Guidelines for Preparing Stock Assessment Reports Pursuant to the 1994 Amendments to the Marine Mammal Protection Act

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1. General Guidelines

Introduction

Sec. 117 of the Marine Mammal Protection Act (MMPA) requires that the National Marine Fisheries Service (NMFS) and the Fish and Wildlife Service (FWS) develop Stock Assessment Reports (Reports) for all marine mammal stocks in waters under U.S. jurisdiction (U.S. waters). These Reports are to be based upon the best scientific information available. Reports are not required for stocks that have a remote likelihood of occurring regularly in U.S. waters (e.g., stocks for which only the margins of the range extends into U.S. waters or that enter U.S. waters only during anomalous current or temperature shifts).

The MMPA requires Reports to include, among other things, information on how stocks were defined, a calculation of Potential Biological Removal (PBR), and an assessment of whether incidental fishery takes are "insignificant and approaching zero mortality and serious injury rate" These reports are to be reviewed annually for "strategic stocks" and for stocks for which new information is available, and at least once every three years for all other stocks. This document provides guidance for how these topics are to be addressed in the Reports.

The MMPA provides some general guidance for developing the Reports; more detailed guidelines were developed at the PBR Workshop in June 1994 and were used in writing the original draft Reports. These original guidelines together with the draft PBR guidelines, were made available for public comment in August 1994 (59 FR 40527). Subsequently, the MMPA Scientific Review Groups met jointly in October 1994 to review the guidelines and to make recommendations for changes. These guidelines are based on the original PBR Workshop guidelines (see Barlow *et al.* 1995) as modified according to public comments and on the consensus recommendations from the Scientific Review Groups, FWS, and NMFS staff. Further modifications were made based on recommendations of the GAMMS Workshop in April of 1996 (Wade and Angliss, 1997). It is anticipated that the guidelines themselves will be reviewed and changed based on additional scientific research and on experience gained in their application. In this regard, FWS and NMFS intend to convene a Stock Assessment Working Group, composed of scientists and managers from both agencies, to examine and recommend revision of the guidelines as part of the required 1-year and 3-year revisions of the Reports. Furthermore, the guidelines in this document do not have to be followed rigidly; however, any departure from these guidelines must be discussed fully within any affected Report.

The intent of these guidelines is to: (1) provide a uniform framework for the consistent application of the amended MMPA throughout the country; (2) ensure that PBR is calculated in a manner that ensures meeting the goals of the MMPA; (3) provide guidelines for evaluating whether fishery takes are insignificant and approaching a zero mortality and serious injury rate; and (4) make the Government's approach clear and open to the public. Where the guidelines provided here are not incorporated into a particular Report, it was agreed that justification for the departure will be provided within the Report. Similarly, the Reports will explain when deviations are made from specific recommendations from the Scientific Review Groups.

FWS and NMFS interpret the primary intent of the 1994 MMPA amendments and the PBR guidelines developed pursuant to the Act as a mechanism to respond to the uncertainty associated with assessing and reducing marine mammal mortality from incidental fisheries takes. Accordingly, this mechanism is increasingly conservative under increasing degrees of uncertainty. The MMPA requires the calculation of PBR for all stocks, including those that are considered endangered under the Endangered Species Act (ESA) and those which are managed under other authorities, such as the International Whaling Commission. However, in some cases allowable takes under these other authorities may be less than the PBR calculated under the MMPA owing to the different degrees of "risk" associated with, and the treatment of, uncertainty under each authority. Where there is inconsistency between the MMPA and ESA regarding the take of listed marine mammals, the more restrictive mortality requirement takes precedence. Nonetheless, PBR must still be calculated for these stocks, where possible, and discussed in the text of the Reports. As mandated in the MMPA, the PBR is calculated as "...the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population." Therefore, a PBR is an upper limit to removals that does not imply that the entire amount should be taken.

Estimates of PBR, human-caused mortality, and classification as to whether a stock is "strategic" or "non-strategic" are required by Sec. 117 to be included in the Reports for all stocks of marine mammals in U.S. waters. However, it should be noted that the co-management of removals of marine mammals for subsistence purposes between the Federal government and Alaska Native organizations is specifically addressed in Sec. 119. In response to Sec. 119, NMFS and FWS are attempting to enter into cooperative agreements with Alaska Native organizations to conserve marine mammals and provide co-management of subsistence use by Alaska Natives. FWS and NMFS believe that it is appropriate to develop management programs for stocks subject to subsistence harvests through the co-management process provided that commercial fisheries takes are not significant and that the process includes a sound research and management program to identify and address uncertainties concerning the status of these stocks. Estimates of PBR and classification as to whether a stock is strategic will be determined from the analysis of scientific and other relevant information discussed during the co-management process.

Definition of "Stock"

"Population stock" is the fundamental unit of legally-mandated conservation. The MMPA defines population stock as "a group of marine mammals of the same species or smaller taxa in a common spatial arrangement, that interbreed when mature." To fully interpret this definition, it is necessary to consider the objectives of the MMPA. In Sec. 2 (Findings and Declaration of Policy) of the MMPA it is stated that "...species and populations stocks of marine mammals...should not be permitted to diminish beyond the point at which they cease to be a significant functioning element in the ecosystem in which they are a part, and, consistent with this major objective, they should not be permitted to diminish below their optimum sustainable population." Further on in Sec. 2, it states "...the primary objective of their management should be to maintain the health and stability of the marine ecosystem. Whenever consistent with this primary objective, it should be the goal to obtain an optimum sustainable population keeping in mind the carrying capacity of the environment." Therefore, stocks must be identified in a manner that is consistent with these goals. For the purposes of management under the MMPA, a stock is recognized as being a management unit that identifies a demographically isolated biological population. It is recognized that in practice, defined stocks may fall short of this ideal because of a lack of information, or for other reasons.

Many types of information can be used to identify stocks of a species: distribution and movements, population trends, morphological differences, genetic differences, contaminants and natural isotope loads, parasite differences, and oceanographic habitat differences. Evidence of morphological or genetic differences in animals from different geographic regions indicates that these populations are reproductively isolated. Reproductive isolation is proof of demographic isolation, and thus separate management is appropriate when such differences are found. Failure to detect differences experimentally, however, does not mean the opposite. Dispersal rates, though sufficiently high to homogenize morphological or genetic differences detectable experimentally between putative populations, may still be insufficient to deliver enough recruits from an unexploited population (source) to an adjacent exploited population (sink) so that the latter remains a functioning element of its ecosystem. Insufficient dispersal between populations where one bears the brunt of exploitation coupled with their inappropriate pooling for management could easily result in failure to meet MMPA objectives. For example, it is common to have human-caused mortality restricted to a portion of a species' range. Such concentrated mortality (if of a large magnitude) could lead to population fragmentation, a reduction in range, or even the loss of undetected populations, and would only be mitigated by high immigration rates from adjacent areas.

Therefore, careful consideration needs to be given to how stocks are defined. In particular, where mortality is greater than a PBR calculated from the abundance just within the oceanographic region where the human-caused mortality occurs, serious consideration should be given to defining an appropriate management unit in this region. In the absence of adequate information on stock structure and fisheries mortality, a species' range within an ocean should be divided into stocks that represent defensible management units. Examples of such management units include distinct oceanographic regions, semi-isolated habitat areas, and areas of higher density of the species that are separated by relatively lower density areas. Such areas have often been found to represent true biological stocks where sufficient information is available. There is no intent to define stocks that are clearly too small to represent demographically isolated biological populations, but it is noted that for some species genetic and other biological information has confirmed the likely existence of stocks of relatively small spatial scale, such as within Puget Sound, WA, the Gulf of Maine, or Cook Inlet, AK.

In trans-boundary situations where a stock's range spans international boundaries or the boundary of the U.S. Exclusive Economic Zone (EEZ), the best approach is to establish an international management agreement for the species. In the interim, if a stock is migratory and it is reasonable to do so, the fraction of time in U.S. waters should be noted, and the PBR for U.S. fisheries should be apportioned from the total PBR based on this fraction. In a non-migratory situation, the PBR for U.S. fisheries should be calculated based on the abundance estimate of the stock residing in U.S. waters. For situations where a species with a broad pelagic distribution which extends into international waters experiences mortalities within the U.S. EEZ, PBR calculations should be based on the abundance in the EEZ area unless there is evidence for movement of individuals between the EEZ and offshore pelagic areas.

PBR Elements

The 1994 amendments to the MMPA mandate that, as part of the Reports, PBR estimates must be developed for each marine mammal stock in U.S. waters. The PBR is defined as "the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population." PBR is, therefore, calculated as the product of three elements: the minimum population estimate (N_{min}); half the maximum net productivity rate ($0.5\ R_{max}$); and a recovery factor (F_r). The guidelines for defining and applying each of these three elements are described below. Further specific guidance on the calculation of PBR is provided in part 2 (Technical Details) of this document.

Minimum Population Estimate (N_{min})

N_{min} is defined in the MMPA amendments as an estimate of the number of animals in a stock that:

> "(A) is based on the best available scientific information on abundance, incorporating the precision and variability associated with such information; and,

(B) provides reasonable assurance that the stock size is equal to or greater than the estimate."

Consistent with these MMPA definitions, N_{min} should be calculated such that a stock of unknown status would achieve and be maintained within OSP with 95% probability. Population simulations have demonstrated (Wade 1994) that this goal can be achieved by defining N_{min} as the 20th percentile of a log-normal distribution based on an estimate of the number of animals in a stock (which is equivalent to the lower limit of a 60% 2-tailed confidence interval):

$$N_{min} = N/\exp(0.842 * (\ln(1+CV(N)^2))^{½}) \qquad (1)$$

where N is the abundance estimate and CV(N) is the coefficient of variation of the abundance estimate. If abundance estimates are believed to be biased, appropriate correction factors should be applied to obtain unbiased estimates of N. In such cases, the coefficient of variation for N should include uncertainty in the estimation of the correction factor. In cases where a direct count is available, such as for many pinniped stocks, this direct count could alternatively be used as the estimate of N_{min}. Other approaches could also be used to estimate N_{min} if they provide the same level of assurance that the stock size is equal to or greater than that estimate.

Clearly, projections of current abundance estimates become less dependable with time after a survey has occurred. When abundance estimates become many years old, at some point estimates will no longer meet the requirement that they provide reasonable assurance that the stock size is presently greater than or equal to that estimate. Therefore, unless compelling evidence indicates that a stock has not declined since the last census, the minimum population estimate of the stock should be considered unknown if 8 years have transpired since the last abundance survey of a stock. Eight years was chosen, in part, because a population that declines at 10% per year from carrying capacity would be reduced to less than 50% of its original abundance after 8 years. A 10% decline per year over at least 8 years represents the greatest decline observed for a stock of marine mammals in U.S. waters. If N_{min} is unknown, then PBR cannot be determined, but this is not equivalent to considering PBR equal to zero. If there is known or suspected human-caused mortality of the stock, decisions about whether such stocks should be declared strategic or not should be made on a case-by-case basis. Stocks for which N_{min} becomes unknown should not move from "strategic" to "not-strategic", or v.v., solely because of an inability to estimate N_{min}.

Maximum Rate of Increase (R_{max})

One-half R_{max} is defined in the MMPA as "one-half of the maximum theoretical or estimated 'net productivity rate' of the stock at a small population size", where the term “net productivity rate” means “the annual per capita rate of increase in a stock resulting from additions due to reproduction, less losses due to natural mortality."

Default values should be used for R_{max} in the absence of stock-specific measured values. To be consistent with a risk-averse approach, these default values should be near the lower range of measured or theoretical values (or 0.12 for pinnipeds and sea otters and 0.04 for cetaceans and manatees). Substitution of other values for these defaults should be made with caution, and only when reliable stock-specific information is available on R_{max} (e.g., estimates published in peer-reviewed articles or accepted by review groups such as the MMPA Scientific Review Groups or the Scientific Committee of the International Whaling Commission).

Details on rounding and precision, and on averaging more than one estimate of abundance to calculate N_{min}, can be found in part 2 of this document.

Recovery Factor (F_r)

The MMPA defines the recovery factor, F_r, as being between 0.1 and 1.0. The intent of Congress in adding F_r to the definition of PBR was to ensure the recovery of populations to their OSP levels, and to ensure that the time necessary for populations listed as endangered, threatened, and depleted to recover was not significantly increased. The use of F_r less than 1.0 allocates a proportion of expected net production towards population growth and compensates for uncertainties that might prevent population recovery, such as biases in the estimation of N_{min} and R_{max} or errors in the determination of stock structure. Population simulation studies demonstrate that the default F_r for stocks of endangered species should be 0.1, and that the default F_r for depleted and threatened stocks and stocks of unknown status should be 0.5. The default status should be considered as "unknown". Stocks known to be within OSP (e.g., as determined from quantitative methods such as dynamic response or back-calculation), or stocks of unknown status that are known to be increasing, or stocks that are not known to be decreasing taken primarily by aboriginal subsistence hunters, could have higher F_r values, up to and including 1.0, provided that there have not been recent increases in the levels of takes. Recovery factors for listed stocks can be changed from their default values, but only after careful consideration and where available scientific evidence confirms that the stock is not in imminent danger of extinction. Values other than the defaults for any stock should usually not be used without the approval of the regional Scientific Review Group, and scientific justification for the change should be provided in the Report.

The recovery factor can be adjusted to accommodate additional information and to allow for management discretion as appropriate and consistent with the goals of the MMPA. For example, if human-caused mortalities include more than 50% females, the recovery factor should be decreased to compensate for the greater impact of this mortality on the population (or increased if less than 50% female). Similarly, declining stocks, especially ones that are threatened or depleted, should be given lower recovery factors, the value of which should depend on the magnitude and duration of the decline. The recovery factor of 0.5 for threatened or depleted stocks or stocks of unknown status was determined based on the assumption that the coefficient of variation of the mortality estimate is equal to or less than 0.3. If the CV is greater than 0.3, the recovery factor should be decreased to: 0.48 for CVs of 0.3 to 0.6; 0.45 for CVs of 0.6 to 0.8; and 0.40 for CVs greater than 0.8.

Recovery factors could also be increased in some cases. If mortality estimates are known to be relatively unbiased because of high observer coverage, then it may be appropriate to increase the recovery factor to reflect the greater certainty in the estimates. Thus, in an instance where the observer coverage was 100% and the observed fishery was responsible for virtually all fishery mortality on a particular stock, the recovery factor for a stock of unknown status might be increased from 0.5 (reflecting less concern about bias in mortality, but continued concern about biases in other PBR parameters and errors in determining stock structure). Recovery factors of 1.0 for stocks of unknown status should be reserved for cases where there is assurance that N_{min}, R_{max}, and the kill are unbiased and where the stock structure is unequivocal.

Annual human-caused mortality and serious injury

The Reports should contain a complete description of what is known about current human-caused mortality and serious injury. Information about incidental fisheries mortality should be provided, including sources such as observer programs, logbooks, fisher's reports, strandings, and other sources, where appropriate. It is expected that this section of the Reports will include all pertinent information that is subsequently used to categorize fisheries under Sect. 118. Therefore, any additional information that is anticipated to be used to categorize a fishery should be provided here.

In general, the most recent appropriate information about annual human-caused mortality and serious injury ("annual mortality") should be used. If mortality estimates are available for more than one year, a decision will have to be made about how many years of data should be used to estimate annual mortality. There is an obvious trade-off between using the most relevant information (the most recent data) versus using more precise information (pooling across a number of years). It is recognized that it is inappropriate to give one specific rule defining which years of data should be used, as this depends upon the quality and quantity of data available in each case. It is suggested that mortality estimates could be averaged over as many years necessary to achieve a CV of less than or equal to 0.3, but should usually not be averaged over a time period of more than the most recent 5 years for which data have been analyzed. However, information that is more than 5 years old should not be ignored if it is the most appropriate information available in a particular case. Also, in some cases it may not be appropriate to average over as many as 5 years even if the CV of an estimate is greater than 0.3. For example, if it is known that within the last 5 years the amount of total fishing effort has changed substantially, or the mortality rate per unit of fishing effort has changed substantially, it will probably be most appropriate to use only the most recent relevant data to most accurately reflect the current level of annual mortality. When mortality is averaged over years, it is recommended that an un-weighted average be used, as it is possible and likely that true mortality varies from year-to-year

A summary of incidental fisheries mortality and serious injury should be presented in a table, providing the name of the fishery, the current number of vessels, and for each appropriate year, observed mortality, estimated extrapolated mortality and serious injury and its CV, and percent observer coverage in that year, with the last column providing the average annual mortality estimate for that fishery. Information should be provided (in either the table or the text) about the number of mortalities and the number of injuries, and what injuries are considered "serious" (i.e., leading to mortality), if any. For fisheries without observer programs, information about incidental mortality from logbooks, fisher's reports, strandings, and other sources should be listed instead, where appropriate. Such information should be presented in brackets to distinguish it from actual estimates of total mortality in the fishery. All fisheries listed as interacting with the stock in the List of Fisheries should be listed in the table with as much information as possible. Further guidance, including a sample table, is provided in the third section of these guidelines.

It is often difficult to determine if an injury is serious or not. Stocks which have estimated known mortality (not including injuries) that is less than PBR but have total estimated mortalities and injuries that is greater than PBR (or similarly which have estimated known mortality that is less than 10% of PBR but have total estimated mortalities and injuries that is greater than 10% of PBR) should be clearly identified. Research to determine which injuries are serious will be necessary for such stocks. If injuries have been determined to be serious, the Report should indicate how this determination was made.

There is a general view that marine mammal mortality information from logbook or fisher report data can only be considered as a minimum estimate of mortality, although exceptions may occur. Logbook or fisher report information can be used to determine whether the minimum mortality is greater than the PBR (or greater than 10% of the PBR), but it should not be used to determine whether the mortality is less than the PBR (or 10% of the PBR). Logbook data for fisher reports should not be used as the sole justification for determining that a particular stock is not strategic or that its mortality and serious injury rate is insignificant and approaching zero rate.

Further guidance on averaging human-caused mortality across years and across different sources of mortality can be found in part 2 (Technical Details) of this document.

Mortality Rates

Sec. 118 of the 1994 MMPA Amendments reaffirmed the goal set forth in the Act when it was enacted in 1972 that the take of marine mammals in commercial fisheries is to be reduced to insignificant levels approaching zero mortality and serious injury rate, and further requires that this goal be met within 7 years of enactment of the 1994 Amendments (April 30, 2001). This fisheries-specific goal is referred to as the "zero mortality rate goal" (ZMRG). The Stock

Assessment Reports are not the vehicle for publishing determinations as to whether a specific fishery has achieved the ZMRG. A review of progress towards the ZMRG for all fisheries is required to be submitted to Congress by April 30, 1998.

However, Sec. 117 of the amended MMPA does require that stock assessment reports include descriptions of fisheries that interact with (i.e., kill or seriously injure) marine mammals, and these descriptions must contain "an analysis stating whether such level is insignificant and is approaching a zero mortality and serious injury rate." As a working definition for the Reports, this analysis should be based on whether the total mortality for a stock in all commercial fisheries with which it interacts is less than 10% of the calculated PBR for that stock. The following wording is recommended:

"The total fishery mortality and serious injury for this stock is (or is not) less than 10% of the calculated PBR and, therefore, can (or cannot) be considered to be insignificant and approaching a zero mortality and serious injury rate."

Status of Stocks

This section of the Reports should present a summary of 4 types of "status": 1) legal status under the MMPA and ESA, 2) status relative to OSP (within OSP, depleted, or unknown), 3) designation of strategic or non-strategic, and 4) a summary of trends in abundance and mortality.

The MMPA requires a determination of a stock's status as being either strategic or non-strategic and does not allow for a category of unknown. If abundance or human-related mortality levels are truly unknown (or if the fishery-related mortality level is only available from logbook data), some judgement will be required to make this determination. If the human-caused mortality is believed to be small relative to the stock size based on the best scientific judgement, the stock could be considered as non-strategic. If human-caused mortality is likely to be significant relative to stock size (e.g., greater than the annual production increment) the stock could be considered as strategic. In the complete absence of any information on sources of mortality, and without guidance from the Scientific Review Groups, the precautionary principle should be followed and the default stock status should be strategic until information is available to demonstrate otherwise.

The MMPA requires for strategic stocks a consideration of other factors that may be causing a decline or impeding recovery of the stock, including effects on marine mammal habitat and prey. Therefore, such issues should be summarized in the Status section for all strategic stocks. If substantial issues regarding the habitat of the stock are important, a separate section titled "Habitat Issues" should be used. If data exist that indicate a problem, they should be summarized and included in the Report. If there are no known habitat issues or other factors causing a decline or impeding recovery, this should be stated in the Status section.

References

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2. Technical Details

In this section, technical details are given for making appropriate calculations of PBR and mortality. The first section provides details on precision and rounding issues. The second section provides details for combining more than one abundance estimate for calculating N_{MIN}. The third section contains details for calculating the estimate of annual human caused mortality and its associated variance.

Precision and Rounding

The following rules on precision and rounding should be applied when calculating PBR and other values:

> (a) N (the abundance estimate), CV(N), R_{max}, and F_r should be reported in the Report to whatever precision is thought appropriate by the authors and involved scientists, so long as what is reported is exactly what the PBR calculation is based on.
> (b) PBR should be calculated from the values for (a) to full precision, and not be calculated from an intermediary rounded off N_{min}. However, N_{min} should be reported as a rounded integer.
> (c) PBR and mortality should be reported with one decimal place if they are below 10. Otherwise, PBR and mortality should be reported as a rounded integer.
> (d) If PBR and mortality round to the same integer, the Report will report both values to the precision necessary to determine which is larger. This would also be done if 10% of PBR and mortality round to the same integer.

Computation of Average Abundance and its Variance

When estimates of abundance are available for more than one year or from more than one source in the same year, it may be appropriate to combine those estimates into an average abundance for the time period in question. It was agreed that a weighted mean was probably the most appropriate average to use, where the weights are equal to the inverse of the associated variance:

$$mean(\hat{a}_1, \hat{a}_2, \ldots \hat{a}_n) = \bar{a} = \sum_{i=1}^{n} w_i \, \hat{a}_i \quad ,$$

where:

$$w_i = \frac{1/var(\hat{a}_i)}{\sum_{j=1}^{n} 1/var(\hat{a}_j)}$$

The variance of a weighted mean of several abundance estimates is calculated as:

$$var(\bar{a}) = w_1^2 var(\hat{a}_1) + w_2^2 var(\hat{a}_2) + \ldots w_2^2 var(\hat{a}_n) = \sum_{i=1}^{n} w_i^2 var(\hat{a}_i) \quad .$$

Finally, the variance is parameterized as a CV in the provided equation for calculating N_{MIN}. The CV is calculated as:

$$CV(\bar{a}) = \frac{\sqrt{var(\bar{a})}}{\bar{a}}$$

Computation of Average Human-Caused Mortality and its Variance

When estimates of human-caused mortality and serious injury (called here "mortality") are available for more than one year and/or from more than one source, such as a fishery, it is necessary to calculate an estimate of the mean annual mortality along with its associated variance (or CV). The following section provides guidelines for doing this. For convenience, the section refers to averaging the incidental by-catch of fisheries, but the guidelines apply equally well to estimates of human-caused mortality from other sources.

Calculating the overall mean annual by-catch

First, it was agreed that it was most appropriate for the bycatch estimates from a fishery to be averaged UN-WEIGHTED across years, as the true bycatch might be different in each year, and thus is not stationary. This is just the simple average of the available estimates of by-catch. If estimates are available from more than one fishery, a mean annual by-catch from each fishery should be calculated first, and then the annual mean from each fishery should be summed to calculate an overall estimate of the mean annual by-catch.

Calculating the coefficient of variation (CV) of the mean annual by-catch of a single fishery

There are two potential methods for calculating the CV or variance of the mean annual by-catch of a single fishery. Method 1 involves using standard statistical formulas for combining the variances of the individual yearly by-catch estimates (assuming they are available). Method 2 involves estimating the variance empirically from the 2-5 years of point estimates of by-catch, which is done by calculating the standard deviation of the 2-5 mortality estimates and dividing it by the square root of *n*, where *n* is the number of years available. Both methods are valid. However, two points favor Method 1.

First, because the true bycatch might be different in each year, and thus is not stationary, estimating the variance using Method 2 above could over-estimate the true variance of the estimates of bycatch, and this positive bias would be related to how much the bycatch truly varied from year to year independent of observation error.

Second, Method 1 is likely to give a more precise estimate of the variance because it has more degrees of freedom. Using Method 2 involves estimating the variance from a sample size of just 2-5, and ignores the information that is known about the precision of each individual estimate.

Obviously, Method 2 is the only method that can be used if there are no estimates of the variance of the bycatch estimates available. Method 1 is the recommended method if the estimates of by-catch in each year do have an estimated variance (or CV).

Method 1

Table 1 outlines the computations needed for estimates of average by-catch mortality by f fisheries operating over n years. Table 2 gives an example computation for f=3 fisheries operating over a horizon of n=3 years and all of the estimates are non-zero. Most variance estimators will provide an estimate of 0 for the variance when the estimated mortality is zero; however, the true variance is non-zero. In this case, a more realistic estimate of the variance can be developed by averaging the variances for those years which have a positive variance. The variance computations in Table 1 are simply modified by dividing by the square of the number of years with a non-zero variance. The computation of the average is unaffected with the zero included in the average (Table 3). In certain circumstances a fishery may have been operating but was not monitored for mortality. Missing estimates should be dropped both from the calculation of the average and the variance (Table 4).

Method 2

In Method 2 the only change is in how the variance is calculated for the estimate of average by-catch mortality for each fishery over n years. In Method 2 the variance of the average by-catch is estimated empirically from the several point estimates of by-catch available from different years. This is done by calculating the variance of those estimates and dividing it by n, where n is the number of years used in calculating the average:

$$var(\bar{m}_{i.}) = \frac{\sum_{j=1}^{n} \frac{(m_{ij}-\bar{m}_{i.})^2}{n-1}}{n}$$

The above formula would thus be substituted for the formula for $var(\bar{m}_{1.})$ presented in Table 1. The second step of combining variances across fisheries is identical to Method 1.

Table 1. Computation table for average mortality for *n* years with *f* fisheries. The mortality estimate for fishery *I* during year *j* is m_{ij} and the corresponding variance estimate is v_{ij}. The estimated total mortality for year *j* is $m_{.j}$, the sum of mortality estimates for each fishery and the variance is $v_{.j}$, the sum of the variances. The average mortality for fishery *I* is $\bar{m}_{I.}$ and its variance is $v_{i.}$, which is the sum of the variances for each year within the fishery divided by the number of years (*n*) squared.

Fishery	Year 1	Year 2 ...	Year *n*	Average	
1	m_{11} var(m_{11})	m_{12} var(m_{12})	m_{1n} var(m_{1n})	$\bar{m}_{1.} = \sum_{j=1}^{n} m_{1j} / n$	$var(\bar{m}_{1.}) = \sum_{j=1}^{n} var(m_{1j}) / n^2$
2	m_{21} var(m_{21})	m_{22} var(m_{22})	m_{2n} var(m_{2n})	$\bar{m}_{2.} = \sum_{j=1}^{n} m_{2j} / n$	$var(\bar{m}_{2.}) = \sum_{j=1}^{n} var(m_{2j}) / n^2$
f	m_{f1} var(m_{f1})	m_{f2} var(m_{f2})	m_{fn} var(m_{fn})	$\bar{m}_{f.} = \sum_{j=1}^{n} m_{fj} / n$	$var(\bar{m}_{f.}) = \sum_{j=1}^{n} var(m_{fj}) / n^2$
Total				$\bar{m}_{..} = \sum_{i=1}^{f} \bar{m}_{i.}$	$var(\bar{m}_{..}) = \sum_{i=1}^{f} var(\bar{m}_{i.})$

Table 2. Example computation of average mortality and its variance for 3 fisheries over 3 years.

Fishery		Year 1	2	3	Average
1	m	10	3	19	10.67
	v	4	2	8	1.56
2	m	2	13	6	7.00
	v	2	14	4	2.22
3	m	6	33	5	14.67
	v	8	23	4	3.89
Total	m				32.33
	v				7.67

Table 3. Example computation of average mortality and its variance for 3 fisheries over 3 years when some estimates are zero.

Fishery		Year 1	2	3	Average
1	m	10	0	19	9.67
	v	4	0	8	3.00
2	m	2	13	6	7.00
	v	2	14	4	2.22
3	m	0	0	5	1.67
	v	0	0	4	4.00
Total	m				18.33
	v				9.22

Table 4. Example computation of average mortality and its variance for 3 fisheries over 3 years when some estimates are zero and others are missing.

Fishery		Year 1	2	3	Average
1	m		0	19	9.50
	v		0	8	8.00
2	m	2		6	4.00
	v	2		4	1.50
3	m	0	0	5	1.67
	v	0	0	4	4.00
Total	m				15.17
	v				13.50