Effects of High-Seas Driftnet Fisheries on the Northern Right Whale Dolphin Lissodelphis Borealis

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Ecological Applications, Volume 3, Issue 2 (May, 1993), 221-229.

Ecological Applications, 3(2), 1993, pp. 221–229

EFFECTS OF HIGH-SEAS DRIFTNET FISHERIES ON THE NORTHERN RIGHT WHALE DOLPHIN *LISSODELPHIS BOREALIS*[1,2]

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Abstract. The United Nations (U.N.) resolutions concerning high-seas driftnets called for moratoria by July 1992, unless appropriate conservation measures could be enacted. The analyses presented here show that the population of northern right whale dolphin has been affected by driftnets and that no apparent conservation measures are available.

A number of points emerge: (1) Simple "worst-case" estimates of depletion highlight the importance of accurate estimates of population abundance. Current abundance is 24–73% of the abundance in 1978, depending upon which estimate of current population is assumed. The enormous variability associated with the estimates of current population size will create difficulties for "statistically sound analysis" of management plans, as called for by the U.N. resolutions. In addition, depletion caused by high-seas driftnet fisheries could even be greater than the worst-case estimate reported at a scientific review in June 1991 (Anonymous 1991). (2) The catches of driftnets are highly aggregated. Reporting a kill rate of a fraction of an animal per unit of effort assumes that driftnets "cull" the population of animals and masks the more important effect of large, simultaneous kills of large fractions of pods, families, or other reproductive units. In addition, aggregated catches may lead to underestimates of the necessary level of observer effort. However, the operational characteristics of high-seas driftnet fisheries make impossible any management or conservation plan in which highly aggregated catches do not occur. (3) Any "statistically sound analysis" must include discussion of statistical power. To date, this has not been done. The importance of statistical power is that it places the burden of proof upon the fishing nations that wish to claim either no effect or a successful management plan. In summary, this study of northern right whale dolphin illustrates the following broad points concerning resource protection and conservation: abundance estimates (or trends in abundance) are key to advising on the problem, the statistical characterization of the data must take into account the observed patterns, and statistical power needs to be evaluated to clarify results.

Key words: aggregation of by-catch; conservation; high-seas driftnets; northern right whale dolphin; observer coverage; statistical power; United Nations resolutions on driftnets.

INTRODUCTION

The determination of animal abundance and the response of abundance to human intervention is one of the fundamental problems in applied ecology. Abundance estimation is important for its own sake (i.e., knowing how many individuals of a particular species are present) but also because policy decisions often hinge on such estimates. An example of the latter is the United Nations (U.N.) resolutions concerning high-seas driftnet fishing. These resolutions call for moratoria on all large-scale pelagic driftnet fishing on the high seas by July 1992,

> *with the understanding that such a measure will not be imposed in a region or, if implemented, can be lifted, should effective conservation and management measures be taken based upon statistically sound analysis to be jointly made by concerned parties of the international community with an interest in the fishery resources of the region, to prevent the unacceptable impact of such fishing practices on that region and to ensure the conservation of the living resources of that region.* (UNGA 1990, paragraph 4a)

As a response to U.N. Resolutions 44/225 (paragraph 3) and 45/197, a group of scientists met in Sidney, British Columbia, Canada in June 1991 to conduct a scientific review of North Pacific high-seas driftnet fisheries. This review is summarized in Anonymous (1991), which assessed the impact of driftnet fisheries on many species of fish, marine mammals, and marine birds. Northridge (1991)[3] provides an excellent general review of driftnet fisheries.

The northern right whale dolphin (NRWD) *Lissodelphis borealis* is a focal species, treated in great depth in Anonymous (1991), because it is often caught

[1] Manuscript received 24 December 1991; revised and accepted 27 May 1992.

[2] Dedicated to the memory of John Gulland.

[3] Also: 1992 Report to the Marine Mammal Commission, Washington, D.C., USA.

TABLE 1. Catch history of northern right whale dolphins in the squid driftnet fishery (Tanaka 1991).

	Catch* (no. of animals)		
	CPUE method		Regression
Year	Mean	Range	method
1978	355	285–433	312
1979	355	285–433	303
1980	1007	809–1230	849
1981	982	788–1197	797
1982	8599	6915–10 535	7217
1983	10 044	8098–12 366	8775
1984	13 547	10 927–16 692	11 622
1985	18 581	14 957–22 808	14 692
1986	18 892	15 232–23 261	15 134
1987	19 443	15 671–23 925	14 999
1988	22 128	17 839–27 240	16 666
1989	23 911	19 257–29 377	17 022
1990	19 426	15 637–23 844	13 249
Totals	157 271	126 696–193 340	121 636

* CPUE = catch per unit effort. See *Current abundance and previous catches* for an explanation of the two methods.

in high-seas driftnet fisheries and because there is a sufficient database for the analysis of the effects of the fisheries on the population of NRWD. In this paper, the analysis described in Anonymous (1991) is extended and compared with approaches used there.

In the next section, I consider the current abundance, estimated by two methods described in Anonymous (1991). With these estimates and an estimate of catches, one can construct "worst-case" estimates of depletion caused by the high-seas driftnet fisheries. This is done in the third section of the paper. Population trajectories, using an age-structured model, are described in the fourth section. The fifth section treats further issues, particularly the effects of high variability in the empirical catch distributions and the importance of statistical power when attempting to assess effects of the driftnet fisheries. High variability in catch distributions means that catches are highly aggregated. This has important implications both for setting observer levels and for determining the effects of catch on population dynamics. Statistical power is especially important if one wishes to assert—via statistical analysis—that high-seas driftnet fisheries have not had an adverse effect on stocks.

CURRENT ABUNDANCE AND PREVIOUS CATCHES

Miyashita (1991) used line-transect methods (Burnham et al. 1980) and estimated a mean population size of 247 000 individuals in the North Pacific, with a 95% confidence interval of 61 000—1 004 000 individuals. Miyashita suggests that bias will cause this to be an underestimation. It is generally believed by research workers (S. Swartz, *personal communication*) that the lower limit (61 000 individuals) is not biologically reasonable.

Hiramatsu (1991) estimated abundance from encounter rates of northern right whale dolphin (NRWD) with the high-seas driftnet fisheries. Such estimates of population size by encounter rates have potentially more information than line-transect estimation (Mangel and Beder 1985) because larger sample sizes can be obtained (e.g., each fishing operation provides information). Hiramatsu's model also provides an explanation for the disparity between the sighting ratio of NRWD schools and Pacific white-sided dolphin (PWSD) *Lagenorhynchus obliquidens* schools and the catch ratios of those schools. That is, PWSD are more common in sighting surveys, but NRWD are captured more frequently. Hiramatsu assumes different capture probabilities, given encounters of the school with a vessel. This assumption is sufficient to explain the disparity in sighting and catch ratios. Hiramatsu's mean estimate is 535 000 individuals, with a 95% confidence interval of 394 000–738 000 individuals. The enormous confidence interval associated with the line-transect method is caused, in large part, by the limited number of sightings. A larger database, and subsequently smaller coefficient of variation, is one of the advantages of estimation by encounter rate.

An alternative method would be the Bayesian computation of current abundance. This would immediately produce not only confidence bounds, but probability densities for stock size. Neither Miyashita (1991) nor Hiramatsu (1991) considered Bayesian approaches. Because the purpose of the current paper is to provide further examination of the analyses presented in Anonymous (1991), a Bayesian estimate of abundance is not used.

Tanaka (1991) estimated total catch of NRWD since 1978 by two different catch-per-unit-effort (CPUE) methods (Table 1). In the first method, the value of CPUE in 1990 was assumed to hold for the period 1978–1990 and catch in a given year was estimated as the product of the 1990 CPUE and the effort in that year. This is called the "CPUE method" in Table 1. This method is limited by the assumption that the CPUE in each year is the same as the CPUE in 1990. In the second method, a log-linear model log[CPUE] $= a + bt$ was used to fit CPUE values for 1982, 1986, 1988, and 1989 and this allowed an estimate of CPUE in each other year. Catch was then estimated in a similar fashion. This is called the "regression method" in Table 1.

"WORST-CASE" ESTIMATES OF DEPLETION

In Anonymous (1991), a worst-case estimate of depletion caused by the high-seas driftnet fishery is computed by assuming no net recruitment and the upper estimate of total catch. The depletion level is defined as

$$\text{Depletion level} = \frac{\text{Current population size}}{\text{Carrying capacity}} \quad (1)$$

If a population was at carrying capacity when the fishery started and there were no recruitment or additional sources of mortality, then the carrying capacity can be estimated as the sum of current population size (P) and cumulative catch (C). In such a case, the depletion level is

$$\text{Depletion level} = \frac{P}{P + C} \qquad (2)$$

Using current population size and the catch data in Table 1, it is possible to compute depletion levels (Fig. 1). In Anonymous (1991) the worst-case depletion level is estimated to be 73% of the size in 1978, but this assumes that current population is accurately given by the mean Hiramatsu (1991) estimate. Other estimates of population size can lead to correspondingly more severe levels of depletion.

This worst-case estimate assumes no net recruitment, so that northern right whale dolphin (NRWD) are essentially being "mined." However, it also optimistically assumes no other source of mortality. The minimum yearly mortality estimate proposed by Tanaka (1991) is $M = 0.14$, from which we conclude that a fraction $e^{-0.14} = 0.87$ of the NRWD survive each year, independent of the driftnet mortality. This means that the worst case described in Anonymous (1991) actually assumes a recruitment of nearly 15% per year, to replace individuals lost by natural mortality, which occurs independent of driftnets. This worst-case estimate, unlike the model described below, assumes no compensatory processes in recruitment.

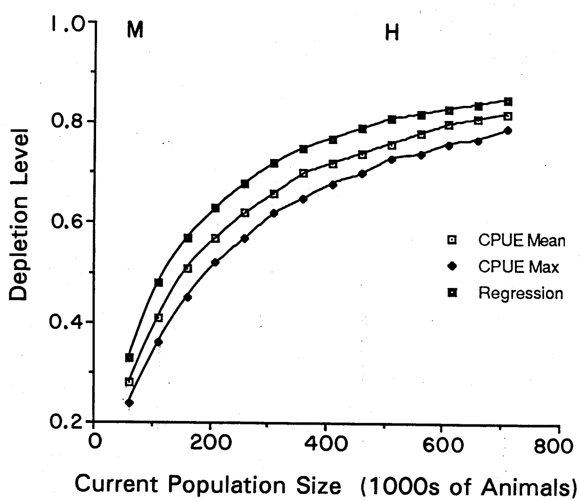

FIG. 1. Depletion level as a function of the current population size. The three curves correspond to catches estimated as the mean and upper limit of the catch-per-unit-effort (CPUE) method in Table 1 and the Regression method in Table 1. The mean estimates of current population size are: 247 000 (Miyashita) and 535 000 individuals (Hiramatsu), and lower 95% confidence limits are 61 000 and 394 000 individuals, respectively. The "M" is above the 95% confidence interval associated with the estimate by Miyashita, and the "H" is above the estimate used in Anonymous (1991) in which a worst-case depletion level of 0.73 is reported.

Use of a Simplified Version of the "Hitter–Fitter" Model to Construct Population Trajectories

Tanaka (1991) used a simplified version of the "Hitter–Fitter" model to determine population trajectories of the northern right whale dolphin since 1978. The Hitter–Fitter model is an age-structured model of population dynamics developed by the International Whaling Commission (de la Mare 1989). It is one of a number of models used by the International Whaling Commission to estimate population abundance and trajectories.

In order to ensure that the present paper is as self-contained as possible, Appendix 1 contains a derivation of the simplified version of the Hitter–Fitter model. The main features of the model are:

1) The population is age-structured; maturity and recruitment to the fishery can occur at different ages.

2) Catch is assumed to be uniformly distributed over those age classes that are available (recruited) to the fishery.

3) Reproduction is, in general, a nonlinear function of both total population size and size of the mature population. Reproduction is determined by carrying capacity and by three additional parameters that characterize the birth rate and survival of young to the first age class, the degree of compensation, and the response of the population to harvest. (Because the model assumes some level of compensation in reproduction, it does not really allow for the consideration of worst-case situations.)

4) Two important measures of population size and responsiveness are the Maximum sustained yield level (MSYL):

$$\text{MSYL} = \frac{\text{Population size at maximum sustained yield}}{\text{Carrying capacity}}$$

and Maximum sustained yield rate (MSYR):

$$\text{MSYR} = \frac{\text{Catch at MSYL}}{\text{MSYL}}.$$

The value of MSYL determines the degree of compensation in reproduction and the value of MSYR determines the degree of response of the population to harvest (see Appendix 1). According to Tanaka (1991), appropriate best estimates for MSYL and MSYR are 0.6 and 0.01, with ranges 0.6–0.8 and 0–0.03, respectively.

Because of limited data, Tanaka (1991) only used the "Hitter" portion of the model, which proceeds by (1) specifying a population size in a given year, (2) specifying a history of catches, and (3) then searching for the value of carrying capacity that matches the modeled and specified population sizes in the target year. Tanaka assumed "best" estimates for parameters

TABLE 2. Parameters used in the "Hitter–Fitter" Model for the northern right whale dolphin population trajectories (Tanaka 1991).

Parameter	Best estimate	Range
M (natural mortality rate, yr)	0.16	0.14–0.19
MSYR (maximum sustainable yield rate)	0.01	0.0–0.03
a_r (age of recruitment, yr)	1	1–3
a_m(age of sexual maturity, yr)	7	5–9

(Table 2) and conducted a sensitivity analysis by varying one parameter at a time and letting MSYR range from 0.0 to 0.03. The depletion level (population size in 1990 divided by carrying capacity) was 0.80 to 0.88. Similarly, by varying one parameter at a time while keeping the others fixed at the best estimate, Tanaka conducted a sensitivity test in which the depletion level ranged from 0.74 to 0.87.

Those results can be extended by considering simultaneous variation parameters. To do this, I ran the model from 1900 to 1977, assuming that no catch occurred until 1978, to ensure a stable, equilibrium distribution in 1977. The value of population size in 1989 is based on the estimate of either Miyashita (1991) or Hiramatsu (1991). The search over possible values of carrying capacity was done in increments of 5000 animals. I simultaneously varied the values of MSYR, M, MSYL, and the current estimate of population size.

The two parameters of the model with the most uncertainty are the natural mortality (M) and the estimate of current population size. The model was run for values of M ranging from 0.14 through 0.19 in steps of 0.01, values of current estimate of population size ranging from 75 000 individuals to 750 000 individuals in steps of 75 000, for MSYR = 0 through 0.03, and all other parameters at the best values. The justification for focussing on these is as follows. For fish stocks, it has been documented that uncertainties in M can lead to considerable errors in reconstruction of stock trajectories (Bradford and Peterman 1989, Lapointe et al. 1989, Lapointe and Peterman 1992); the response of the "Hitter" model may be different but certainly deserves scrutiny in these cases. The simple worst-case analysis of the previous section shows that the estimate of current population size plays an extremely important role in the estimate of depletion level.

The results (Fig. 2) of this extension generally agree with those of Tanaka (1991) in that the majority of cases had depletion levels in the range of 80–85%. However, there were instances of depletion levels as low as 25–55%. In some cases the most severe depletion levels may correspond to biologically unlikely assumptions about population size and mortality (low current abundance and high mortality). The general conclusion, however, is that the level of depletion may be more severe than the 80–90% suggested by Tanaka (1991).

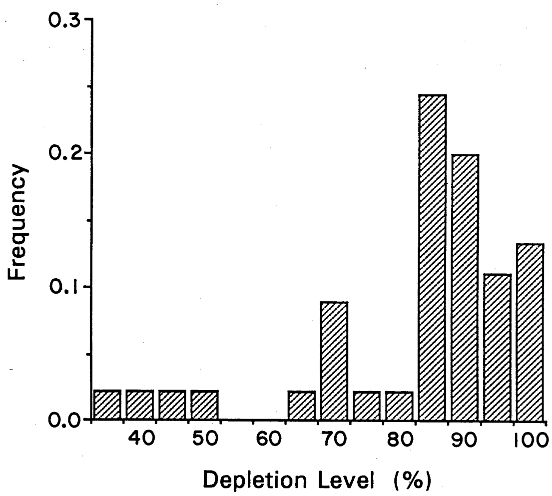

FIG. 2. Depletion levels observed using the simplified "Hitter–Fitter" Model (described in Appendix 1), cycling over values of the maximum sustainable yield rate (MSYR) and maximum sustainable yield level (MSYL), the natural mortality rate (M), and the 1989 estimate of population size. Details are described in *Use of a simplified version of the "Hitter–Fitter" Model to construct population trajectories.*

ADDITIONAL CONSIDERATIONS FOR FUTURE WORK

Aggregated catches

According to current agreements with Japan, Korea, and Taiwan, fishing effort is measured in standardized tans (a tan is essentially a section of net) of 50 m, and observed by-catch (incidental catch of non-target species) is reported in summarized form by 1° cartographic squares and 1-mo period (Anonymous 1991). The objective of such a summary appears to be the construction of a single measure of by-catch as a catch rate per 1000 tans. However, this procedure masks variability in the by-catch rates. Because variability is reduced in the summarizing procedure, (1) the levels of observer effort may be set too low and (2) the chance of by-catch of groups of animals (e.g., family or other reproductive units) may be highly underestimated. That is, the catch may not be uniformly spread over age classes or smaller reproductive units (as assumed in the previous section). The available data are sketchy, but Iwasaki (1991: Figs. 6 and 7) presents information suggesting that the catch is not uniform over age, with limited information about reproductive status.

The summary data consist of tabulations (by 2-wk interval and 1° cartographic square) of effort (measured in 50-m tans), number of operations observed, number

TABLE 3. Summary data reported in International North Pacific Fisheries Commission (1990). Number of operations observed and the number of northern right whale dolphins (NRWD) taken are given according to vessel.

	No. operations observed	No. NRWD taken
	66	24
	73	30
	44	13
	43	16
	49	23
	40	30
	63	27
	55	28
	71	20
	26	0
	31	48
	49	1
	2	4
	85	1
	62	46
	85	20
	91	20
	46	6
	70	7
	52	28
	36	13
	49	5
	60	16
	44	8
	28	4
	35	4
	47	13
Total	1402	455

TABLE 4. Number of operations observed and take of northern right whale dolphins (NRWD) in June 1989 by the Japanese squid driftnet fishery (based on INPFC [1990], Tables 2 and 7).

Longitude	Operations observed	NRWD taken
171° E	1	0
172° E	1	0
175° E	5	1
176° E	1	0
177° E	3	1
179° E	1	0
179° W	11	0
178° W	4	0
177° W	7	0
176° W	3	0
173° W	2	0
172° W	3	0
171° W	4	0
170° W	1	1
169° W	3	1
168° W	5	0
167° W	5	0
166° W	10	1
165° W	9	0
164° W	10	0
163° W	9	1
162° W	3	16
161° W	7	5
160° W	9	7
159° W	13	6
158° W	20	6
157° W	7	6
156° W	7	7
155° W	13	8
154° W	12	4
153° W	3	0
152° W	9	7
151° W	2	1
150° W	2	0
146° W	2	0

of operations, and number of animals captured. Because these data are highly aggregated, the variances are very small relative to the means, hence the conclusion that the by-catch rate is essentially constant across operations.

It is possible to unmask some of the variability by cross-tabulating operations and observed by-catch. To do this, an example is presented using data from INPFC (1990). Table 3 shows the summary data (by vessel) reported in INPFC (1990), corresponding to the 1989 observer program. The average and variance of the kill per operation are 0.3245 and 3.813×10^{-3}, respectively, from which the coefficient of variation is 0.1903. The purpose of such summarizing procedures appears to be the use of normal distributions to characterize by-catch levels. Such an approach implicitly assumes that the driftnets "cull" populations by removing a "fraction" of an individual upon each encounter. This reporting method, however, tends to *underestimate* the variability in take rates substantially.

For the purposes of example, I re-analyzed the data for 39° N and the month of June. By melding the effort data (INPFC 1990: Table 2) with the by-catch data (INPFC 1990: Table 7), it is possible to construct a table showing, by 1° square, the number of operations and the take of northern right whale dolphin (NRWD) (Table 4). There is considerable variability, with no take occurring during many operations. For the 207 operations shown in Table 4, at least 74 operations occurred with no NRWD captured. The fraction of operations in which no NRWD were taken was much higher, but the analysis that follows uses the 74 of 207 operations. The effect of these "zeroes" is to increase the variability in the estimated take rate. Based on this 1°-square summary, the average kill rate is 0.3816 NRWD per operation and the variance is 0.13995, giving a coefficient of variation of 0.9802. Thus, by disaggregating the data, the coefficient of variation increases by a factor of ≈ 5. Because the variance of the catch rate is a parameter used in the determination of observer effort, underestimation of this variance by summarizing the data will usually underestimate the level of observer effort required.

Presumably, in a large fraction of the operations, no marine mammals are encountered at all, but when marine mammals are encountered, if one is taken, then it is likely that more than one is taken. Under these circumstances, the assumption of a normal distribution for the take per operation may not be appropriate. In fact, it is not clear that a normal model is appropriate at all, since we want to focus on the *number* of animals

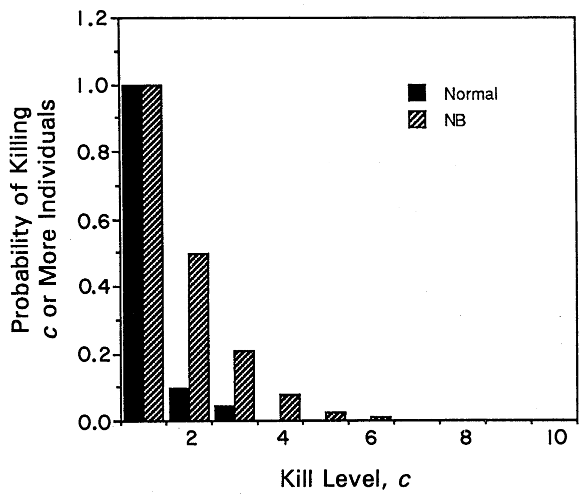

FIG. 3. Conditional by-catch distributions, under the normal and negative binomial (NB) assumptions. The conditional distribution asks for the probability that c animals are killed, given that at least one animal is killed.

killed per operation as the fundamental variable, rather than the kill *rate*. In that case, the analogue of the normal distribution would be a Poisson distribution, for which

$$\Pr\{\text{take in single operation} = c\} = \frac{e^{-\lambda}\lambda^c}{c!}. \quad (3)$$

Here the Poisson parameter λ is the mean take in a single operation. A more robust model is the negative binomial (NB), obtained by assuming that the Poisson parameter itself varies across vessels and operating conditions (Mangel 1985). The "m,k" form of the NB distribution is

$$\Pr\{\text{take in a single operation} = c\}$$
$$= p(c\,|\,k,m) = \binom{k+c-1}{c}[k/(k+m)]^k[m/(k+m)]^c \quad (4)$$

with two parameters, m and k. The mean of the NB distribution is m and the variance is $m + (m^2/k)$, which can be very large when the overdispersion parameter k is small. From Eq. 4 the probability that the take is zero is $[k/(k + m)]^k$, which can be considerable when k is small, even if m is large (Mangel 1987).

We can compare the probability that c or more animals are taken, given that at least one animal is taken under the normal and negative binomial assumptions. For the normal assumption (with mean by-catch μ and variance σ^2), this probability is

$$\text{Prob}\{c \text{ or more animals taken} \,|\, \text{at least one animal taken}\}$$
$$= c_n\int_c^\infty \exp\left(\frac{(u-\mu)^2}{2\sigma^2}\right)du \quad (5)$$

Here c_n is the normalization constant

$$c_n = 1 \bigg/ \int_1^\infty \exp\left(-\frac{(u-\mu)^2}{2\sigma^2}\right)du.$$

Under the negative binomial approximation,

$$\text{Prob}\{c \text{ or more animals taken} \,|\, \text{at least one animal taken}\}$$
$$= c_{nb}\sum_{j=c}^{\infty} p(c\,|\,m,k), \quad (6)$$

and here the normalization constant

$$c_{nb} = 1 \bigg/ \sum_{j=1}^{\infty} p(c\,|\,m,k).$$

In these equations, $m = \mu$ 1.197, $\sigma^2 = 0.2727$, and k can be determined from these parameters. Under the normal assumption, the probability of ≥ 4 animals being killed is essentially 0, whereas the negative binomial assumption attributes almost 10% probability to ≥ 4 animals being killed (Fig. 3). The implications of this computation are that family or other reproductive units of NRWD may have a much higher probability of being killed than previously thought. In fact, since many of the species captured by the driftnet fisheries travel in pods, schools, or flocks, the chance that a large number of individuals may simultaneously be captured means that kin or other reproductive units may be decimated by a single section of driftnet.

To summarize:

1) The current procedures for reporting by-catch focus on estimation of a single catch rate and present data in highly summarized form;

2) The highly summarized data masks variability in catch rates at the level of operations by individual vessels; and

3) Because the variability is masked, (a) levels of observer effort may be too low, (b) the probability of simultaneous catches of many animals may be severely underestimated, and (c) kin or other reproductive units may be decimated by a single section of driftnet.

Statistical power and the status of stocks

Ultimately, any conclusions concerning the status of stocks affected by high-seas driftnet fisheries will be based on statistical methods, especially the use of models in which parameters are fluctuating or uncertain.

The assessment of an effect of the driftnet fisheries on the species of interest will then rely upon the statistical technique of hypothesis testing. For example, the hypothesis might be framed as "H_0: The status of NRWD has not been affected through high-seas driftnet fisheries."

A Type-I error occurs when the hypothesis is actually true and is rejected. The probability associated with this error is usually denoted by α and most statistical tests are designed to a value of α such as .1, .05 or .01.

A Type-II error occurs when the hypothesis is actually false and is not rejected. The probability associated with this error is usually denoted by β. The *statistical power* $1-\beta$ is the probability that the hypothesis is rejected when it is false.

If one wishes to claim that high-seas driftnet fisheries have not affected a certain species, it is insufficient to show that the hypothesis cannot be rejected using the data. In addition, one must show that the power of the analysis is sufficiently high to have confidence in the conclusion (Peterman 1990*a, b*). That is, if the statistical power is low, even if the hypothesis cannot be rejected, it is unjustifiable to conclude that there is no effect of high-seas driftnet fisheries on the species. Statistical power is not described at all in Anonymous (1991). However, because the data used there are so limited, it is likely that the statistical power is very low for all of the species for which "no effect" is concluded.

Conclusions

The simple "worst-case" estimates of depletion highlight the importance of accurate estimates of population abundance. In this simple case, the depletion level ranges from 24% to 73% of the population in 1978, depending upon which estimate of current population is assumed. This lower value (24%) may correspond to biologically unlikely values of population size, but in any case the depletion is significant. The enormous variability associated with the estimates of current population will create difficulties for "statistically sound analysis" of management plans.

A fuller analysis, using a version of the International Whaling Commission's "Hitter" model for population dynamics, suggests that the depletion caused by high-seas driftnet fisheries could even be greater than the "worst-case" estimate reported in Anonymous (1991). This is caused by the combination of natural mortality and high variance in the estimate of population size.

The catches of driftnets are highly aggregated catches. Reporting a kill rate of a fraction of an animal per operation or per 1000 tans assumes that driftnets "cull" the entire population of animals and masks the more deadly effect of large, simultaneous kills of entire pods, families, or other reproductive units. The operational characteristics of high-seas driftnet fisheries prohibit management or conservation plans in which highly aggregated catches do not occur.

Finally, the United Nations resolution called for "statistically sound analysis." Any such analysis must include discussion of statistical power. To date, this has not been done. The importance of statistical power is that it places the burden of proof upon the fishing nations that wish to claim either no effect or a successful management plan. Current models can be used to test the power of such management plans.

Between the time of the U.N. resolutions (UNGA 1990) calling for either a moratorium on large-scale driftnet fishing on the high seas or a statistically sound management plan and the July 1992 U.N. deadline for such a moratorium, the United States and Japan arrived at an agreement whereby Japan would move toward a global moratorium by the end of 1992 (see Appendix 2 for text of the agreement). Because of this agreement, the current paper should be read as a kind of "lessons learned" concerning this subject. As a retrospective, it may prove valuable in similar, future situations.

In summary, this study of northern right whale dolphin illustrates the following broad points concerning resource protection and conservation: (1) abundance estimates (or trends in abundance) are key to advising on the problem, (2) the statistical characterization of the data must take into account the observed patterns, and (3) statistical power needs to be evaluated to clarify results.

Acknowledgments

This work was partially supported by the Marine Mammal Commission and by the Center for Population Biology, University of California Davis. I thank Steve Swartz and two anonymous referees for comments on the manuscript. I also thank R. Peterman and P. E. Bradshaw for numerous, helpful conversations.

Literature Cited

Anonymous. 1991. Scientific review of North Pacific high seas driftnet fisheries, Sidney B.C., June 11–14, 1991. Report for presentation to the United Nations pursuant to Resolutions 44/225 and 45/197. Canada Department of Fisheries and Oceans, Institute of Ocean Sciences, Sidney, British Columbia, Canada.

Bradford, M. J., and R. M. Peterman. 1989. Effects of ocean variability on recruitment and an evaluation of parameters used in stock assessment models. Canadian Special Publications of Fisheries and Aquatic Sciences **108**:87–99.

Burnham, K. P., D. R. Anderson, and J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildlife Monographs Number 82. The Wildlife Society, Washington, D.C., USA.

Hiramatsu, K. 1991. Estimation of population abundance of northern right whale dolphin in the North Pacific using the by-catch data from the Japanese squid driftnet fishery. Paper J016. Appendix 6 to Anonymous (1991), Scientific review of North Pacific high seas driftnet fisheries.

INPFC [International North Pacific Fisheries Commission]. 1990. Final report on squid and bycatch observations in the Japanese driftnet fishery for neon flying squid (*Ommastrephes bartrami*) June–December, 1989, observer program. Joint report by the National Sections of Canada, Japan, and the United States. Available from the Alaska Fisheries Science Center, Seattle, Washington, USA.

INPFC [International North Pacific Fisheries Commission]. 1991 Final report of 1990 observations of the Japanese high seas driftnet fisheries in the North Pacific Ocean. Joint report by the National Sections of Canada, Japan, and the United States. Available from the Alaska Fisheries Science Center, Seattle, Washington, USA.

Iwasaki, T. 1991. Preliminary analysis of life history parameters of Pacific white-sided dolphins and northern right whale dolphins. Paper J014. Appendix 6 to Anonymous (1991), Scientific review of North Pacific high seas driftnet fisheries.

Lapointe, M. F., and R. M. Peterman. 1992. Spurious correlations between fish recruitment and environmental factors due to errors in the natural mortality rate used in virtual population analysis (VPA). Journal du Conseil International Exploration de la Mer, *in press*.

Lapointe, M. F., R. M. Peterman, and A. D. MacCall. 1989. Trends in fishing mortality along with errors in natural mortality rate can cause spurious time trends in fish stock abundances estimated by virtual population analysis (VPA). Canadian Journal of Fisheries and Aquatic Sciences **46**: 2129–2139.

Mangel, M. 1985. Search models in fisheries and agriculture. Lecture Notes in Biomathematics **61**:105–138.

———. 1987. Sampling highly aggregated populations with application to California sardine management. *In* T. Vincent, editor. Modeling and management of resources under uncertainty. Lecture Notes in Biomathematics **72**:247–263.

Mangel, M., and J. H. Beder. 1985. Search and stock depletion theory and application. Canadian Journal of Fisheries and Aquatic Sciences **42**:150–163.

de la Mare, W. K. 1989. The model used in the Hitter and Fitter Programs (Program Fitter SC40). Report of the Scientific Committee of the International Whaling Commission **39**:150–151.

Miyashita, T. 1991. Distribution and preliminary abundance estimates of Pacific White-Sided dolphins and Northern Right Whale dolphins. Document J015. Appendix 6 to Anonymous (1991), Scientific Review of North Pacific high seas driftnet fisheries.

Northridge, S. P. 1991. Driftnet fisheries and their impacts on non-target species: a world-wide review. Report to Marine Resources Assessment Group, London, England. Available from the Marine Mammal Commission, Washington, D.C., USA.

Peterman, R. M. 1990*a*. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Sciences **47**:2–15.

———. 1990*b*. The importance of reporting statistical power: the forest decline and acidic deposition example. Ecology **71**:2024–2027.

Tanaka, E. 1991. Population trajectories and effects of incidental takes by the squid driftnet fishery on Pacific White-Sided and Northern Right Whale dolphin using Hitter/Fitter model. Document J017. Appendix 6 to Anonymous (1991), Scientific review of North Pacific high seas driftnet fisheries.

UNGA [United Nations General Assembly]. 1990. General Assemby Resolution 44/225. Large-scale pelagic driftnet fishing and its impact on the living marine resources of the world's oceans and seas. United Nations Publication Sales Number E.84.V.3. Document A/CONF.62/122. United Nations Press, New York, New York, USA.

APPENDIX 1

The Hitter–Fitter Model

This appendix contains a description of a simplified version of the "Hitter–Fitter" model (de la Mare 1989) used by the International Whaling Commission (IWC). In the simplified model, individuals are recruited (i.e., available to be captured) to the fishery before they are sexually mature. The age at which individuals are recruited to the fishery is denoted a_r and the age at which they are sexually mature is denoted by a_m, with $a_m > a_r$. In addition, there is a maximum lifespan $a_{\max}$.

Let $U(a,t)$ and $N(a,t)$ denote, respectively, the numbers of unrecruited individuals and of recruited individuals of age a in year t. In addition to mortality due to the fishery (experienced only by the recruited individuals), there is a natural mortality rate, M. In the absence of the fishery, the fraction of individuals surviving from one year to the next is e^{-M}.

Individuals are recruited to the fishery at the end of the first year of life. Hence, for individuals of age 2,

$$N(2,t+1) = U(1,t)e^{-M}. \qquad \text{(A1)}$$

The total catch in year t, $C(t)$, is uniformly spread over the population so that the fraction of the catch acting on any single age class is $\dfrac{C(t)}{\sum_{a=a_r}^{a_{\max}} N(a,t)}$. Consequently, the dynamics of the recruited ages are

$$N(a+1,t+1) = e^{-M}N(a,t)\left\{1 - \frac{C(t)}{\sum_{a=a_r}^{a_{\max}} N(a,t)}\right\}. \qquad \text{(A2)}$$

Reproduction is assumed to be given by

$$U(1,t+1) = \tfrac{1}{2}P(t)B_0\{1 + A[1 - (N(t)/K)^z]\}. \qquad \text{(A3)}$$

In this equation, $\tfrac{1}{2}P(t)$ is the number of females in a reproducing population

$$P(t) = \sum_{a=a_m}^{a_{\max}} N(a,t), \qquad \text{(A4)}$$

B_0, A, and z parameters (described in detail below), $N(t)$ is the total exploitable population given by

$$N(t) = \sum_{a=a_r}^{a_{\max}} N(a,t), \qquad \text{(A5)}$$

and K is the carrying capacity of the environment (assumed to be constant).

The parameter B_0 implicitly measures birthrate and survival to the first age class. It can be found by considering a population at equilibrium and carrying capacity. If $u(1)$ and $n(a)$ denote the equilibrium population sizes, then the dynamic equations Eqs. A2 and A3 become

$$\begin{aligned} u(1) &= \tfrac{1}{2}B_0 \sum_{a=a_m}^{a_{\max}} n(a) \\ n(2) &= e^{-M}u(1) \\ n(3) &= e^{-M}n(2) \\ n(4) &= e^{-M}n(3) \ldots . \end{aligned} \qquad \text{(A6)}$$

From these, we see that $n(a) = e^{-(a-1)M}u(1)$, and substituting this into the first equation of Eq. 6 gives

$$u(1) = \tfrac{1}{2}B_0 \sum_{a=a_m}^{a_{\max}} e^{-(a-1)M}u(1), \qquad \text{(A7)}$$

from which we obtain

$$B_0 = \frac{2}{\sum_{a=a_m}^{a_{\max}} e^{-(a-1)M}}. \qquad \text{(A8)}$$

The parameter z measures the degree of compensation and is determined by specifying the maximum sustainable yield level, MSYL. Throughout the computations reported here, I used $z = 2.39$, which corresponds to MSYL = 0.6 (de la Mare 1989).

The parameter A measures the resilience of the population in terms of its response to harvest. It is usually found (de la Mare 1989, Tanaka 1991) by specifying the maximum sustainable yield rate MSYR. That is, suppose that the catch removes a fraction y of the population. Then, if the population is at steady state, reproduction must compensate the catch. The latter three equations in Eq. A6 will be replaced by

$$n(2) = e^{-M}(1 - y)u(1)$$
$$n(3) = e^{-M}(1 - y)n(2)$$
$$n(4) = e^{-M}(1 - y)n(3), \ldots, \quad \text{(A9)}$$

from which we see that $n(a) = e^{-(a-1)M}(1 - y)^{a-1}u(1)$. Since the population is assumed to be at steady state, $\text{MSYL} = \frac{n}{K}$, where $n = n(2) + n(3) + n(4) + \ldots$ and Eq. A3 becomes

$$u(1) = \tfrac{1}{2}\left(\sum_{a=a_m}^{a_{\max}} e^{-(a-1)m}(1 - y)^{a-1}u(1)\right) \times B_0\{1 + A[1 - (\text{MSYL})^z]\}, \quad \text{(A10)}$$

which can be solved for the resilience parameter.

This model differs from the one used by Tanaka (1991) only in that Tanaka allowed the age of recruitment to the fishery to be 1, 2, or 3 yr. However, the "best" estimate for age of recruitment is 1 yr. Other parameters, used by Tanaka, are shown in Table 2.

APPENDIX 2

United States and Japanese Agreement on Driftnet Fishing

On 26 November 1991 the Department of State of the United States announced that the United States and Japan had reached agreement on large-scale high-seas driftnet fishing. The agreement reads (emphasis added):

The United States and Japan agreed today on a moratorium ending large-scale driftnet fishing on the high seas. By making this decision, Japan has demonstrated its commitment to the protection of living marine resources. This is a clear victory for the ocean environment.

Consistent with a resolution to be introduced in the United Nations General Assembly, beginning January 1, 1992, Japan will reduce its fishing effort in large-scale high seas driftnet fishing operations by 50 percent, to be achieved by June 30, 1992. The global moratorium will be fully in effect by December 31, 1992.

Data collected in 1990 indicated that over 41 million non-target fish, sharks, sea birds, marine mammals and sea turtles were killed in the Japanese squid driftnet fishery alone. The cumulative and global effect of this impact on the living marine environment justifies the imposition of the moratorium.

The United Nations General Assembly had adopted two previous resolutions on large-scale high seas driftnet fishing in 1989 and 1990. In those resolutions, the world body noted that large-scale driftnet fishing on the high seas can be a highly destructive and wasteful fishing practice that threatens the conservation of living marine resources.

The U.S. calls on all those who fish with large-scale driftnets on the high seas to support the global moratorium.