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RECOMMENDATIONS FOR POOLING ANNUAL BYCATCH ESTIMATES WHEN EVENTS ARE RARE

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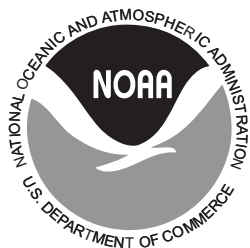La Jolla, CA 92037

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Recommendations for pooling annual bycatch estimates when events are rare

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Abstract

Fishery bycatch estimates reported in U.S. marine mammal stock assessment reports (SARs) are typically pooled over multiple years to increase precision and reduce small-sample biases in resulting mean annual estimates. Such pooling can remedy biases in single-year estimates resulting from interannual variability in marine mammal abundance, oceanographic conditions, or observer coverage. Bias is defined as systematic over- or underestimation of true bycatch levels over any particular pooling period. Current SAR guidelines suggests that pooling bycatch estimates for periods of five years is typically adequate to obtain an acceptable level of precision, generally defined as a coefficient of variation (CV) of ≤ 0.30. However, this guidance is based on an assumption that bycatch is a relatively common event with adequate sample sizes and sufficient observer coverage. Pooling over longer periods is also acceptable if additional years accurately represent the current state of the fisheries and their inclusion reduces estimation error. For rare events, estimation error can be severe, with problems that include 1) an inability to document bycatch that is occurring because observer coverage is too low to detect rare events (negative bias) and 2) exaggerated estimates of annual bycatch when observer coverage is low and observed bycatch events are extrapolated by a large multiplicative factor (positive bias). Rare bycatch events often involve species that pose management concerns because their abundance and potential biological removal (PBR) levels are low to begin with. As such, it is important to reduce estimation error for these species. We report the results of a simulation trial for rare bycatch events in a hypothetical fishery with 20% observer coverage, showing how estimation error is reduced as a function of the number of years that annual estimates are pooled beyond the 5-year time period most typically used in marine mammal stock assessments.

Introduction

In marine mammal stock assessments, NOAA Fisheries utilizes a strategy of pooling bycatch estimates across multiple years to account for interannual variability in observer coverage, cetacean abundance and distribution, oceanography, and fishing practices. Annual estimates of bycatch are typically pooled across 5-year periods to calculate mean annual mortality levels (NMFS 2005, Moore and Merrick 2011), though guidelines for the preparation of stock assessment reports (NMFS 2005) allow for the use of other pooling periods:

"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."

For rare events, attaining a coefficient of variation (CV) of ≤ 0.3 from just a few years of bycatch estimates is unrealistic, because of small sample sizes. Furthermore, annual estimates of bycatch may suffer from small-sample bias, especially where observer coverage is low (Moore and Merrick 2011). Rare bycatch events typically involve populations with low allowable mortality levels, or potential biological removal (PBR) (Wade 1998), that may range from a few individuals to less than one in some cases. If true bycatch mortality is low, but near PBR, then estimation bias needs to be reduced to allow reliable evaluation of the bycatch estimate against a low removal threshold. When observer coverage levels are too low to detect most rare events, resulting bycatch estimates are likely to include a high percentage of false zeros or estimates with severe positive bias when bycatch is detected. Either type of bias is undesirable when management thresholds such as PBRs are so low that bias results in overestimation or underestimation of risk to populations.

Consider a hypothetical rare event bycatch process where the true rate of bycatch follows a Poisson process with an expectation of two animals caught per 1,000 fishing sets and observer coverage is 20% annually. Assume that PBR is also two animals per year. In this example, because the annual bycatch rate equals the PBR, minimizing estimation error is critical. Fishery observers may record zero, one, two, three, etc. bycatch events annually. Where annual bycatch estimates are generated with a widely-used method such as the ratio estimator (Julian and Beeson 1998, Carretta et al. 2005, Ye 2002), resulting estimates can only take on a limited range of discrete values that are zero (if none observed) or multiples of five, given 20% coverage (Table 1). If the true average annual bycatch value is > 0 but less than a few animals per year, and if observer coverage remains at 20%, then none of the annual estimates will reflect the true bycatch rate. Pooling over multiple years provides a better estimate of the true rate of bycatch, with increased precision. Determining the amount of pooling necessary to obtain unbiased bycatch estimates for such a rare event is the goal of this paper.

Table 1. Hypothetical estimates of annual bycatch in a fishery with 20% observer coverage where bycatch is a rare event. The true expected bycatch is 2 animals per year.

Number Observed	Bycatch Estimate
0	0
1	5
2	10
3	15
4	20

Methods

Simulations were used to randomly generate *true* annual bycatch for each of 1,000 years, assuming a Poisson process with a mean rate of two animals from 1,000 fishing sets each year (i.e., bycatch in a given year could be 0, 1, 2, 3…). Observer coverage was set at 20% annually, such that 200 sets were drawn randomly without replacement from the simulated 1,000 annual sets to represent 'observed sets'. Annual bycatch ($\hat{B}$) in year y was estimated as

$$(1) \qquad \hat{B}_y = \frac{n_y}{s_{obs}} * E_y$$

where $\hat{B}_y$ = the annual bycatch estimate
$\quad n_y$ = number of bycatch events observed
$\quad s_{obs}$ = number of fishing sets observed (s_{obs} =200 for all simulations)
$\quad E_y$ = estimated total fishing effort in year y. (E_y =1,000 sets for all simulations)

This is analogous to using a simple ratio estimator, such as those currently used to estimate bycatch in California gillnet fisheries (Carretta et al. 2004, Julian and Beeson 1998). From the distribution of 1,000 annual bycatch estimates, we pooled estimates for periods ranging from 1 to 50 years by randomly drawing x annual estimates (where x = 1 to 50). For each x-year period, we generated a different 1,000 sets of pooled estimates. Mean, median, and 25th and 75th quartiles for the bycatch estimates were calculated from the 1,000 estimates in each x-year pooling period. The probability of not observing a single bycatch event during an x-year period was also estimated as the fraction of pooled estimates over x-years that contained all zeros. We also calculated an error metric for pooled estimates, defined as the fraction of estimates that deviated >25% (plus or minus) from the true bycatch rate of 2.0 animals per year. Thus, 'accurate' estimates were considered to be mean values that ranged from 1.5 to 2.5 animals per year. This simulated bycatch rate and level of observer coverage is analogous to actual bycatch processes observed for leatherback sea turtles and sperm whales in the California drift gillnet swordfish fishery, which have posed management problems in past years (Federal Register 2001, 2013). We also evaluated the amount of pooling necessary to achieve a bycatch CV of 0.3 by calculating the CV of the 1,000 mean bycatch estimates for each x-year pooling period.

Results

The simulated range of possible annual bycatch estimates varied depending on the pooling period (Figure 1). Estimates converged towards the true mean as the number of pooled years increased (Figures 1-3). The probability of simulated estimates falling within 25% of the true mean of 2.0 animals per year was zero for 1-year pooling periods. This is because single-year estimates can only take on values of zero or multiples of five. Only after 10 years of pooling, did the probability of estimates falling within 25% of the true bycatch rate exceed 50% (Figure 4). Thus, 10 or more years of pooling was required before the odds of getting an 'accurate' estimate was better than 1:1. The probability of observing zero events over different pooling periods decreased from 0.67 for one year to 0.14 for five years (Table 2). After 10 years of pooling, the probability of observing all zeros dropped to approximately 0.01 (Table 2). Approximately 25 years of pooling was necessary before bycatch CVs approached a value of 0.3 considered adequate for management (NMFS 2005) (Figure 5). Because performance metrics for bycatch estimates may vary depending on the particular management problem (e.g. should estimates be within 10% or 25% of the true bycatch rate?), we cannot offer a precise recommendation for the number of years to pool, other than providing general advice that "more is better", and that this is particularly important for rare-event situations. Caveats to this advice are that managers and analysts must assess whether characteristics of the fishery have remained sufficiently constant to justify a particular pooling period.

Discussion

Current use of the 5-year pooling period for calculating mean annual bycatch is not sufficient to accurately estimate mean annual bycatch for rare events. Use of this 5-year time frame is predicated on the ability to produce bycatch estimates with relatively low uncertainty (CVs ≤ 0.30), which is simply not possible for rare bycatch events (Figure 5).

The problem of rare event bias may also be addressed by using estimation methods that are model-based rather than sample-based. Methods such as classification and regression trees (Breiman 2001), delta-lognormal methods (Barlow and Berkson 2011), generalized linear and generalized additive models (McCracken 2004) have all been applied to rare bycatch situations with varying success. Such models that make use of prior years' data to predict bycatch in current years are alternatives that may reduce the interannual volatility in bycatch estimates sometimes produced with ratio estimators, but they are also likely to yield positive bycatch estimates even in years when zero events are observed.

Acknowledgements

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Table 2. Probability of observing zero bycatch events during different pooling periods.

Years Pooled	Probability of observing all zeros
1	0.667
2	0.438
3	0.318
4	0.183
5	0.147
6	0.093
7	0.06
8	0.038
9	0.026
10	0.012
11	0.013
12	0.006
13	0.008
14	0
15	0.002

Figure 1. Plot of possible values of mean bycatch estimates for 1 to 50-year pooling periods. Vertical blue line denotes typical 5-year pooling used in marine mammal stock assessments. Horizontal red line denotes simulated mean annual bycatch of 2 events per 1,000 fishing sets.
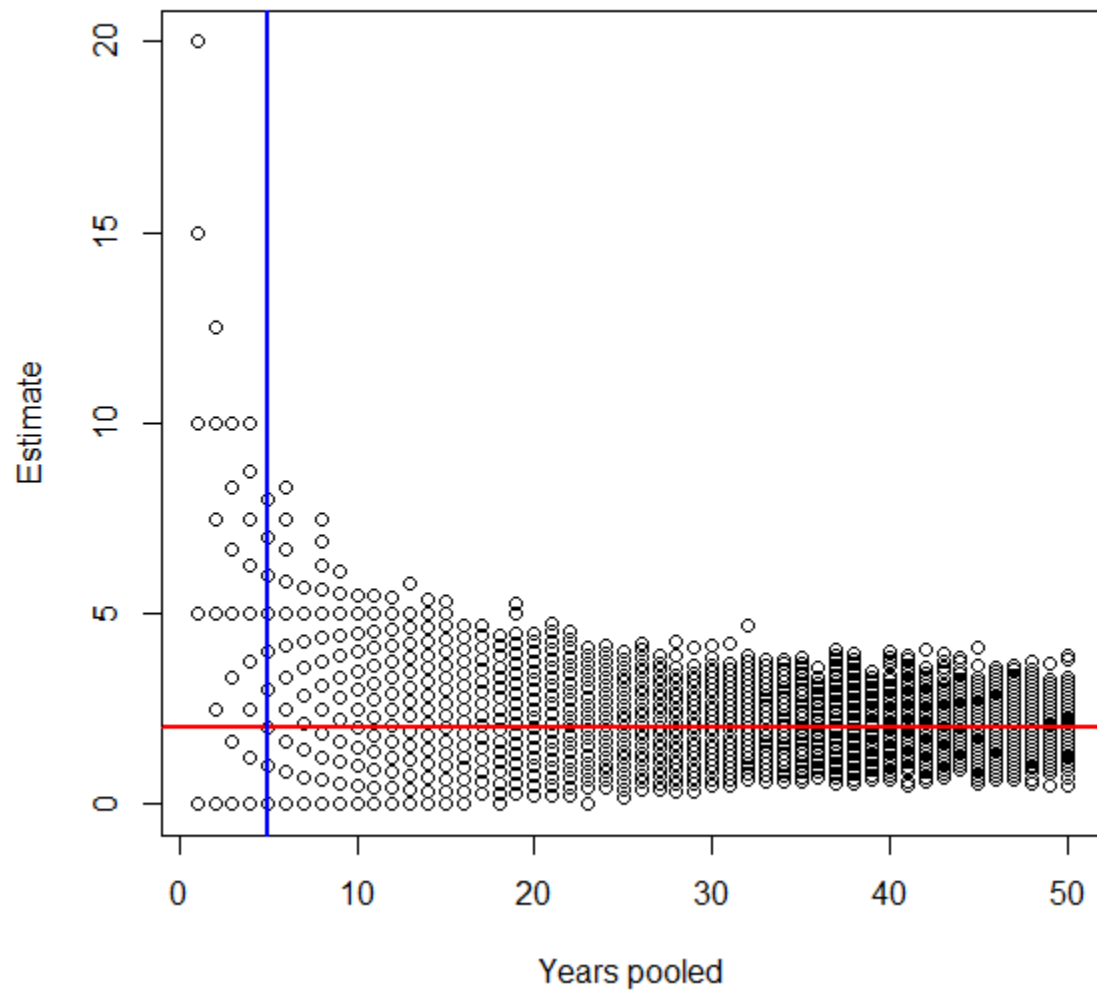
Figure 2.   Boxplot showing median bycatch estimates over pooling periods of 1 to 50 years. Whiskers denote the full range of bycatch estimates, boxes denote the 25th and 75th percentiles of pooled estimates, and dark horizontal bars shown the median estimate. The true rate of bycatch of 2.0 animals/year is denoted by the horizontal red line. Horizontal blue lines bound bycatch values within ±25% of the simulated annual rate of 2.0 animals/year.
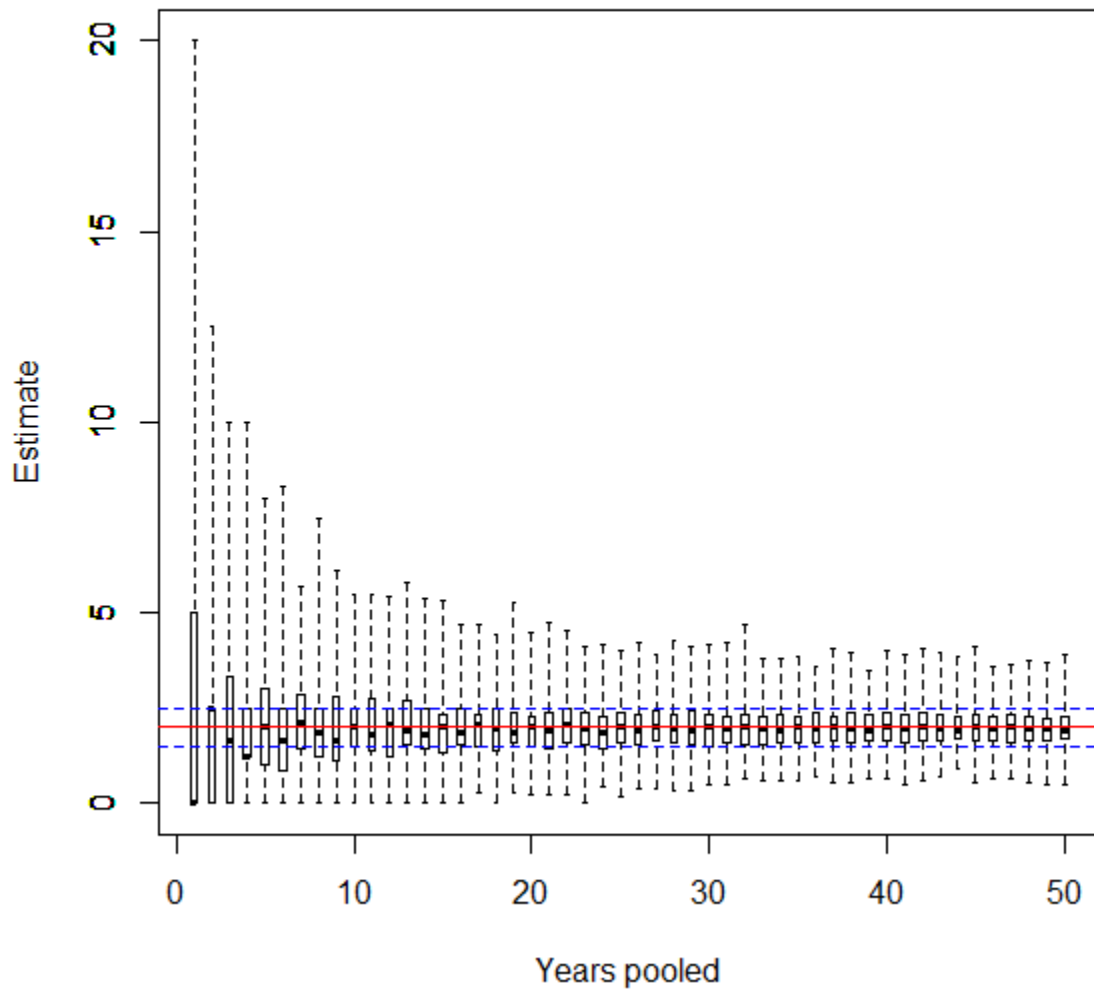
Figure 3. Boxplot showing median bycatch estimates over pooling periods of 1 to 20 years. This plot contains the same data shown in Figure 2, except this plot shows only 1 to 20 years of pooling. Whiskers denote the full range of bycatch estimates, boxes denote the 25th and 75th percentiles of pooled estimates, and dark horizontal bars shown the median estimate. The true rate of bycatch of 2.0 animals/year is denoted by the horizontal red line. Horizontal blue lines bound bycatch values within ±25% of the simulated annual rate of 2.0 animals/year.
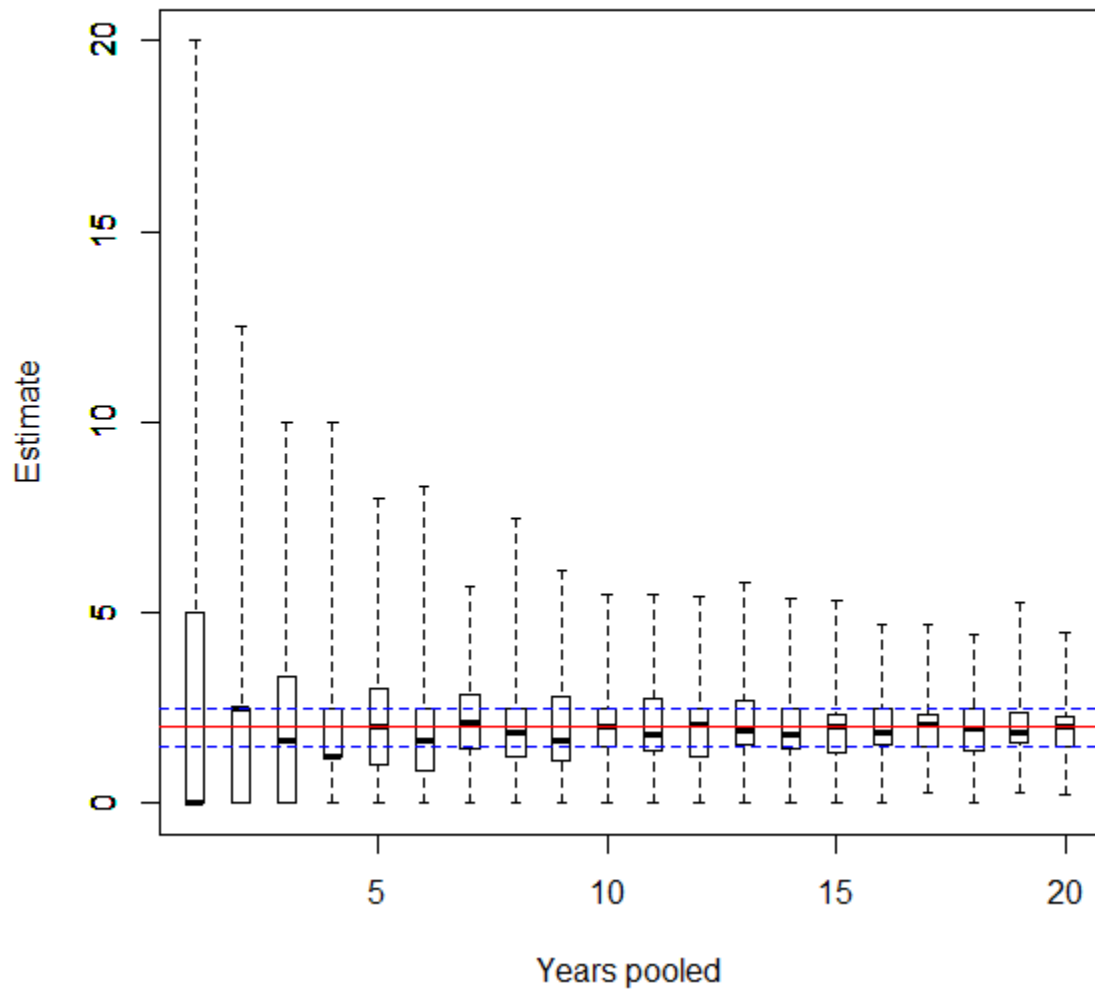
Figure 4. Probability of mean annual estimate being within 25% of the simulated 'true' mean of 2.0 animals per 1,000 sets fished. A 50% or greater probability of estimating a pooled mean within 25% of the true bycatch rate does not occur until 10 years of estimates are pooled. The 50% probability line is denoted by the horizontal line.
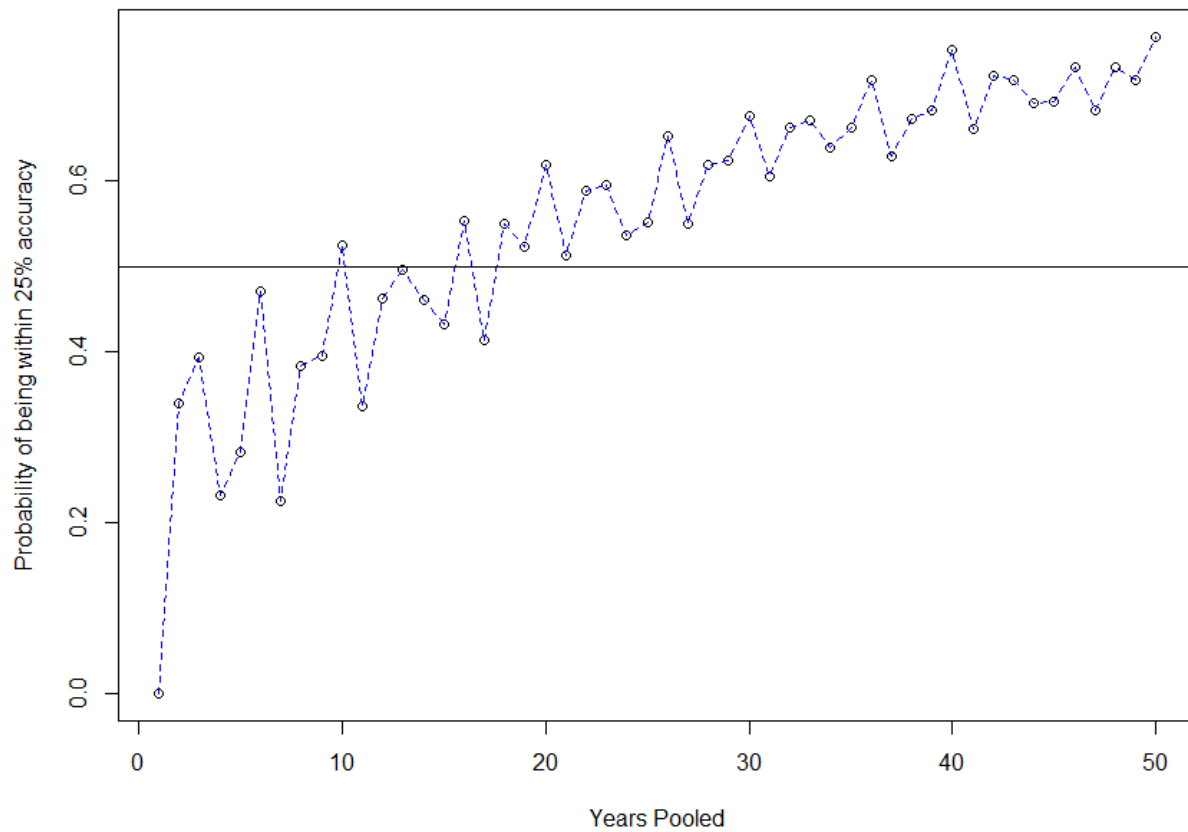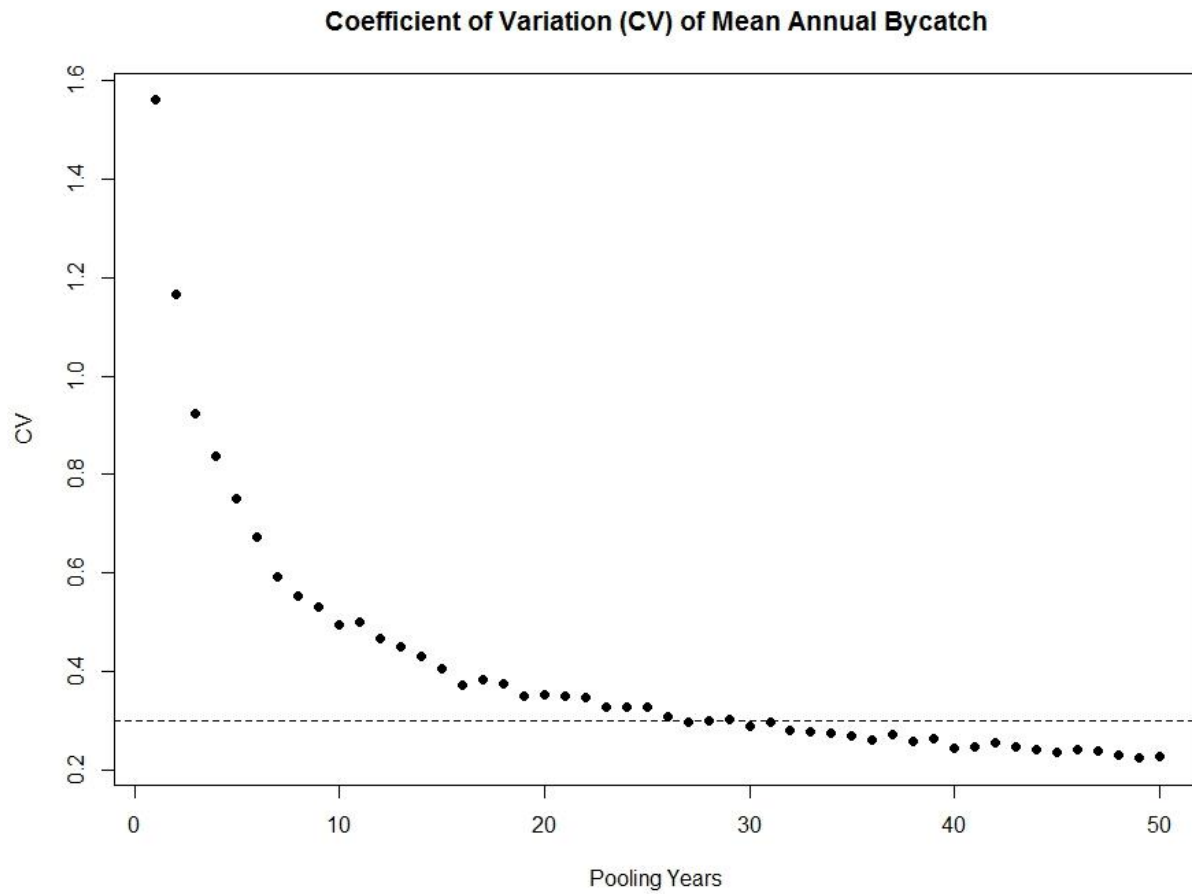
Figure 5. Coefficient of variation (CV) of mean annual bycatch estimates over x-year pooling periods. Horizontal dashed line represents the management goal CV of 0.3.

Coefficient of Variation (CV) of Mean Annual Bycatch

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