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Review of Biological Reference Points with Specific Recommendations for North Pacific Billfishes

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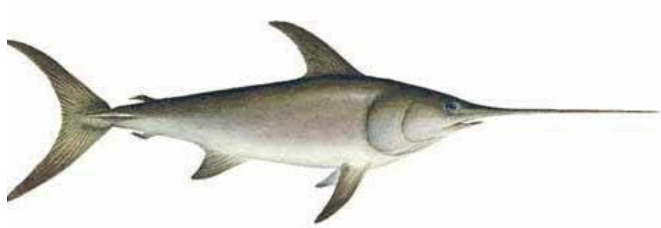

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Introduction

Overview

Biological Reference Points (BRP) are simple metrics used to assess the relative health of fish stocks and the relative intensity of fishing. Management bodies use the estimates of current stock conditions measured against BRP to determine if fishing mortality (F) or catch can be increased or should be decreased in the coming years. Almost as importantly, BRP's are also used to convey to wider audiences the broader questions of the health and sustainability of the fisheries as a whole.

The Northern Committee (NC) of the Western-Central Pacific Fisheries Commission in their September 2009 Nagasaki meeting tasked the International Scientific Committee with defining BRP for stocks under its jurisdiction. Thus each Working Group of the ISC is compiling a list of BRP's for consideration and making recommendations on the suitability of the BPR for use.

Purpose

The purpose of this paper is to introduce concepts and definitions of various BPR's to help guide the decisions on appropriate metrics for billfish. We describe relative characteristics of BRP's that are important for categorizing the wide array of BRP's available to the working group. We describe BRP's currently calculated by the various working groups of the ISC and to provide guidance on their suitability for billfish based upon the characteristics described.

Characteristics of reference points

Rate vs Status

BRP's fall into two classes depending on what they are to be measured against. BRPs that measure the intensity of fishing (Rate) are sometimes referred to as overfishing reference points and those that measure stock status (Status) as overfished reference points. Rate measurements are the quantity that management strategies can actually manipulate. Status measurements are the resulting biological reaction to management/environment and as such the most direct measurement of stock health. For clarification the Kobe diagram (Figure 1) displays this relationship between Rate and Status.

Recruitment or growth

BRP's can loosely be grouped based upon what process they reference. The first group can be considered recruitment or productivity type reference point as exceeding those results in potential diminishment of future recruits. These can be either direct measurement of spawner recruit relationships (eg. F_{MED}, F_{τ}) or indirect and usually based on analogy (e.g. FSPR).The second type of reference points refer to measures of yield or growth overfishing as exceeding them results in loss of yield due to non-optimal harvesting practices (e.g. F_{MAX}). Some BRP's (e.g. MSY) incorporate both processes into a single value.

Target vs Limit

Both Rate and Status BRP's are further subdivided into Limit and Target reference points. Limit BRPs are generally classified as levels not to be exceeded. Targets in contrast are those levels that on average management measures attempt to attain. Thus in practice we generally expect that fishing intensity or stock levels will fluctuate around the Target BRP with roughly 50% of the years on either side. Limits are usually associated with some probability of recruitment failure. Targets are associated with ideas of Optimum Yield that considers other factors such as ecosystem, economics, sociology and potentially even management uncertainty. Because the cost of exceeding the Limit BRP's is an unacceptable risk of recruitment failure, Target BRP is always set less than or equal to the Limit BRP (Figure 1). Although not covered here, a control rule is often used to adjust the Target F (or catch) based upon some relationship between the Limit and Target Overfished BRP (Figure 2). These control rules are used to insure that unforeseen circumstances do not result in stocks falling below the Limit Status BRP. As a similar idea, Garcia (1995) described a third BRP point termed a "threshold" which is essentially an early warning of potential problems. As such the relationship among Target, Limit and Threshold F would be Target$<$Threshold$<$Limit. However, defining a Threshold BRP and establishing a control rule was not tasked to the Billfish WG and is not covered in the rest of this paper.

Relationship to Assessment model

The types of reference points available for calculation depends upon the assessment models used. Assessment models are based on the types of data (eg catch, life history, indices of abundance, composition) used in recreating the stock dynamics. In regard to the Billfish WG we will need to consider only biomass dynamic (surplus production) and statistical catch at age models (e.g. Stock Synthesis, Multifan CL and VPA) as these are the only ones currently used to provide management advice (Table 1). For the purpose of this paper the difference between the two models is that the age structure of the population is estimated using catch at age type models and not in the simplified biomass dynamics. Thus while the statistical catch at age modeling provides a more comprehensive recreation of the dynamics, it also requires more information. Choice of modeling approach should not be driven by BPR's estimated, but the choices of BRP's may be driven by models used.

Candidate Reference Points

All reference points are listed in Table 2 along with the characteristics assigned above.

Rate BRP

F_{MSY} –The fishing mortality rate that on average produces the maximum sustainable yield. When based on estimates from age structured models (with S/R relationship) it is heavily reliant on the shape of the Spawner/Recruit relationship. If this shape is not well determined proxies for MSY are sometimes used. This BPR and age structured models can account for time varying life history parameters and changes in fishery practices (eg. selectivity pattern). MSY type reference points incorporate both recruitment and growth aspects. It is an appropriate BRP for both age structured and biomass dynamic assessments.

$F_{\%SPR}$- The fishing mortality that produces a defined percentage (X) of the unfished spawning biomass per recruit (SPR). Because this is now a per recruit calculation the S/R curve is not needed. SPR ratios from 10%-50% are used depending primarily on an assumption about the productivity of the stock. In addition, measures such as eggs per gram (and others) can be included to incorporate maternal effects on productivity. F_{SPR} is a proxy type BRP (generally of MSY) and can be thought of as indirect productivity/recruitment type of reference point. This method accounts for time varying life history parameters and changes in fishery practices (eg. selectivity pattern). This BRP is only appropriate for age structured assessments. Mace and Sissenwine (1993) recommended $F_{20\%}$ as a Limit BRP for stocks with average resilience and $F_{30\%}$ for stocks with unknown resilience.

F_{MED}- The fishing mortality corresponding to the median S/R ratio in the relationship of S/R against F over a period of time (preferably a relatively long period that includes low estimates at low spawning biomass). Because this BRP implicitly assumes a S/R relation (diminishment of absolute recruitment with loss of parental stock at low stock sizes), it is not appropriate in assessments with steepness of the Beverton and Holt S/R relationship assumed to be 1 or if the observed recruits is based on a narrow range of SSB. F_{MED} may be close to $F\tau$, F_{MSY} or 0 (Gabriel and Mace 1999) and thus does not always provide a robust BRP depending on the range of SSB used in the calculation. This method accounts for time varying life history parameters and changes in fishery practices (eg. selectivity pattern). Explicitly this is a recruitment overfishing BRP and is only appropriate for age structured assessments. It should be noted that values other than the median can be calculated (eg. $F_{90\%}$, $F_{10\%}$) for either a more precautionary or risk tolerant reference point. ($F\tau$ is special case of this family of BRPs see below)

$F\tau$- The fishing mortality based on the slope at the origin of the S/R curve that results in extinction. By definition this is THE recruitment BRP and can only be interpreted as a Limit. Only applies to age structured models.

F_{MAX}- The fishing mortality that produces the maximum yield per recruit. F_{MAX} can be difficult to estimate when the yield curve is flat topped (asymptotical). Fishing beyond F_{MAX} is generally interpreted as growth overfishing as there is no direct connection to recruitment or recruitment failure. This BRP is only appropriate for age structured assessments.

$F_{0.1}$ - The fishing mortality corresponding to $1/10^{th}$ the slope of the Y/R curve at the origin. Because the slope of the Y/R curve is =0 at F_{MAX}, $F_{0.1}$ is always a more conservative measure. $F_{0.1}$ does not suffer from the same difficulty of estimation as F_{MAX} when the yield curve is flat. Fishing beyond $F_{0.1}$ is generally interpreted as growth overfishing as there is no direct connection to recruitment or recruitment failure. This BRP is only appropriate for age structured assessments.

$F_{SSB\text{-}ATHL}$- A simulation based BRP based on a fishing mortality rate in which the probability of SSB falling below the average of the 10 lowest observed SSB levels in at least one year during a 25-yr projection period is 50%. This is the accepted BRP of the albacore WG (Uosaki and Kiyofuji 2004; Conser et al. 2005; Conser et al 2006a and Conser et al. 2006b), and is considered a Limit BRP by the WG. A different selection of observed SSB levels could be used and qualify as a Target. This approach could be used with both biomass dynamic and age structured assessments.

Status BRP

B_{MSY} –The average biomass (or spawning biomass) resulting from fishing at F_{MSY} in equilibrium conditions. When based on estimates from age structured models (with S/R relationship) it is heavily reliant on the shape of the Spawner/Recruit relationship. If this shape is not well determined proxies for MSY are sometimes used. This method accounts for time varying life history parameters and changes in fishery practices (eg. selectivity pattern). MSY type reference points incorporate both recruitment and growth aspects. It is an appropriate BRP for both age structured and biomass dynamic assessments.

B_{MAX} -The biomass (or spawning biomass) produced when $F=F_{MAX}$ in equilibrium conditions. F_{MAX} can be difficult to estimate when the yield curve is flat topped (asymptotical). Because this is a yield concept there is no direct connection to recruitment or recruitment failure. This BRP is only appropriate for age structured assessments.

$B_{0.1}$ The biomass (or spawning biomass) produced when $F=F_{0.1}$ in equilibrium conditions. Although more conservative than B_{MAX} there is no direct connection to recruitment or recruitment failure. This BRP is only appropriate for age structured assessments.

$B_{X\%}$- A percentage (X) of unfished biomass (or spawning biomass) and is usually referred to as a measure of depletion. This BRP is generally interpreted as a proxy of B_{MSY}. The percentage is usually chosen by analogy to other stocks or based upon life history type analysis (see Clark) and this can include potential stock recruit relationships. Therefore it can be a recruitment type reference point. $B_{X\%}$ can be calculated for both age structured and biomass dynamic models. For stocks with average or better resilience, B20% may be an appropriate limit (Mace and Sissenwine 1993 and Mace 1994).

$B_{\%OBS}$- Calculated as some percentile of the observed biomass (or spawning biomass) timeseries from the assessment. Usually some period of years are chosen to represent a time when the stock was able to generate enough recruits to sustain both the population and the fishery. Any percentile can be chosen, with 10-25th percentile common as Limits. Caution should be exercised as incorporating new years into the calculation as a stock decline can create a negative feedback loop. A variation of this is used in the Albacore WG with the limit corresponding to the average of the 10 lowest observed spawning biomasses (SSB-ATHL). However a different range of observed spawning biomasses could be used as a Target.

Discussion and Recommendations

Billfish resilience

Implicit in deciding upon BRPs is the inherent productivity of the species as measured by such things as the shape of the S/R curve, natural mortality and growth (Mace 1994). Although relatively little is known about the life history of many billfish species, it appears that billfish are at least as resilient as the average family of exploited fish stocks (Myers et al. 1999). My recommendations in this discussion are based on that premise.

Precautionary Approach

No discussion of reference points is complete without introducing the idea of the “Precautionary approach” (Garcia 1995; Gabriel and Mace 1999). It is clear that at its core the Precautionary Approach intends to set guidelines to insure that exploited fish stocks are not at risk due to either excessive fishing rates or stock sizes reaching unsustainable levels. Recommendations in this paper are consistent with this concept by defining Limit BRP’s which if exceeded imparts unacceptable risk to the stock. More conservative Target BRP’s are set as the goal and include an acceptable level of stock risk.

Limit BRP’s are by definition not to be exceeded due to excessive risk to the stock. Here I define stock risk as the inability of the stock to perpetuate itself under that fishing intensity or at that biomass level. Thus by definition this is a recruitment based idea and the Limit BRP should be taken from a candidate that explicitly includes ideas of stock productivity/recruitment. It is my belief that the working group should focus first and foremost on setting appropriate Limit BRPs because they are the most important references. Pamela Mace (2001) argues that Limit BRPs are taken more seriously because exceeding them entails risks that are more easily understood, while targets are often defined as levels that will be exceeded (either catch or F) 50% of the time. Thus it is the cumulative impacts of consistently violating the targets that are important and therefore the yearly violations are less easily understood.

Recommending F_{MSY} as Limit Rate BRP

I suggest that F_{MSY} be the default Limit Rate BRP for the Billfish WG. The FAO (1995) defined Limit BRP's as "… boundaries to constrain harvesting within safe biological limits within which the stocks can produce MSY...". Furthermore it goes on to say "..the F that generates MSY should be regarded as a minimum standard for limit reference points…". To this end many of the Regional Fisheries Management Organizations (RFMO) use F_{MSY} as their default rate BRPs for the purposes of management or reporting (Gabriel and Mace 1999). Calculation of MSY includes concepts of both yield and recruitment and thus satisfies the need for Limit BRP's to conceptualize recruitment failure. Other reference points such as F_{MED} may also be applicable depending on the S/R assumptions and the relative range of spawning stock observed. Indeed a range of BRP's should still be calculated to insure that F_{MSY} is not well in excess of other similar methods. MSY based BRP's are also available to both the biomass dynamic as well as the age structured assessments standardizing reporting in a multi-species WG. A single reporting metric facilitates the reporting of assessment results to the ISC Plenary, NC, WCPFC and the public.

MSY has often been criticized (Larkin 1977) due to difficulty in estimation and ineffectiveness in curtailing some stock collapses (Punt and Smith 2001). However the effectiveness of MSY in practice has been severely limited by the use of constant catch management practices and the use of MSY as targets. Applying constant F rather than constant catch (although a quota in catch can be estimated from the F) and using F_{MSY} as a Limit BRP alleviates much of those concerns. It has been shown in deterministic analyses that $F_{MSY} < 0.5F\tau$ (the fishing mortality that causes extinction) across a wide range of S/R shapes (Mace 1994). In practice, the use of MSY based BRP's is primarily limited by our inability to estimate the curvature of the S/R function (Conn et al. 2010). This is a problem only for catch at age assessments. Recent life history based methods (Mangel et al. 2009) give us another method of specifying steepness based on lifehistory traits. However proxies for MSY may be necessary if the curvature of the S/R curve is deemed inestimable. I suggest $F_{20\%SPR}$ as the proxy for F_{MSY}. However, we should keep in mind that proxies are also built on imperfect estimates of other life history traits (natural mortality, growth).

Recommending ½ BMSY as Limit Status BRP

F_{MSY} may be appropriate as the Limit Rate BRP, however B_{MSY} may be more of a Target Status BRP. Due to natural fluctuations in populations we can expect that population size to change even with fishing rates below the Limit BRP. Management measure can directly control F or catch, but only indirectly control population sizes. Therefore it is common to set Status Limit BRP's at levels below those associated with the Limit rate BRP. US fisheries equate ½ B_{MSY} as the Status Limit BRP associated with the Rate Limit BRP of F_{MSY}. Another common proxy for stocks with at least above average resilience is $B_{20\%depletion}$ (Francis and Shotton 1997).

What about Targets?

Targets BRP's are more difficult to set because there are more considerations beyond recruitment failure. Thus setting of Targets will likely entail direct interactions from the NC and WCPFC. However I offer these topics as points of discussion.

a. Appropriate risk

Fishing by nature will always impart some addition risk to a stock beyond those of the environment. Limit BRP's, given our knowledge of the systems, are set at levels to be avoided because exceeding them has an unsatisfactory risk. Targets are by definition set at less risky levels but what level of risk is acceptable? Although this question is perhaps the most important it is also not totally a scientific issue and can only be fully addressed at the policy level.

b. Scientific uncertainty

Target fishing rates should consider the scientific uncertainty in both the stock assessment and the estimate of Limit BRP's. Targets should be set with enough precaution to insure that uncertainty in estimation does not unknowingly lead to fishing intensity that exceeds the Limit BRPs and to account for the possibility that estimates of the BRP's are themselves in error. Estimates of parameter uncertainty (e.g normal approximation, MCMC, bootstrapping) may provide some guidance. In addition to the parameter uncertainty the quality of the stock assessment should be considered. Quality of the assessment would include the different kinds of data and realism included in the model in addition to the parameter uncertainly of the final estimates. Inclusion of more data does not always result in smaller parameter uncertainty, but the higher variance may reflect a more realistic assessment of the uncertainty. Thus it may be easy to agree that assessments based on strong science (realism and small parameter variance) should have Targets set closer to Limits than weaker science (limited data and high variance). However in cases of realism with large parameter variance or limited data with small parameter variance the issues become much less straightforward.

c. Management Uncertainty

Targets may also need to account for management uncertainty. Without control rules Target BRP's may need to include precautionary adjustments that account for either incomplete management (lack of timely reporting of catch/effort) or lack of enforcement. However, in my opinion the WG may not be equipped to deal with this issue alone and will need interaction from the NC to fully discuss this issue.

d. Optimum yield

Targets may be set to maximize return to components or sectors of the fishery within the constraints of a precautionary approach. However it has been shown that the concept of Pretty Good Yield (Hilborn 2009) can occur over a wide range of relative stock sizes (depletion levels 10-50%) and given natural variability of all systems that this thinking may be more realistic than "optimizing" for some hypothetical. Addition factors beyond yield may also be important and could include economics, social or even safety. In my opinion the WG is not equipped to deal with this issue and this should be left to the NC.

Summary of Recommendations

1. WG should focus on setting Limit BRPs.
2. F_{MSY} should be the default Limit Rate BRP until a more appropriate BRP is shown on a species by species basis. $F_{20\%SPR}$ is likely a good proxy for F_{MSY} if the curvature of the S/R relationship is unknown.
3. The default Limit Status BRP should be ½ B_{MSY} again subject to new work for individual species. If proxies are used instead of MSY then the Limit Status BRP $B_{20\%}$ of virgin. We should note that fishing at $F_{20\%SPR}$ may result in an equilibrium biomass less than 20% of virgin if there is some curvature of the S/R relation.
4. Final Target BRPs may require more interaction from the management body (NC, WCPFC), thus we can only inform the NC of appropriate adjustments from the Limt BRP's made on the basis of scientific uncertainty (variance estimates and data available).

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Table 1. Billfish stocks assessed and the type of assessment used to determine stock status. BD is a biomass dynamic model and AS is an age structured model.

Species	Stock	Approach	Reference
White Marlin	Atlantic	BD	ICCAT (2000)
Sailfish	East Atlantic	BD	ICCAT (2000)
	West Atlantic	BD	ICCAT (2000)
Blue Marlin	Atlantic	BD	ICCAT (2001)
	Atlantic	BD	ICCAT (2002)
Blue Marlin	Indian	BD	Yoshida (1981); Weatherall et al. (1979)
	Pacific	BD	Hinton and Uozumi (2001)
	Pacific	AS	Kleiber et al. (2003)
Striped Marlin	N. Pacific	BD	Uozumi (1999)
	NE Pacific	BD	Hinton et al. (2003)
	SE Pacific	BD	Suzuki (1989)
	NPO	AS	ISC (2006)
	Indian	BD	Honma and Ueyanagi (1979)
Swordfish	NPO	BD	ISC (2009)

Table 2. Biological reference points from ISC working groups. Each BRP is referenced against the criteria discussed in this paper.

BRP	Target or limit	Recruitment /productivity Based	age structure needed	reference
		RATE		
F_{MSY}	Limit	Yes	No	Russel 1931; Hjort et al. 1933; and Graham 1935
F_{SPR}	Either	Yes	Yes	Mace and Sissenwine (1993); Mace (1994)
F_{MED}	Limit	Yes	Yes	Mace and Sissenwine (1993); Mace (1994)
F_{τ}	Limit	Yes	Yes	Mace and Sissenwine (1993); Mace (1994)
F_{MAX}	Either	No	Yes	Beverton and Holt 1957
$F_{0.1}$	Either	No	Yes	Beverton and Holt 1957
$F_{SSB\text{-}ATHL}$	Either	Yes	No	Conser et al. 2006
		STATUS		
B_{MSY}	Target	Yes	No	Russel 1931; Hjort et al. 1933; and Graham 1935
B_{MAX}	Either	No	yes	Beverton and Holt 1957
$B_{0.1}$	Either	No	yes	Beverton and Holt 1957
$B_{X\%}$ (depletion)	Either	Yes	No	
B_{OBS}	Either	Yes	No	Conser et al. 2006

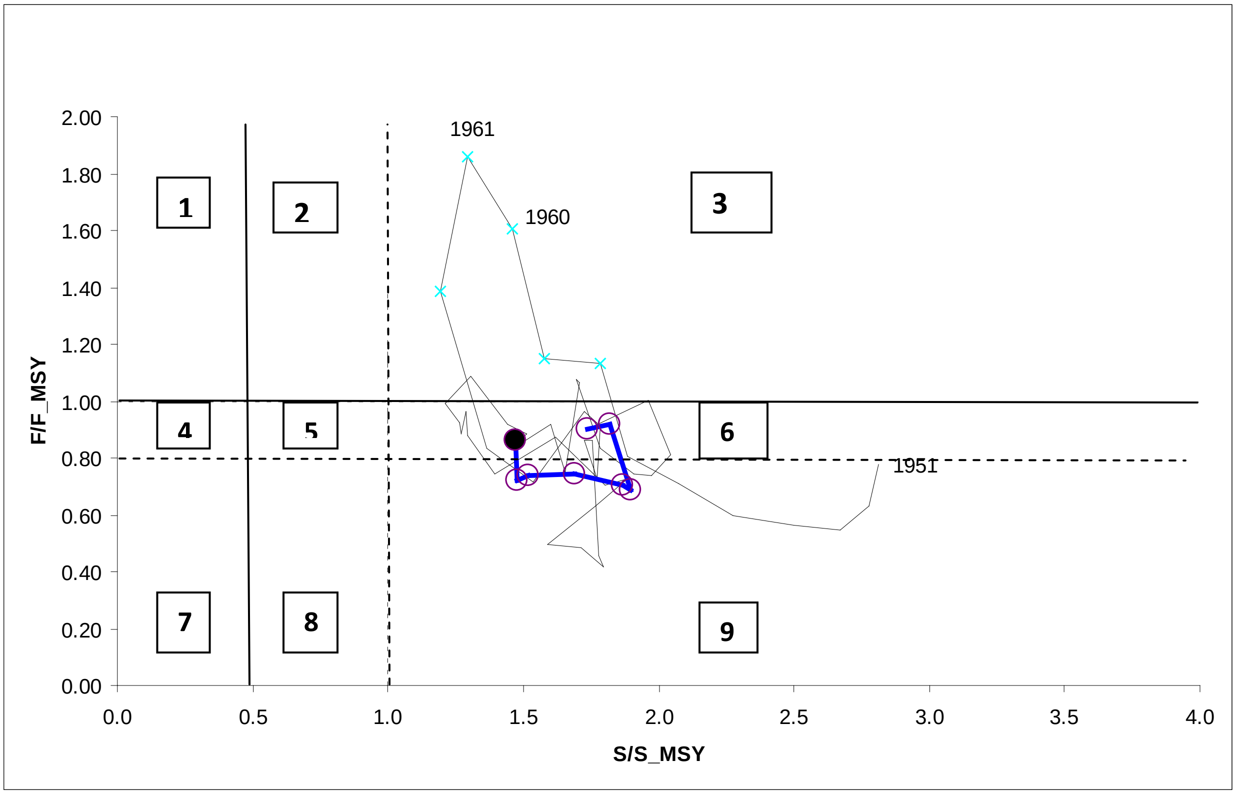

Figure1. Example of typical Kobe plot depicting Target and Limit as well as Status and Rate BRP's (taken from Courtney and Piner 2009). Solid (▬) lines indicate the relative location of the Limit Status (horizontal axis) and Rate (vertical axis) BRP's. Hypothetical location of Target BRP's are given by dotted (---) lines. The current stock Rate and Status is denoted by (●). The different zones corresponding to potential locations of a fish population relative the Limit and Target BRP's are denoted by numbers 1-9. Zones are defined as follows:

1= the stock is overfished and experiencing overfishing.
2 = the stock is in a precautionary Status (above Limit but below Target Status) and experiencing overfishing.
3= the stock is in good status but experiencing overfishing
4=the stock is overfished but experiencing precautionary fishing rate (below Limit but above Target Rate).
5= the stock is in a precautionary Status and experiencing precautionary fishing rate.
6= the stock is in good status but experiencing precautionary fishing rate.
7= the stock is overfished but fished at good rate.
8= the stock is in a precautionary Status but fished at good rate.
9= the stock is in good status and fished at good rate.

Thus in this example the current stock (●) is in good shape but fully exploited.

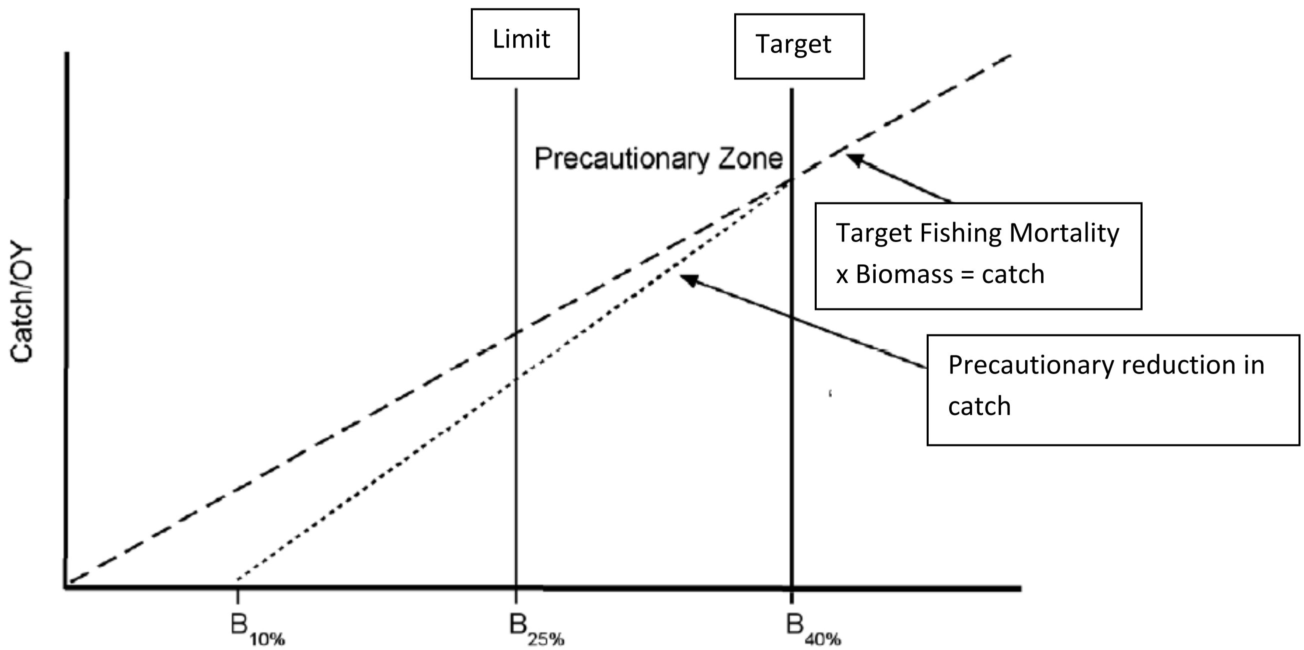

Figure 2. Demonstration of typical control rule linked to stock Status (expressed as biomass/unfished biomass) as used by the US Pacific Council management of groundfishes. The Limit Status BRP is $B_{25\%}$ and the Target Status BRP is $B_{40\%}$. When the stock biomass is above the Target catch is denoted by the dashed line (----). As the stock falls below the Target level catch is reduced to the level corresponding to the dotted line (……). This is a precautionary reduction in catch that effectively reduces Fishing Mortality as the stock falls below the target biomass. In this case catch would hypothetically go to zero if the stock is reduced to 10% of the unfished biomass.