are currently fishing for tuna in the ETP using any of these set types.

However, the decrease in the size of the U.S. fleet has been offset by increases in the sizes of non-U.S. fleets so that the overall size of the international fleet has remained relatively constant since the mid-1980's. Although many of the non-U.S. vessels are still fishing "on dolphin," increasing numbers of vessels changed during the study period to school and log fishing in response to pressures from the canneries, the MMPA, and the IDCA. Because all large ETP purse-seiners use the same type of gear, fishing procedures, and vessels, a rough estimate of tuna discard for the entire international fleet can be obtained by simply applying the ratio of discard of total catch for the U.S. fleet to total catches reported for the international fleet, under the assumption that non-U.S. fleets discarded tuna in the same manner as the U.S. fleet[9] during the study period.

Average annual commercial catch (short tons landed, all tuna species combined) by U.S. vessels fishing in the ETP during 1989–91 was 76,425 short tons.[10] Estimated average annual discard for the U.S. fleet during the study period was 6,080 short tons. Thus, estimated total annual discard by the U.S. fleet under observed patterns of effort was 7.96% (6,080/76,425 x 100) of the average annual commercial catch (Hall[11]). As noted previously, predicted total annual discards from the U.S. fleet for redistributions of dolphin sets to log or school sets (or both) increased predicted total discard by 1.25 times for redistribution to school sets, 2.31 times for redistribution to a combination of log and school sets, and 3.37 times for redistribution to log sets (Fig. 5).

Average annual commercial catch for the international fleet during the study period was 395,768 short tons.[12] If observed effort patterns of the U.S. fleet during the period were the same as effort patterns of the international fleet, then discard from the international fleet under hypothetical redistributions of dolphin effort can be simply estimated as 7.96% of 395,768 short tons, i.e. 31,500 short tons. Assuming that changes in effort would affect discard in the same way for the international fleet as for the U.S. fleet, then discard under hypothetical redistributions of dolphin effort can be predicted as 1.25 times, 2.31 times, and 3.37 times 31,500 short tons, for redistributions to all school sets, combined school and log sets, and all log sets, respectively. The predictions are then 39,200, 72,700, and 106,000 short tons of tuna discarded, respectively (Fig. 6).

The significance of these discard predictions for future tuna resources depends on their magnitude in relation to the total stocks of tuna in the ETP. Although the amount of tuna that is potentially discarded appears high, it will not be particularly important if it represents only a few percent of the to-

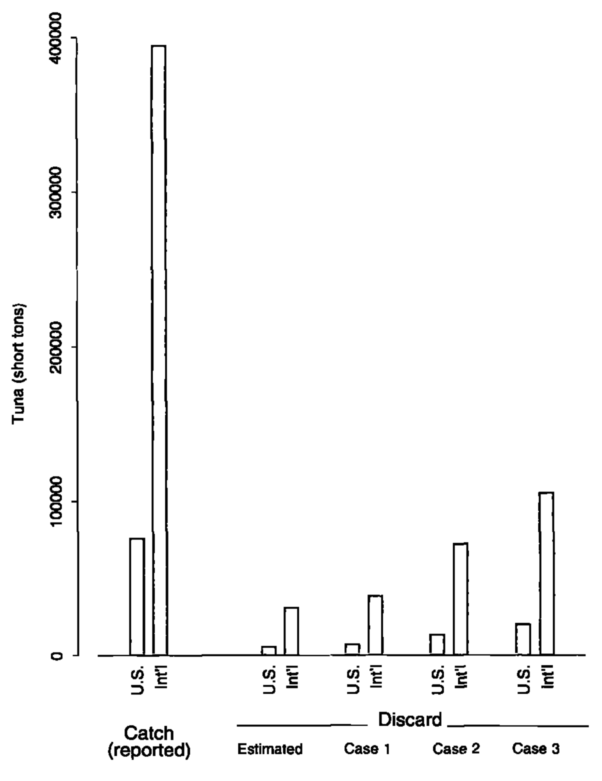

Figure 6

Average annual commercial tuna catch and estimated average annual tuna discard by the U.S. and international purse-seine fleet fishing in the eastern tropical Pacific Ocean, 1989–92, under observed effort patterns and redistributed effort patterns where all dolphin sets were redistributed exclusively to school sets (case 1), equally to school and log sets (case 2), and exclusively to log sets (case 3).

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[9] Although we cannot test this assumption at present, presumably all vessels selling fish to canneries serving international markets have the same constraints on acceptable sizes for individual tuna retained for sale. It is possible that smaller sizes may be acceptable by canneries located in individual countries, but we are not aware of any such policy. The implications for population dynamics of affected tuna will be the same regardless of whether the fish are marketed or not (they are removed from the population in either case).

We also assume here that the effort distribution is the same for both the international and U.S. fleets. That is not strictly true, but the main difference tends to be that the international fleet, composed mostly of Mexican vessels, fishes more inshore areas (i.e. more in area 1) than does the U.S. fleet alone. Fishing more inshore would increase the fraction of school and log sets in the data. Thus, extrapolation from the U.S. data will, if anything, underestimate the extent of bycatch on school and logs.

[10] Estimated annual catches of tuna (all species combined, surface fishing only) for the U.S. fleet were 110,981, 79,530, and 38,765 short tons for the years 1989, 1990, and 1991, respectively (IATTC, 1991), averaging 76,425 short tons annually for the period.

[11] This compared well with IATTC data showing 7.4% of all sampled tuna captured during 1993 and 1994 were discarded (13,500 short tons of tuna discarded from 181,422 short tons of tuna caught) (Hall, M. 1995. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA 92037. Unpubl. data).

[12] Estimated annual catches of tuna (all species combined, surface fishing only) for the international fleet were 441015, 407445, and 338,385 short tons for the years 1989, 1990, and 1991 respectively (IATTC[5]), averaging 395,768 short tons annually for the period.

tal fish currently in the ecosystem, or a few percent of annual fishery recruitment (i.e. new young fish becoming vulnerable to purse-seine fishing each year), or individuals from a stock with very short life span and high annual ability to restock. Potential significance of discard calculations can be determined by combining estimates of recruitment with information about the species and size composition of fish discarded. These calculations are a rough estimate of the number of fish discarded (i.e. lost from the future commercial population) in relation to fish available for commercial catch. Estimates of discards of young, small fish are especially important in terms of future resources because these young fish have the most biomass to gain per individual, as well as the greatest reproductive potential.

Data recently collected by the IATTC as part of their bycatch investigations indicate that both the fraction and the size composition of yellowfin tuna discards change dramatically with set type (Hall and Deriso[13]). These data can be used to estimate the numbers of yellowfin tuna discarded under various fishing regimes.

IATTC data show that yellowfin tuna composed 92% (by weight) of tuna discard from dolphin sets, 50% of discard from school sets, and 22% of discard from log sets during the years 1993 and 1994 (Table 2). Of this yellowfin tuna discard, small yellowfin tuna (defined as less than 2.5 kg, or 5 lb) discarded from log sets were by far the most serious type of loss, particularly in the scenario where all dolphin-set effort was redistributed to log sets. Although small yellowfin tuna composed only 3% and 17% (by weight) of yellowfin tuna discards from dolphin and school sets, they composed about 76% of the discard from log sets (Table 2).

These data can be used to predict yellowfin tuna discard under different fishing regimes, given the percentage of total effort devoted to each of the set types. Assuming, as before, that effort patterns of the international fleet were similar to effort patterns of the U.S. fleet during the study period, we can use the percentages of total observed discard resulting from each set type in the U.S. fleet to estimate tonnages of discard from each set type for the international fleet during the same period.

Of the total annual discard of 6,080 short tons from the U.S. fleet under observed patterns of effort, 88 short tons (1.44%) resulted from dolphin sets, 595 short tons resulted from school sets (9.78%) and 5,400 short tons resulted from log sets (88.8%). Application of these percentages to the estimated total annual discard of 31,500 short tons of tuna from the international fleet produces estimates of 454 (31,500 × 1.44%), 3,079 (31,500 × 9.78%) and 28,000 (31,500 × 88.8%) short tons of tuna discarded annually from dolphin, school, and log sets by the international fleet (Table 2). The percentages of discard composed of

Table 2

Steps in estimating number of individual yellowfin tuna of different sizes discarded from each set type. "% yellowfin" is the sum of all yellowfin bycatch divided by the sum of all tuna bycatch for the years 1993–94 in the IATTC bycatch data base. "% small yellowfin" is the average of percent values for 1993 and 1994; "% medium yellowfin" and "% large yellowfin" were calculated similarly. "Small" yellowfin are less than 2.5 kg. "Medium" yellowfin are 5–15 kg. "Large" yellowfin are greater than 15 kg. Weights are expressed in short tons.

Set type	Total tuna discard (tons)	% yellowfin	Yellowfin discard (tons)	% small yellowfin	% medium yellowfin	% large yellowfin	Small yellowfin (tons)	Medium yellowfin (tons)	Large yellowfin (tons)
dolphin	475	92	437	3	31	66	13	135	288
school	2,976	50	1,488	17	31	53	253	461	789
log	28,177	22	6,199	76	24	1	4,711	1,488	62

Ranges of percent values:
(left = 1993, right =1994)

Set type	% yellowfin	% small yellowfin	% medium yellowfin	% large yellowfin
dolphin	(92–99)	(1–5)	(20–42)	(57–74)
school	(49–50)	(16–17)	(25–36)	(48–57)
log	(19–29)	(73–78)	(20–27)	(0.2)

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[13] Hall, M., and R. Deriso. 1995. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, La Jolla, CA, 92038. Personal commun.

yellowfin tuna can be applied to these set-specific tuna tonnages to produce estimates of 418, 1,540, and 6,150 short tons of yellowfin tuna discarded annually by the international fleet, under the assumption of observed U.S. effort patterns (Table 2). These estimates compare reasonably well with estimates of total short tons of yellowfin tuna discarded by the international fleet during 1993 and 1994 of 449–917 short tons from dolphin sets, 606–2,108 short tons from school sets, and 3,802–4,150 short tons from log sets (IATTC[14]).

Yellowfin tuna discards under redistributed patterns of effort can be predicted from tonnages predicted under the different effort regimes. The "worst-case" discards will obviously occur when all dolphin sets are redirected to log sets. The total tonnage of tuna discard in this circumstance is the sum of discards from dolphin sets (by definition 0, because we redistributed the dolphin sets effort to log sets), school sets (3,080 short tons, the same as under observed effort patterns because school effort is assumed to be unchanged), and log sets (103,000 short tons; estimated as log discard from observed patterns, 28,000 short tons, multiplied by 3.69, the increase factor for discard observed in U.S. data when redistributing all dolphin sets to log sets). The tonnage of yellowfin tuna in each of these set categories is 0 × 0.92 = 0 short tons for dolphin sets, 3080 × 0.5 = 1,540 short tons for school sets, and 103,000 × 0.22 = 22,700 short tons for log sets, with the "fraction yellowfin" from IATTC's data base.

Obviously, changing entirely from dolphin sets to an equal number of log sets dramatically increases predicted total bycatch of yellowfin tuna. A particularly unfortunate feature of this increase is the number of small yellowfin tuna involved; the vast majority of log-set yellowfin tuna discards are new recruits to the fishery that have grown just large enough to be caught in the seine (Table 2). This increase in yellowfin tuna bycatch is unfortunate for two reasons: first, removing these small fish removes their potential to grow larger and more valuable, thus reducing overall yield per recruit for the fishery (Punsly et al., 1994); second, these small fish are prereproductive. No stock-recruitment relationship has yet been demonstrated for yellowfin tuna in the ETP, but if one exists, these increased losses to bycatch might become troublesome over long periods of time.

The actual effect of these discards of small fish on future yield per recruit depends on the number discarded in comparison with the number recruited. Fortunately, the annual recruitment of yellowfin tuna has been estimated by the IATTC.[5] The number of small fish discarded can be estimated from the weight discarded by assuming that all small discarded yellowfin are new recruits (Table 2). This is reasonable because the "small" size class of discards is defined in the IATTC bycatch data base as fish less than 2.5 kg (Table 2), and Cole (1980) reported that yellowfin tuna recruit to the ETP tuna purse-seine fishery at sizes ranging from 0.7 to 2.0 kg. Thus a short ton of "small" discarded yellowfin tuna, at 907 kg per ton, should include between 454 and 1,296 individual fish.

According to inferred effort patterns, estimated average annual discard of small yellowfin tuna by the international fleet was 4,950 short tons , representing 2.3–6.4 million fish (Table 2). If all dolphin sets are assumed to be replaced by an equal number of log sets, then predicted discard of small yellowfin tuna increased to 17,562 short tons, representing 8.0–22.7 million fish (0 short tons from dolphin sets plus 262 short tons from school sets plus 17,300 short tons from log sets).

By comparison, the estimated annual recruitment of small yellowfin tuna to the ETP fishery for 1983–91 was 98 million fish (IATTC[5]); thus observed effort patterns may have been generating discards representing 2–7% of total recruitment each year. On the other hand, a redistribution of all dolphin-set effort to log sets could increase discards to 8–24% of annual recruitment, depending on the actual sizes of the discarded fish (smaller fish would lead to greater losses per ton of discard, although the increase in catchability with size in this range suggests that much of the discard might be closer to 2 kg than 0.7 kg).

These estimated discards would occur in addition to an expected 25% reduction in yellowfin tuna catch biomass if all dolphin-fishing effort were redistributed to log-fishing effort (Punsly et al., 1994). By implication, a change entirely to log fishing could reduce yellowfin tuna catch in the ETP by as much as 30–50%. A change to a combination of school and log fishing would be less detrimental, but the actual effect would depend on the ratio of school-set effort to log fishing effort. Historical patterns of purse-seine fishing in the ETP, in which 50% or more of effort was directed to dolphin sets, obviously minimized any removal of new recruits from the fishery. Replacement of the entire dolphin-set effort with log-set effort would reverse that characteristic of the fishery, with potentially troublesome effects. Losses to "observed" recruitment as high as 50% may not be likely (Deriso[15]), but it is not difficult to imagine that sus-

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[14] IATTC Third Quarter Report. 1995. Table 10. Inter-American Tropical Tuna Commission, c/o Scripps Institute of Oceanography, 8604 La Jolla Shores Drive, La Jolla, CA 92038.

[15] It is also possible that a shift to log fishing could make some areas, particularly offshore areas, uneconomical to fish so that

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tained losses of even 30% annually might pose long-term problems for the fishery.

Caveats

Our results are based on a number of assumptions, including among others 1) similarity between effort patterns of the U.S. and international fleets in the ETP and 2) constancy in discard per set within each set type, regardless of changes in ecological or economic forces (e.g. oceanographic conditions, fish prices, or both), proportions of effort devoted to each set type, or times and areas fished. In addition, our study does not address possible limitations on the availability of nondolphin sets, e.g. limitations on the number of available schools or logs, possible changes in fleet sizes with the elimination of dolphin sets (e.g. seiners leaving the ETP), or the possibility of greater emphasis on log fishing through increased use of FAD's (fish aggregating devices). Our analysis also assumes that the catch per vessel, the number of vessels in the fleet, and the geographic distribution of set types would remain constant regardless of the amount of effort expended within each set type.

One or more of these assumptions may be invalid (e.g. Punsly et al., 1994), but at present the effects of violating them cannot be assessed quantitatively. For example, relatively greater effort in area 1 would increase tuna discard more than we have estimated in the present study, but increased competition for logs might decrease overall fishing success. Conversely, increased availability of "logs" (where the population of logs has been increased by deployment of FAD's) could mitigate this competition and lead to an increase in fishing success. Conversely yet again, increased availability of logs might "dilute" the available tuna resource per log, leading to decreased fishing success. The actual system response cannot be ascertained at this time.

In addition, the fine-scale size structure of the discards, particularly from log sets, is unknown. The estimated number of individuals potentially lost per short ton varies by a factor of three; at the lower estimate, only about 8% of recruits would be lost to discard; at the higher estimate, closer to 25% would be lost. More estimates await subsampling studies not yet completed. However, even a moderate estimate of 15% loss per year is difficult to dismiss as unimportant, particularly in combination with the significant increase in landed recruits that will result from increased log fishing.

More detailed data on size structure of the bycatch would also make it possible to address the issue of changes in the discard of medium to large yellowfin tuna that might occur in response to changes in effort distribution. Large and medium yellowfin can only become discard in the event that they grow to medium or large size; increases in log fishing will decrease survival of young yellowfin tuna and decrease the probability that these fish will show up later either as direct catch or as discards. Such detailed size-structure data would also make it possible to translate all discard data to a standardized age, making it easier to compare discards between size classes (e.g. a single 2-year-old yellowfin tuna might be found to be equivalent to 100 or more 6-month-old fish if mortality remained the assumed constant average over time). These more detailed studies should be possible in future given the intensive discard sampling program initiated recently by the IATTC (Deriso).[16]

Conclusions

The work presented here provides only a general overview of the apparent situation based on data available to date, but the implications of our simple study are serious and merit further consideration. Our calculations, although only approximate, imply strongly that a change from dolphin to school or (especially) log fishing (or both), although it might alleviate the problem of dolphin mortality, could have significantly detrimental effects on other components of the eastern tropical Pacific Ocean ecosystem, not the least of which is the commercial resource upon which the fishery rests.

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[15] *continued*

the predicted redistribution of log and school effort to those areas might not occur. Instead, the fishery would likely contract to more nearshore areas, similar to the situation during the 1960's. Yellowfin tuna resident in the offshore zones would escape all exploitation with the resulting appearance of a much smaller stock—on the order of another 25% reduction in recruitment (Deriso, R. 1995. IATTC, c/o Scripps Institute of Oceanography, 8604 La Jolla Shores Drive, La Jolla, CA, 92038. Personal commun.).

[16] Deriso, R. 1996. IATTC, c/o Scripps Institute of Oceanography, 8604 La Jolla Shores Road, La Jolla, CA 92038. Personal commun.

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