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PREPARATION OF THIS DOCUMENT

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ABSTRACT

The Conference was co-hosted by the Governments of Australia and Canada in co-operation with the Food and Agriculture Organization of the United Nations (FAO) and with the support of the National Oceanographic and Atmospheric Administration (NOAA), USA, and the New South Wales Department of Fisheries, Australia. More than 160 delegates from 26 countries participated and 26 papers were presented. The Conference was held in response to a recommendation made at the 1996 FAO/Japan Technical Consultation on Wastage in Fisheries (Tokyo) which identified as a key concern the lack of reliable, basic level data from the majority of global fisheries, particularly when attempting to estimate global discards and the incidental mortality of non-target species. The purpose of the Conference was to address the challenges and opportunities of fisheries monitoring that are common to many fisheries. The Conference speakers, panel discussions, and workshops were organized around the following five main themes: 1) Rational for monitoring programmes - conceptual and legal frameworks, 2) Perspectives on monitoring from key stakeholders, 3) Designing, executing and analysing monitoring programmes, 4) Key components and issues for monitoring programmes; and 5) Integrated monitoring. The recommendation that came out of the Conference was presented to the 1999 Meeting of the FAO Committee on Fisheries (COFI). It stated that the FAO Fisheries Department should undertake the preparation of guidelines for the integrated monitoring of fisheries within the context of the FAO Code of Conduct for Responsible Fisheries with the aim to improve the management of fisheries and the sustainable use of living resources, through the formulation of an appropriate framework for the collection of relevant data and information from fisheries and their associated ecosystems.

Estimating the ecological impacts of fisheries: What data are needed to estimate bycatches?

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1 Introduction

In many fisheries, the focus of attention has shifted from the traditional single-species management concerns to a new awareness of effects that may cause far reaching ecological impacts on target and non-target species. The magnitude of these impacts should be estimated and their causes understood in order to achieve the elusive goal of ecosystem management (Alverson *et al.* 1994, Dayton *et al.* 1995, Hall 1996). When a fishery places one or more species in danger, or when it has adverse effects on a whole ecological community, management plans to eliminate or mitigate its effects are necessary. These plans require a good knowledge of several elements of the population dynamics, such as recruitment, abundance and mortality of the species involved. Based on these statistics, and guided by the precautionary approach (FAO Code of Conduct for Responsible Fisheries, Article 7.5), targets and objectives can be set to control the problem. Trends in relative or absolute abundance estimates can be monitored to assess the changes and make the policy decisions. Because it is also one of the key elements in determining the effects of fishing on ecosystems, the emphasis of this paper is on the estimation of incidental mortality caused by fishing practices. Although this is largely a statistical problem, the approach discussed here should be useful to the many non-statisticians who are dealing with these issues.

2 Estimating the incidental mortalities of the main bycatch species

Very frequently the drive to assess the ecological impacts of a fishery will come from concerns over the fate of one or a few species which are suspected of being taken at unsustainable levels or which are charismatic enough to generate special attention from the public or from managers. When that is the case, the first priority is to get the best possible estimate of that impact on the "main bycatch species." In exceptional cases (e.g. Hall 1998), it is possible to have full coverage of the fleet causing the incidental mortality. More often, however, economic or logistic constraints allow only sampling of the activity of the fleet in question. The discussion of sampling design which follows addresses the following issues: biases, level of precision, representativeness of samples, observer effects, and other uncertainties (cryptic mortality).

The estimate in question will, in some cases, be a composite estimate, with its components being:

Mortality = (number of individuals captured) x (proportion of those captured that die)

In some cases it may be known or assumed that all individuals captured are killed, the proportion becomes one and the estimate is limited to the first term.

2.1 Estimating the numbers of individuals captured

Direct and indirect methods have been used to estimate the number of individuals captured. Direct estimates are those in which the simple average caught or killed per unit of fishing effort is used. An example of this is the number of individuals caught per crab pot or per lobster trap and in this case the unit of effort is reasonably homogeneous. When the bycatch is correlated with some other variable, such as the total catch of a set of pots or nets, ratio or regression estimates can be used (Cochran, 1977). In this case records are kept, not only of the mortality, but also of the catch per unit of effort. For instance, if the bycatch species is a predator of the target species in a fishery, it may be that for ecological reasons there is some relationship between the size of a school of the target species and the number of predators that follow it, feed from it, *etc*. The knowledge of this relationship may provide a way to improve the estimation of the bycatch, if good estimates for the overall distribution of catches per set, or at least, a cumulative total, can be obtained. In the case of the tuna purse-seine fishery of the eastern Pacific, the average mortality of dolphins per ton of tuna captured was used (Hall and Boyer 1986).

In other fisheries, there is heterogeneity in the use of the gear that affects bycatches (i.e. gillnets of different lengths or trawls hauled for different periods). If the sampling unit is a net set, or a haul, there is no *a priori* selection of the length or duration, and these are treated as random variables. The probability of an individual being taken is proportional to the area of the gillnet (or to its length if depth is constant), or to the volume filtered by the trawls, which is proportional to the duration of the tow for trawls with similar dimensions, towed at similar speeds. Thus information on the characteristics of the fishing operation increases our ability to estimate the bycatch. If there is information available to extrapolate to total gillnet length, or to total hours trawled, then the sampled ratio of mortality to gillnet length or hours trawled can be used effectively. As the length of the net sampled is a random variable, the sampling process produces both a random mortality and a random length that have to be combined in a ratio.

These methods require an estimate of the average impact of each unit of effort, which can be called the "bycatch per unit of effort" (BPUE) which parallels the concept of catch per unit effort (CPUE). BPUE and CPUE are not equivalent, however, and the effort measure used for both of them in the same fishery may be different (Hall 1996). In the purse-seine fisheries, for example the CPUE can be expressed in units of catch per hour searched, but the BPUE must be expressed in units of mortality per set (or per ton of tuna caught), because a set is the unit of fishing activity that can result in bycatch. Searching for fish doesn't cause mortality.

The estimates of BPUE have to be extrapolated to the total level of "effort" to complete the estimation process. The fisheries literature provides many examples of this type of extrapolation. Again, there are two options, one is used when effort is known, or assumed to be known, without error, and the other is used when there is also error in this estimate.

The new formula can be written as:

Mortality = BPUE x (total level of effort) x (proportion of individuals captured that die).

2.2 Estimating BPUE

The conditions, considerations and caveats relating to the estimation of CPUE and detailed in section 2.1 also apply to the estimation of BPUE.

2.3 Estimating the level of effort

The effort level that has to be estimated or measured is the one used in the extrapolation of the BPUE ratio. It can be obtained from observer data, fisher's logbooks, port records, or landings data. If it is estimated with error, this source of variance must be included in the overall estimate.

2.4 Estimating the proportion of individuals captured that die

When some of the individuals captured survive after having been released, it is necessary to include an estimate of the probability of death for those captured. This value could come from a best guess, or from an experiment performed for that purpose. The variance coming from this term is easy to obtain, but its validity when applied to fishery data needs to be explored.

2.5 Biases

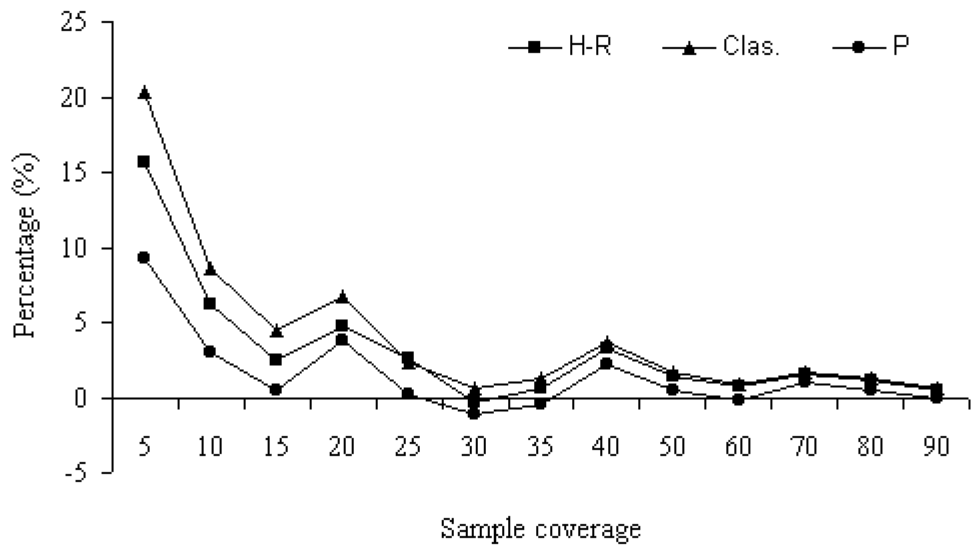
Ratio estimates of the kind described above are biased when sample sizes are small (Cochran 1977), and frequently data obtained from new observer programmes falls into this category. There are several ways, other than the simple one of increasing sample size, to address this issue. These include (a) the use of one of the several formulas with bias-adjusting terms that have been proposed for this purpose (Rao 1969) and (b) the use of a bootstrap correction (Efron 1982, Efron and Tibshirani 1993).

The sample coverages during the early years of the tuna-dolphin programme were very low and there were questions concerning how much coverage was needed to produce reliable estimates, and what happened to the estimates when coverage was very low.

To answer these questions, a simulation approach was used to study the magnitude of the bias, and our ability to adjust for it by using the various formulae available for this purpose. Data were available for a series of years with observer coverage of around 25% - 30%. As there were no clear trends within this period, samples from three consecutive years were combined into one, with roughly the same number of trips as the total for a single year. This became a "simulated universe," whose properties were perfectly known. From this universe, samples of different coverage levels were extracted, and several hundred replicates were made at each level.

After testing several formulae, the three with the lowest biases (the Hartley-Ross and Pascual formulae (Rao 1969)), and one with bootstrap bias correction (Efron and Titbshirani 1993) were selected for a more detailed comparison of performance. Figure 1 shows the results for these three cases. The biases were almost always positive, tending to overestimate the mortality per ton ratio; as sample coverage increases, the bias approaches zero. The bootstrap adjustments for bias, applied to the classical or to the bias-adjusted formulae, are effective in all cases, improving the accuracy of the estimates.

Figure 1. Relative bias (%) in MPT ratio in the estimates of mortality of the eastern spinner dolphin. H-R = Hartley-Ross formula, Clas. = Classical formula, P. = Pascual formula.

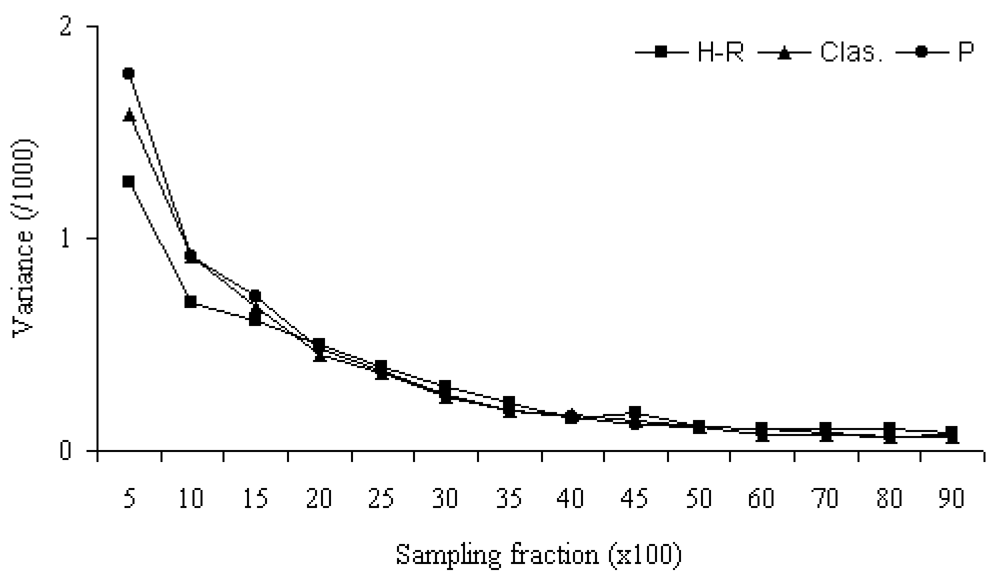


2.6 Precision

The precision of the estimates will depend on the three sources of variance previously identified: one coming from the estimate of BPUE, one from the estimate of the level of effort, and one from the estimate of the probability of death. Of these, the level of effort can be known with enough accuracy that the error may be considered negligible. The error of the probability of death is likely to be set in an experiment, so it may become a fixed component, unchanging over time, unless the experiment is repeated or expanded. The sampling design, therefore, will be dictated mostly by the error in the BPUE estimate. The statistical distribution of the bycatches is a complicated issue because of the variety of cases that are routinely observed. This variety ranges from rare species that encounter the gear at random, which probably follow a Poisson distribution, to schooling species that are either absent or present in large numbers. To handle all the variety, it is advisable to use bootstrap methods to estimate the variance of the BPUE (Efron and Tibshirani 1993); again, simulation methods can provide a good approach to produce realistic estimates which are independent of assumptions about the underlying statistical distributions. Variance estimates for the BPUE and the probability of death can be combined to obtain an estimate of variance for mortality from formulae for the variance of a product of random variables (Goodman 1960) or the delta method (Rice 1988), if all three components have associated error.

In most cases the "main bycatch species" will be the reference point for the sampling decisions, including those concerning the level of precision. Figure 2 shows the changes in variance with increasing sample size, obtained from the simple simulation described above. This type of curve makes the trade-offs between precision and cost visible to those involved in decision-making on the subject. Other than at low sampling rates (<10%) it appears that all three formulae give essentially the same answer.

Figure 2. Changes in variance with sampling coverage using mortality of eastern spinner dolphin per ton for a combined data set. Average of 1,000 simulations. Bootstrap estimates M=100. True ratio = 0.026. H-R = Hartley-Ross formula, Clas. = Classical formula, P. = Pascual formula.



2.7 Representativeness

Many factors can affect the representativeness of the data, and may seriously bias bycatch estimates.

2.7.1 Selection of units of effort to be sampled

It is expected that the sampling design follows a pattern established by the researcher (random, systematic, stratified, etc.), but deviations are common. One example of this are the programmes where vessels take observers on a voluntary basis. It is impossible to know if the tendency to volunteer is correlated with some performance level (*e.g.* only vessels without problems agree to take observers). In international programmes, different national fleets may have different levels of experience, different regulations, *etc*., and the extrapolation of data from one to the other may not be valid. Logistics may prevent the adequate sampling of some sectors of the fleet (*e.g.* small vessels that don't have the space to take observers, or vessels operating from ports with difficult or costly access may get a smaller share than they should). Again, for logistical reasons, random or systematic designs may have to be modified to accommodate constraints in the number of observers, their location, *etc.* Complex stratified sampling designs may be developed which take into account the logistical constraints imposed on the programme by the fishery. Whatever the case, sampling coverage must include the main areas of the fishery and the entire fishing season, to provide the necessary information on possible spatial and temporal sources of heterogeneity. Simulations with real data coming from pilot samples may again help sort these issues.

2.7.2 Observer effect on crew performance

It is possible that the presence of an observer may affect in some way the behaviour of the captain or the performance of the crew. A captain may chose to fish in areas with lower mortality rates when an observer is on board, or the crew may make extra efforts to release alive the individuals captured. Compliance with regulations, and use of safety equipment will most likely be different when they are being reported.

Can these effects be detected? By comparing the fishing areas, species and size composition of the catch, catch rates, trip duration, *etc*., of the observed sector of the fleet with the rest, it may be possible to test whether the selection of fishing grounds, and other operational decisions depart from the unobserved fleet pattern (assuming that a combination of data, and samples at landing ports could provide these data). But without information on unobserved vessels, comparisons of crew performance in release procedures, compliance with requirements and regulations, *etc.* are not possible.

2.7.3 Unobserved mortality

The presence of an observer on a vessel is no guarantee that all the mortality will be observed. The reasons for this include; negligence (e.g., not being present during the fishing operation), temporary disability (e.g., the observer may be sick or injured), poor visibility (e.g., sets in darkness or in rough seas), disappearance of the dead individual prior to observation (e.g., dropping from a hook or falling out of a net, taken by a predator from a net or hook, *etc*.). A special category of unobserved mortality is that of the individuals that die as a result of the fishing operations, as a result of delayed effects (e.g., animals released with internal injuries, or external injuries that were erroneously believed not to lead to mortality, facilitated predation as a result of alterations in schooling or other behaviour as a result of the fishing operation; stress-or fatigue-induced mortality, *etc.).*

2.7.4 Underreporting of mortality

Even though it is possible to conceive of some circumstances under which an observer may intentionally overestimate mortality (antagonism with crew, overzealous protection of the species involved, *etc*.), it is much more likely that the mortality will be under-reported. There are three basic motivations that could lead to this: (i) observers spending prolonged trips at sea may develop bonds of friendship with captains and crews, and that may affect their reports; (ii) captains and crews may intimidate the observer, and the observer may underreport out of fear; and (iii) the observers may be bribed to falsify their reports. Of these three, intimidation should disappear when the vessel arrives in port, and the observer has an opportunity to correct the data and report the incident for the corresponding sanction. The other two are more difficult to identify and correct. The records of the observers could be followed over long periods of time, and those consistently reporting below average values, compared to other observers, could be monitored very closely or eliminated from the programme. In such cases their data would be eliminated from some or all the analyses. Besides these statistical checks, there are very few alternatives to detect these biases. Lie detector tests are not fully accurate, and their legal value is not clearly established. Sting operations or observations on spending patterns by some individuals may identify a few guilty parties, but they do not make it possible to quantify the bias. Placing a sub-sample of "trusted" observers or volunteers mixed with the regular pool could help quantify this difference, by comparing the figures from this and the other group.

2.8 Factors affecting BPUE

All the considerations of the previous sections are focused on the objective of obtaining a good estimate of the incidental mortality of the main bycatch species but none of them contributes to understanding its causes. In addition to producing an estimate of a problem's magnitude, an observer programme should serve as a tool to solve the cause of incidental mortality. To achieve this goal it is necessary to identify possible factors that cause the incidental mortality or increase the average BPUE. These factors can be of several types, depending on the fishery. Some can be environmental factors (visibility, sea state, presence of currents, *etc*.) and others are related to the gear and its deployment (is the right gear used? Is it deployed in the right way?, *etc*.). Unfortunately, at the beginning of the studies on estimation and mitigation of bycatches it is not known which factors affect BPUE, so it is recommended that a broad approach be taken, trying to include as many factors as possible. The list of factors is potentially very long, but those affecting the ability of the animals to detect the gear, their behaviour, and the behaviour of the gear should be considered first. Once an adequate database becomes available, statistical techniques, such as generalised linear models (McCullagh and Nelder 1989, Stefánsson 1996) can be used to determine which factors are significant.

Acquiring knowledge about the factors affecting BPUE allows one to: (a) improve the estimation of the bycatch levels; and (b) develop mitigation procedures (regulations, technology, education, *etc*.) to address them. The latter constitutes the basis for most bycatch reduction programmes. It is recommended that input from fishers be given a high priority when establishing the list of factors to consider.

3 ESTIMATING THE MORTALITY OF OTHER, MOSTLY NON-TARGET, SPECIES

Most of the problems, and solutions, mentioned for the target species apply for the other components of the bycatch. If the sampling design is based on the main bycatch species, however, it is quite possible that the estimates for other species have broader confidence intervals, and may be biased. This could be a serious problem if the bycatch of the "main" species has a uniform or random distribution, and some of the secondary species are very patchy in their distribution.

4 SPATIAL AND TEMPORAL DISTRIBUTION OF THE BYCATCHES

Knowledge of the spatial and temporal distribution of the bycatches is crucial to the quality of the estimates, and to the mitigation programmes. From the estimation point of view, the stratification of the data into spatial and temporal units that reflect real heterogeneities, will be an effective way to improve the estimates and reduce the costs of the sampling programmes. From the point of view of the mitigation programmes, it provides a quick assessment of the feasibility of spatial and temporal closures as mitigation measures.

5 RELATIVE OR ABSOLUTE ABUNDANCE OF THE SPECIES TAKEN

To put in perspective the impact of a fishery, it is very important to compare the level of mortality with the population size, and its net recruitment. The "relative mortality" is the ratio of mortality to population size. These data may come from the fishery, but most commonly will require special surveys, tagging experiments, or other procedures. Without them, the mortality data have only limited value because the assessment of their significance is left to the "gut feelings" of those interested. Time series of BPUE data could be used to monitor trends in the populations taken, but only after the same careful procedures that should be used in the interpretation of CPUE data. An additional problem in the use of BPUE data is that many possible actions taken to reduce bycatches would result in lowering the BPUE without reflecting any population changes. A system where the index of abundance is also a performance measure is not likely to be very informative over time because the trends in the population will become confounded with the performance changes that may be the objective of management.

6 BYCATCH TO CATCH RATIOS

Bycatches should be expressed as a function of the catches in the same fishing operations to facilitate the comparison among areas, gears, *etc*. Some ratio estimates may require the catches In other cases the catches will put the bycatches into perspective by showing the ecological costs of different operations under a comparable standard (Hall 1996.)

7 CONCLUSIONS

This paper provides a brief description of the data requirements to implement an effective bycatch mitigation programme. The value of simulations performed on real data from pilot samples is emphasised as a tool to provide statistical insights into the problem without the need for complex theoretical analyses. The use of resampling techniques to deal with bias and precision problems is also proposed as a major component of the estimation process. Finally, in order to contribute to the solution of bycatch problems, the exploration of the causes of the bycatch must be an integral part of the sampling scheme.

References

ALVERSON, D.L., FREEBERG, M.H., MURAWSKI, S.A. & POPE, J.G. 1994. A global assessment of fisheries bycatch and discards. F.A.O. Fish. Tech. Paper No. 339, Rome, 233 pp.

COCHRAN, W.G. 1977. Sampling Techniques. 3rd ed. J. Wiley & Sons, London, 428 pp.

DAYTON, P.K., THRUSH, S.F., AGARDY, M.T. & HOFMAN, R.J. 1995. Environmental effects of marine fishing. Aquatic conservation. *Mar. Freshw. Ecosystems*, 5: 205-232.

EFRON, B. 1982. The jack-knife, the bootstrap and other resampling plans. CBMS Regional Conference Series in Applied Mathematics 38, S.I.A.M., Philadelphia, 92 pp.

EFRON, B., & TIBSHIRANI, R.J. 1993. An introduction to the bootstrap. Monographs on Statistics and Applied Probability 57, Chapman and Hall, New York, 436 pp.

HALL, M.A. 1996. On bycatches. *Rev. Fish Biol. Fisheries*, 6: 319-352.

HALL, M.A. 1998. An ecological view of the tuna-dolphin problem: impacts and trade-offs. *Rev. Fish Biol. Fisheries*, 8: 1-34.

HALL, M.A. & BOYER, S.D. 1986. Incidental mortality of dolphins in the eastern tropical Pacific tuna fishery: description of a new method and estimation of 1984 mortality. *Rep. Int. Whal. Commn*., 36: 375-381.

GOODMAN, L.A. 1960. On the exact variance of products. *American Statistical Association Journal*, 55: 708-713.

MCCULLAGH, P. & NELDER, J.A. FRS. 1989. Generalized Linear Models, Second edition. Chapman & Hall, London, 511 pp.

RAO, J.N.K. 1969. Ratio and regression estimators. *In* N.L. JOHNSON & H. SMITH Jr., eds., *New developments in survey sampling.* Wiley Interscience, London. 732 pp.

RICE, J.A. 1988. Mathematical Statistics and Data Analysis. Wadsworth & Brooks/Cole, Pacific Grove, California, 595 pp.

STEFÁNSSON, G. 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. *ICES J. Mar. Sci.*, 53: 577-588.