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PRELIMINARY ESTIMATES OF 2003 DOLPHIN ABUNDANCE IN THE EASTERN TROPICAL PACIFIC

by

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ADMINISTRATIVE REPORT LJ-05-05

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ABSTRACT

A large-scale line-transect survey was carried out in 2003 to estimate the abundance of dolphins involved with the yellowfin tuna purse-seine fishery in the eastern tropical Pacific Ocean. Preliminary 2003 estimates of abundance for northeastern offshore spotted dolphins and eastern spinner dolphins, the stocks most affected by the fishery, are 737,000 (CV=0.15) and 613,000 (CV=0.22), respectively. Estimates of abundance are also given for 8 other dolphin stocks in the study area: western/southern offshore spotted, whitebelly spinner, striped, rough-toothed, common, bottlenose and Risso's dolphins. Estimates of abundance for northeastern offshore spotted and eastern spinner dolphins are slightly higher than recent past estimates. Results are preliminary until some differences from past surveys are better understood, and until all past estimates are reanalyzed with 2003 school size calibration factors.

INTRODUCTION

In 1997 the U.S. Congress directed the Secretary of Commerce to determine whether chasing dolphins and deployment of purse-seine nets around dolphins during tuna fishing operations in the eastern tropical Pacific (ETP) was having a significant adverse impact on depleted dolphin stocks (International Dolphin Program Conservation Act, Public Law 105-42). A portion of this law directed NOAA Fisheries to undertake three large-scale cruises between 1998 and 2000 to estimate the current abundances of dolphin populations affected by the fishery.

Among other results, data from the 1998-2000 cruises indicated that northeastern offshore spotted and eastern spinner dolphin populations, the stocks most affected by the fishery, were not recovering as expected (Gerrodette and Forcada 2005, Reilly et al. 2005). Accordingly, the Southwest Fisheries Science Center plans to conduct a cruise every 3 years and to continue monitoring dolphins affected by the fishery. The 2003 Stenella Abundance Research cruise (STAR03) was the first of these planned surveys.

This report presents preliminary estimates of 2003 abundance of ten dolphin stocks in the ETP, based on line-transect data collected during STAR03. A question of primary interest for northeastern offshore spotted and eastern spinner stocks is whether the populations are recovering now that direct fishery-related mortality has been reduced to a low level. Therefore, data in this report have been analyzed in a way to make them most comparable to previous estimates. Such an analysis, however, does not use the most recent school size calibration data (see Methods). Until the entire time series is reanalyzed with the 2003 calibration data, and some patterns in the 2003 data are better understood (see Discussion), the estimates of abundance in this report should be considered preliminary.

METHODS

Study area and stratification

The study area was the same as for the 1998-2000 cruises. The study area extended from the US/Mexico border, south to the territorial waters of Peru, bounded on the east by the continental shores of the Americas, and to the west by Hawaii, roughly from 32° N to 18° S latitude, and from the coastline to 153° W longitude (Fig. 1).

Survey effort within the study area was stratified according to the geographic distribution of the primary stocks affected by the fishery: the northeastern (NE) offshore stock of the pantropical spotted dolphin, *Stenella attenuata attenuata*, north of 5EN and east of 120EW (Perrin et al. 1994), and the eastern spinner dolphin, *Stenella longirostris orientalis* (Perrin 1990). Strata for the 2003 survey were the same as for the 1998-2000 surveys, except that the western boundary of the "core" stratum was expanded to the west to include more of the range of eastern spinner dolphins. For purposes of estimating abundance of the NE offshore spotted dolphins, which by definition occur only east of 120EW longitude, this expanded core stratum was subdivided into 2 parts, designated Core and Core2 (Fig. 1). Within each stratum, transect lines were randomly but not uniformly spaced, given the logistical constraints of ship range and speed. Ships moved at night, which contributed to some independence among daily transects. The starting point of each day's transect effort was wherever the ship happened to be at dawn along the overall trackline.

The STAR03 survey was carried out with NOAA Ships *David Starr Jordan* and *McArthur II* between July 29 and Dec 10, 2003, the same time as previous surveys (Jackson et al. 2004). The *Jordan* has been used for ETP cetacean surveys for many years. It is 52.1m in length and has an observer eye height of 10.7m. The *McArthur II* was used on ETP surveys for the first time in 2003. It is a larger ship, with a length of 68.3m and an observer eye height of 15.2m. Also, because of its design, the *McArthur II* rolls less and has less vibration than the *Jordan*. Due to the greater height and stability of the *McArthur II*, dolphins may be detected at greater distances and/or with higher probability on this ship.

Field methods

Methods of collecting data followed standard protocols for line-transect surveys conducted by the Southwest Fisheries Science Center (Kinzey et al. 2000). In workable conditions, a visual search for cetaceans was conducted on the flying bridge of each vessel during all daylight hours as the ship moved along the trackline at a speed of 10 knots. The team of 3 observers rotated positions every 40 minutes; thus, each observer stood watch for 2 hours, then had 2 hours rest. Two observers, one on each side of the ship, searched with pedestal-mounted 25x150 binoculars. Each 25X observer scanned from abeam (90E from the trackline) to the trackline. Together, the two 25X observers thus searched the 180E forward of the ship. This was a slight change from previous searching protocol. On past cruises, each observer scanned from abeam to 10E past the trackline on the opposite side; thus, there was a 20E area of overlap near the trackline. The 25X binoculars were fitted with azimuth rings and reticles for angle and distance measurements. The third observer searched by eye and with hand-held 7X binoculars, covering areas closer to the ship over the whole 180E forward of the ship.

When a marine mammal was sighted, the horizontal and vertical angles to the sighting were measured, and the third observer entered the data in a portable computer using a customized data entry program, WinCruz. The program computed the radial and perpendicular distances to the sighting based on these angles. If the sighting was less than 5.6 km (3.0 nautical miles) from the trackline, the team went "off-effort" and directed the ship to leave the trackline and approach the sighted animal(s). The observers identified the sighting to species or subspecies (if possible) and made school-size estimates. Each observer team had at least one observer who was highly experienced in the field identification of marine mammals in the ETP. Observers discussed distinguishing field characteristics in order to obtain the best possible identification, but they estimated school sizes and, in the case of mixed-species schools, school composition, independently. The computer was connected to the ship's Global Positioning System, recording the position of each sighting and all other data events.

Effort and sightings

Estimation of dolphin abundance was based on search effort and sightings that occurred during on-effort periods. A small number of sightings and effort in rough seas (Beaufort >5) were not included, due to very low cetacean sighting rates under these conditions. Sightings and effort within a day were summed; thus, one day of search effort was considered the sampling unit. If a transect crossed a stratum boundary during a day, separate transects were recorded for each stratum.

In this report, we estimate abundance for the following dolphin species and stocks: spotted (*Stenella attenuata*, northeastern offshore, western/southern offshore, and coastal stocks), spinner (*S. longirostris*, eastern and whitebelly stocks), striped (*S. coeruleoalba*), rough-toothed (*Steno bredanensis*), short-beaked common (*Delphinus delphis*, northern, central, and southern stocks combined), bottlenose (*Tursiops truncatus*), and Risso's (*Grampus griseus*).

School (group) size

The *David Starr Jordan* carried a Hughes 500D helicopter equipped with medium-format, motion-compensated, military reconnaissance cameras. In suitable conditions of sea state, sun angle and school configuration, it was possible to photograph entire schools of dolphins and count the number of dolphins directly from the negatives. However, aerial photographs were available for only a subset of schools seen from the *Jordan*, and none of the schools seen from the *McArthur II*. For most schools, school size was estimated from the best, high and low estimates made by each observer.

By comparing each observer's estimates of the photographed schools to the counts from the negatives, individual correction or calibration coefficients have been estimated (Gerrodette et al. 2002). The calibration coefficients adjust for each observer's tendency to over- or under-estimate dolphin school size. These coefficients, based on data collected from 1987 to 2000, were used to produce the current set of abundance estimates (Gerrodette and Forcada 2002). The application of these calibration coefficients to improve observers' estimates of school sizes has a strong effect on the estimates of abundance. The 2003 aerial photography data modify these coefficients to some degree, and thus affect all past estimates of abundance. To facilitate comparison of the 2003 abundance estimates with past estimates, we have used the same calibration coefficients as used in previous analyses, treating observers new in 2003 as any other uncalibrated observer (Gerrodette and Forcada 2002). That is, we have not included the 2003 aerial photography data in the calibration coefficients because that would make the 2003 estimates presented here not entirely comparable to past estimates. Future work will incorporate the 2003 calibration data in the 2003 estimates as well as all past estimates.

Abundance

Estimation of abundance was based on distance sampling (Buckland et al. 2001, Marques and Buckland 2003, Buckland et al. 2004) and followed methods described in Forcada (2002) and Gerrodette and Forcada (2002). A multivariate extension of conventional line-transect analysis estimated abundance as

$$\hat{N} = \sum_j \frac{A_j}{2L_j} \sum_i \hat{f}_{ij}(0, c_{ij})\, \hat{s}_{ij} \ ,$$

where A_j is the area and L_j the length of search effort in stratum j, $\hat{f}_{ij}(0, c_{ij})$ the estimated probability density evaluated at zero perpendicular distance of the sighting i in stratum j under conditions c_{ij}, and $\hat{s}_{ij}$ the estimated school size of the ith sighting in stratum j (or subschool size of the species of interest in the case of mixed-species schools). Estimation was based on search effort and sightings that occurred during on-effort periods, in conditions of Beaufort sea state ≤ 5. The vector of covariates c_{ij} included the continuous variables school size, Beaufort, swell height and time of day, and the categorical variables ship, sighting cue, method of sighting, presence/absence of glare on the trackline, and presence/absence of seabirds. Sea state measured on the Beaufort scale was actually a discrete variable, but the ordinal Beaufort scale could be modeled satisfactorily as a continuous variable (Barlow et al. 2001). All dolphin schools on or near the trackline were assumed to be detected.

For consistency with previous analyses, we used the half-normal model to estimate f_{ij} $(0,c_{ij})$, with sightings truncated at 5.5 km. Each species was treated separately for estimation of f_{ij} $(0,c_{ij})$, but stocks within species were pooled, including sightings identified to species but not stock (*e.g.*, unidentifed spotted dolphins). Sightings of unidentified dolphins, unidentified small delphinids and unidentified medium delphinids were pooled together into a single category to estimate f_{ij} $(0,c_{ij})$. Covariates were tested singly and in combination, and a set of models was chosen on the basis of Akaike's Information Criterion corrected for sample size (AIC_c) (Hurvich and Tsai 1989). For computational efficiency, we retained all models with an AIC$_c$ difference (ΔAIC) of less than 2 from the model with the minimum AIC$_c$. Final estimates of f_{ij} $(0,c_{ij})$ were estimated by averaging across all the retained models, using the AIC$_c$ scores as weights. The weight of the estimate from the jth model was $\exp(-0.5\Delta AIC_j)/\sum_j \exp(-0.5\Delta AIC_j)$ (Burnham and Anderson 1998).

Pooled components of the abundance estimates were computed to provide additional summary and diagnostic statistics. Pooled components $\hat{f}(0)$, expected school size $\widehat{\mathrm{E}(s)}$, school encounter rate n/L, and percentage of the total abundance estimate due to the prorated abundance of unidentified sightings (see next section) were calculated across all sightings i and strata j as

$$\hat{f}(0) = \sum_j \sum_i \hat{f}_{ij}(0,c_{ij}) \Big/ \sum_j n_j$$

$$\widehat{\mathrm{E}(s)} = \sum_j \sum_i \hat{f}_{ij}(0,c_{ij})\, \hat{s}_{ij} \Big/ \sum_j \sum_i \hat{f}_{ij}(0,c_{ij})$$

$$n/L = \sum_j n_j \Big/ \sum_j L_j$$

$$\%\ \text{pro} = 100 \sum_j \hat{N}_{unid,j} \Big/ \sum_j \left(\hat{N}_{unid,j} + \hat{N}_{id,j} \right)$$

for each stock and year. For stratum j, n_j is the number of sightings, $\hat{N}_{id,j}$ is the estimated abundance based on identified sightings, $\hat{N}_{unid,j}$ is the estimated abundance based on unidentified sightings.

Specific code in S-Plus (Insightful 2003) was written to implement the analysis. The code included calls to FORTRAN routines for the maximum likelihood optimization of the covariate density models. These routines are modifications of Buckland's (1992) algorithm to fit maximum-likelihoods of density functions using the Newton-Raphson method.

Unidentified sightings

Not all sightings could be identified to stock with certainty. The number of sightings recorded as unidentified was first reduced by assigning sightings recorded as "probable" to that identified category. For the remaining unidentified sightings, we estimated abundance for the unidentified category and prorated abundance among appropriate stocks in proportion, by stratum, to the estimated abundance from identified sightings of those stocks that were included in the broader unidentified category. The general form of the proration was

$$\hat{N}_{ij} = \hat{N}^*_{ij} + \hat{N}_{uj} \left(\frac{\hat{N}^*_{ij}}{\hat{N}^*_{ij} + \sum_k \hat{N}^*_{kj}} \right),$$

where $\hat{N}_{ij}$ is the revised abundance estimate of stock *i* in stratum *j*, $\hat{N}^*_{ij}$ is the abundance of stock *i* in stratum *j* estimated from identified sightings of stock *i*, $\hat{N}_{uj}$ is the abundance of the unidentified category estimated from unidentified sightings in stratum *j*, and $\hat{N}^*_{kj}$ is the abundance of stock *k* in stratum *j* for stocks other than *i* included in the unidentified sighting category. The proration is based the assumption that all taxa within the unidentified category were equally likely to be unidentified. While probably unrealistic, no data were available to relax this assumption.

We estimated and prorated abundance of six unidentified sighting categories:

Unidentified sighting category	Prorated to dolphin stock or species
Unidentified spotted dolphin	Northeastern, western/southern, and coastal spotted
Unidentified spinner dolphin	Eastern and whitebelly spinner
Unidentified common dolphin	Short-beaked and long-beaked common
Unidentified small delphinid	All of the above, plus striped
Unidentified medium delphinid	Risso’s, rough-toothed, and bottlenose
Unidentified dolphin	All of the above

The proration of unidentified dolphins and unidentified small dolphins did not include sightings of Fraser’s (*Lagenodelphis hosei*), Pacific white-sided (*Lagenorhynchus obliquidens*), or dusky (*L. obscurus*) dolphins. These species are rare in the core of the study area, and we did not attempt to estimate their abundance for this report. The exclusion of these species from the proration of unidentified dolphin abundance has a negligible effect on the estimates of abundance of the other species.

Precision

Precision of the abundance estimates and pooled abundance components was estimated by balanced nonparametric bootstrap (Davison and Hinkley 1997). Within each stratum, a balanced bootstrap sample was constructed by sampling transects (days on effort) with replacement, so that all transects were selected the same number of times in total. To include variability due to school-size estimation and the observer aerial-photo calibration procedure, for each school size estimate $\hat{s}$ in the bootstrap sample, the logarithm of a new school size was chosen from a normal distribution with mean $\ln(\hat{s})$ and variance $\mathrm{var}[\ln(\hat{s})]$, equal to the estimated mean and variance of the sighting’s school-size estimate obtained by calibration. For each bootstrap sample, the full estimation procedure was carried out, including proration and model averaging. To include model selection uncertainty and to avoid overestimating precision, multiple models were used in each bootstrap. Models for $f_{ij}(0,c_{ij})$ estimation were restricted to the set of models with $\Delta AIC \leq 2$, based on the original data, plus the univariate half-normal model. We computed the standard errors (SE), coefficients of variation (CV) and 95% confidence intervals (percentile method, Davison and Hinkley 1997) of the estimates of total abundance and pooled abundance components from 1,000 bootstrap samples.

Trend estimation

To examine trends in the time-series for NE offshore spotted and eastern spinner dolphins, current estimates were compared with previous estimates developed using the same analytical approach (Gerrodette and Forcada 2002). Weighted linear and quadratic (second-order) models were fitted to the series of estimates, using the inverses of variances as weighting factors. Statistical significance was tested against the null hypothesis of no change in population size with time, using a Type 1 error rate of $\alpha = 0.05$. Gerrodette and Forcada (2005) estimated statistical power for similar data, and found that type 2 error rates were small for rates of change > 2%.

RESULTS

Effort and sightings

During STAR03, there was a total of 25,247 km of transect effort on 223 transects, 11,967 km by the *Jordan* and 13,280 km by the *McArthur II*. Effort and number of transects by stratum are shown in Table 1 and Fig. 2.

All on-effort sightings for species and stocks whose abundance is estimated in this report are shown in Figs. 3-10. The category-specific numbers of sightings used for abundance estimation (with perpendicular distance ≤ 5.5 km and Beaufort < 6) are shown by stratum in Table 1.

School size

School size varied both between and within species (Table 2, Fig. 11). Short-beaked common dolphins had the largest observed mean school sizes (143.1), while rough-toothed dolphins had the smallest (9.1). Among the focal species, the mean observed school size for NE offshore spotted dolpins was 89.5 and for eastern spinner dolphins 129.4.

Detection function

Perpendicular distances to cetacean sightings from the *McArthur II* tended to be greater than those from the *David Starr Jordan* (Fig 12A). Species differed in their detection probabilities. Fig. 13 shows histograms of sighting frequency as a function of perpendicular distance for each dolphin species in 2003. Univariate halfnormal curves for all sightings are provided as visual summaries.

School size was the most common covariate selected (Table 3). Of the eight categories for which a detection function was estimated, six had school size as an important covariate affecting detection probability. For spotted, spinner, striped and short-beaked common dolphins, the model with school size (or, for striped dolphins, school size together with Beaufort sea state) was clearly better than all other models, as measured by the AIC criterion. Other species had more than one plausible model. The univariate halfnormal function (“pd only” in Table 3) was among the original set of retained models for two species, bottlenose and rough-toothed dolphins.

Abundance

The estimates of 2003 abundance for 10 dolphin species and stocks are given in Table 4. The populations of NE offshore spotted and eastern spinner dolphins, the two stocks of primary interest, were estimated to be 737,000 (CV = 14.7%) and 613,000 (CV = 21.9%), respectively. The most abundant dolphins in the study area were striped dolphins (1.47 million) and the least abundant (among these 10) were rough-toothed dolphins (48,000). The estimate of abundance for short-beaked common dolphins (*D. delphis*) includes parts of the northern and southern stocks as well as the central stock.

Pooled components of abundance $f(0)$, expected school size and encounter rate are also given in Table 4, along with the proportion of the abundance estimate due to the proration of unidentified sightings. For each estimate, the standard error, coefficient of variation, and lower and upper ends of a 95% confidence interval are reported from the bootstrap results.

Trends

Weighed linear regressions indicated a small positive trend for both species over the whole time-series (Fig. 14), but neither trend was significantly different from zero. The estimated rate of increase was 0.6%/year for NE offshore spotted and 1.1%/year for eastern spinner dolphins, with standard errors approximately equal to the estimates. For both species, linear models were significantly better than quadratic models (**)**$AIC_c > 2$). Estimates of abundance for both NE offshore spotted and eastern spinner dolphins were higher in 2003 than any of the estimates from 1998-2000, and within the range of the estimates from 1986-1990 (Fig. 14). Compared to the means of the estimates from 1998-2000 and 1986-1990, the 2003 estimates were 15% and 6% higher for NE offshore spotted dolphins, and 37% and 9% higher for eastern spinner dolphins. Again, however, given the uncertainty in the estimates, these differences are not statistically significant.

DISCUSSION

The 2003 cruise, like previous ETP cruises, was designed to estimate abundance for NE offshore spotted dolphins and eastern spinner dolphins, the two stocks of pelagic dolphins most affected by the fishery. Estimation of abundance for other species or stocks in the study area is possible, but the estimates are generally less precise because the survey was not optimized for them. Furthermore, estimates of abundance for other species or stocks are more variable from year to year because the animals may move into or out of the study area. The estimates for western/southern offshore spotted, whitebelly spinner, striped, rough-toothed, common, bottlenose and Risso’s dolphins were generally similar to previous, mostly unpublished, estimates using the same methods.

The estimates given in this report are preliminary and subject to revision with further analysis. The 2003 aerial photography data of dolphin schools will modify both current and past estimates of abundance. For comparability with past estimates, the 2003 school size calibration data have not been included in this analysis. Depending on whether the new 2003 observers tended to be lower or higher than average in their school-size estimation tendencies, final 2003 estimates will be more or less than estimated here. Past estimates will also be affected but to a lesser degree.

School size was an important covariate affecting detection probability for most species (Table 3). The univariate model with perpendicular distance as the only predictor was among the top models for only two of the eight species, and it was not the best-supported model for any species. The higher and more stable platform from the new *McArthur II* was probably the reason perpendicular distances tended to be greater than from the *David Starr Jordan* in 2003 (Fig. 12A). In previous years with the smaller *McArthur*, sightings distances were similar (Fig. 12B, 12C) or larger (Fig 12D) for the *Jordan*. The height of the flying bridge of the *McArthur* was approximately the same as the *Jordan*, whereas the height of the flying bridge of the *McArthur II* was nearly 50% higher. The distributions of perpendicular distances can differ between the ships for several reasons besides the height of the viewing platform. The ships cover different parts of the study area, encounter different species, and operate in different weather conditions. Moreover, the *McArthur II* had less vibration when searching through the large binoculars. Whatever the cause in 2003, however, ship was not as important a factor as school size on detection probability, at least for these species and for a truncation distance of 5.5 km. Ship was selected as a covariate in only one case, the third model for bottlenose dolphins (Table 3). Nevertheless, the distinct differences between the ships deserves further study and possible inclusion in the model. Different truncation distances and possibly different detection functions between the two ships may improve the analysis.

The components of abundance for the 2003 data showed complex patterns which require further analysis. For the two target species, NE offshore spotted and eastern spinner dolphins, encounter rates were generally higher than in previous years, which contributed to the higher abundance estimates. Estimates of $f(0)$, however, were lower, and effective strip width wider, than in nearly all previous years. This was particularly true for spinner dolphins (Fig. 13). A wider effective strip width would be expected because of the greater height and stability of the *McArthur II*, but most eastern spinner sightings were made by the *Jordan*. Mean school size in 2003 was smaller than in previous years for spotted dolphins, but similar to previous years for spinner dolphins. The use of a new ship and a slight change in the searching protocol (no overlap at the trackline) may have contributed to these differences, but this is not yet clear. Abundance estimates should be considered preliminary until the effects of these factors on abundance estimates are better understood.

Previous studies (Lennert-Cody et al. 2001, Wade et al. 2002, Gerrodette and Forcada 2005) have concluded that neither of these dolphin stocks is recovering at a rate consistent with their depleted status and low reported bycatch. While the higher preliminary 2003 estimates are encouraging, it would be premature to conclude that the populations are now beginning to recover. Because of the patchy spatial distribution and large range of the dolphins, the confidence intervals on the estimates are large, and none of the differences are statistically significant. In other words, the higher estimates in 2003 could be due to chance alone. Similar fluctuations have occurred in the past (Fig. 14). Because these two stocks occur in similar areas and often school together, their estimates are correlated; the occurrence of higher estimates for both stocks in 2003 are not independent events.

Nevertheless, the preliminary estimates have influenced our perceptions of the status of these stocks. Wade et al. (2002) found that a model indicating a decline in eastern spinner dolphins was slightly more supported by the data than a model indicating a slight increase in recent years. With the 2003 abundance estimates, such a model would probably not be supported for eastern spinner dolphins, and this causes us to be more optimistic about the status of this stock than previously. Gerrodette and Forcada (2005) suggested that a possible explanation of non-recovery is a delay due to intra- and interspecific effects on dolphin population dynamics. There is uncertainty about the rates at which these stocks should recover, and more sophisticated modeling, using other data in addition to the population estimates (Wade et al. 2002, Hoyle and Maunder 2004), is needed to improve our assessments of these stocks. Further monitoring will be necessary to reveal whether the higher, 2003 estimates are statistical noise, or whether the populations of NE offshore spotted and eastern spinner dolphins are beginning to recover.

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Table 1. Area, effort, number of transects, and number of dolphin sightings used to estimate abundance, by stratum.

	Stratum				
	Core	Core2	Outer	N. coastal	S. coastal
Area (km^2)	1,711,268	172,617	4,135,916	155,929	49,991
Effort (km)	10,831	805	9,679	2,842	1,091
Number of transects	95	10	73	35	10
Number of sightings					
Offshore spotted	105	2	37	15	0
Coastal spotted	0	0	0	79	5
Eastern spinner	70	2	1	1	0
Whitebelly spinner	8	0	25	0	0
Striped	100	1	63	1	0
Rough-toothed	26	0	5	7	0
Short-beaked common	44	4	16	13	3
Bottlenose	39	1	14	75	12
Risso’s	17	0	11	18	3
Unid. spotted	2	0	0	22	0
Unid. spinner	2	1	3	0	0
Unid. common	0	0	0	2	0
Unid. small delphinid	12	0	1	7	1
Unid. medium delphinid	1	1	2	4	2
Unid. dolphin	27	2	30	6	1

Table 2. School size summary statistics, for sightings used to estimate abundance. “qrt” = quartile. Distributions are shown graphically in Fig. 11.

Species/stock	min	1st qrt	median	mean	3rd qrt	max	n
Offshore spotted	1	30.5	63	89.5	133	394	159
Coastal spotted	1	12	26	61.1	63.3	678	84
Eastern spinner	2	33.8	79	129.4	150.8	713	74
Whitebelly spinner	5	24	82	80.8	113	194	33
Striped	1	25	40	54.4	67	198	165
Rough-toothed	2	6	9	9.1	11.8	18	38
Short-beaked common	3	54	104	143.1	180	683	80
Bottlenose	1	8	17	42.6	31	2117	141
Risso’s	1	8	14	22.3	24	108	49
Unidentified dolphin	1	2	5	8.4	12.8	37	66

Table 3. Models for detection probability estimation. All models included perpendicular distance (pd), plus covariates indicated. For each species, Model 1 is the model with lowest AIC. Additional models are shown if the AIC difference from Model 1 is less than 2.0. School size = total size of dolphin school, beaufort = Beaufort sea state, time = local time of day, cue = sighting cue which led to detecting the animals (blow, splash, animals, etc).

	Model 1	Model 2		Model 3	
Dolphin species	covariate(s)	covariate(s)	ΔAIC	covariate(s)	ΔAIC
Spotted	school size				
Spinner	school size				
Striped	school size, beaufort				
Rough-toothed	school size, time	school size	0.77	pd only	0.96
Short-beaked common	school size				
Bottlenose	Ship	pd only	0.24	ship, time	1.38
Risso’s	school size	school size, time	0.41		
Unidentified dolphin	Cue	cue, time	0.16	cue, swell height	0.84

Table 4. Estimates of abundance, pooled components of abundance, and measures of their precision. *N* = abundance, *f*(0) = pooled probability density function of detection evaluated at zero perpendicular distance in km^{-1}, E(*s*) = pooled expected school size, 100*n/L = pooled encounter rate in sightings per 100 km, % pro = pooled percentage of abundance estimate contributed by unidentified sightings, SE = standard error , CV = coefficient of variation expressed as a percentage, and LCL and UCL= lower and upper 95% confidence limits.

Species / stock		Estimate	SE	CV	LCL	UCL
Northeastern offshore spotted dolphin						
	N	736737	108169	14.7	526487	984562
	f (0)	0.279	0.017	6.2	0.247	0.309
	E (*s*)	84.1	7.1	8.2	71.1	99.6
	100*n/L	0.878	0.101	11.5	0.689	1.072
	% pro	5.8	2.9	54.0	1.4	12.1
Western/southern offshore spotted dolphin						
	N	627863	197663	30.9	296760	1112638
	f (0)	0.279	0.017	6.3	0.247	0.314
	E (*s*)	80.0	17.7	21.4	53.7	122.4
	100*n/L	0.344	0.089	25.8	0.189	0.577
	% pro	2.2	0.7	30.1	1.2	4.1
Coastal spotted dolphin						
	N	149393	40015	26.6	84652	226418
	f (0)	0.344	0.043	13.5	0.261	0.406
	E (*s*)	48.8	13.0	23.8	35.8	87.4
	100*n/L	0.333	0.068	20.6	0.195	0.474
	% pro	12.8	4.9	39.9	2.7	20.3
Eastern spinner dolphin						
	N	612662	133093	21.9	374055	868732
	f (0)	0.251	0.023	9.4	0.195	0.276
	E (*s*)	117.0	16.4	13.8	91.2	148.6
	100*n/L	0.293	0.048	16.2	0.198	0.384
	% pro	3.0	1.5	47.7	1.0	7.0
Whitebelly spinner dolphin						
	N	441711	195897	44.6	124423	836693
	f (0)	0.262	0.029	11.5	0.196	0.294
	E (*s*)	74.7	11.2	14.9	53.1	95.7
	100*n/L	0.131	0.042	31.8	0.054	0.221
	% pro	6.2	2.8	48.2	1.6	10.7
Striped dolphin						
	N	1470854	197727	14.9	960348	1702417
	f (0)	0.366	0.029	9.1	0.274	0.379
	E (*s*)	49.9	4.9	9.4	42.6	62.3
	100*n/L	0.654	0.081	12.4	0.497	0.787

% pro	2.2	0.7	28.0	1.3	4.2
Rough-toothed dolphin					
N	47921	14217	28.6	27384	87179
f (0)	0.457	0.049	10.7	0.364	0.571
E (*s*)	8.7	0.8	9.1	7.3	10.7
100*n/L	0.150	0.024	16.0	0.107	0.198
% pro	2.3	2.0	81.4	0.7	8.8
Short-beaked common dolphin					
N	1098429	243892	21.9	684904	1642408
f (0)	0.310	0.032	10.8	0.239	0.355
E (*s*)	126.5	18.7	13.7	104.9	179.2
100*n/L	0.317	0.056	17.8	0.229	0.422
% pro	2.1	0.7	33.0	1.3	4.4
Bottlenose dolphin					
N	277568	72452	24.6	172970	449748
f (0)	0.324	0.022	6.8	0.290	0.377
E (*s*)	40.2	16.6	39.6	21.0	78.1
100*n/L	0.558	0.069	12.4	0.422	0.685
% pro	1.8	1.2	65.1	0.7	4.7
Risso's dolphin					
N	76595	16255	21.0	47292	108806
f (0)	0.362	0.041	11.3	0.292	0.463
E (*s*)	18.0	3.4	18.9	12.0	26.2
100*n/L	0.194	0.043	22.3	0.124	0.277
% pro	2.5	1.5	58.9	1.0	7.0

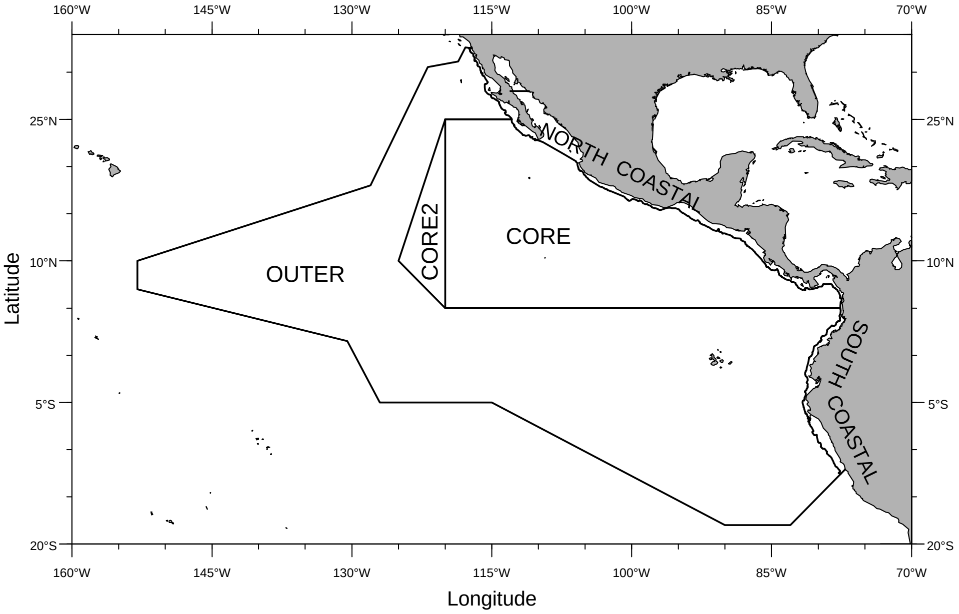

Fig. 1. Strata for the 2003 cruise.

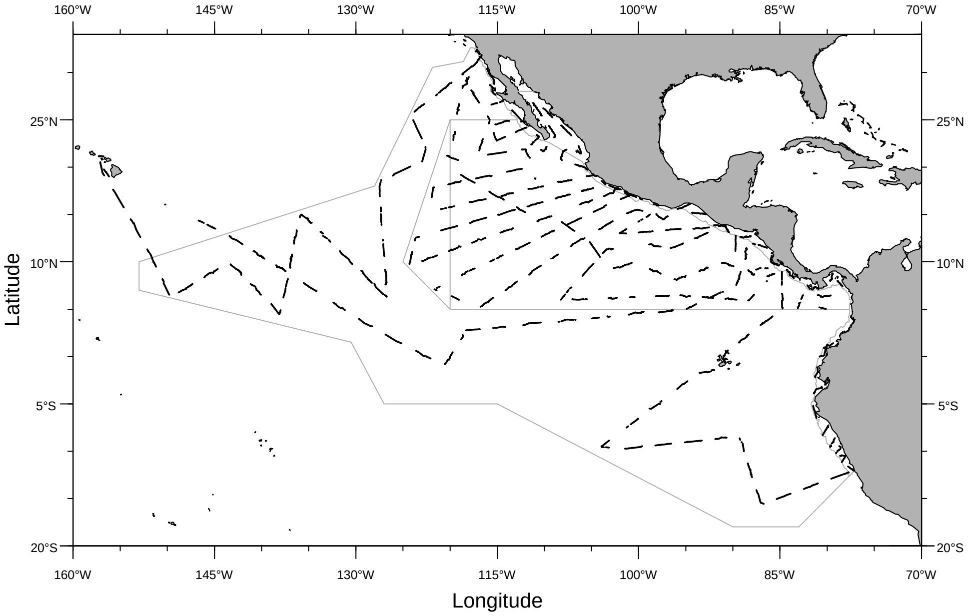

Fig. 2: Line-transect effort (dark lines) during STAR03. Stratum boundaries are shown as solid gray lines.

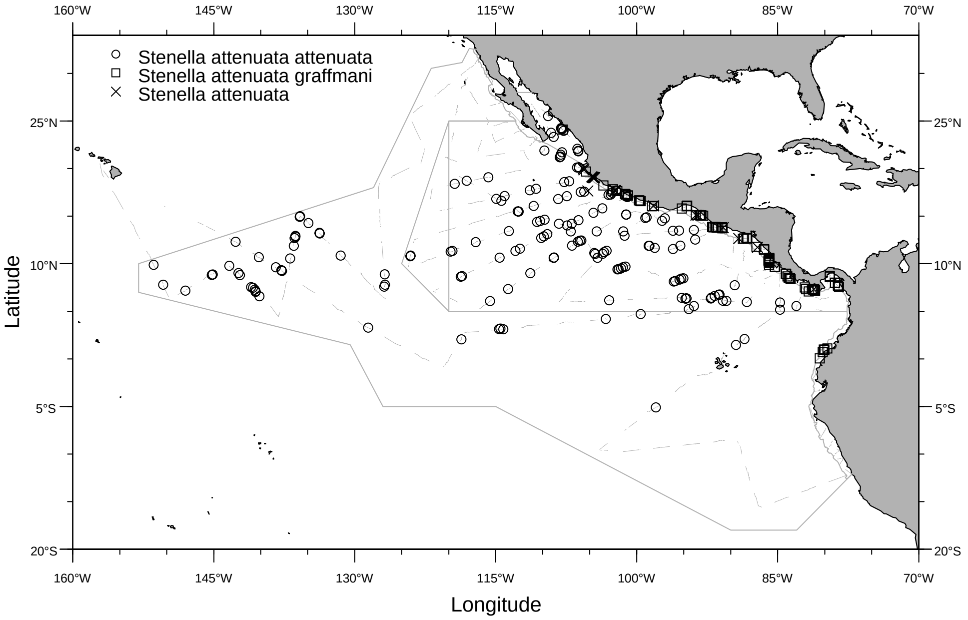

Fig. 3: Spotted dolphin sightings. Gray lines are stratum boundaries and survey effort.

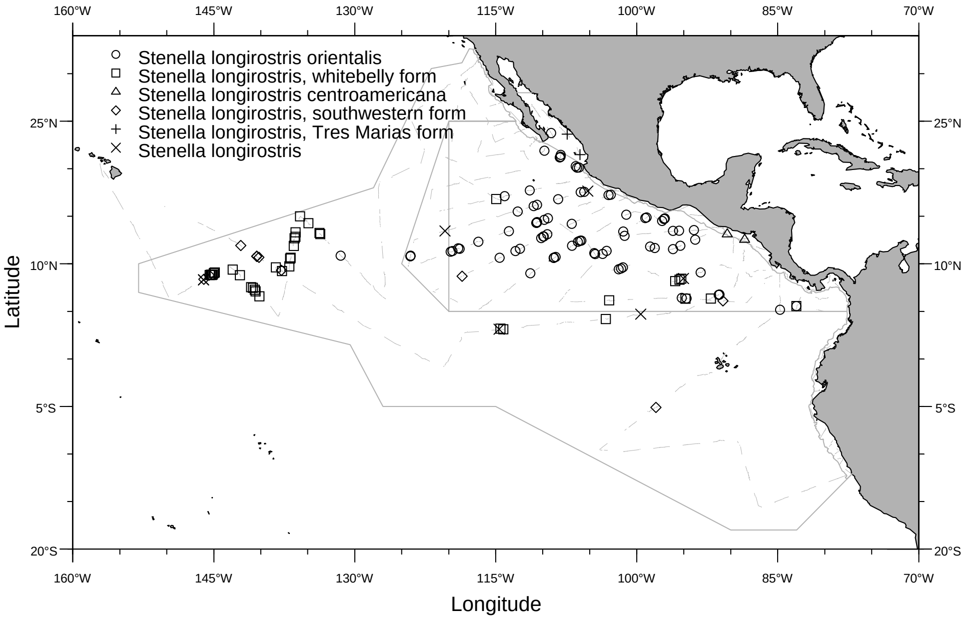

Fig. 4: Spinner dolphin sightings. Gray lines are stratum boundaries and survey effort.

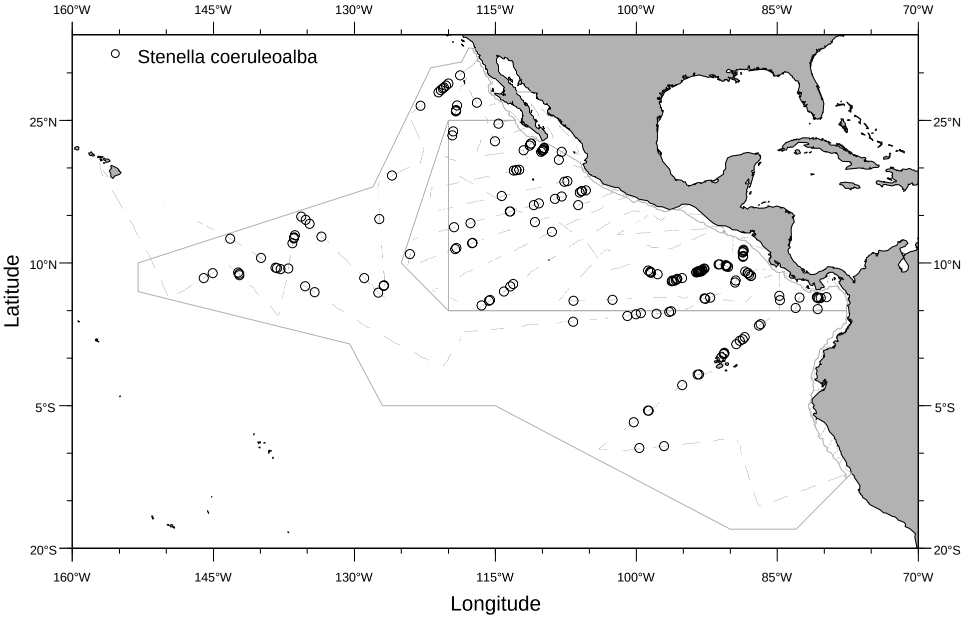

Fig. 5: Striped dolphin sightings. Gray lines are stratum boundaries and survey effort.

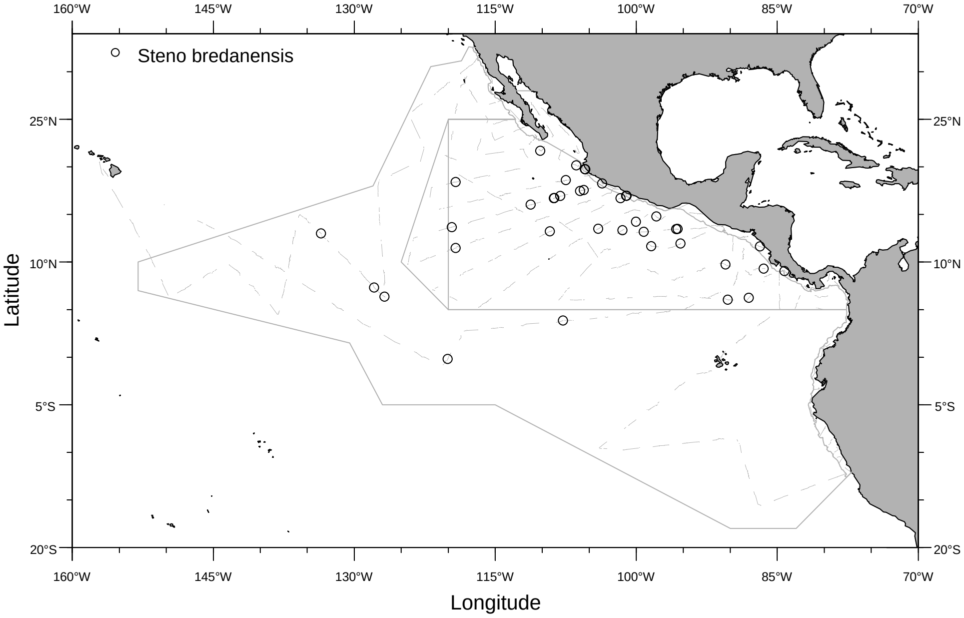

Fig. 6: Rough-toothed dolphin sightings. Gray lines are stratum boundaries and survey effort.

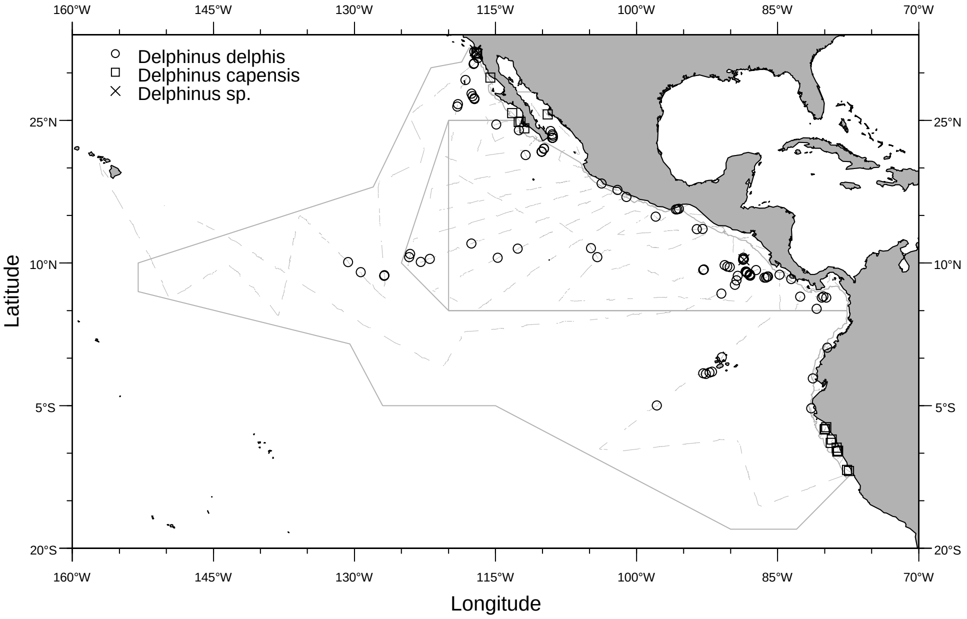

Fig. 7: Common dolphin sightings. Gray lines are stratum boundaries and survey effort.

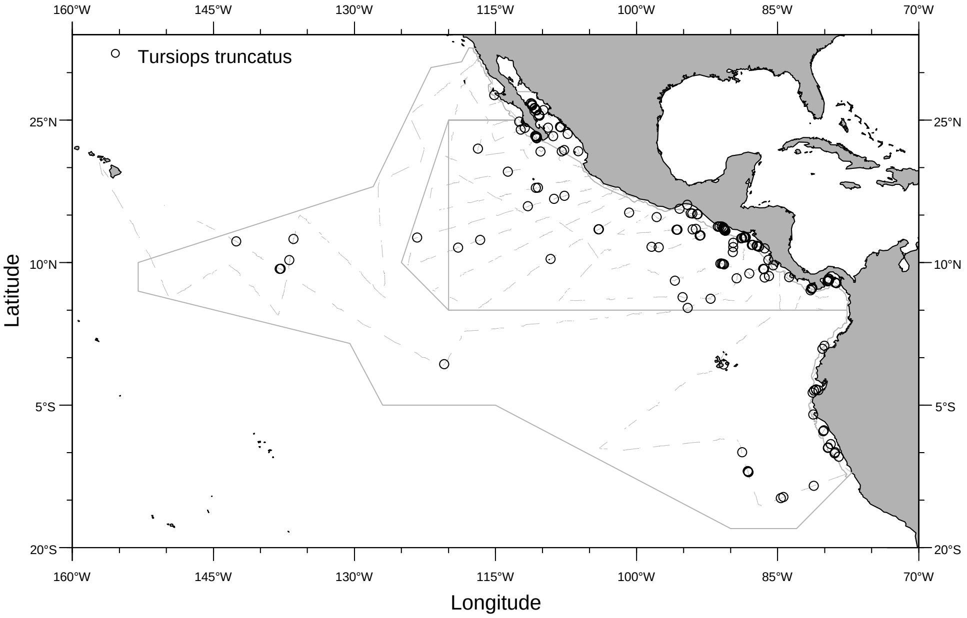

Fig. 8: Bottlenose dolphin sightings. Gray lines are stratum boundaries and survey effort.

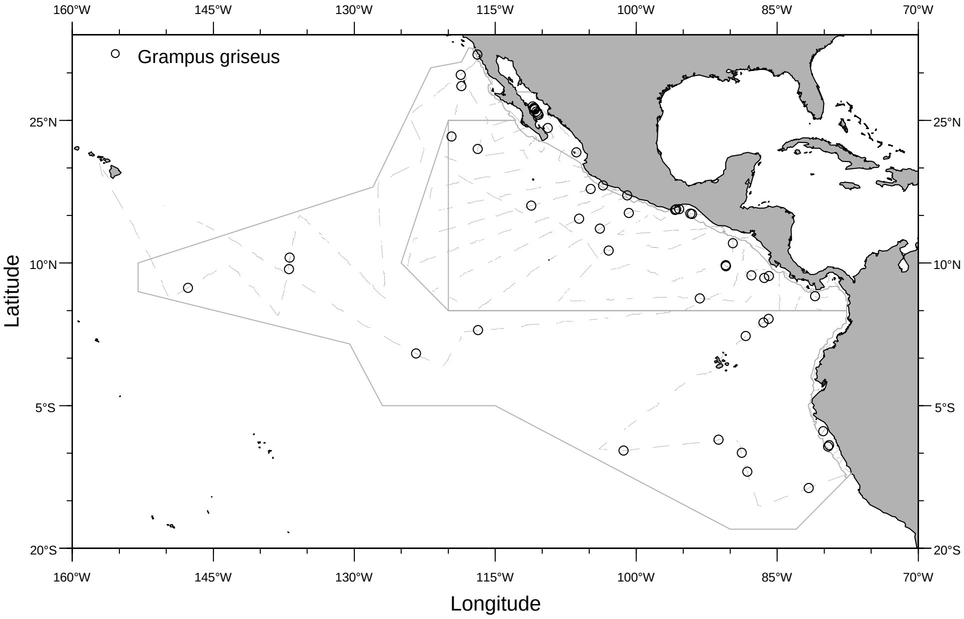

Fig. 9: Risso's dolphin sightings. Gray lines are stratum boundaries and survey effort.

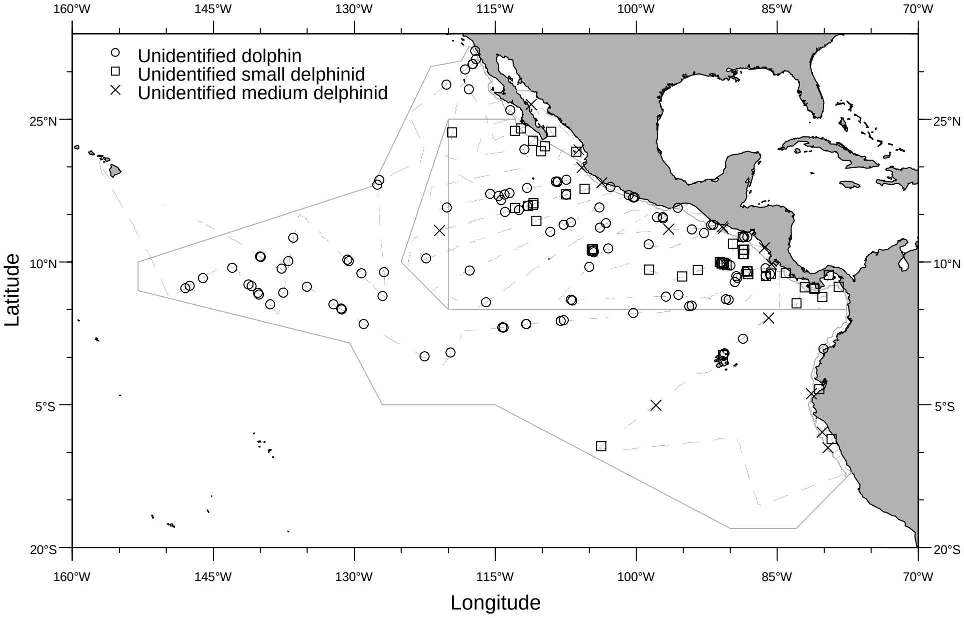

Fig. 10: Unidentified dolphin sightings. Gray lines are stratum boundaries and survey effort.

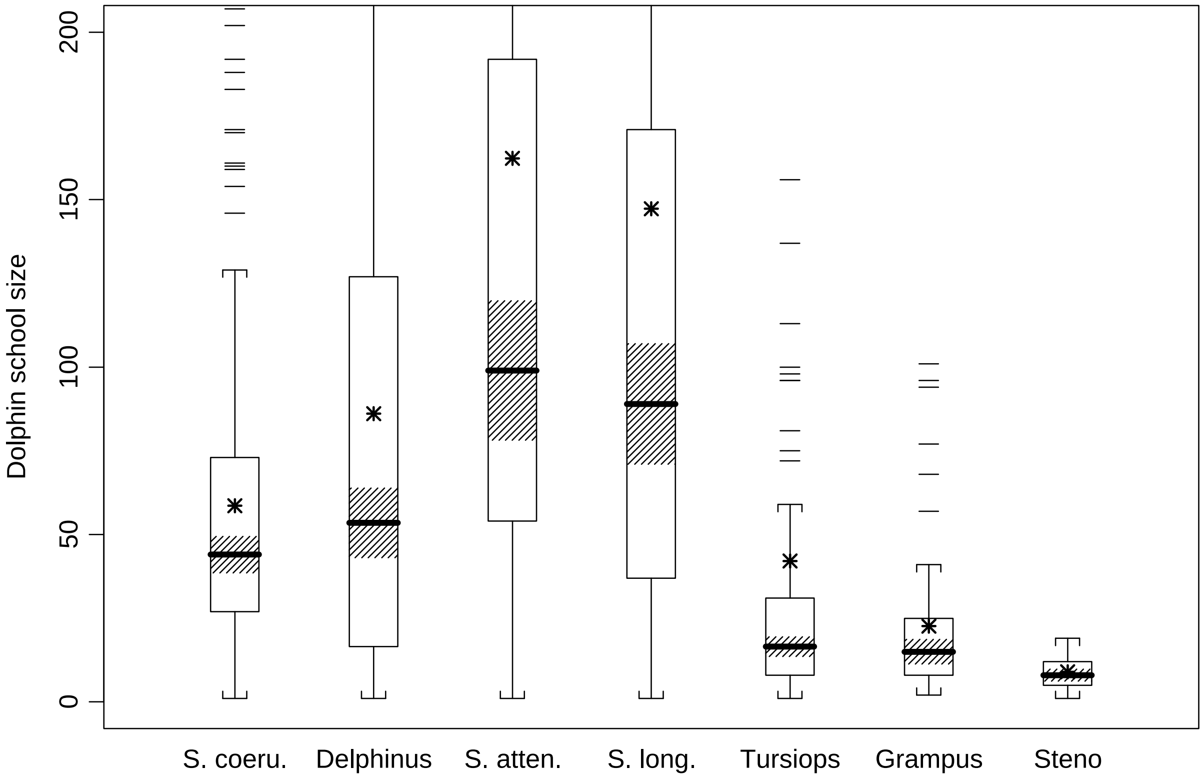

Fig. 11. Boxplots of school size distributions. For each species, means (*), medians (heavy horizontal lines), 95% confidence intervals on the medians (hatched boxes), interquartile ranges (open boxes) and standard spans (whiskers and staples) are shown for sightings used in abundance estimation. Outliers are shown as small horizontal lines beyond the staples. Values are given in Table 2.

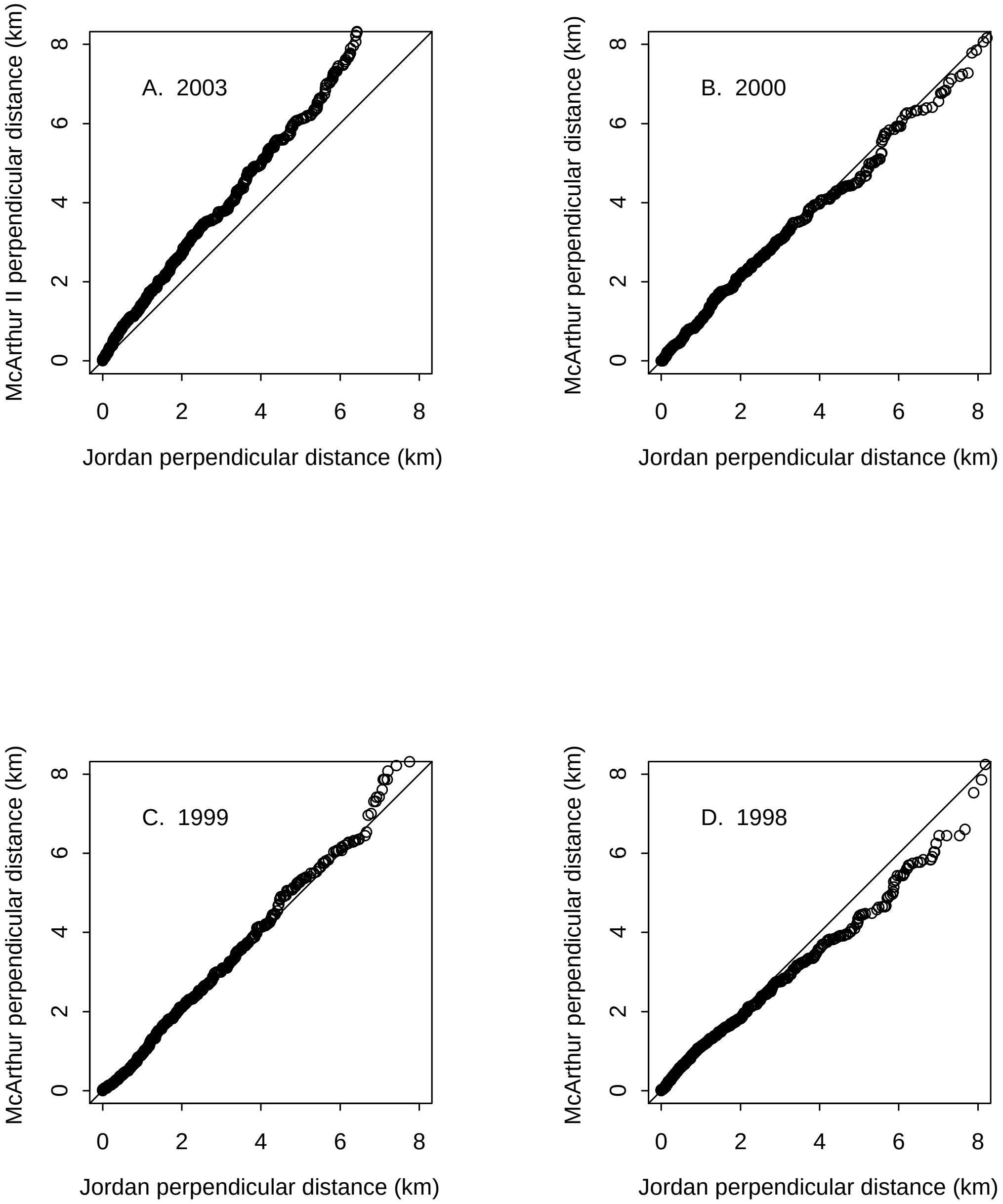

Fig. 12: Quantile-quantile plots of the distributions of perpendicular sighting distances for all cetacean sightings for the *David Starr Jordan* and the *McArthur* or *McArthur II*, by year for the four most recent ETP surveys. The 1:1 line is shown for reference.

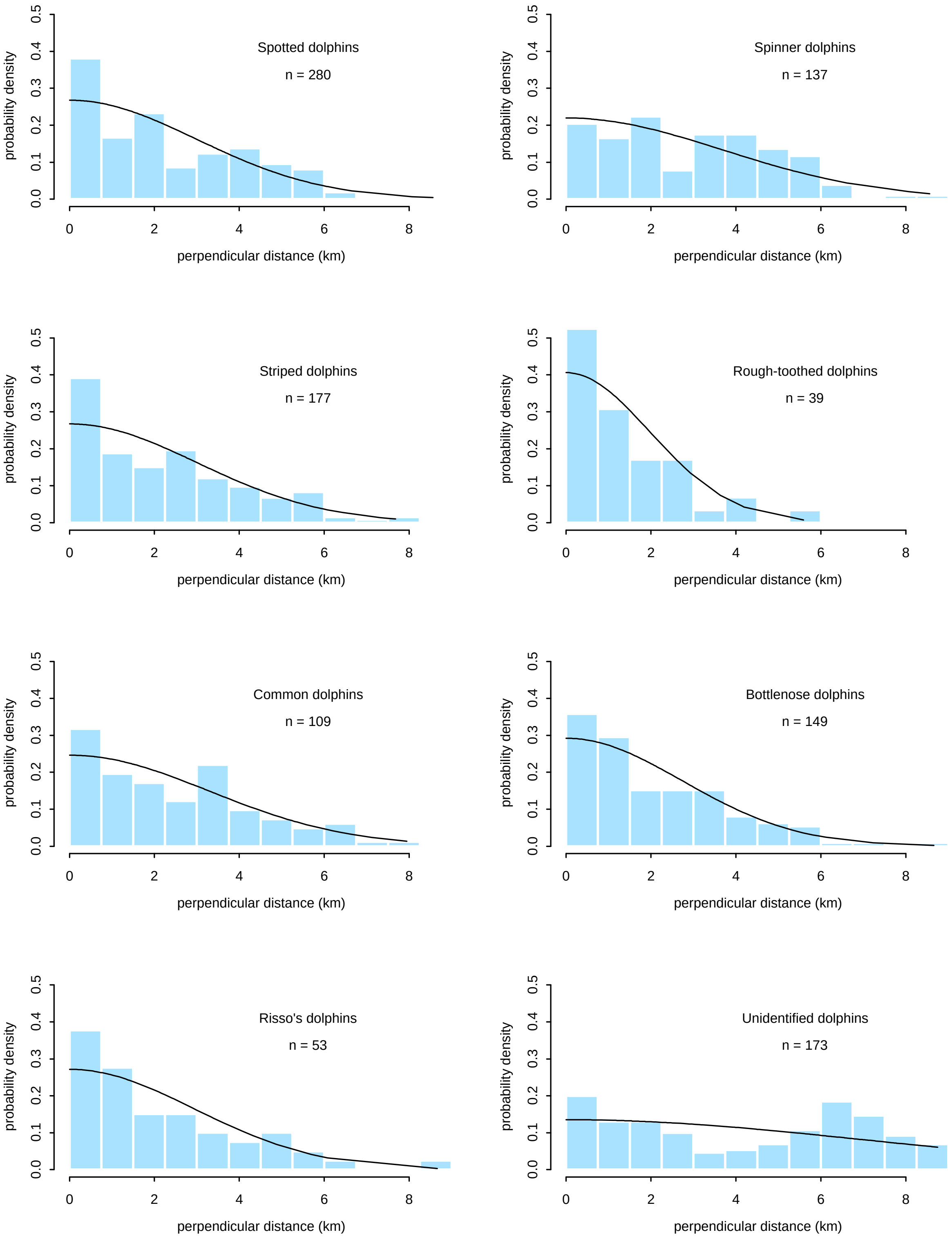

Fig. 13: Histograms of perpendicular distance to all sightings (no truncation), with univariate halfnormal function.

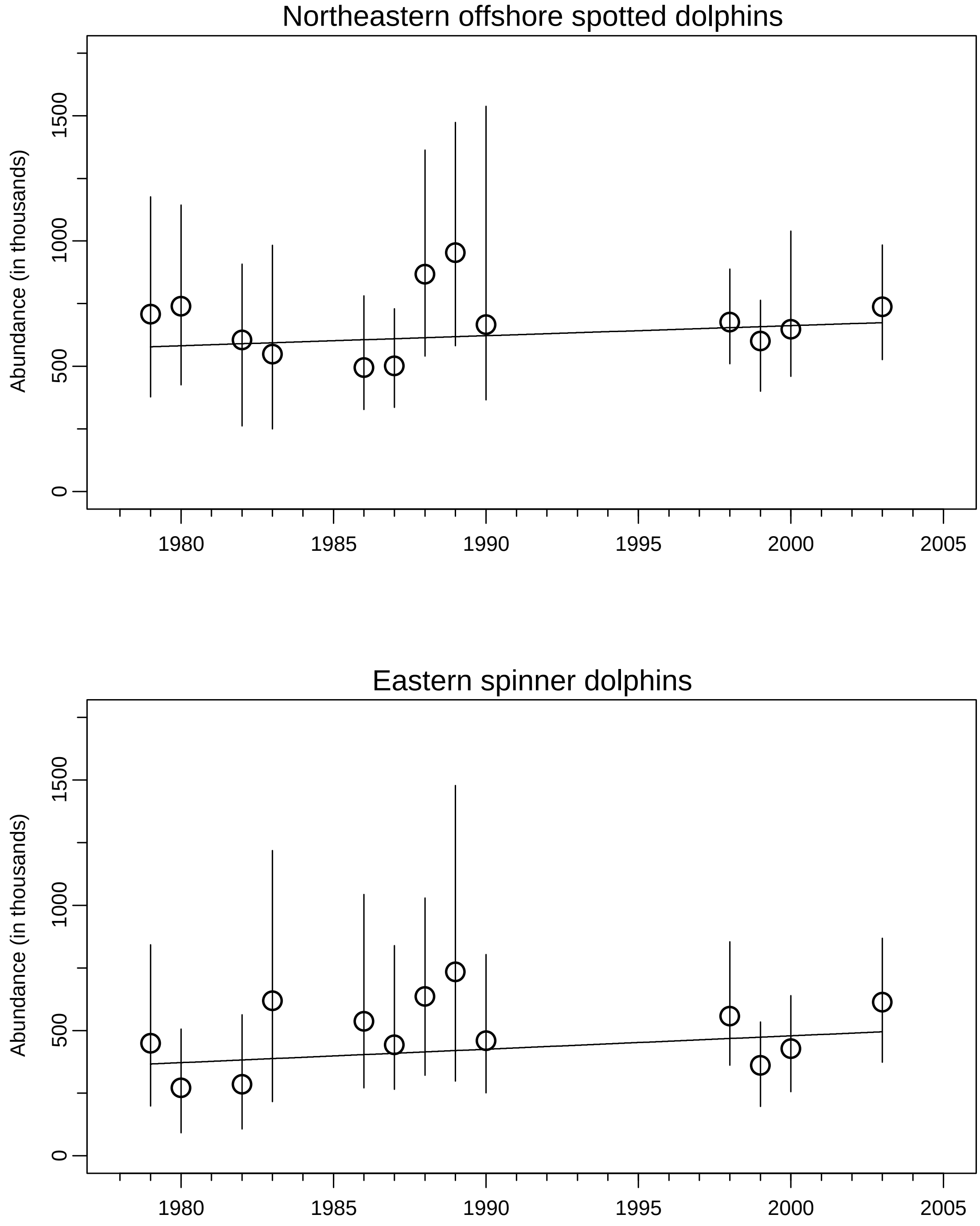

Fig 14: 2003 estimates of abundance for northeastern offshore spotted and eastern spinner dolphins compared to past estimates, with weighted linear regressions. Vertical lines show 95% confidence intervals on the point estimates.

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