Northwest and
Alaska Fisheries
Center

National Marine
Fisheries Service

U.S. DEPARTMENT OF COMMERCE

NWAFC PROCESSED REPORT 86-12

FINAL REPORT

Design of Surveys for Density of Surface Marine Debris in the North Pacific

April 1986

DESIGN OF SURVEYS FOR DENSITY OF SURFACE MARINE DEBRIS IN THE NORTH PACIFIC

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11 April 1986

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NOAA CONTRACT NO. 43-ABNF5-2498

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I. Introduction

The problems and impacts of marine debris on marine animals and on human activity in the oceans has been reviewed and discussed extensively by Shomura and Yoshida (1985). The purpose of this report is for guidance in development of future surveys to determine the amount, density, composition and spatial-temporal distribution of surface marine debris in the North Pacific ocean, particularly the Gulf of Alaska and Bering Sea. The sources of information used are existing data sets, published literature concerning marine debris worldwide, general statistical survey methodology, and special published statistical reports and reference material applicable to the situation. The focus of this report is on statistical precision of estimates of debris density by spatial location and debris type. Physical methods of survey are largely determined by precedent and practicality, however some suggestions for experimental approaches are made.

Cost of surveys is considered only indirectly because of the widespread use of platforms of opportunity to obtain debris information. Though dedicated surveys would certainly yield valuable information, the very large cost ratio relative to platforms of opportunity makes a quantitative comparison of cost-benefit tradeoffs a trivial exercise. Further, lack of detailed information concerning within-agency costs (for example, for beach surveys) contributed to a decision that such considerations were best omitted from this report; they can be more easily evaluated by agency executives.

We considered the survey to have two objectives:

(1) the estimation of density of debris within a year,

(2) the detection of change in debris density between years using density estimates or indicators of trend.

We assumed that density estimates for floating debris potentially harmful to marine organisms (specifically nets, particulate and fragmented plastic pieces, and strapping bands) was of primary interest and each type was equally important. Gerrodette (1985) discussed how the debris of interest can change with different survey objectives. However, general principles and guidelines discussed here are applicable to any other floating debris of interest.

Primary emphasis is on precision of estimates based on direct ocean surveys using platforms of opportunity (Gerrodette 1985, Lenarz 1985). Platforms of opportunity are defined to be any survey platform not launched specifically for the purpose of surveying marine debris. Precision of existing survey estimates is calculated and tables giving sampling intensity for a desired relative error are given, based on assumptions of similar variance. Recommendations concerning problems in knowledge of the spatial distribution of ocean debris, relative to past sampling locations, are made.

Emphasis is placed on the use of indirect survey methods, i.e., beach surveys as an indicator of ocean debris. Precision of existing survey estimates is calculated and tables giving sampling intensity for a desired percentage minimum detectable amount of change in density are calculated. Methods relating beach debris to ocean debris density are discussed. Considerations for future beach survey design to enable time trend estimation and eliminate accuracy problems due to uncertainties of beach debris lifetime are discussed.

II. Methods

The methodology for determination of density of debris of any type in an ocean area depends on the way in which the debris is distributed. Specifically, the variance is a quantitative measure of the differences in probable amount of debris among locations which will determine the required sampling intensity for a given accuracy in the density estimate and for a given (assumed or measured) distribution. If an assumption can be made about the type of distribution, the required sample size for a given variance will be reduced. For example, if debris is distributed so that each unit area within the survey area has approximately constant probability of containing a unit of debris, then the debris is binomially distributed. The normal distribution can be used as an approximation to the binomial for sample size computation, and the variance of the distribution is known whenever the mean density is known. If this assumption cannot be made, a distribution free (non-parametric) method for sample size determination requiring an explicit measure of variance must be made.

Both parametric and non-parametric methods are developed and applied. Existing debris surveys are considered as preliminary surveys for the purpose of distribution determination and survey design. If the variance estimated in the non-parametric method is about the same as the variance estimated using assumptions about debris distribution, then the debris distribution could be approximated by a parametric distribution.

The basic methodology that we used for density surveys of surface debris in an area was the strip transect. For nets, the observer could be either on a ship or in an airplane. The assumption in either case is that transects have a fixed width and that all objects are seen within that width. For particulate and fragmented plastic, a tow with a surface sampler is the method for implementing a strip transect. The width of the transect is determined by the opening of the surface sampler. The use of a surface sampler is based on an article by Carpenter (1976) which also discussed various types of samplers.

Since there are no sightings of strapping bands in ocean surveys of any kind, the only recommendation which can be made for this type of debris is that other surface debris surveys be alerted for the presence of bands. If bands are recorded in future ocean surveys, then those data can be used as a basis for a future sampling program.

Beach surveys are of interest primarily as indicators of trends in ocean debris density. The accuracy of beach debris estimates is of interest in terms of the minimum fractional change (percent detectable difference) which could be detected by subsequent surveys. This methodology, described below, depends upon distributional assumptions as well as assumptions about lifetime of beach debris, and the definition and independence of sample units.

II.A.i. Estimating sample sizes for ocean surveys assuming a binomial distribution of debris.

Assume simple random sampling. Let one sampling unit (SU) be defined. For our analysis of nets, one sampling unit (equivalent to one transect) will be 1 hour of observation on a ship going 2 nm/h with a 200 m wide effective search width. Based on the 1984 data from the marine mammal observer program (Jones and Ferrero 1985, data courtesy of L. Jones and J. Flanders, National Marine Fisheries, see Section III for further discussion of the data), one hour is the median length of one watch (equivalent to one transect) and 2 nm is the median distance covered in one watch. For simplicity of analysis and from the fragmentary data available (L. Jones pers. comm.), objects within 100 m of the ship have a high probability of being seen. For this analysis and until further information is available, we will assume that all nets within 100 m of the ship are seen. For particulate and fragmented plastic, one sampling unit or transect will be defined as one tow of a surface sampler for one nautical mile (Shaw 1977). The width of the sampler used by Shaw (1977) was 0.4 m which will be considered the effective search width for this analysis.

Randomly sample k search units and count n nets.

Assume $n \sim \text{bin}(k,p)$, where p is the density of nets. Further assume that the normal approximation holds. This means the finite population correction factor is negligible. Then, $n \approx N(kp, kpq)$ where N stands for the normal distribution, kp is the mean μ, kpq is the variance σ^2, and $q = 1 - p$.

We estimate p by $\hat{p}$.

$\hat{p} = n/k$ = number of nets/SU.

The expectation of $\hat{p}$ is p and the variance of $\hat{p}$ is pq/k.

We now estimate D, the density of nets in an area, by $\hat{D}$.

$\hat{D} = \dfrac{\hat{p}}{a}$ where $\hat{p}$ is in units of nets/SU, and a = area associated with one SU (nmi^2/SU).

The area associated with one sampling unit is a constant, c, so $\hat{D} = c\hat{p}$.

Since $\hat{p} \approx N(p, \frac{pq}{k})$, $\hat{D} \approx N(cp, c^2\frac{pq}{k})$.

We want to control the relative error rate θ (from Cochran 1977, p. 77 where r = θ). This means we want to control the probability that the difference between the estimate and the true value is greater than some percent of the true value. More formally,

$P(|\hat{D} - cp| \geq \theta cp) = \alpha$, where α is a small probability.

Now, $\theta cp = t\sigma_{\hat{D}}$ where t = the abscissa of the normal curve that cuts off an area of α at the tails

and $\sigma_{\hat{D}} = c\sqrt{\frac{pq}{k}}$

so $\theta p = t\sqrt{\frac{pq}{k}}$.

Now we can solve for k, the number of sampling units required for a particular relative error rate and α : $k = \frac{t^2 q}{\theta^2 p}$.

To calculate k, put into the formula an estimate of p, the desired α , and relative error rate.

II.A.ii. Estimating sample sizes with no distributional assumptions.

This second approach is based on Burnham et al. (1980).

First, the density of objects is estimated since number of objects is a simple function of density and the area covered. Let D = density of objects in the area to be sampled. The objects do not need to be independently distributed or uniformly distributed.

In our analysis, we will be using a strip transect method. That means we assume that all objects are seen in the width of the transect. The estimator of D, $\hat{D}$, is then

$\hat{D} = n/(2Lw)$, where n = number of objects seen, L = length of the transect, and w = 1/2 width of the transect.

Applying the equations on p. 35 of Burnham et al. (1980) to a strip transect method, we get

$E(n) = 2LDw$ and

$(cv(\hat{D}))^2 = \frac{var(n)}{(E(n))^2}$ where $cv(\hat{D})$ is the coefficient of variation of $\hat{D}$ and var(n) is the sampling variance of n, the number of objects seen.

Further, to a first approximation, $var(n) = a_1 n$ where a_1 is a constant. The constant a_1 is an unknown parameter and is estimated from a pilot study. Replacing E(n) by n, we get

$$(cv(\hat{D}))^2 = \frac{a_1}{n}.$$

A pilot study is necessary to determine preliminary estimates of a_1 and the coefficient of variation of $\hat{D}$.

In this derivation, achieving a specific coefficient of variation determines the sample size needed. If a distributional assumption is made, $cv(\hat{D})$ can be related to relative error, θ.

Let L_s and n_s be the length of the pilot transect and the number of objects seen, respectively, then

$a_1 = n_s\,(cv(\hat{D}))^2$ where $cv(\hat{D}) = sd(\hat{D})/\hat{D}$ calculated from the pilot study

and

$$L = \text{required length of transect} = \frac{a_1}{(cv(\hat{D}))^2}\left(\frac{L_s}{n_s}\right).$$

Using a normal approximation for the distribution of $\hat{D}$:

$\theta = t\,cv(\hat{D})$ where θ = relative error, and t = the abscissa of the normal curve that cuts off an area of α at the tails.

so $cv(\hat{D}) = \frac{\theta}{t}$

and

$$L = \frac{t^2 a_1}{\theta^2}\left(\frac{L_s}{n_s}\right).$$

Then, number of sampling units = k = $L / \left(\frac{1 \text{ SU}}{x \text{ nmi}} \right)$

where x nmi = number of nautical miles per sampling unit.

To calculate k, put into the formula an estimate of a_i, L_S, n_S, the desired α, and relative error rate.

II.B. Estimating percent detectable difference for beach surveys

We wanted to investigate the question: "Given a difference in amount of debris on an island between 2 years, what was the probability of detecting that change?". We assumed that the debris on the island in year 1 was independent of the debris in year 2, that the variances stayed constant from year to year, and that the distribution of debris on the beaches could be approximated by the normal distribution. Then we used the two-sample t-test with a two-sided alternative to determine the minimum detectable change as a percent of the original survey density estimate.

Formally,

$$P\left[\frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(ns_1^2 + ms_2^2)/(n+m-2)\ \left(\frac{1}{n} + \frac{1}{m}\right)}} \geq t_o\right] = \alpha/2$$

where $\bar{x}_1$ = mean number of objects in year 1,
$\bar{x}_2$ = mean number of objects in year 2,
s_1^2 = variance of sample in year 1,
s_2^2 = variance of sample in year 2,
n = sample size in year 1 (number of beaches),
m = sample size in year 2 (number of beaches).
t_o = the abscissa of the Student's-t curve that cuts off an area of α at the tails.

Minimum detectable change = $\frac{(\bar{x}_1 - \bar{x}_2)}{\bar{x}_1}$ 100%.

The values for $\bar{x}_1$ and s_1^2 were calculated using data from beaches of the same substrate type on the same island. There were 5 groups: Yakutat-sand, Kruzof-sand, Amchitka-North Pacific-sand, Amchitka-Bering Sea-sand, and Amchitka-Bering Sea-boulder.

Since we assumed that the variance does not change from year to year and that the sample size stayed the same from year to year, the above formula can be simplified to:

$$P\left[\frac{\bar{x}_1 - \bar{x}_2}{\sqrt{(2s_1^2/(n-1))}} \geq t_0\right] = \alpha/2.$$

We used an alpha of 0.05 in the analyses. The length of the transects was standardized to 1000 m.

This same formula can be used to investigate the effect of increasing the number of transects of any standard length on percent detectable difference. The length of the transect used for analysis was 100 m. The t-value was based on the normal distribution (i.e. large sample size).

III. Review of Existing Data

Before a survey methodology can be discussed, previous data sets must be found to give the surveyor some idea of the distribution of objects, variability of the objects, etc. This section summarizes the available data sets which deal with the Bering Sea and Gulf of Alaska (North Pacific). To be useful for planning a survey, the published articles must contain the following data:

1. debris type and number found per transect,
2. area where transects were done,
3. the location and length of each transect on which debris was found (not location of found debris),
4. number of transects done and length of each transect (if not constant) or the standard length of a transect (whether or not debris was found on the transects). The number of hours of observation is not sufficient.

Information in (1) determines what debris types were present Information in (2) determines how representative the areas surveyed were to the total sampling frame. Without (3) and (4), density of debris and, more importantly, variance estimates cannot be made. The information in the articles then becomes anecdotal and surveys cannot be designed on this basis. Due to these requirements, relatively little information is available. Conclusions regarding densities and distribution of debris based on the data must be tentative and used only for guidance until more data become available.

Confidence intervals for density estimates are given in the discussion. The data are most useful as a guide to required sampling intensity for future surveys.

III.A. Net surveys

Jones and Ferrero (1985) describe their observations of net debris encountered by biologists collecting marine mammal sighting data onboard Japanese salmon research and commercial vessels. Data used in that paper have been made available to us for further analysis (L. Jones and J. Flanders, pers. comm.). The data were collected from boats in the Bering Sea and the North Pacific Ocean. The salmon fishery uses gill nets so most of the sightings were of that net type. The area sampled was the area where the most nets would be expected. Jones and Ferrero (1985) present the data collection method in detail. Since observers were instructed in 1984 to look for drifting nets, the 1984 data were used for analysis. There is not enough information to separate gill and trawl nets. We will use these results for all nets until further information becomes available. The median watch length was 1 hour and the median distance traveled by the ship was 2 nautical miles (nm). There were 1,410 watches (after deletion of ambiguous data records) and 12 nets seen for a density estimate of 0.0085 nets/watch with a standard deviation of 0.099 nets/watch. This does not weight the watches by the distance travelled on the watch. These data give an interval estimate with 90% confidence of 0.0033 - 0.0137 nets/watch. Using the median distance travelled, this gives an interval estimate of 0.0016 - 0.0068 nets/nm. This corresponds to a relative error (1/2 confidence interval width divided by mean density) of 0.61.

There is little information on nets outside the area sampled by the marine mammal observers. Venrick et al. (1973) and Dahlberg and Day (1985) saw few nets using a cruise track down the 155 W longitude line. Yoshida and Baba (1985a,b) report relatively few nets around the Pribilof and Aleutian Islands. The distribution of nets in the ocean is probably some sort of clumped distribution with the largest concentration in the areas where the fishing fleets are located.

III.B. Particulate and Fragmented Plastic Surveys

The only ocean survey of plastic in the Bering Sea and Gulf of Alaska where the raw data were published was done by Shaw (1977). Seventy-one tows were made with a surface sampler using 363μm nets in 1975; 51 tows were in the Gulf of Alaska and 20 were done in the Bering Sea. Each tow was one nautical mile. Five pieces of plastic were found in the Gulf of Alaska and one piece was found in the Bering Sea. From the data in the paper, there were 0.098 plastic pieces/nm (s.d. = 0.300) in the Gulf of Alaska. In the Bering Sea, there were 0.05 plastic pieces/nm (s.d. = 0.22). Using an effective search width of 0.4 m and the method of Burnham et al. (1980), the density of plastic in the Gulf of Alaska was 454 plastic pieces/square nm (s.d. = 195) and, for the Bering Sea, the density was 232 pieces/square nm (s.d. = 232). Dahlberg and Day (1985) ran a survey for plastic in the Gulf of Alaska along 155 W longitude. In this study, visual observations were made for debris. Using the data from Table 3 of Dahlberg and Day (1985) for all stations north of 46°N and assuming the distance between of degrees latitude was covered in one transect, there were 10 transects made between 46° and 56°N latitude on the 155°W longitude line. Based on these transects, there were 0.30 pieces/transect (s.d. = 0.61) without weighting the estimates by length of transect. To get a density estimate using the method of Burnham et al. (1980), we assumed all plastic pieces were seen within 50 m of the ship (as assumed by Dahlberg and Day 1985). This results in a density estimate of 0.088 pieces/ square nm (s.d. = 0.093) for the Gulf of Alaska. If the raw data were available, better estimates of the density and variance could be made.

The only other article dealing directly with marine debris in the North Pacific is by Venrick et al. (1973). Venrick et al. (1973) made observations of debris on cruises in the Gulf of Alaska down to Hawaii along 155 W longitude. Venrick et al. (1973) visually observed large pieces of plastic haphazardly which limits the usefulness of the data.

Shaw (1977) found no evidence of the plastic concentrating in one place. Dahlberg and Day (1985) indicated that plastic may have been concentrated in certain areas (34° N and 31° N along 155° W longitude). Tows for plastic from 56° N to 22° N along 158° W (Shaw and Mapes 1979) did not recover plastic pieces until 38° N, which is south of the Gulf of Alaska.

Due to the scanty information available, we will be using a random distribution for particluate and fragmented plastic. This is the same assumption made by Venrick et al. (1973) when extrapolating their counts to a density estimate. When more information is available, stratifying by area could be attempted. Since there are no density estimates available for different areas within the Bering Sea and Gulf of Alaska similar to the information available for the East Coast (Colton et al. 1974), we will not stratify by area in this study.

III.C. Beach Surveys

Surveys of beaches facing the Gulf of Alaska and the Bering Sea have been done by Merrell (1984,1985). He has generously provided the raw data for the Amchitka surveys in 1982 and the Juneau-area surveys in 1984. The data have been recompiled to emphasize the debris that could entangle marine mammals: trawl nets, gill nets, other nets, and strapping. Since strapping was not distinguished between open and closed straps on Amchitka, both types are included in the strapping category. Open and closed straps were distinguished in the Juneau-area surveys and are included as separate categories. Because the surveys were done in different years, comparison between the Amchitka surveys and the Juneau-area surveys is not possible.

Since the beaches are of varying lengths, all data were standardized to number of debris/1000 m of beach. The North Pacific sand beaches and the Bering Sea sand beaches probably collect the same numbers of trawl web and strapping (Mann-Whitney U, $p = 0.05$) but there is less overall debris on the Bering Sea sand beaches (Mann-Whitney U, $p = 0.025$). The Bering Sea boulder and sand beaches appear to collect the same amount of debris by type and total (Table 1) (Mann-Whitney U, $p > 0.10$ for trawl web, strapping, and total). The same is true for the sand beaches and the sand/gravel beaches in the Juneau area (Table 2) (Mann-Whitney U, $p > 0.10$ for trawl web, combined strapping, and total).

We cannot determine what the sampling unit was from the way the survey was run. The sampling unit could have been the beach or the island. If the island was the sampling unit, we need to see how representative a single beach is for an island since, in some cases, only one beach per island was surveyed. To look at this, the data were divided into beaches by island for the Juneau-area data. The descriptive statistics by island are presented in Table 3. The coefficients of variation for each debris type by island are given in Table 4. In the two cases with sufficient data, the coefficient of variation was large for the three categories and was about the same for the two islands. This indicates there is a large amount of variation within an island. Whether a single beach represents an entire island would depend on the selection process. No information on how beaches were chosen was available to us. If the beach was the sampling unit, we can only look at beaches with a sand substrate. The other beach substrate types have too few data to be useful. The descriptive statistics by beach type are presented in Tables 1-2. If the beach is the sampling unit, we do not have any information on how the beaches were selected. This is critical so further analysis by using beach as the sampling unit is not pursued. We will use the island as the sampling unit and restrict further analysis to data from islands with more than one beach surveyed.

Table 1. Descriptive statistics for number of debris/1000 meter found on Amchitka beaches surveyed in 1982. n = sample size which is the number of beaches and is listed in the Ocean column.

Ocean	Beach Type	Debris type	$\bar{x}$	s.d.
North Pacific (Makarius, Rat Beach, Clevenger Creek) n = 3	Sand	Trawl Web	57	53
		Gill Net	0.7	1.1
		Strapping	117	110
		Total	1,181	711
Bering Sea (Crown Reefer, Petrel Point, Sand Beach Cove, Sea Otter Point) n = 4	Boulder	Trawl Web	31	15
		Gill Net	0.7	0.5
		Strapping	33	25
		Total	320	115
Bering Sea (Silver Salmon, Square Bay, Stone Beach Cove) n = 3	Sand	Trawl Web	39	36
		Gill Net	0	0
		Strapping	32	9
		Total	313	131

Table 2. Descriptive statistics for number of debris/1000 meter found on Juneau-area beaches surveyed in 1984. All beaches face the Gulf of Alaska. Sample size is in parentheses under Beach Type.

Beach Type	Debris type	$\bar{x}$	s.d.
Sand (12 beaches)	Trawl Web	14	14
	Gill Net	0.9	1.3
	Other Net	0.3	0.6
	Open Straps	9	7
	Closed Straps	0.6	0.9
	Total	899	1,036
Sand/Gravel (3 beaches)	Trawl Web	9	16
	Gill Net	4	4
	Other Net	0	0
	Open Straps	10	16
	Closed Straps	0.3	0.6
	Total	812	1,082

Table 3. Descriptive statistics for number of debris/1000 meter found on Yakutat Island (all sand beaches), Kruzof Island (all sand beaches), and Middleton Island (all different substrate types). All surveys were done in 1984.

Islands:	Yakutat		Kruzof		Middleton	
Sample Size:	5 beaches		3 beaches		3 beaches	
Debris Type	$\bar{x}$	s.d.	$\bar{x}$	s.d.	$\bar{x}$	s.d.
Trawl Web	9.8	6.8	3.2	2.0	30.4	14.3
Gill Net	0.4	0.9	0	--	5.8	4.2
Other Net	0	--	0.3	0.6	0	--
Straps						
Open	8.4	3.0	3.5	1.4	19.4	11.8
Closed	0.2	0.4	0.7	0.6	1.3	0.6
Total Debris	421.6	229.9	690.3	342.0	1608.6	867.0

Table 4. Coefficients of variation for trawl web, open straps, and total debris for Yakutat and Kruzof Islands surveyed in summer 1984. All the beaches on each island had the same substrate type. Sample size is listed in parentheses under Island.

Island	Debris Type	Coefficient of Variation
Yakutat (5 beaches)	Trawl Web	.69
	Open Straps	.35
	Total	.54
Kruzof (3 beaches)	Trawl Web	.58
	Open Straps	.46
	Total	.44

IV. Survey Design

This section presents various possible designs along with areas where further information is needed. We also discuss the basic sampling intensity required to achieve given levels of accuracy in density estimates based on the results of past surveys.

From the analysis of published data, nets must be considered to be rare events that, at the end of the fishing season, are probably clustered in relation to the fishing effort. Particulate and fragmented plastic are more common but no information is available for deciding on its distribution.

Estimation of rare events is an unresolved sampling problem, according to Kish (1965); the following is based on his discussion. For nets, one possibility is to use disproportionate stratified sampling or optimum allocation. The standard error of the mean has a higher sampling variability when the underlying distribution is highly skewed (which is the case for rare items). This in turns affects the sample size of the survey. Better variance estimates can lead to more accurate sample sizes for a given precision. The variance estimate can be reduced substantially if over 90% of the rare items can be located within 10% of the population area. This means that areas that contain many nets should be sampled heavily in relation to the rest of the areas. This, in essence, may be what the marine mammal observer program is currently doing since most of their effort is put into the areas where the probability of a net is the highest. The actual sampling fractions are computed based on the standard deviation per sampling unit within the strata and a constant, C, which depends on an assumption of equal cost for strata (Kish 1965). The information needed is an estimate of net concentration in different areas, the variances within strata, and an estimate of C. We only have information for one potential stratum for one year. Further analysis is fruitless until more data become available.

For the more common items like plastic, stratification can also be used to reduce the variance estimate (a common reason for using stratification, see Cochran 1977). However, in order to stratify, you need a stratification variable: space, time, etc. For plastic, the particles may concentrate in small-scale eddies (suggested by Dahlberg and Day 1985 and discussed for pelagic tar by Shaw and Mapes 1979). In addition, plastic may be concentrated around areas of human activity such as the coast or established shipping lanes. Information is lacking on this point and stratification cannot be attempted. If stratification is done without large differences between the strata, variance estimates will be larger than the variance estimate from simple random sampling.

IV.A. Ocean Surveys

Nets:

The ocean surveys have been designed to take advantage of platforms of opportunity, specifically the marine mammal observer program for Dall's porpoise. The marine mammal observer program currently takes place in the area where density of nets is expected to be highest. This can be taken into account by using a stratification by fishing effort or fishing fleet location. However, areas outside of the fishing area must be surveyed to make a complete survey. If non-fishing areas are not surveyed, generalizability to the entire area of interest will be compromised (see Rosander 1977 for a discussion of sampling frames).

The effective search width assumption of 200 m needs to be investigated. For example, it may be found that height above the water (height of the flying bridge) may necessitate different transect widths. Also, standard methodology for detecting objects, such as not using binoculars for initial sightings, must be used. We have based our recommendations on the technique currently used by the marine mammal observer program.

Particulate and Fragmented Plastic:

The method for sampling plastic pieces has been developed more than that for nets (Carpenter 1976). Sampling for plastic by surface tows has been done mainly in the Atlantic Ocean (Carpenter and Smith 1972, Carpenter et al. 1972, Colton et al. 1974, Morris 1980b) with a few surveys done in the Pacific Ocean (Wong et al. 1974, Shaw and Mapes 1979) and in the coastal waters of Great Britain (Morris and Hamilton 1974). The main decision seems to be what surface sampler to use and what net size to use. There is no concensus. At this time, a net size of 363 μm used by Shaw (1977) should be adequate. If a standard net size is agreed upon, we would recommend adopting that size. Carpenter (1976) discusses possible types of samplers as well as other types used in the previously mentioned studies. Some surveys (Venrick et al. 1973, Morris 1980a, Dahlberg and Day 1985) have used visual observations of plastic pieces. Some of those studies were not planned but others were planned. Given how many previous researchers have used surface samplers, a justification for visual observations must be made for a planned study. If visual observations are chosen, all the problems and considerations associated with visual searching for nets will have to be resolved for visually searching for plastic before good density and variance estimates for plastic can be made.

Carpenter (1976) discusses concentrations of particles due to various oceanographic factors. Dahlberg and Day (1985) suggest a small-scale eddy may account for the concentration of plastic seen in their study. At the present time, we do not have enough information to design a stratification scheme. We would recommend a pilot study to gather further information to stratify the particulate and fragmented plastic survey.

IV.A.i. Sample sizes for nets

Table 5(a-b) presents estimates of the various sample sizes (numbers of transects, see Methods for definition) needed for different relative errors for alpha of 0.05 and 0.10 using a binomial model and a nonparametric model for the Gulf of Alaska and Bering Sea combined. As the relative error decreases, number of transects needed increases. Also, if a higher degree of error in the difference between the estimate and the parameter can be tolerated, a smaller relative error can be achieved with the same sample size (compare Tables 5a and 5b).

The Methods discuss the actual procedure in detail. For the Binomial model, we used an estimate of p of 0.004 nets/nm. For the Nonparametric method, we used an estimate of a_1 of 1.2288, L_S was 3509.2693 nautical miles and n_S was 12 nets. These estimates were based on the 1984 marine mammal observer data discussed in

Section III. One sampling unit or transect was defined to be 1 hour of observation on a ship going 2 knots/hour. See the Methods section for further details.

The two models for determining sample size do not agree that well (Table 5a-b). This is an indication that the nets are not distributed as a binomial random variable. The 1984 marine mammal observer program had 1,410 watches. This number is about equal to the sample size needed for a relative error of 0.70 with an alpha of 0.05 and a relative error of 0.60 with an alpha of 0.10.

Table 5a. Number of sampling units (transects) needed for various relative errors using an alpha of 0.05 for a binomial distribution (Binomial) of nets and an unspecified distribution (Nonparametric) of nets for the Gulf of Alaska and the Bering Sea combined.

Relative Error	Number of Sampling Units Binomial	Nonparametric
1.00	448	690
0.95	496	765
0.90	553	852
0.85	619	955
0.80	699	1079
0.75	796	1227
0.70	913	1409
0.65	1059	1634
0.60	1243	1917
0.55	1480	2282
0.50	1790	2761
0.45	2210	3409
0.40	2798	4314
0.35	3654	5635
0.30	4973	7669
0.25	7161	11044
0.20	11189	17256
0.15	19892	30677
0.10	44758	69024
0.05	179032	276095

Table 5b. Number of sampling units (transects) needed for various relative errors using an alpha of 0.10 for a binomial distribution (Binomial) of nets and an unspecified distribution (Nonparametric) of nets for the Gulf of Alaska and the Bering Sea combined.

Relative Error	Number of Sampling Units Binomial	Nonparametric
1.00	313	483
0.95	347	535
0.90	387	597
0.85	434	669
0.80	490	755
0.75	557	859
0.70	639	986
0.65	742	1144
0.60	870	1342
0.55	1036	1597
0.50	1253	1933
0.45	1547	2386
0.40	1958	3020
0.35	2558	3945
0.30	3482	5369
0.25	5014	7732
0.20	7834	12081
0.15	13927	21478
0.10	31336	48325
0.05	125345	193301

IV.A.ii. Sample sizes for particulate and fragmented plastic

Table 6(a-b) presents the estimates of the number of sampling units needed (number of tows, see Methods for details) needed for different relative errors for alpha of 0.05 and 0.10 using a binomial model and a nonparametric model for the Gulf of Alaska and Bering Sea combined. As the relative error decreases, number of tows needed increases. Also, if a higher degree of error in the difference between the estimate and the parameter can be tolerated, a smaller relative error can be achieved with the same sample size (compare Tables 6a and 6b).

For the Binomial model, we used a $\hat{p}$ of 0.0845 pieces/nm. For the Nonparametric method, we used an estimate of a_1 of 0.9126, L_5 was 71 nm, and n_5 was 6 pieces of plastic. These estimates were based on the combined Bering Sea and Gulf of Alaska data in Shaw (1977) discussed in Section III. One sampling unit was defined to be 1 tow of a surface sampler for one nautical mile. See the Methods section for further details.

The two models for determining sample size agree well (Table 6a-b). This is an indication that the distribution of particulate and fragmented plastic may be approximated by a random distribution. Shaw (1977) did 71 tows for plastic. This number is about equal to the sample size needed for a relative error of 0.75 with alpha = 0.05 and a relative error of 0.65 with alpha = 0.10.

Table 6a. Number of sampling units (transects) needed for various relative errors using an alpha of 0.05 for a binomial distribution (Binomial) of particulate and fragmented plastic and an unspecified distribution (Nonparametric) of particulate and fragmented plastic for the Gulf of Alaska and the Bering Sea combined.

Relative Error	Number of Sampling Units: Binomial	Nonparametric
1.00	42	41
0.95	46	46
0.90	51	51
0.85	58	57
0.80	65	65
0.75	74	74
0.70	85	85
0.65	98	98
0.60	116	115
0.55	138	137
0.50	166	166
0.45	205	205
0.40	260	259
0.35	340	339
0.30	462	461
0.25	666	664
0.20	1040	1037
0.15	1850	1848
0.10	4162	4149
0.05	16648	16594

Table 6b. Number of sampling units (transects) needed for various relative errors using an alpha of 0.10 for a binomial distribution (Binomial) of particulate and fragmented plastic and an unspecified distribution (Nonparametric) of particulate and fragmented plastic for the Gulf of Alaska and the Bering Sea combined.

Relative Error	Number of Sampling Units Binomial	Nonparametric
1.00	29	29
0.95	32	32
0.90	36	36
0.85	40	40
0.80	45	45
0.75	52	52
0.70	59	59
0.65	69	69
0.60	81	81
0.55	96	96
0.50	117	116
0.45	144	143
0.40	182	181
0.35	238	237
0.30	324	323
0.25	466	465
0.20	728	726
0.15	1295	1291
0.10	2914	2904
0.05	11656	11618

IV.B. Beach Surveys

Beach surveys have the advantage that they are relatively inexpensive to implement. The cost of transportation to the various islands and the salaries of the surveyors are the principal costs. We consider the merit of beach surveys only as an indicator of ocean debris, since beach debris presumably does not significantly endanger marine mammals or birds. There is a variety of information about ocean debris which might be extrapolated from beach survey results. We will consider several types of information about ocean debris and discuss the beach survey requirements and possibility of success of each.

These types of information are:

1. Indicator of types of ocean debris,
2. Estimate of ocean debris density,
3. Index of ocean debris density,
4. Index of possible change with time in ocean debris density,
5. Index of spatial variability in ocean debris density.

As an indicator of types of ocean debris, a beach survey is valuable chiefly for indicating the presence of possibly dangerous debris which is difficult, expensive or impossible to survey by direct ocean methods. The current surveys have been valuable in this context by indicating the presence of plastic strapping bands which have never been reported by a direct ocean survey aside from reports of trapped marine mammals. There are no particular requirements of a beach survey design to fulfill this function, aside from a record of different debris types.

As a method for directly estimating density of ocean floating debris, beach survey data would require both a theoretical model for beach deposition and a simultaneous beach and ocean survey for empirical calibration. The theoretical model would give a framework for interpreting beach debris densities in terms of ocean densities. The empirical studies would allow calibration of unknown parameters in the theoretical model.

A simple theoretical model of beach deposition would equate beach deposition rate per unit time and beach length with the product of ocean density and an effective movement rate normal to the beach orientation. The movement rate would, in physical terms, be a complex combination of integrated currents, wind and a coupling factor unique to the type of debris (Reed and Schumacher 1985). Beach density seen by a survey and resulting from the deposition rate would then be the integral of the rate discounted by a "removal" decay rate. Such removal might be due solely to single, relatively rare catastrophic events (e.g. major storms) or it might be more continual (e.g. tidal action). A single event (say, annual) or an exponential model would be appropriate for these two modes of removal, respectively; data should probably be analyzed using both models and results compared. This model would be the basis for evaluation and testing of assumptions regarding beach survey data discussed below. A mathematical version of this model is contained in Appendix I along with further discussion of its applications, assumptions, and limitations.

The deposition rate would be virtually impossible to calculate from meteorological and physical data (see Reed and Schumacher 1985 or Galt 1985 for a discussion) particular time and area from simultaneous beach/ocean surveys. For example, if one is willing to ignore the time difference between the ocean and beach surveys, a beach density of 5.7 nets/100m and ocean density of 0.460 nets/ 1000 square nm, and mean retention time for beach debris of one year, then the average effective deposition velocity would be 2.62 knots. If the ratio of ocean density of nets and strapping are comparable to the ratio of the average number of nets and straps found on the beach, then there would be 0.944 straps/1000 square nm in the ocean. Consideration of the confidence limits on beach and ocean density estimates could be used to calculate similar limits to this figure. Though there are substantial <u>caveats</u> associated with this calculation, the result is not unreasonable considering North Pacific winds and weather. The calculation illustrates the basic method which could be used to develop a correspondence between beach and ocean surveys at a point in time.

In order to use beach surveys to estimate change over time of ocean density, the variability of the deposition velocity in space and time would have to be considered. This would in turn affect the variability of beach density considered as an index of ocean density, and would further increase the necessary sample size of beach surveys used for this purpose. However the evaluation of the variability could be undertaken; the tables given below for beach survey intensity as a function of desired minimum detectable change could be modified accordingly.

Use of the beach survey data to detect or indicate spatial variability in ocean debris density is probably practical only in very widely separated areas, e.g. Southeast Alaska versus Aleutian Islands. This is due to the inherent high variability of the beach densities and an assumption that adjacent spatial areas are likely to have similar densities, making a statistical distinction very difficult.

There are many assumptions behind a beach survey that must be examined before its usefulness can be assessed. The most important assumption is that the amount of debris on the beaches is an some way, quantitatively and statistically, associated with the amount of debris out in the ocean. We know the debris on the beach originated in the ocean and the main problem then is to correlate the amount on the beach with the amount in the water. No study has addressed this problem. If a beach study is to be adopted, this assumption must be investigated. A second assumption, often implicit, is that the surveys are done far enough apart in time so that the debris on the beach at time t (the first survey) is buried or removed so that there is no time-t-debris on the beach at time t+1 (the second survey). This is an important assumption which has not been checked; otherwise a person could be counting the same debris twice. Removal mechanisms were considered explicitly in the model discussed above.

A third assumption, also related to removal mechanisms, is that the debris that washes ashore between surveys stays ashore. This is not so important as the second assumption as long as the forces affecting removal of debris stay the same over time. Both the second and third assumptions can be checked by using a mark-recapture experiment on debris. For example, all debris would be marked uniquely at time t, then the beach is visited periodically between the time of the first survey and the time of the second survey. At each visit, the debris is remarked and old marks tallied. A check of the beach on the second survey to see what debris are left will give some indication of the deposition and decay rates. Gerrodette (1985) suggested using radio- or sonar-taggs to monitor and determine the fate of marine debris.

Merrel (1980) gave some information about loss rates for one type of debris (gillnet floats) on two Amchitka beaches, one facing north and the other south. The weighted average loss in a year was 41% corresponding to an instantaneous loss rate of 0.89/year (k in the equations in Appendix I). This loss rate corresponds to a mean residence time (assuming smoothed exponential loss) of 0.33 years for this type of debris and beach. However, the two beaches differed by 95% in their loss rates, indicating a need for substantially more information with larger sample sizes in order to reliably incorporate measured loss rates into calculations which index ocean density from beach density. Information is also needed on loss rates of other debris types, notably nets.

Variability between substrate types may have to be controlled for. Preliminary analysis (see section III) indicates this may not be a problem. A specifically designed study to look at this factor would lay all doubts to rest. If substrate type does need to be controlled it could be considered a stratifying variable.

Another subject that will be addressed further below is the frequency of survey of the beaches. We do not have enough information on decay and deposition rates for these beaches so we can only give some general guidelines. The objective of the beach surveys must be clarified. For example, are the data going to be used to see if an enforcement of "no-dumping" laws is effective? Then once a year beach surveys probably will not give enough information to answer that question. But, if detection of general long-term trends in the amount of debris is desired, then once a year may give enough information.

IV.B.i. Beach Surveys - minimum detectable change

In any survey, sample size is critical. Besides the effect on the variability of the density estimators, the amount of change between surveys that could be detected is determined largely by sample size. Table 7 presents minimum detectable changes for 5 island-beach substrate groups that were defined in the previous data analysis section (Section III). What is seen from the table is that the change, either an increase or decrease, would have to be drastic before the change would be statistically detectable. Table 8(a-d) is an estimate of the minimum detectable change as sample sizes change assuming variance remains approximately constant. As can be seen, as the sample size increases, the minimum detectable difference decreases. The sample size can be increased in two ways. More 1000 m transects could be surveyed or a shorter transect length, such as 100 m, could be used and more of these shorter transects surveyed.

Table 7. Minimum detectable change (in percent) for a variety of debris groupings for the 5 island-beach substrate groups defined in the methods. NP = North Pacific, S = Sea.

Debris Group	Yakutat Sand (5 beaches)	Kruzof Sand (3 beaches)	Amchitka NP Sand (3 beaches)	Amchitka Bering S Sand (3 beaches)	Amchitka Bering S Boulder (4 beaches)
Total Debris	89	137	167	116	68
Nets+ Strapping	85	95	214	51	122
Nets Only	118	177	145	185	94
Strapping (open+ closed)	51	69	263	81	156

Table 8a. Effect of increasing the number of transects of 100 m in length surveyed per island on minimum detectable change in percent for total debris. Possible number of transects was determined for each island by dividing the total transect lengths done on each island by 100. NP = North Pacific.

	% Minimum Detectable Change				
N	Yakutat Sand	Kruzof Sand	Amchitka NP Sand	Amchitka Bering Sea Sand	Amchitka Bering Sea Boulder
5	76	68	83	58	47
10	51	45	56	39	32
15	41	36	45	31	25
20	35	31	38	27	22
25	31	28	34	24	19
30	28	25	31	21	18
35	26				16
40	24				15
45	23				
50	22				

Table 8b. Effect of increasing the number of transects of 100 m in length surveyed per island on minimum detectable change in percent for all nets and strapping. Possible number of transects was determined for each island by dividing the total transect lengths done on each island by 100. NP = North Pacific.

	% Minimum Detectable Change				
N	Yakutat Sand	Kruzof Sand	Amchitka NP Sand	Amchitka Bering Sea Sand	Amchitka Bering Sea Boulder
5	72	47	107	26	85
10	48	32	71	17	57
15	39	25	57	14	45
20	33	22	49	12	39
25	29	19	44	10	35
30	27	18	40	9	31
35	25				29
40	23				27
45	22				
50	21				

Table 8c. Effect of increasing the number of transects of 100 m in length surveyed per island on minimum detectable change in percent for all nets. Possible number of transects was determined for each island by dividing the total transect lengths done on each island by 100. NP = North Pacific.

	% Minimum Detectable Change				
N	Yakutat Sand	Kruzof Sand	Amchitka NP Sand	Amchitka Bering Sea Sand	Amchitka Bering Sea Boulder
5	100	88	73	92	66
10	67	59	48	62	44
15	54	47	39	49	35
20	46	40	33	42	30
25	41	36	30	38	27
30	37	33	27	34	24
35	34				22
40	32				21
45	30				
50	29				

Table 8d. Effect of increasing the number of transects of 100 m in length surveyed per island on minimum detectable change in percent for open and closed strapping. Possible number of transects was determined for each island by dividing the total transect lengths done on each island by 100. NP = North Pacific.

	% Minimum Detectable Change				
N	Yakutat Sand	Kruzof Sand	Amchitka NP Sand	Amchitka Bering Sea Sand	Amchitka Bering Sea Boulder
5	43	35	131	41	108
10	29	23	87	27	72
15	23	18	70	22	58
20	20	16	60	19	50
25	18	14	54	17	44
30	16	13	49	15	40
35	15				37
40	14				35
45	13				
50	12				

V. Discussion and Conclusions

The greatest single need is for coordination of all types of surveys. Survey objectives need to be clarified. Barnard et al. (1985) discuss, in general, how survey objectives, sampling design, and analyses interact. Gerrodette (1985) discussed aspects dealing direcly with marine debris and some of the discussion below amplifies his comments. Common survey objectives would lead to a standard sampling unit, agreement on stratification variables, and a coordination of areas surveyed, sampling intensities (to obtain uniform variance of estimates), times of survey, methods of debris classification, and collection and recording methodology. The apparent lack of such coordination is probably an artifact of the recent establishment of the survey program. The authors are aware of increased coordination in surveys for which data compilation and analysis are currently in progress. But the enormous areas to be covered and the length of time to obtain results from surveys makes it difficult for these authors to be fully aware of the most recent survey plans and results still in analysis phase or in-house reports. However the problems with, for example, comparison of beach and ocean survey results, point up the importance of such coordination for a long term debris survey program.

Ocean net surveys

The most readily apparent problem with the existing survey data (1984 observer data reported by Jones and Ferrero) is associated with the total sampling intensity and the spatial coverage. The precision of the estimate of net density from that survey (about 60% relative error with 90% confidence) seems to these authors to be at the outer margin for use for such purposes as detection of future change or quantification of total amount of debris in an area. While this variability is not very large by standards of marine system data in general, it could cause problems in detection of change over time, from one area to another, or for use in other scientific studies related to marine animal problems. Without a specific proposed application, a recommendation for a target precision must have both subjective and arbitrary components to a certain extent. If an estimate of density is to be used for multiple comparisons with other estimates, as, for example, in examination of a time series for a change in density, then the confidence level at which comparisons are made is much more critical. The ability to detect a 50% change in density at the 95% confidence level seems to be a reasonable target. In this case, reduction of the relative error in ocean density estimates to below 50% at the 95% level would require two to three times the intensity of sampling of that in the 1984 survey, or a sample size of about 2800.

The spatial coverage of the 1984 survey presents a much greater problem. On a strictly areal basis, the coverage is not at all representative of the entire North Pacific (see Fig. 1 of Jones and Ferrero, 1985). More importantly from the standpoint of stratification, coverage weighted by fishing effort is more complete but still spotty. There are several criteria for judging adequate spatial coverage: stratification objective in conjunction with areas where debris originates (e.g., fishing areas), areas of mammal concentrations, general spatial coverage, etc. The choice of these criteria depends upon agency objectives in the survey program. A reasonable objective might be the determination of areas of critical debris problems with respect to marine mammal entrapment. With such a criterion, broad areal coverage with approximately balanced sampling intensity would be very important, at least for initial surveys to guide stratification. Tables 5(a,b)-6(a,b) give sampling intensity guidelines to be able to distinguish debris densities in different areas as well as over time. In comparison of one or more areas to detect statistically significant differences in density, it is the total number of samples in all areas which determines the error degrees of freedom. This means that in comparison of n areas, each area should have a sample size of approximately 1/n of the table values to achieve a given level of precision.

Some literature reports of local debris accumulations were noted in the text. Such accumulations have a drastic effect on the precision of density estimates because they represent a radical alteration in the distribution of debris. In the absence of other information, a relatively uniform distribution of debris allows use of normal distribution assumptions. Although there is no direct evidence of a strong clumping effect, the comparison of variability of the ocean net survey data in Table 5 by methods which do and do not assume a uniform distribution shows that there is some alteration of a uniform distribution (with respect to the distribution of sample transects). This alteration is sufficient to increase the required sampling intensity by about 50%. The preferred method to deal with the problem of a heterogenous distribution is to stratify the sampling according to debris density. This requires *a priori* information about the distribution of debris. On a broad, trans-ocean scale, this can be achieved by breaking the survey into area units with adjusted sampling intensities determined by type of allocation (optimal or proportional). On a smaller spatial scale, say one mile or less, local debris accumulations should be reported as a single grouping with a separate report of debris density within the local accumulation.

There is virtually no quantified information available upon which to base the assumption of a 200 meter transect width. The visibility of debris is certainly variable with type as well as the immediate survey environment. Uncertainty associated with this width is a major contributor to the unquantifiable uncertainty in debris density and distribution. Southwest Fisheries Center has applied the nonparametric approach of Burnham et al. (1980) to estimate the sighting function for dolphin schools rather than using a constant strip width (Holt 1984). In this approach, perpendicular distance to the sighted object is needed; such information would not normally be available for marine debris sightings. Also, Barnard et al. (1985) argued that parametric modelling of detectability would be more fruitful than the approach of Burnham et al. (1980). It is conceptually not difficult to design a debris sighting sea trial to determine effective transect width in an area of known debris density. A vessel running a repeated diagonal pattern through parallel rows of fixed debris types with various observers blind to the trial configuration would yield the desired information. Exact vessel and debris locations during the trial would be required; the experiment would need to be repeated in various weather and sea conditions, perhaps with different vessels, speeds, etc. It would also be useful to repeat the trial periodically over several years to detect possible changes in effective width due to unforeseen or unknown factors. Environmental factors found to significantly affect search width should be recorded during subsequent surveys.

Beach surveys

The usefulness of beach survey information is almost entirely dependent upon the capability to infer ocean debris conditions from the beach information. At the present time almost no such inference is possible because of lack of beach and ocean survey information which is coordinated in time and space, and because parameters associated with beach debris lifetime and deposition rate are unknown. Correction of this condition requires coordinated planning of both types of survey to maximise the correspondence between the two. Beach surveys should be done in areas where and at times when there are concomitant ocean surveys.

Beach surveys should have a component designed to measure debris lifetime for all debris types. Time series information about beach debris could be important to detect changes in density, however care should be taken to assure independence of successive counts. Clearing or tagging of beach segments subsequent to counting could be used to determine debris lifetimes as in Merrell (1980) but with greater sample sizes and more comprehensive coverage. Depending upon the relation between lifetimes and resurvey frequency, independence may not be a problem. If lifetimes are sufficiently long, then regular tagging of the long lifetime items may be required.

Establishment of a relationship between beach and ocean density requires the development of a quantitative model, such as that described in the text, for beach deposition. Calibration and testing of the model could be done using data gathered by methods described in the above two paragraphs. A small project to do this development and testing should be established. If successful, the trade-off between information gathered by the two types of survey, in terms of costs versus information gained, could be evaluated and an optimal division of effort planned. If no relation can be established, the usefulness of beach surveys is limited as a method for quantitatively infering ocean debris conditions.

Several design considerations for beach surveys should be mentioned. Consider the contrast between ocean and beach surveys. In the ocean, several thousand sampling units (a watch of about an hour) result in detection of very few rare events (less than one in a hundred sampling units). On the beach, a sampling unit (1000m strip) typically records tens to hundreds of items but there are only three to five sampling units in a time-area stratum. Data from these two types of surveys must be compared. Any effort at increasing the sample size on the beach survey has a high payoff in decreased variance of resulting estimates. Since many events are recorded in the present transect size, preliminary variance estimates may be made by subdividing each transect by ten or more. Much more information is gained in terms of increased precision in the estimate of density (i.e. decreased variance of the density estimate). The information cannot be reliably imputed to the area being sampled unless the sampling units are either randomly or systematically distributed; this requires more labor in the sampling procedure than simply subdividing transects. It is important that the sampling unit (e.g., beach, island, ocean area) be defined; from this will follow the appropriate sampling procedure as well as determining the proper interpretation of the resulting statistics. Conditions which may change the debris capturing properties of a beach must be considered in the sampling, however. Gravel versus sand beaches may have different capture characteristics; orientation, exposure, slope and other characteristics may be important. Evaluation of a beach-ocean relation must consider all of these possibilities. Sampling either must represent a wide range of such characteristics with an adequate sample size within each, or the surveys should be limited to one or a small number of "indicator" type beaches. The same comments made under Ocean Surveys concerning sample stratification with respect to aggregations of debris also apply to beach surveys.

Particulate and Fragmented Plastic Surveys and miscellaneous topics

Very little information is available about the North Pacific Ocean distribution and density of plastic. The usefulness of stratification depends largely on this information. A pilot study to gather this information is important. Possibly a model using knowledge of wind and current patterns (Galt 1985, Reed and Schumacher 1985) could be used to predict areas of probable high concentration of plastic. The technique for sampling plastic particles by neuston samplers has been well established on the East Coast of the United States (Carpenter 1976) and we recommend following that procedure. Since some types of plastic, particularly closed plastic strapping bands, have been implicated in harm to marine animals, some effort should go into additional survey information. The very rough estimate made of ocean density of strapping bands made in this study extrapolated from beach and ocean survey information, is probably the only quantitative estimate of floating strapping bands available. An effort at explicit determination of the sightability of strapping bands would be useful; it could probably be done in conjunction with the strip width determination experiments described above.

Kish (1965) discusses the problems of combining surveys to estimate more than one type of item at the same time. This can lead to insolvable problems especially if optimal allocation is used. In any case, the same allocation procedure should be used for each item and sample sizes compared. If the sample sizes are comparable, a compromise can be made; otherwise design changes have to be made.

Reliability of survey information could be improved by a careful program to standardize survey methodology, especially to insure a comprehensive, standard data collection and processing procedure. Though it is clearly not practical to control the survey environment when using platforms of opportunity to detect rare events, data recording and subsequent processing can be more easily adjustd. There is no serious problem with the ocean survey forms used in 1984, however environmental conditions during search effort could be more consistently and quantifiably recorded. This will be particularly important if the search width trials are held, as an effective search width for each watch could then be calculated. Coordination between design of the search width experiment and environmental data which could be recorded during surveys is important. Occurrence of a debris sighting event should also be recorded on the same form as search effort. Beach survey forms should also be revised to include some location information for debris types, in order to help implement the increased sample size recommendations discussed above.

The possiblility of enhancing sampling intensity using aerial platforms, especially platforms of opportunity, is too valuable to be ignored until it is shown to be infeasible. Only certain flight modes (i.e. low altitude, low speed) are at all likely to be effective, however there may be some possibilities. There may be information in the possession of the Coast Guard or other agencies regarding such feasibility. The only sure way to determine the practicality of aerial surveys is with a dedicated trial involving known distributions and types of debris.

Finally, the use of seabirds as biological indicators of trend of plastic particle pollution has been suggested (Boersma 1986). There is a large program on the east coast that makes use of biological indicators for pollution. However, as pointed out by Barnard et al. (1985), in order to correctly interpret data and identify sources of variability much basic research on the response of organisms to such contaminants must be done. Unless a comprehensive program such as that on the east coast is established, we cannot recommend the use of biological indicators for use in the marine debris survey at this time.

VI. Recommendations

Based on the above results and discussion, the following recommendations concerning future debris sampling programs are made. These are listed in an approximate order of priority for the greatest improvement in knowledge of ocean debris over that given by the existing data sets. The authors are aware that some of these suggestions are already being implemented in ongoing surveys and survey planning.

1. Establish a coordinated program with specific survey objectives and assure that each survey component is designed to interrelate to others in a manner which will meet objectives; establish a single data analysis point which will receive, analyze and report on all data collection in a timely manner to meet program objectives.

2. Seek additional platforms of opportunity (or other methods) to increase the intensity of ocean sampling to about 2800 samples per year. The objective is to decrease relative error to the point that a 50% reduction or increase in debris density can be detected at the 95% confidence level.

3. Establish yearly ocean surveys so that long term time trends in ocean debris can be detected.

4. Expand spatial coverage of surveys in the Bering Sea, eastern and western Gulf of Alaska so that an approximate spatial distribution of debris may be determined. Areas which have not yet been sampled should have a pilot survey from which required sampling densities can be determined. These data should be collected for use in future stratification schemes.

5. Report data in such a manner that local accumulations of debris can be detected and used to stratify sampling accordingly.

6. Determine a model for effective search width for a range of vessel and enviromental conditions by conducting trials at sea with known distributions of debris. Determine if distance to objects can be measured accurately.

7. Design beach surveys with well defined sampling units, increased sample sizes and concomitant ocean surveys and provide specific spatial and temporal coverage. Sample in a manner such that local debris accumulations can be detected and the information used to stratify sampling.

8. Determine lifetime parameters for beach debris by doing cleared beach resurveys and/or tagged debris studies.

9. Establish a project to develop the relationship between ocean and beach debris density and evaluate the cost-effectiveness trade-off between the two.

10. Establish an initially experimental program of plastic surveys using towed drogues similar to those described in literature articles concerning the Atlantic. Determine

practicality of such a sampling program in the North Pacific, especially information for development of a sampling design and stratification scheme.

11. Assure that survey methodology is standardised: searching modes, watch lengths, vessel speeds, data collection forms, etc. Make marginal changes in data recording procedures to increase information content.

12. Determine sightability of plastic strapping bands in ocean surveys by sea trials with known distributions.

13. Test the feasibility of aerial surveys under a variety of conditions (aircraft types, speeds and altitudes, weather conditions) using known debris distributions.

VII. Acknowledgements

We would like to thank the following people for sharing their unpublished data sets and for taking the time to talk to us about the marine debris problem:

Linda Jones, National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, Seattle, Washington.

Joanna Flanders, National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, Seattle, Washington.

Robert DeLong, National Marine Mammal Laboratory, National Marine Fisheries Service, NOAA, Seattle, Washington.

Theodore Merrell, Northwest and Alaska Fisheries Center, Auke Bay Laboratory, National Marine Fisheries Service, NOAA, Auke Bay, Alaska.

Jay Barlow, Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, California.

We also thank Michael Dahlberg (Northwest and Alaska Fisheries Center, Auke Bay Laboratory, NOAA) and two anonymous reviewers for taking the time to read the draft report and for their helpful comments.

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APPENDIX I

Mathematical Model Relating Beach and Ocean Debris Densities

The basic relation between beach and ocean densities can be stated as:

$$b = V\ s$$

where b = beach deposition rate, numbers/(time length)

s = sea density of objects, numbers/area

V = effective concentration velocity, length/time.

V is an effective instantaneous velocity of debris movement normal to a beach length segment. For a dynamic model of beach debris, the density of debris per unit length may be considered as the result of dynamic deposition and loss processes. If d is beach density, numbers/length, then the processes can be represented by the differential equation

$$\dot{d} = b - l(t)$$

where $\dot{d}$ is the time derivative of density, d, measured in units of numbers/(length time), and l(t) is the time variable beach loss function. This function, while certainly erratic in time, might be approximated by a smoothed exponential function by using a linear formulation in the differential equation.

$$l(t) = k\ d$$

with instantaneous average rate constant k, units of 1/time. The full model becomes

$$\dot{d} = V\ s - k\ d$$

This model approximates the highly variable (in space; less variable in time) ocean density as a constant. Similarly, the concentration factor, V, is assumed constant in space and for a period of time (say, 1 year), but should be considered unique to a particular beach or to beaches of a given type in an area. To assume otherwise would necessitate a much more complex, distribution formulation, probably involving a partial differential equation representation of ocean currents and drift-related processes. Considering the observed variability of drifting objects at sea (see Reed & Schumacher, 1985) a more complex formulation than this would be unlikely to yield useful results. This beach model could be coupled with an appropriate ocean density model of the type discussed by Gerrodette (1985). This might allow evaluation of the time delays between changes in ocean and beach debris densities.

A more comprehensive model for combined ocean and sea dynamics could be formulated as a linear compartment model (for example, see Bledsoe & Van Dyne 1971) with compartments corresponding to various ocean areas and beaches as well as other known sinks for debris (i.e. benthos and disintegration). This model would have the advantage of allowing for differential inputs and movements of debris to various fates; the associated matrix of rate coefficients might be estimated with data from a comprehensive and coordinated ocean and beach sampling program.

The solution to the differential equation model, for an initially clear beach, is

$$d(t) = [Vs/k]\ [1 - \exp(-kt)]$$

In general, and on the average, under this model beaches will change density of debris in response to a step shift in ocean density with an exponential time constant of k. Based on the beach loss experiments for gillnet floats reported by Merrell (1980), k had a value of ln(0.41) = 0.89/year, which corresponds to a mean residence time of 0.33 year. The factor relating ocean and beach densities at equilibrium is V/k.

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