Northeast Fisheries Science Center Reference Document 93-23

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ABSTRACT

Estimates of bycatch and summer abundance of harbor porpoise in the Gulf of Maine and Bay of Fundy are presented based on data collected from 1990 to 1992. These estimates are directly comparable to earlier estimates made using the same methodology (NEFSC 1992, Bisack 1993, Palka 1993). The biological significance of the bycatch is measured by the ratio of total annual bycatch to summer Gulf of Maine abundance, following NEFSC 1992. The estimated bycatch in 1992 is 900 (95% CI 700 to 1200). This is significantly lower than estimates for 1990 (2400, 95% CI 1600 to 3500) and for 1991 (1700, 95% CI 1100 to 2500). The 1992 estimate is lower because the bycatch rate in the southern Gulf of Maine in January to May, 1992 was significantly lower than in the same period in 1991. The estimated abundance of harbor porpoise in the northern Gulf of Maine in 1992 is 67,500 (%CV=23.1, 95% CI 32,900 to 104,600). This estimate is higher than the estimate based on the 1991 sighting survey data (37,500, %CV=28.8, 95% CI 26,700 to 86,400; Palka 1993). The 1991 estimate has a higher coefficient of variation, but a lower standard error. The greater uncertainty for the 1992 estimate is due almost entirely to significantly greater spatial heterogeneity of sighted animals in 1992 than in 1991. As difference between the 1991 and 1992 abundance estimates is not significant, the two estimates were combined in inverse proportion to their estimated variances, yielding an average abundance for the two years of 47,200 (%CV=19.0, 95% CI 39,500 to 70,600). The ratio of estimated 1992 bycatch to the combined estimate of population size is 1.9% (95% CI 1.2% to 2.9%). The corresponding ratios for 1990 and 1991 are 5.1% (95% CI 3.0% to 8.6%) and 3.6% (95% CI 2.1% to 6.1%), respectively. The difference between the 1990 and 1992 and the 1991 and 1992 ratios are significant, indicating that the biological significance of bycatch by the Gulf of Maine demersal gillnet fishery probably decreased between 1990 and 1992. However, it appears that more harbor porpoise were in the northern Gulf of Maine and Bay of Fundy in 1992 than in 1991, raising uncertainty about summer distributions and population structure. The implications of these estimates for understanding the status of the harbor porpoise population subject to bycatch by the Gulf of Maine demersal gillnet fishery is discussed, and research and data collection needs are described.

INTRODUCTION

The biological significance of bycatch of harbor porpoise in demersal gillnet fisheries in eastern North America was reviewed in an international workshop in May 1992 (NEFSC 1992). Available information on biology, seasonal distribution, abundance, and bycatch was discussed. That workshop concluded that sufficient information was available to assess the likely impact of the bycatch in the U.S. fishery in the Gulf of Maine, but that insufficient data were available on bycatch in Canadian fisheries and in U.S. fisheries south of the Gulf of Maine. The principal recommendations made were:

1) test the assumption of three separate populations in northeastern North America,
2) obtain additional information on bycatch rates and levels of fishing activity in both U.S. and Canadian fisheries,
3) validate the 1991 estimate of abundance in the northern Gulf of Maine and Bay of Fundy (Palka 1993) by replicating the sighting survey, with appropriate design adjustments, and
4) obtain estimates of summer abundance in the Gulf of St. Lawrence and Newfoundland.

Additional research undertaken to address some of these recommendations is reported here. New data were collected in the Gulf of Maine on abundance and bycatch. Continuing a sampling program that began in June 1989, observers were placed on U.S. fishing vessels using demersal gillnets in the Gulf of Maine. In addition, port samplers continued to collect information on the amount of fishing activity in this area. Samplers also conducted direct interviews with fishermen at other times to determine the identity and characteristics of individual vessels. In the summer of 1992, a harbor porpoise sighting survey was conducted in the northern Gulf of Maine and Bay of Fundy, using the same field methods used in 1991 (Palka 1993). This provided improved information on estimates of bycatch in the Gulf of Maine and the area immediately south of Cape Cod, and on abundance of harbor porpoise in the northern Gulf of Maine in summer months. Analyses of these data provide estimates of annual bycatch and summer abundance that were used to calculate the ratio of bycatch to abundance as an indication of the likely biological significance of the bycatch by the U.S. demersal gillnet fishery.

METHODS

BYCATCH OF HARBOR POROPISE

Two sources of data collected by NEFSC are used to estimate annual harbor porpoise bycatch. One is the weighout (WO) data collection program, which is used to estimate the total fishing effort in the demersal gillnet fishery. Port agents, assigned to one or more fishing ports, collect landings information. These data may be based on personal interviews with fishermen at the time of landing, or weighout slips filled out by the marketer to whom the fish have been sold. Fishing activity is reported in terms of both fishing effort and pounds of fish landed by species.

The second source of data is the sea sampling (SS) data collection program, which is used to estimate a bycatch rate. The sea sampling program places observers on vessels to observe fishing activity, fish catch and discards, and marine mammal interactions. Fishing trips were selected for sampling by month and port agent statistical area (SA, Figure 1) in proportion to the reported number of fishing trips from the WO data in each month and statistical area in the previous year. Total bycatch of harbor porpoise is estimated by combining the bycatch rate information and the total fishing effort information.

The WO and SS data are combined into three geographic strata and three seasonal strata, following Bisack (1993). The geographic strata are defined in terms of statistical areas: northern Gulf of Maine (N.GOM - SA 511,512), southern Gulf of Maine (S.GOM - SA 513,514,515), and south of Cape Cod (S.CAPE - SA 537-539). The southernmost stratum was sampled by the SS program only in 1992. The three seasonal strata are winter (W - January to May), summer (S - June to August) and fall (F - September to December).

In addition to the regular SS observations, there were 74 fishing trips sampled in November and December of 1992 during an experiment to test the value of gear modifications for reducing

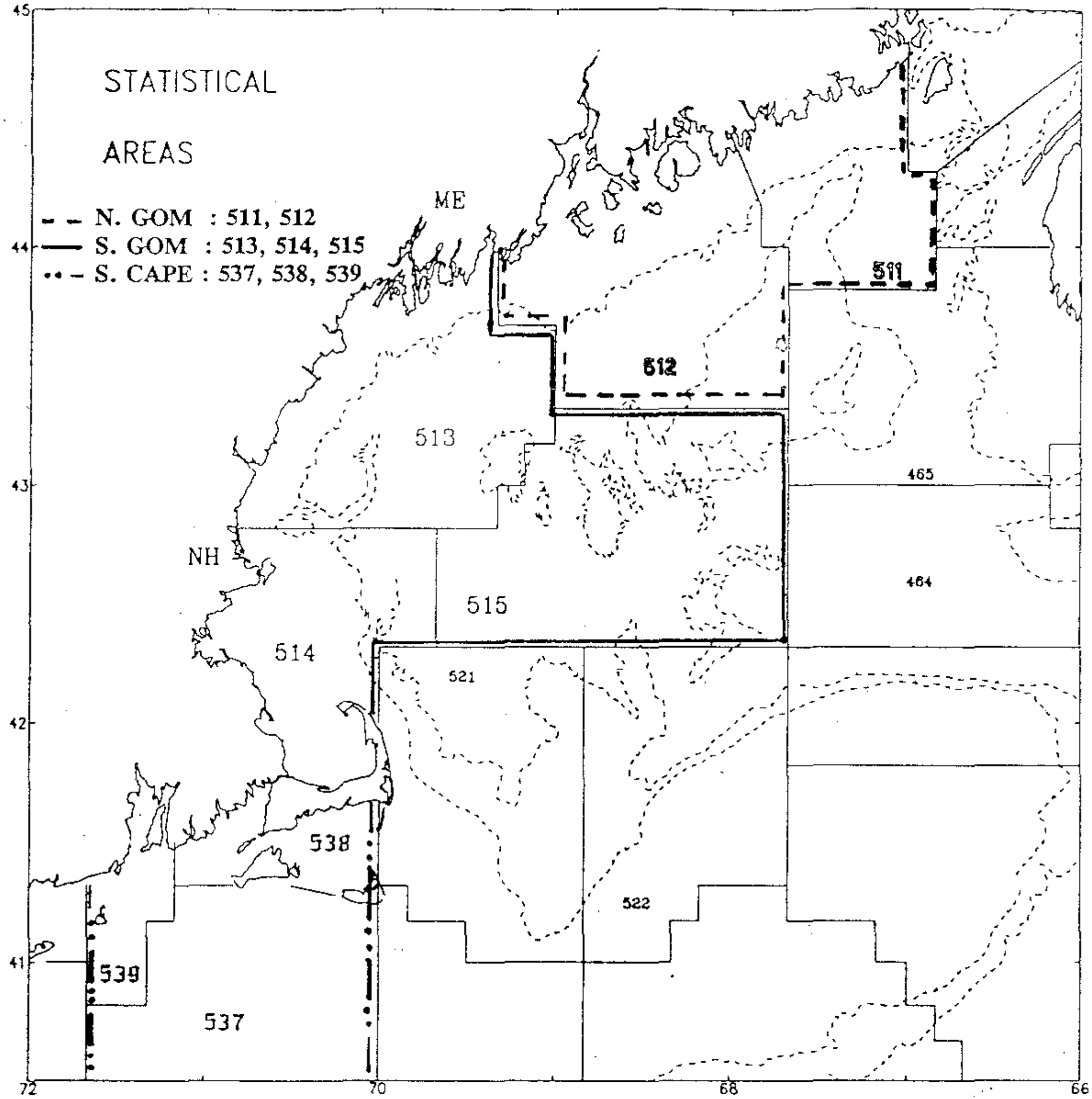

Figure 1. Map showing the statistical areas (SA) used in collection of bycatch data in the Gulf of Maine in 1990-1992, and the grouping of those into the strata used in estimating bycatch of harbor porpoise.

harbor porpoise bycatch. The SS data from these trips were not used in estimating the 1992 bycatch rate.

Total harbor porpoise bycatch is estimated from the WO and SS data using a ratio estimator involving the number of harbor porpoise observed killed, and observed and reported landings of fish (Bisack 1993, Cochran 1977), assuming that the landings are known without error. Estimates for each of the nine geographic and seasonal strata are made, and these are summed to estimate total annual bycatch (Equation 1). Confidence intervals were approximated assuming a log-normal distribution (Burnham *et al.* 1987).

ABUNDANCE

A cetacean sighting survey aimed at harbor porpoise was conducted between July 29 and September 6, 1992, using the *R/V Abel-J*. Field and analysis procedures were similar to those reported in Palka (1993). The area surveyed was in the Gulf of Maine - Bay of Fundy - Scotian shelf region north of Portland, Maine, south of St. John, New Brunswick and west of Port Joli, Nova Scotia. The study area was stratified, first by water depth. The deep-water region was further stratified using data on harbor porpoise density from the 1991 survey. This resulted in four strata: shallow water inshore, high-density, in-

(Equation 1)

$$\hat{R}_{t,l} = \sum_{i=1}^{n_{t,l}} k_{i,t,l} / \sum_{i=1}^{n_{t,l}} c_{i,t,l}$$

$$\hat{k}_{t,l} = \hat{R}_{t,l} * C_{t,l}$$

$$\hat{K} = \sum_{t=1}^{3} \sum_{l=1}^{3} \hat{k}_{t,l}$$

$$\hat{\sigma}^2_{\hat{K}} = \sum \sum \hat{\sigma}^2_{\hat{k},t,l} = \sum_{t=1}^{3} \sum_{l=1}^{3} \frac{N_{t,l}^2 (1 - f_{t,l})}{n_{t,l}} \left(S^2_{k,t,l} + \hat{R}^2_{t,l} S^2_{c,t,l} - 2 \hat{R}_{t,l} S_{k,c,t,l} \right)$$

where:

t	=	time: 1 = winter, 2 = summer, 3 = fall
l	=	location: 1 = N.GOM, 2 = S.GOM, 3 = S.CAPE
$k_{i,t,l}$	=	total kills on trip i, stratum t,l
$c_{i,t,l}$	=	tons of fish kept on trip i, stratum t,l (SS data)
$C_{t,l}$	=	tons of fish landed (WO) in stratum t,l
$\hat{R}_{t,l}$	=	estimate of kills per ton kept in stratum t,l
$\hat{k}_{t,l}$	=	estimated kill in stratum t,l
$\hat{K}$	=	total estimated kill
$n_{t,l}$	=	total observed (SS) trips in stratum t,l
$N_{t,l}$	=	total WO trips stratum t,l
$f_{t,l}$	=	$n_{t,l}/N_{t,l}$
$S_{k,c,t,l}$	=	covariance of kills and fish kept, stratum^{t,l}
$S^2_{k,t,l}$	=	variance of kills, stratum t,l
$S^2_{c,t,l}$	=	variance of fish kept, stratum t,l

termediate-density, and low-density (Figure 2). The strata used in 1992 differed from those used in 1991 as follows:

1) The high-density stratum in 1992 contained a 30 nautical mile (nmi) strip of water south of Grand Manan Island, New Brunswick, in addition to the area north of Grand Manan Island as defined in 1991.

2) During 1992, this 30 nmi strip of water was removed from the intermediate-density stratum as defined in 1991.

3) The area between Port Joli, Nova Scotia and Liverpool, Nova Scotia was eliminated from the 1992 intermediate-density stratum (very few porpoise groups were seen in this area in 1991).

4) The 1991 intermediate-density stratum along the Maine coast was divided into a nearer shore portion, assigned to the intermediate-density stratum, and a further offshore portion, assigned to the low-density stratum.

In 1992, we planned to allocate the length of track line within the strata in proportion to the spatial distribution reflected in the 1991 survey data. However, the actual track length was allocated approximately proportionate to the area of the respective stratum, with the exception that the length of track line within the low-density stratum was lower than proportional. The shift back to proportional sampling was made after the first few days of surveying revealed a substantially different geographic pattern of harbor porpoise than had been seen in 1991.

The two-team sighting procedure that was used in 1991 and 1992 allowed the estimation of the probability of detecting an animal group on the transect line, g(0). The upper team was located on a platform 14 m above the sea surface. The lower team was located directly below the first team at 9 m above the sea surface. Each team consisted of four people who rotated among three observation positions and a rest position. Half of the people who participated in the 1992 survey also were in the 1991 survey. On days when the Beaufort sea state was less than or equal to 4, and when visibility was greater than 500 m, the survey was conducted from 6 AM to 6 PM (with one hour off for lunch). When a marine mammal group was detected, the following information was recorded:

- time of detection,
- distance between the ship and animal group,
- angle between line of sight to the group and the line on which the ship was traveling (track line),
- species composition of the group,
- best, high and low estimates of group size
- direction in which the group was swimming,
- number of mother-calf pairs,
- sighting cue,
- behavior of the group.

In addition, when observers rotated or sighting conditions changed, the following information was recorded: time, latitude and longitude, ship's speed and heading, Beaufort sea state, and other environmental conditions.

Total abundance of harbor porpoise in the study area in 1992 was estimated using the "direct-duplicate method" (Palka 1993). The abundance of animals, $\hat{N}$, was estimated using Equation 2.

Following Palka (1993), the sighting detection function and average school size were estimated using the simplest models consistent with the data. The estimate of $\hat{f}_{up}(0)$ and $\hat{f}_{lo}(0)$ used all sightings from the respective team, regardless of the stratum. This procedure was possible because the $\hat{f}(y)$ curves estimated from the different strata within a team were similar to each other. Therefore, pooling over all strata for this parameter created a more parsimonious model (Burnham *et al.* 1987).[1] Values of $\hat{f}_{up}(0)$ and $\hat{f}_{lo}(0)$ were estimated using the hazard-rate model with the software package DISTANCE (Buckland *et al.* 1993), where the maximum perpendicular distance was selected to be 400 m. The average of the best estimates of group size was used to estimate $\hat{E}(s_i)$ because there was no evidence of size-bias (Drummer and McDonald 1987), as determined by using the software packages SIZTRAN (Drummer 1991) and DISTANCE.

The inshore stratum was sampled differently in 1992 than it had been in 1991. In the 1991 survey, the *R/V Abel-J* did not go into the inshore stratum, but surveyed an offshore area immediately adjacent to the inshore stratum. In 1991 the *M/V Sneak Attack* surveyed both the inshore stratum and the adjacent offshore area; the abundance in the inshore stratum was calculated by applying the ratio of sighting rate of porpoise groups seen from the *M/V Sneak Attack* while in the inshore stratum to the sighting rate found in the adjacent offshore area to the density of animals calculated from data collected on the *R/V Abel-J* while surveying in the adjacent offshore area. In 1992, the *R/V Abel-J* surveyed the inshore stratum, but used only one sighting team, which occupied the upper team position. The density was estimated using only that team's data, and g(0) was assumed to be that from the upper team in the intermediate-density stratum.

Because the number of sightings in the low-density stratum was small (upper team: 10; lower team: 18), Equations 2 and 3 could not be used. The abundance for this stratum was estimated using the observed sightings, track line length, and area of the low-density stratum, with the sighting detection function and school size, $\hat{f}(0)$ and $\hat{E}(s)$, estimated for the intermediate-density stratum.

Estimates of statistical variability, standard error (SE) and confidence intervals (CI), were made using bootstrap resampling techniques (Palka 1993). The contribution of sighting rate (number of groups sighted per nmi surveyed), group size, and effective strip width ($1/\hat{f}(0)$) to the magnitude and variance of the estimate of abundance was evaluated by examining estimates of the magnitude and variance of each factor for different strata and teams.

The estimate of abundance from the 1992 survey, developed earlier, and that from the 1991 survey (Palka 1993) were combined by averaging the best estimates, weighted inversely by their estimated variances (Equation 4).

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[1] The difference in the estimates of abundance in NEFSC 1992 and Palka 1993 resulted from the adoption of a more parsimonious model based on recommendations for further analysis included within NEFSC 1992. In particular, better methods were adopted for handling the variance due to the determination of duplicate sightings, and the bootstrap resampling was based on survey transects rather than on days.

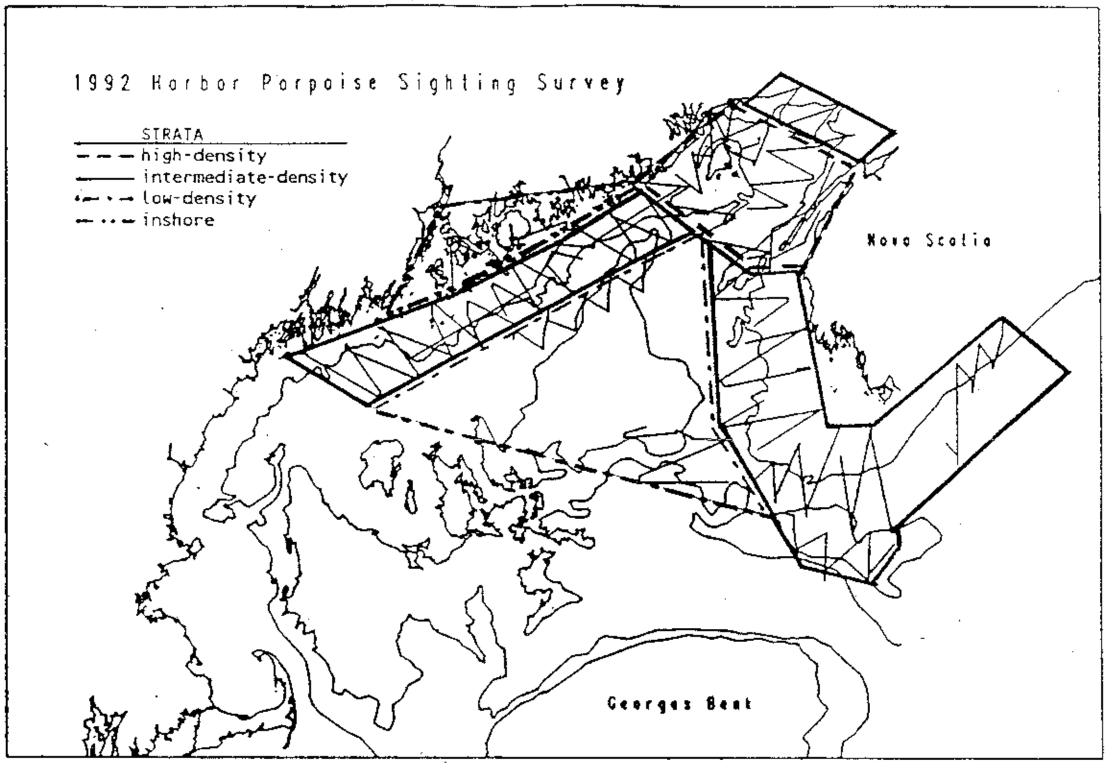

Figure 2. Map showing the survey strata and track lines used in 1992 harbor porpoise sighting survey, with the four analysis strata, the one inshore stratum, and the three strata defined on the basis of expected density, high, intermediate, and low.

$$\hat{N} = \sum_{i=1}^{4} \hat{N}_i = \sum_{i=1}^{4} \hat{D}_i \cdot A_i = \sum_{i=1}^{4} \frac{\hat{D}_{iup} \cdot \hat{D}_{ilo}}{\hat{D}_{idup}} \cdot A_i \qquad \text{(Equation 2)}$$

where:

$\hat{N}_i$ - abundance of animals within stratum i

$\hat{D}_i$ - density of animals within stratum i, corrected for $\hat{g}(0)$

A_i - area within stratum i

$\hat{D}_{iup}$ - density of animals using data from upper team, not corrected for $\hat{g}(0)$

$\hat{D}_{ilo}$ - density of animals using data from lower team, not corrected for $\hat{g}(0)$

$\hat{D}_{idup}$ - density of animals using duplicate sightings, not corrected for $\hat{g}(0)$

i - index for stratum, i=1 to 4.

$\hat{D}_{iup}$ was estimated using:

$$\hat{D}_{iup} = \frac{n_{iup} \cdot \hat{f}_{up}(0) \cdot \hat{E}(s_{iup})}{2L_i} \qquad \text{(Equation 3)}$$

where:

n_{iup} - number of animals seen by the upper team within stratum i

$\hat{f}_{up}(0)$ - probability density of observed perpendicular distances from the upper team's data, where distance equals zero

$\hat{E}_{(siup)}$ - expected size of porpoise groups that were detected by the upper team within stratum i

L_i - length of transect line surveyed within stratum i.

$\hat{D}_{ilo}$ and $\hat{D}_{idup}$ were estimated in a similar manner.

(Equation 4)

$$\overline{N}=\frac{V(\hat{N}_t)^{-1}\hat{N}_t+V(\hat{N}_{t+1})^{-1}\hat{N}_{t+1}}{V(\hat{N}_t)^{-1}+V(\hat{N}_{t+1})^{-1}}$$

$$V(\overline{N})=\frac{1}{V(\hat{N}_t)^{-1}+V(\hat{N}_{t+1})^{-1}}$$

(Equation 5)

$$\hat{D}_t=\frac{\hat{K}_t}{\overline{N}}$$

$$V(\hat{D}_t)=\frac{V(\hat{K}_t)}{\overline{N}^2}+\frac{\hat{K}_t^2V(\overline{N})}{\overline{N}^4}$$

$$COV(\hat{D}_t,\hat{D}_{t+1})=\frac{V(\overline{N})\hat{K}_t\hat{K}_{t+1}}{\overline{N}^4}$$

(Equation 6)

$$V(\hat{D}_i-\hat{D}_j)=V(\hat{D}_i)+V(\hat{D}_j)-2COV(\hat{D}_i,\hat{D}_j)$$

A confidence interval for the combined estimate was formed as the 2.5 and 97.5 percentiles of the distribution of the weighted average ($\overline{N}$ in Equation 4) of each of the 1000 pairs of estimates from the original bootstrap distributions of abundance for each survey.

BIOLOGICAL SIGNIFICANCE OF THE BYCATCH

In the absence of data on historical abundance and bycatch levels, and with limited data on population structure, NEFSC (1992) evaluated the biological significance of the harbor porpoise bycatch in the U.S. demersal gillnet fishery by comparing the ratio of the estimated total annual bycatch to the estimated summer abundance, to the likely net productivity of harbor porpoise (International Whaling Commission 1991). For 1991, NEFSC (1992) used the ratio of abundance and bycatch for that year. For 1990, where no estimate of abundance was available, NEFSC (1992) used the ratio of the estimated bycatch in that year to the estimate of abundance in 1991, noting that the actual abundance is unlikely to change rapidly for large mammal populations.

The estimates of abundance and bycatch given here allow the approach of NEFSC (1992) to be extended. As noted there, it is unlikely that harbor porpoise populations vary greatly in size between years, either due to natural causes or to bycatch of the order estimated previously. Further, any changes due to natural causes or bycatch would be so small as to be difficult to detect given statistical variability on the order of the 1991 abundance estimate. Thus, one would not expect large differences in the true abundance over the three years for which we have bycatch estimates. While ratios of the annual estimates could be computed, because of the low expected changes in abundance and in the interest of improving statistical precision, we measure the biological significance of the bycatch using ratios of the estimated bycatch for each year to a combined estimate of abundance (Equation 4). The ratios of bycatch to abundance along with approximate variances and covariances based on a Taylor's series approximation are shown in Equation 5.

A confidence interval can be formed assuming a lognormal distribution. The ratios of bycatch can be compared using a Z-test, where the estimated variance of the differences D_i-D_j include the covariance between estimates because a single averaged abundance estimate is used, shown in Equation 6.

RESULTS

BYCATCH

Fishing activity in the demersal gillnet fishery in the Gulf of Maine and immediately south of Cape Cod has been relatively constant from 1990 to 1992. The annual average over the three years was roughly 13,000 trips, landing roughly 19,000 tons (Table 1). Fishing activity varied greatly geographically and seasonally, with greatest seasonal variability in the northern Gulf of Maine. The number of fishing trips observed in the Sea Sampling Program was roughly proportional to the number of fishing trips in each strata, as recorded in the WO data base, with the exception of the South of Cape Cod stratum. That stratum was not sampled before 1992, when roughly 5% of the trips were sampled. The proportion of trips sampled in the other two strata increased markedly beginning in the summer of 1991, from roughly 1% in 1990 and winter of 1991 to 9% subsequently.

Bycatch rates and their associated standard deviations calculated from the SS data (Table 2) show marked differences among both geographical and seasonal strata. In the northern GOM, bycatch rates were greater than zero in all seasons of 1992, in summer and fall of 1991, and in fall of 1990. Fall and winter rates were generally higher than summer rates for all areas. In the southern GOM, 1992 bycatch rates were similar in winter and fall, and were zero in summer (Table 2). Rates in 1990 and 1991 in summer and fall were generally higher than in 1992. The number of fishing trips with and without bycatch was not significantly different among years in the fall (X^2=4.3 with 2 df, p>.05), but was significantly different in winter (X^2=11.9, 2 df, p<.05).

Sampling coverage was substantially more intense throughout 1992 than in previous years, allowing its representativeness to be examined. The 1992 sampling coverage was roughly proportional to the WO effort within months and statistical areas. Within geographical strata, differences in sampling intensity were apparent when ports were combined into spatially contiguous groups. These differences, however, were either small or occurred where bycatch had been zero, except in the southern GOM. In that region, substantial differences in actual coverage among ports were apparent when the ports were combined into four groups: southern Maine, New Hampshire, and north and south of Boston. For example, 16% of the SS trips were from ports south of Boston while only 2% of the WO trips were. This oversampling corresponded to a systematic undersampling of ports immediately north of Boston. The rate of harbor porpoise bycatch, however, did not differ significantly among groups of ports in the southern GOM in either fall (X^2=5.92, 3 df, p>.05) or winter (X^2=0.37, 3 df, p>.05). The rates were zero for all but one port group in the summer. Thus, differences in the intensity of sampling among ports are unlikely to bias estimates of total bycatch.

The estimated bycatch of harbor porpoise varied greatly by strata and year; most of the bycatch occurred in the southern GOM (Table 3). In the southern GOM, bycatch occurred primarily in the winter and fall. Fall bycatch estimates in 1991 and 1992 are similar, and substantially lower than the 1990 estimate. That latter estimate was higher due to both a higher bycatch rate (Table 2) and higher landings (Table 1). Estimated 1992 winter bycatch is 20% of the estimates for 1990 and 1991. The estimates for 1990 and 1991 are similar, but this similarity is the result of an increase from 1990 to 1991 in the estimated bycatch rate and a corresponding decrease in landings. In 1992, landings are similar to 1991. The significantly lower bycatch rate noted above results in the lower estimate of bycatch for this stratum.

Harbor porpoise bycatch occurred in all three seasons in the northern GOM in 1992 with summer and fall contributing the largest proportion (Table 3). The 1992 bycatch estimates for the fall and summer were roughly 150% of the corresponding estimates for 1991, primarily due to an increase in bycatch rate in both seasons.

Harbor porpoise bycatch south of Cape Cod was observed only in the winter months. The estimate was small compared to the total bycatch, and had low statistical precision. Estimates for this area have not been made for previous years due to lack of sea sampling coverage.

The total estimated harbor porpoise bycatch decreased from roughly 2400 (95% CI 1600 to 3500) in 1990, to 1700 (95% CI 1100 to 2500) in

Table 1. The reported tons of fish landed and number of fishing trips in the weighout data, and the number of harbor porpoise observed killed and fishing trips sampled in the sea sampling (SS) data, for three geographic strata[1] and three time strata[2] for the years 1990 through 1992

Strata		**Sea Sampling Data**						**Weighout Data**					
		Fishing Trips			**Harbor Porpoise Killed**			**Fishing Trips**			**Landings**		
		N.GOM	**S.GOM**	**S.CAPE**	**N. GOM**	**S.GOM**	**S.CAPE**	**N.GOM**	**S.GOM**	**S.CAPE**	**N.GOM**	**S.GOM**	**S.CAPE**
90	W	2	56	0	0	9	-	154	3,082	510	186	2,916	780
	S	6	21	0	0	0	-	856	3,602	197	1,269	7,669	905
	F	2	36	0	1	7	-	433	3,848	465	392	5,564	1,234
	Total	10	113	0	1	16	-	1,443	10,532	1,172	1,847	16,149	2,919
91	W	2	36	0	0	10	-	235	2,693	1,507	215	2,229	1,507
	S	91	325	0	5	2	-	1,033	2,871	317	1,975	5,483	317
	F	33	326	0	3	30	-	429	3,055	1,160	668	3005	1,160
	Total	126	687	0	8	42	-	1,697	8,619	2,984	2,858	10,717	2,984
92	W	7	238	70	1	14	2	111	2,518	1,289	97	1,909	2,163
	S	130	228	26	12	0	0	1,140	3,102	455	2,073	5,347	711
	F	35	199	50	7	15	0	327	3,056	1,200	579	3,718	2,889
	Total	172	665	146	20	29	2	1,578	8,676	2,944	2,749	10,974	5,763

[1] S.GOM= Southern GOM, N.GOM=Northern GOM, S.CAPE=South of Cape Cod)

[2] W=Winter, S=Summer, F=Fall

Table 2. Sample bycatch per trip ($\hat{KPT}$) and sample standard deviations (SD) for 1990, 1991, and 1992, for nine geographic and seasonal strata[1]

Strata	Season	1990 $\hat{KPT}$	1990 SD	1991 $\hat{KPT}$	1991 SD	1992 $\hat{KPT}$	1992 SD
N.GOM	W	0.00		0.00		0.14	0.143
	S	0.00		0.06	0.027	0.09	0.044
	F	0.50	0.500	0.09	0.049	0.20	0.122
S.GOM	W	0.16	0.071	0.28	0.109	0.06	0.025
	S	0.00		0.01	0.006	0.00	
	F	0.19	0.078	0.09	0.018	0.08	0.022
S.CAPE	W	-		-		0.02	0.020
	S	-		-		0.00	
	F	-		-		0.00	

[1] a dash (-) indicates no sampling

Table 3. Estimated bycatch ($\hat{K}$) and standard deviation (SD) for 1990, 1991, and 1992, for nine geographic and seasonal strata and in total[1]

Strata	Season	1990 $\hat{K}$	1990 SD	1991 $\hat{K}$	1991 SD	1992 $\hat{K}$	1992 SD
N.GOM	W	0		0		17	12.1
	S	0		65	27.9	127	50.0
	F	87	399.6	48	21.8	115	39.8
S.GOM	W	1264	158.8	1201	331.0	251	26.3
	S	0		19	16.6	0	
	F	1045	347.1	339	55.4	341	69.4
S.CAPE	W	-		-		49	26.3
	S	-		-		0	
	F	-		-		0	
TOTAL		2396	467	1672	339	900	115

[1] a dash (-) indicates no sampling

1991, to 900 (95% CI 700 to 1200) in 1992. The 1992 bycatch is significantly lower than both the 1990 estimate ($Z=3.11$, $p<.05$) and the 1991 estimate ($Z=2.09$, $p<.05$). Both of these differences were primarily due to the significantly lower bycatch rate in winter of 1992 in the southern GOM.

ABUNDANCE

The 1992 abundance estimate was based on surveying approximately 2000 nmi within 4 strata (Figure 2 and Table 4). In the 3 strata where both teams surveyed, the upper and lower teams saw 613 and 599 groups of harbor porpoises. Of these

Table 4. Results from the 1992 *R/V Abel-J* line transect survey, for the four strata: high density, intermediate density, low density, inshore, and in total

Strata	Track[1] nmi (%)	Area[2] (%)	Number of[3] Groups		Average Group[4] Size	
			Upper	Lower	Upper	Lower
High	387 (.19)	2150 (.16)	255 (218)	238 225)	3.04 (5.1)	2.96 (4.9)
Interm	1175 (.59)	7200 (.54)	346 (296)	341 (315)	2.84 (3.7)	2.50 (3.6)
Low	237 (.12)	3400 (.25)	12 (10)	20 (18)	1.94 (65.9)	3.17 (15.2)
Inshore	204 (.10)	638 (.05)	113 (107)	-	1.99 (5.3)	-
Total	2003 (1.0)	13,388 (1.0)	726 (631)	599 (558)	2.91 (3.0)	2.68 (2.9)

[1] Length of transect line (nmi), percent of total length in parentheses
[2] Percent of total area in parentheses
[3] Total number of groups detected by the upper and lower teams. Number of groups within a perpendicular distance of 400 m from the transect line given in parentheses
[4] Average size of groups within 400 m, percent coefficient of variation in parentheses

Table 5. Results of the 1992 survey, showing estimated abundance, estimated standard deviations (SD), % CV, and upper and lower 95% confidence interval (UCL and LCL) for the 4 strata and all strata combined, based on Equation 2

Strata	Abundance	SD	% CV	LCL	UCL
High	24,477	9,815	40.1	8,715	44,980
Interm	31,865	11,503	36.1	12,394	57,131
Low	2,330	685	29.4	1,015	3,620
Inshore	8,805	2,421	27.6	5,377	14,950
Total	67,478	15,587	23.1	32,902	104,602

sightings, 524 and 558 groups of harbor porpoises were within 400 m of the vessel, the maximum perpendicular distance selected for analysis. Only one team surveyed within the inshore stratum, sighting 113 groups of porpoises, of which 107 were within 400 m of the track line. The average size of groups sighted within 400 m in all strata were 2.9 (CV=3.0%) and 2.7 (CV=2.9%), for the upper and lower teams, respectively.

The estimate of total harbor porpoise abundance from the 1992 survey data is roughly 67,500 (CV=23%, 95% CI 32,900 to 104,600) (Table 5). This corresponds to roughly 5.0 animals per nmi^2. The high density and inshore strata account for 50% of the estimated abundance, while constituting only 21% of the geographic area.

The 1991 abundance estimate (37,500, CV=29%, 95% CI 26,600 to 86,400; Palka 1993) was 51% of the 1992 estimate. Although the difference was not significant (Z=1.57, p=0.17), the causes of the difference can be seen by comparing the two surveys in more detail. The components of the abundance equation can be compared among years, strata, and teams. The

Table 6. Mean of the ratio of number of groups sighted and the length of transects (n/L), with estimated standard deviations (SD) and number of transects (m) for the 1991 and 1992 sighting survey data

Year	n/L	SD	m
1991	.22	.45	220
1992	.38	.67	202

primary factors constituting the estimate of total abundance are the sighting rate (the number of groups sighted per nmi searched), the average group size, and the effective strip width, 1/f(0). The sighting rate was significantly higher in 1992 than in 1991, 0.38 and 0.22, respectively ($Z=1.98$, $p<.05$; Table 6). The other two factors do not differ significantly between years, and are consistent among strata teams, but contribute sufficient additional statistical uncertainty to result in the lack of significant difference in the total abundance estimates.

To account for the differences in stratification and specific areas surveyed, the data were post-stratified to define an area of roughly 12,000 nm^2, which was surveyed in both years in a similar manner. The 1991 estimated density (estimated number of animals divided by area) in this area was roughly 52% lower than the density in 1992 in the same area. The estimated density was lower in 1991 in all portions of this area, with the greatest difference occurring in the central Maine coastal region. Thus, there is a difference in the spatial distribution between the two years.

Although the CV of the 1992 abundance estimate (Table 5) was less than the 1991 estimate (23% versus 29%), the standard deviation of the 1992 abundance estimate was 44% greater than that for 1991 (Palka 1993). This increase is related directly to an increase in the spatial heterogeneity of the animals, as can be seen in the significantly greater variability of the sighting rate in 1992 ($F=2.22$ with 201 and 219 df, $p<.05$; Table 6).

The significant difference in the sighting rate between the two years, the higher estimated densities in the comparable strata formed by post-stratification, and the different degree of spatial heterogeneity all suggest that there were more animals in the study area in 1992. That is, there was a substantial difference in the migration patterns.

BIOLOGICAL SIGNIFICANCE OF THE BYCATCH

This difference in abundance between the two years raises several uncertainties about how to measure the biological significance of the bycatch. Annual variation in migration must necessarily involve either animals from the population affected by the primarily fall and winter bycatch, or animals from other populations. If only animals from the affected population are involved, and disregarding statistical precision issues, the effect of bycatch should be measured by using the highest abundance estimate. That estimate would account for a larger portion of the affected population. If, on the other hand, animals from the affected population are joined in the northern Gulf of Maine and Bay of Fundy by variable numbers of animals from other populations, the effect of bycatch might better be measured by using the lowest abundance estimate. That estimate would more nearly account for the size of the affected population, although it would likely overestimate its size unless no animals from other populations migrate to this region in some years.

Of course, intermediate situations are possible that involve variable migration of both the affected population and one or more other populations. Further, while NEFSC (1992) assumed that the animals in the Gulf of Maine and Bay of Fundy belonged to one population, isolated from animals in the Gulf of St. Lawrence and Newfoundland, it also noted that there is no information on whether animals from these regions mix at different times of the year.

Given the lack of information on population structure and migration it is difficult to select an appropriate level of abundance for evaluating the significance of the bycatch. If estimates of abundance were not significantly different, the average of available estimates of summer abundance would be appropriate, and at least provides better statistical precision. Given that the estimates were significantly different, if one also knew there was no migration from other populations, then using a high estimate would provide an appropriate basis for management. If on the other hand one knew that some migration from other populations occurred, the lower estimate would be a more appropriate basis for management although it still might be too high.

Table 7. Estimates of the ratio (K/N, percent) of bycatch to abundance for 1990, 1991, and 1992, using the annual estimates of bycatch and the average estimate of abundance. Also shown are the lower and upper 95% confidence limits (LCL & UCL)

Year	K/N	CV (%)	LCL	UCL
1990	5.1	27.1	3.0	8.6
1991	3.6	27.4	2.1	6.1
1992	1.9	22.7	1.2	2.9

Table 8. Variances (diagonal elements) and covariances (upper right elements) of, and correlation coefficients (lower left elements) among, estimates of the ratio of bycatch (percent) of the average abundance in 1990, 1991, and 1992, from Equation 5

Year	1990	1991	1992
1990	1.90	0.65	0.34
1991	0.48	0.98	0.24
1992	0.57	0.57	0.19

One could compute the ratios of the annual bycatch estimates to the 1991 abundance estimate; this would allow the hypothesis of migration of animals from another population. On the other hand, one could compute the ratios of the annual bycatch estimates to the 1992 estimates; this would allow the hypothesis that wherever the additional animals came from in 1992, they are part of a single interbreeding population. It would not be appropriate in either case to compute the ratios of the annual estimates of bycatch and the annual estimates of abundance, as the abundance estimates are not mutually consistent. In lieu of these calculations, and especially to provide a statistically more stable reference point for management use, we use the ratios of annual bycatch to pooled abundance, effectively giving equal likelihood to alternative hypotheses about population structure.

The weighted average of the 1991 and 1992 estimates of abundance (Equation 4) is 47,200 (CV=19%, 95% CI 39,500 to 70,600). The ratios of the estimated bycatches to this average abundance (Equation 5) decreased from 1990 to 1992 (Table 7) suggest a declining trend. The estimated variances also decrease over time, because the bycatch sampling intensity increased (Table 8). The estimated covariances among the three ratios are large, corresponding to correlation coefficients in the range of 0.48 to 0.57 (Table 8).

Pair-wise differences in the estimated ratios of bycatch to abundance were significantly different between 1990 and 1992 (Z=2.69, p=.007) and between 1991 and 1992 (Z=2.06, p=.04).

DISCUSSION

The 1992 annual bycatch estimate of harbor porpoise in the Gulf of Maine demersal gillnet fishery was significantly lower than the estimates for 1990 and 1991. The greatest change between the 1992 and 1991 estimate was due to the significantly lower bycatch rate in the in the southern GOM winter of 1992. This change may be related to the increased sampling intensity, changes in fishing methods (either aboard sampled fishing trips or by all vessels), and changes in vulnerability of harbor porpoise to the fishing gear. Depending on the actual causes, there is the possibility that the winter rate may be higher in the future.

The 1992 bycatch estimate is better than those for previous years because it is based on more intense sampling, and includes bycatch immediately south of Cape Cod. However, several uncertainties remain. Chief among these are unknown levels of bycatch in Canadian demersal gillnet fisheries in the Bay of Fundy and in U.S. fisheries further south. Relative to the latter, more than 50 harbor porpoise have been reported stranded from North Carolina to New York in the first half of 1993. These strandings are consistent with patterns identified previously by Polacheck and Wenzel (1990), and the new data confirm speculation that some harbor porpoise are entangled in fishing nets in that region (Halley and Read 1993). In addition, one harbor porpoise was observed killed in a swordfish drift gillnet in deep (800 m) water near Cape Hatteras in the winter (NEFSC unpublished data[2]). Insufficient

[2] Reported through the NEFSC Sea Sampling Investigation.

data exist, however, either to determine which other fisheries are involved, or to estimate the number of harbor porpoise killed in fishing operations in the Mid-Atlantic region.

Bisack (1993) suggested that several sampling biases exist that may influence the bycatch estimate. These included under-reporting of fishing effort and catch in the WO data, repeated sampling of the vessel in the SS program, possibly undetected fall- out of harbor porpoise during retrieval of fishing gear, and differential sampling coverage among ports.

The problem of some fishing activity not being reported in the WO data (Bisack and DiNardo 1991, Bisack 1993) exists for the 1992 WO data. For example, not all trips observed by sea samplers are found in the WO and there was a case where one particular port was sampled several times in one month, yet there were no WO trips recorded for that port. This under-reporting biases the bycatch estimates downward by an unknown amount. A survey is currently being conducted to determine the number of vessels using demersal gillnets and the amount of their effort in order to evaluate the degree of bias.

Some vessels in the sea sampling program were sampled substantially more frequently than others. The effect of oversampling certain vessels is unknown, but might be expected to bias at least the variances of the estimated bycatch downward. There is a possibility that fishermen who, for whatever reason, have a lower bycatch of porpoise are sampled more frequently, or similarly, that they fish differently when they are sampled. Comparison of SS and WO data on fishing operations (location, landings, *etc.*) by the same vessels with and without an observer, and of WO data from vessels that are more or less frequently sampled could be examined to evaluate this possibility. Efforts to determine the extent to which harbor porpoise fall out of the fishing nets during retrieval before they are detected, as a measure of the potential magnitude of undetected fall-out, have not yet proven successful.

Differences in sampling intensity among some groups of ports, as discussed earlier, suggest the possibility of biases in the bycatch estimates. Although the sample bycatch rates are not significantly different among groups of ports based on the data from 1990 to 1992, there are apparent differences which, if real, could induce biases. Basing sea sampling on ports instead of, or in addition to, statistical area may reduce the potential for this problem.

The abundance estimate from the 1992 survey confirms the conclusion by NEFSC (1992) that the abundance of harbor porpoise in the Gulf of Maine and Bay of Fundy is substantially greater than might have been expected based on earlier, more localized, studies. The significantly higher sighting rate in 1992, however, suggests that more animals were in the area than in 1991. The difference in the density estimates in the post-stratified area surveyed in both years confirms that this difference, while occurring in all areas, was most pronounced in the central Maine region. Other possible explanations for the difference in abundance estimates are that:

1) animals sighted offshore of the Penobscot Bay area early in the survey may have moved north to be counted again in the Grand Manan Island area later in the survey,

2) sighting conditions may have been better in 1992 than in 1991, allowing more animals to be detected, and

3) survey methodology or observer effectiveness may have differed between the two surveys.

These three possibilities are all unlikely, however. Number 1 is unlikely because after the areas from Penobscot Bay to Grand Manan Island were surveyed, one day was spent surveying on a nearly straight transect line from Grand Manan Island to Portland, Maine. During that day, the upper and lower teams recorded 254 groups (702 individuals) and 230 groups (614 individuals) of harbor porpoises, respectively. The data collected on this day were not used in the abundance estimate. The large number of porpoise groups seen on this day indicates the animals sighted off Penobscot Bay earlier had not moved during the survey to become vulnerable to be sighted twice. Number 2 is unlikely because the amount of time spent surveying within the various Beaufort sea states in 1991 and 1992 were not significantly different (X^2 test, p=.21).

Number 3 is unlikely because the sighting procedure, ship, area surveyed, and half of the people were the same during both years. Comparison of the sighting efficiency of those observers who participated in both surveys revealed no substantial differences. Estimated detection function, f(0), average group size, and variability of these factors did not vary substantially between the two surveys for an individual observer.

Thus, the higher sighting rates and the greater spatial heterogeneity in 1992 likely reflect differences in the number of animals in the area from year to year. If so, it is not clear where the additional animals present in 1992 were located during the 1991 survey period, because care was taken in 1991 to determine that the density of animals immediately outside the study area was low (Palka 1993). One possibility is that almost as many animals of the same population occurred on Georges Bank or south of Cape Cod as occurred in the northern Gulf of Maine during the 1991 survey period. Another possibility is that many animals migrated into the Gulf of Maine in 1992 from different populations east of Nova Scotia. In the first case, the biological significance of the bycatch would be most appropriately measured by comparing bycatch estimates to the higher 1992 abundance estimate. In the second case, even using the lower abundance estimate may underestimate the true biological significance of the bycatch.

Taking these uncertainties into account, however, the decline in the ratios of the estimated bycatch of harbor porpoise in the U.S. demersal gillnet fishery to the average estimated summer abundance in the Gulf of Maine and Bay of Fundy indicates that any threat posed by the bycatch due to this fishery was lower in 1992 than 1990 and 1991. That this decrease was due to a lower bycatch rate in one area and season stratum in 1992, however, suggests that the rates could be higher in the future. Preliminary data from the 1993 winter season, for example, suggest a higher bycatch rate than that seen in 1992.

To fully understand the biological significance of bycatch of this species in eastern North America will require additional information on:

1) population structure and movements throughout eastern North America,

2) bycatch and abundance in other regions,

3) improved fishery sampling in the Gulf of Maine fishery, and

4) estimates of net productivity rates.

Repeating the abundance survey in the Gulf of Maine-Bay of Fundy in 1992 served to confirm the general results, and provided a relatively precise estimate of average summer abundance in the study area. However, lack of understanding of population structure and movements make it difficult to fully interpret the difference between the results of the two surveys. Resolving some of these uncertainties is of higher priority than improving the precision of the estimate of average abundance through repeating the survey.

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