MSY, Bycatch and Minimization to the "Extent Practicable"

Joseph E. Powers
Southeast Fisheries Science Center
National Marine Fisheries Service
75 Virginia Beach Drive
Miami, FL 33149
joseph.powers@noaa.gov

Abstract. *--- Two goals of marine fisheries management in the United States are 1) to achieve maximum sustainable yield and 2) to minimize bycatch "to the extent practicable." However, the determination of maximum sustainable yield is contingent upon the selectivity of the various fisheries involved and the mix of these fisheries that management desires. Several methods of computing maximum sustainable yield and associated parameters are compared. The methods make alternative assumptions as to the balance between targeting and bycatch fisheries. The methods were evaluated using a deterministic population simulation model. Additionally, spawning potential ratios computed with and without bycatch are compared so as to evaluate biological risk. While the choice of the method will largely be driven by socioeconomic factors, some implications to management are discussed. Perhaps, the most important implication is that before analysts can calculate maximum sustainable yield and associated parameters, management needs to define their desired mix of fishing and what "to the extent practicable" means.*

Introduction

The Magnuson-Stevens Fishery Management and Conservation Act of the United States (U.S. Congress, 1996; hereafter referred to as "the Act") established several goals and objectives. In particular objectives were specified to maintain fisheries at "optimum yield" and to minimize bycatch "to the extent practicable" [National Standards 1 and 9 (16 U.S.C. § 1851(1), 16 U.S.C. § 1851(9) of the Act, respectively]. Additionally, the term "optimum" was prescribed on the basis of the maximum sustainable yield (MSY) from the fishery, as reduced by any relevant economic, social, or ecological factor (16 U.S.C. § 1021(28)). Clearly, the Act envisioned that management objectives were to be based upon MSY. It, also, envisioned that bycatch should be minimized "to the extent practicable." However, even prior to the passage of this Act, Goodyear (1996) reminded us that the determination of maximum sustainable yield (MSY) was contingent upon the selectivity of the various fisheries involved:

> " ... setting MSY as a management objective will often be insufficient for developing management advice unless the desire long-term age composition of the catch or some other qualifying factor is also specified. This is particularly true for the situation in which fisheries with inherently different selectivities compete for a resource ... "

While Goodyear's analysis was directed at the effects of target fisheries with different selectivities (such as commercial versus recreational), his comments are no less applicable when considering fisheries which discard bycatch of a particular stock in conjunction with other fisheries which target that same stock. The implications of Goodyear's comments are that: MSY cannot be calculated until management has defined "extent practicable"!

This note addresses the previous statement: examples are given of the dilemma faced by analysts when bycatch reduction goals (and allocations) are not defined. Additionally, metrics are suggested for evaluating "practicable" bycatch reduction scenarios in terms of biological risk. Finally, this note encourages debate on socio-economic, biological and ecological implications of bycatch reduction scenarios so that informed definitions of practicable bycatch solutions may be made.

Methods

Consider a stock of fish in which discard mortality occurs in the juvenile stage resulting from one fishery, whereas targeted fishery mortality occurs at older ages from another fishery (Table 1 gives parameters and selectivity schedules). Assume the selectivity schedule of the discarded bycatch fishery

($S_{dby,Age}$, i.e., the relative mortality rate at age resulting from discarded bycatch) is determined by both biological characteristics and by management, as is the selectivity schedule of the targeted fishery ($S_{tar,Age}$). Note, the selectivities are scaled such that the maximum S at age is equal to one, as is the usual form (Table 1). Then the mortality rates imposed by these fisheries are characterized by separable functions $F_{Age} = F_{tar}\ \ S_{tar,Age}$ and $D_{Age} = D_{dby}\ \ S_{dby,Age}$. Note that I am making a distinction between the fishing mortality rate F and the discard mortality rate D even though they both originate from fishing activities. The former directly contributes to the landings of a fishery, whereas the latter does not. Also, in what follows I will use the simplified notation F_{tar}, D_{dby} and F_{msy}, i.e. the "F-multipliers", recognizing that the quantities are actually the sum of the selectivity times the multiplier over all ages.

Since management may alter the selectivities, management objectives need to be introduced to define F_{tar} and D_{dby} and the relationship between the two, i.e. to define "the extent practicable." There is any number of mechanisms that management may choose to do this. However, three will be explored in the Methods below. These are not exhaustive and are meant to demonstrate the effects of the choice on MSY and the spawning stock at MSY (SS_{msy}).

Method I: $D_{dby} = \gamma_1 F_{tar}$

In this case MSY and SS_{msy} are calculated by solving for the F_{tar} that produces MSY subject to the condition that the ratio of discard mortality rate to fishing mortality rate is a constant, γ_1. Thus, $F_{msy}=F_{tar}(1+\gamma_1)$, where F_{tar} maximizes the long term landed catch. This solution implies that a proportional allocation of fishing rate has been made between the two fisheries. For example, this method might be achieved by specifying the amount of targeted effort relative to bycatch effort that mangers want under "optimal" (MSY) conditions.

Method II: $D_{dby} = \gamma_2$

In this case MSY and SS_{msy} are calculated by solving for the F_{tar} that produces MSY subject to the condition that the discard mortality rate is a constant, γ_2. Thus, $F_{msy}=F_{tar}+\gamma_2$, where F_{tar} maximizes the long term landed catch. This solution implies that an absolute allocation of fishing rate has been made to the discard bycatch fishery. This might be implemented by specifying the absolute amount of effort by the bycatch fishery under MSY conditions.

Method III: $D_{dby} = \gamma_3 F_{msynoby}$

In this case MSY and SS_{msy} are calculated by first solving for $F_{msynoby}$, i.e. the directed fishing mortality rate that produces MSY subject to the condition that the discard mortality rate is zero. Then discard mortality rate is assigned to be proportional to $F_{msynoby}$ by a proportional constant, $\gamma_{3;}$ afterwards F_{tar} is computed based on D_{dby} and $F_{msynoby}$. Thus, $F_{msy}=F_{tar}+\gamma_3 F_{msynoby}$, where F_{tar} maximizes the long term landed catch. This solution implies that a rate of discard mortality has been allocated to the discard bycatch fishery as a proportion of the potential targeted fishing mortality rate. Then the mortality imposed by the target fishery is adjusted to allow this discard rate. The implementation of this method in a fishery would be similar to Method II.

One could envision allocating an absolute number or weight of fish to the bycatch fishery. In this case D_{dby} would approximately equal the ratio of bycatch to the stock size at MSY. However, actually implementing a bycatch quota may be difficult. Additionally, a constant bycatch policy is likely to be unstable given existing uncertainties in bycatch estimates. Therefore, constant bycatch methods were not evaluated further in this study.

In order to generate examples of these three Methods, a simple deterministic population was simulated. Population parameters (Table 1) were based on a stock of fish that spawns halfway through the year and lives through 50 years. Recruitment was defined by a Beverton-Holt relationship, growth in length by a von Bertalanffy model, weight-length by an allometric equation, fecundity at age by another power equation and natural mortality rate at age and maturity at age were scheduled (all defined in Table 1 in arbitrary units). Selectivities at age from discard mortality and from targeted fishing mortality (Table 1) assume that the sources of these mortalities arise from two separate fisheries. Spawning stock (SS in Table 1) is characterized as the egg production. Spawning potential ratio (SPR, i.e. the contribution to reproductive potential, SS, of a cohort of animals over its lifetime when undergoing fishing relative to that contribution when no fishing is occurring) was also calculated. This simulated population is loosely based on Gulf of Mexico red snapper, which are impacted by a suite of directed fisheries, as well as by shrimp trawls that catch red snapper as bycatch and subsequently discard them dead. The population model was solved numerically for equilibrium population parameters including MSY, SS_{msy}, $F_{tar\ at\ msy}$, $D_{dby\ at\ msy}$ and SPR_{msy}.

Results and Discussion

Not surprisingly, having a positive bycatch mortality rate reduces the potential for MSY from the target fishery (Figure 1), the larger the rate the larger reduction in MSY. The impact differs with the method chosen to allocate bycatch mortality, i.e. upon how "extent practicable" is defined. Larger allocations of bycatch mortality rate reduce the spawning potential (SS and SPR) at MSY when allocations are made using Methods II and III. However with Method I, SS and SPR increase with larger allocations of bycatch rate (Figure 1). The reason for this is that Method I links the bycatch and target fishing rates in a constant proportion. Thus, a higher bycatch rate is compensated by an even lower targeted fishing rate and MSY at that rate can only be achieved at a higher spawning stock level.

A theoretical maximum sustainable yield occurs when the yield-per recruit and the excess recruitment (the difference between the recruitment and spawners at MSY) are simultaneously maximized. This maximization could be accomplished by harvesting all of the excess recruits at the instant that the natural mortality and growth were equal (Goodyear 1996, Ricker 1975). This, of course, does not happen in real-world fisheries, therefore any deviation in selectivity from the theoretical instant results in a calculation of yield that is less than the theoretical MSY. Indeed, even when one uses age-grouped surplus production models, the implicit assumption is that MSY and related statistics are contingent on the inherent selectivity of the effort data used to obtain estimates from model fits (Schaefer 1957). Therefore, in a practical sense no estimate of MSY exists without prior specification of the desired selectivity of the "optimal" state (Goodyear 1996, Restrepo, *et al.* 1998). When there is bycatch mortality resulting from a different fishery from that which targets the stock, then the importance of this prior specification becomes important.

However, the specification of bycatch mortality objectives (the definition of extent practicable) has not been forthcoming for many stocks. The lack of bycatch objectives is even more important when the stock has been depleted and is in recovery. In these instances not only is the desired mix of selectivities at MSY required, but the transition of those selectivities over the recovery period are also needed. Nevertheless, analysts are still asked questions like: how much bycatch mortality can we have and still allow the stock to recover to SS_{MSY} by the year 2025? If the stock can recover within that time horizon with no fishing (either target or bycatch), then the answer to the question is: "it depends on how much target fishing and bycatch fishing you want!" In other words, what level of bycatch is equivalent to reducing it to the extent practicable?

In these examples (Fig. 1), if the chosen rates of bycatch are small then the impact on the value of MSY and spawning biomass at MSY is minimal, i.e. it makes little difference which of these three methods of defining MSY is used. However, when bycatch rates are large, then the resulting differences in MSY may change 20-30% in these examples and the spawning biomass as much as 50% (Fig 1). Recovery rates of an overexploited stock would also be significantly impacted.

Regardless of the choice of Methods, a critical issue is the actual levels of bycatch allowed, i.e. the γ's. The choice will be driven by social objectives and, perhaps, legal interpretations. However, the fishing mortality rates defined in the three Methods above may be transformed into SPRs in order to examine the impacts on the stock and to define the biological risks (the simulated population of Table 1 is used here as an example). Comparing SPR at MSY under various conditions does this. Scenarios which result in lower SPRs imply that MSY will occur at smaller spawning biomasses; thus, the population is more at risk:

1) SPR at MSY when there is both bycatch and target fishing relative to no fishing; this is the standard determination of SPR expressing the risk imposed on the population of all fishing mortality sources (Figure 1-G);
2) SPR at MSY when there is bycatch mortality and no target fishing relative to SPR at MSY when there is neither bycatch nor target fishing; this comparison addresses the risk imposed on the population due to bycatch mortality, alone, without any other fishing mortality (Figure 1-H); and
3) SPR at MSY when there is target fishing relative to when there is both target fishing and bycatch; this comparison evaluates the incremental risk imposed by bycatch over and above the target fishing mortality rate (Figure 1-I).

The first calculation above (1) examines the risk to the population of bycatch alone; the second (2) looks at the total risk to the population under all fishing mortality; and the third addresses the relative, incremental risk imposed by bycatch beyond that of the target fisheries.

What is the most appropriate way to define F_{msy}? Again, there may be no biological rationale to choose between these three methods, the choice will be driven by social objectives and legal interpretations. For example, if the target fishery existed historically and then in more recent times the bycatch fishery developed, then one might say that MSY should be defined on the basis of the targeted fishery alone. Then some bycatch could be allowed based on direct negotiations of proportions of the fishing mortality rate. The bycatch rate would be "set aside" and the targeted fishery would be structured to maximize long term landed catch given the set aside. This scenario argues for Method III.

Conversely, if the bycatch fishery existed historically and the targeted fishery developed later, then one could argue that bycatch rates should be based on historical values (reduced by some proportion through negotiation to achieve bycatch reduction goals). The targeted fishery would maximize long term landed catch given the set aside. This scenario results in Method II.

Finally, if a balance between fishing rates of the bycatch and targeted fisheries is negotiated, then MSY may be defined using Method I. F_{msy} is computed by adjusting bycatch and targeted fishing mortality rates up or down in the same ratio until the computed yield is maximized.

While there is no biological reason for a preference for one of these three Methods (or for that matter some other method), Method II is attractive because of its simplicity. Method II is a direct calculation (γ_2) that would facilitate the debate on what appropriate levels should be and foster transparency in the process. Whatever the method, before analysts can calculate MSY and associated parameters, management needs to define their desired mix of fishing and what "to the extent practicable" means.

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Table 1. Models and parameters used in population simulation.

Recruitment:	$R = \alpha\,(SS)/(1 + \beta\,SS) = N_{Age=½}$	$\beta = ((R_2 / SS_2) - (R_1 / SS_1)) / (R_1 - R_2)$ $\alpha = R_1\,(1 + \beta\,SS_1) / SS_1$ R_1=0.7 SS_1=800 R_2=1 SS_2=2000
Length at Age:	$L_{Age} = 10^3\,\{1 - e^{-0.2\,[(Age) + 1]}\}$	
Weight at Age:	$W_{Age} = 10^{-6}\,L_{Age}^{3}$	
Fecundity at Age:	$Fec_{Age} = 10^{-15}\,L_{Age}^{6}\,Mature_{Age}$	
Number at Age:	$N_{Age+1} = N_{Age}\,e^{-Z_{Age}}$	$Z_{Age} = D_{dby}\,S_{dby,Age} + F_{tar}\,S_{tar,Age} + M_{Age}$ $F_{Age} = F_{tar}\,S_{tar,Age}$
Yield at Age:	$Y_{Age} = ½\,C_{Age}\,[W_{Age} + W_{Age+1}]$	$C_{Age} = F_{Age}\,N_{Age}\,\{1 - e^{-ZAge}\}/\,Z_{Age}$
Yield:	$Y = \Sigma_{Age}\,[Y_{Age}]$	
Spawning Stock:	$SS = \Sigma_{Age}\,[Fec_{Age}\,N_{Age}]$	
Spawning Potential Ratio (when F=x):	$SPR_{F=x} = (SS\|\,F= x, R) / (SS\|\,F=0, R)$	

Age	Bycatch selectivity ($S_{dby,Age}$)	Target selectivity ($S_{tar,Age}$)	M_{Age}	$Mature_{Age}$
½ - 1	0.4	0.0	0.5	0.0
1-2	1.0	0.0	0.3	0.1
2-3	0.0	0.2	0.1	0.5
3-4	0.0	0.4	0.1	1.0
4-5	0.0	1.0	0.1	1.0
5-6	0.0	0.8	0.1	1.0
6-7	0.0	0.6	0.1	1.0
7-8	0.0	0.4	0.1	1.0
8-9	0.0	0.2	0.1	1.0
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50-51	0.0	0.2	0.1	1.0

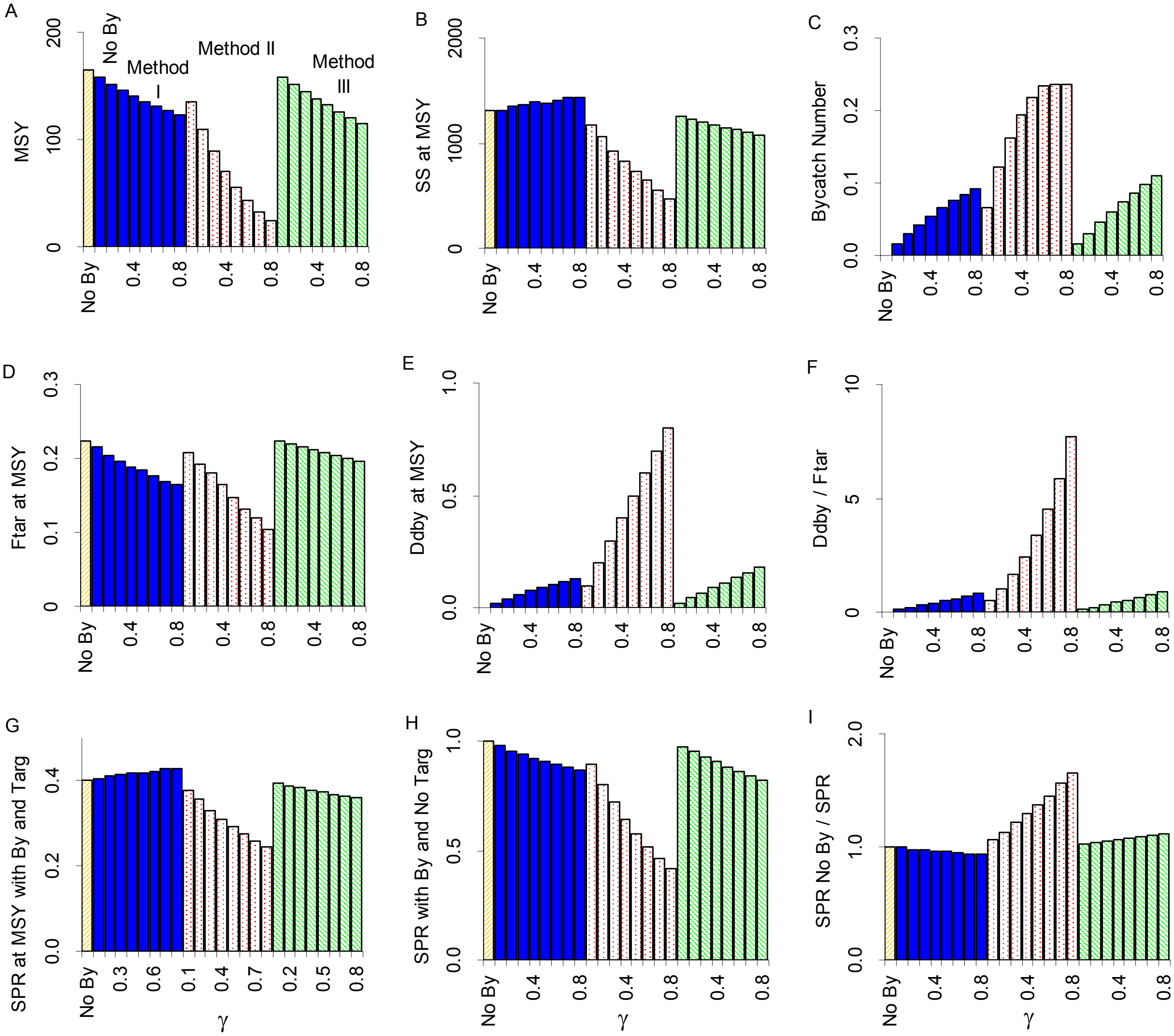

Figure 1. MSY (A), spawning stock at MSY (SS at MSY, B), bycatch (C), target fishing mortality rate at MSY (F_{tar} at MSY, D), bycatch discard mortality rate at MSY (D_{dby} at MSY, E), and fishing mortality rate ratio (F_{tar} at MSY relative to D_{dby} at MSY, F). Methods I, II and III refer to the method of computing MSY (see text); γ refers to the rate of bycatch mortality (from 0.1 to 0.8 from left to right) as defined in the text for each Method). "No By" refers to results when there is no bycatch discard mortality; it is used for comparison. Also, SPRs at MSY (G), SPR at MSY when there is no target fishing (only bycatch, H) and the ratio of SPR at MSY when there is only target fishing relative to when there is both target fishing and bycatch (I) are given.