

BALANCING SAMPLING PRECISION AND FISHERIES MANAGEMENT OBJECTIVES: MINIMAL METHODS

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ABSTRACT

Density-dependent and environmental effects on population size are both too weak to be useful for short term fishery management (Smith, 1985). Year-to-year variation of recruitment rate may be of the same order of magnitude as measurement uncertainty and population changes may have to be sustained for 2 to 3 years to be detectable using the precision available from current techniques. As fishing rates accelerate, the dependence of the fishable biomass on recruitment is increased. Pre-recruit survival and growth may be more episodic than adult survival and fecundity (Smith and Moser, 1988). The episodic nature of recruitment combined with higher fishing rates may make more frequent biomass estimates necessary. When variable recruitment and high total instantaneous mortality rates (ITMR) reach a certain level, effective fisheries management will require development of recruitment prediction procedures in addition to virtual population and biomass monitoring. Annual biomass surveys may be redundant because many stocks contain several year classes. The costs of implementing recruitment prediction and systems to monitor biomass may be a significant fraction of the value of the added catch and this should be considered during management planning.

For many modern fisheries, overfishing occurs before effective management measures can be taken (Murphy, 1977). Traditional measures of overfishing, like declining size composition of the catch or declining catch per unit of effort of young fish, may not be sufficiently timely for fisheries on populations with short life cycles or in unstable habitats (Mangel, 1991). In the relatively short history of clupeoid fisheries there have already been many population changes of several orders of magnitude (Murphy, 1977; Lluch-Belda et al., 1989). One of the principal dangers of overfishing on these stocks is that the population distribution contracts into a small area where catch per unit of effort remains high even though the stock has declined to a small fraction of its original size (MacCall, 1990). Based on several decades of fisheries management experience on several stocks in the North Atlantic, it seems clear that neither density-dependent nor density-independent effects on population size will be sufficiently clear for predictive purposes of management (Smith, 1985).

It is the purpose of this paper to show how 1) the precision of biomass estimates, 2) the scale of short term changes in abundance and 3) mortality rates experienced by exploited stocks affect fisheries management.

Accuracy and Precision

A typical response of a population to fishing mortality is a decrease in the relative contribution of the older fish to reproduction (Murphy, 1968). Under these conditions population estimates may need to be made more often. Decisions on the required frequency of biomass estimates could be based on the life history of the species under management (Garrod and Knight, 1979; Shelton, 1987; Smith and Moser, 1988) or on the time scales of variability in the environment (Bernal, 1981; Bernal and McGowan, 1981; Chelton et al., 1982; McGowan, 1989). In extreme cases, such as the fishery on Peruvian anchoveta (Pauly et al., 1987) the instantaneous total mortality rates (ITMR), fishing and natural, exceed a value of 1 and thus would appear to require more frequent spawning biomass estimates and recruitment prediction procedures to be managed successfully.

Table 1. Recruits as a fraction of the fishable stock under a wide range of annual instantaneous total mortality rates (ITMR)

ITMR (Z)	Recruits as fraction of stock $(1 - e^{-Z})$	Years to 1% of recruited cohort size
0.01	0.010	529
0.02	0.020	264
0.05	0.049	105
0.1	0.095	52
0.2	0.181	26
0.5	0.393	10
1	0.632	5
2	0.865	2
5	0.993	1
10	1.000	0

Population estimates from accurate methods such as virtual population analysis are often delayed for years and estimates from fishery independent methods like spawning biomass estimation or acoustic-trawl procedures may be overly expensive. Based on the best methods available (Bindman, 1986; Prager and MacCall, 1988; Hightower, 1990), it does not seem likely that coefficients of variation (standard error of estimate divided by estimate) less than 30% will be affordable by any method. This means that a fish stock could actually decline at a high rate but that conventional methods like virtual population analysis could not detect the decline for several years. Even direct spawning biomass estimates (Lasker, 1985), which provide an instantaneous estimate of spawning stock size in a given year, may not detect meaningful changes of population size for 1 or 2 years, given the limits of precision for a given cost. In addition to the "recruitment" problem on the short term, there will likely be a need to detect the onset of long term "climatic regime" shifts in fish production (Lluch-Belda et al., 1989).

Natural and Fishing Mortality

When the fishery depends heavily on recruitment, management measures must be timely to respond to the usual recruitment variability (Hennemuth et al., 1980). For example, one could assume an exponential rate of decline of the cohort following recruitment at any age:

$$N_{t-t_0} = N_0 \cdot e^{-(F+M) \cdot (t-t_0)}$$

where N_{t-t_0} is the number of fish remaining at time "t"; N_0 is the number of fish recruited; and, M and F are the instantaneous natural and fishing mortality rates. Thus, one can use the number of useful cohorts in a population (>0.5% of recruits remaining) under various conditions of M and F. Using the simplifying assumptions of 1) changes in total mortality are principally caused by changes in the rate of fishing, 2) the mortality is even with age following recruitment, and, 3) the number of recruits is the same at each time zero. Changes in the number of useful cohorts in the population result from any change of natural and fishing mortality rates: thus, an increase in either natural or fishing mortality rates will increase the dependence of the fishery on the newly recruited fraction of the stock.

Hennemuth et al. (1980) reported that recruitment per unit spawning biomass is log-normally distributed. This means that if the policy were adjusted to reflect the spawning biomass estimated in the preceding year plus an allowance for an "average" recruitment, one should anticipate an occasional high recruitment but a majority of recruitments would be well below "average."

Recruitment Dependence

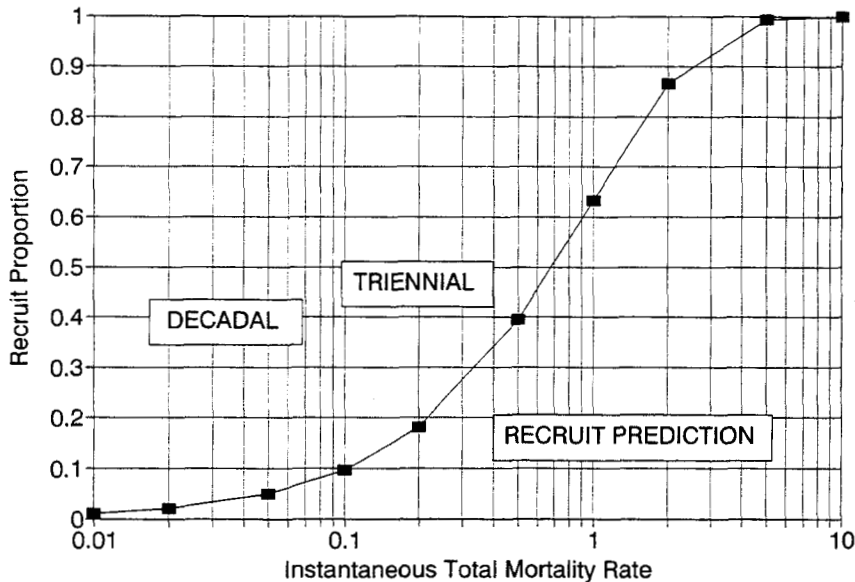


Figure 1. Relationship among population characteristics, intensity of fishery, and management biomass assessment practices. Instantaneous total mortality is the sum of natural mortality, mortality caused by other monitored species, and projected fishing mortality. The "decadal" scale is used for long lived species with smaller fisheries. The "triennial" scale is used for stocks with shorter life spans. The "prediction" scale is for recruitment prediction of stocks.

Frequency of Estimate

As the fishery management process matures, dozens of stocks will be fished and additional species may also have to be monitored for fisheries impact: the cost of providing annual estimates of the health of all populations may be prohibitive. It could be determined, for each population, what interval is tolerable between estimates of population size. Empirical and simulation techniques (Reddingius and den Boer, 1970; Garrod and Knight, 1979) exist for determining the time course of a population change. As an example one could establish regions on a graph of ITMR versus recruitment rate as in Figure 1. For instance if the ITMR is below 0.1, one may need no more than a single biomass estimate to establish the population level on an absolute basis and thereafter relative measures of population growth and decline could be sufficient. One could envision that absolute measures of biomass could be on the decadal scale in that case. On the other hand, if the ITMR is above 1.0, more than 60% of each year's catch would be from recruits, no existing monitoring method might be sufficient: recruitment prediction methods would need to be developed.

Population Areal Distribution

MacCall (1990) has discussed the interactions among population size, population density, and population area. For Pacific sardine and northern anchovy, these relationships had also been shown by Ahlstrom (1967). One of the dangers

of managing fish using catch per unit effort (CPUE) is that this measure, at best, estimates a local population density in the fishing area. It seems likely that catch per unit effort data could be usefully augmented by a measure of spawning area during a fishery. If a fishing moratorium were in place, the spawning area, by itself, could provide a useful measure of the stock size. This practice was initiated by Wolf and Smith (1985) for the sardine moratorium following the apparent low level recovery of the stock (Wolf and Smith, 1986; Wolf et al., 1987). A theoretical basis for the decision to use area-based or spawning-rate-based biomass estimation methods was discussed by Mangel and Smith (1990).

The primary reason an area-based estimate of sardine biomass works relatively well is that the quantitative methods work so badly. Most of the eggs are deposited in a small area, possibly as a sperm-conservation tactic: with a small number of observations, it is unlikely to encounter the primary concentration and, when encountered, the rare sample appears as an outlier (Smith, 1973). While the egg samples can be approximated by a log-normal distribution, the presence of the eggs is distributed as a binomial. As the eggs disperse, they soon cover most of the area where spawning fish have been in the past several days. A simulation of the egg distribution shows that a single sample has only a 22% chance of getting "0" eggs in the spawning area and five samples have only a 1% chance of missing all eggs (table 2 in Wolf and Smith, 1985). The same simulation shows that one must take 500 samples to obtain a standard error 30% of the mean. Further evidence on egg distribution and sampling error is contained in Smith and Hewitt (1985) and Jahn and Smith (1987). One caution is that bootstrapping techniques use the samples collected up to this time and later sampling will undoubtedly increase the upper limit of egg concentrations.

CONCLUSION

Minimal measures need only to include monitoring the catch rates for certain long lived, lightly fished populations; some fisheries may become so intensive that no monitoring scheme is adequate to prevent over-fishing in a changeable environment. For these latter fisheries, it is necessary to develop recruitment predictions. To decide the preliminary approach to new fisheries or new levels of fishing on existing fisheries, one merely derives a crude estimate of the spawning biomass, natural mortality, and projected fishing mortality. If this indicates a low level of fishing and natural mortality ($ITMR < 0.1$) the population may need only a low level of monitoring effort, such as monitoring of spawning area or catch per unit of effort. Intermediate intensities of fishing ($0.1 < ITMR < 0.4$) require accurate triennial biomass monitoring. If the $ITMR$ is projected to be above 0.4, existing biomass monitoring procedures would not likely provide sufficient and timely information for management decisions. It is particularly critical that the skewed distribution of recruitment, essentially log-normally distributed (Hennemuth et al., 1980), be considered when setting management procedures and fishing mortality rates. For the most intensive levels of fishing mortality in variable habitats, recruitment prediction probably will be the only feasible way of managing fisheries. There are no direct measurements or acoustic survey procedures implemented for this purpose and the costs of development will be substantial.

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