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Reference Points

Measuring success in fisheries management

Overview

Fisheries managers are responsible for ensuring the health of both fisheries and fish populations. How is health defined, and how can success be measured? Through biological reference points, such as the biomass needed to provide maximum sustainable yield (B_{MSY}). Scientists have used reference points for over 50 years to evaluate stock status and now are applying them more broadly; in fact, reference points are emerging as one of the most widespread and effective bases for modern fisheries management.

Setting reference points is a critical step in the development of harvest strategies, because reference points are closely tied to several other strategy components. Reference points are the benchmarks that scientists and managers use to compare the current status of a stock or fishery to a desirable (or undesirable) state, and hence help to determine the success of the harvest strategy. For fisheries with clear management objectives, reference points can be used to assess progress toward meeting those objectives. In some cases, the reference points are set at the beginning of the harvest strategy process, functioning as de facto management objectives.

Managers should choose reference points based on scientific advice, which ideally should be informed by management strategy evaluation (MSE) analyses that assess how well the candidate reference points are likely to perform in the context of the broader harvest strategy. Reference points might not reflect the full suite of trade-offs encompassed within a fishery's management objectives but can be used to guide development of the harvest control rule (HCR)—the harvest strategy's operational component—by providing concrete anchor points for the HCR's management action.

Limit, target, and trigger reference points

In fisheries management, there are three main types of reference points: limit reference points (LRPs, or B_{lim} and F_{lim}), target reference points (TRPs, or B_{TARGET} and F_{TARGET}), and trigger reference points.

Limit reference points should define the danger zone, the point beyond which fishing is no longer considered sustainable. In a well-managed fishery, managers avoid this zone with a very high degree of certainty and, if it is inadvertently violated, take immediate action to return the stock or fishing pressure to the target level. Importantly, LRPs should be based exclusively on the biology of the stock and its resilience to fishing pressure. LRPs should not consider economic factors because the LRP defines the point that the stock should never hit due to threat from a biological perspective. For example, limit reference points can be set to avoid recruitment overfishing, the undesirable state in which adults of a species are so overfished that they cannot reproduce fast enough to replenish the stock.

Target reference points define the ideal fishery state. In a well-managed fishery, management measures should therefore be designed to consistently achieve this state with a high degree of certainty. Given all of the unknowns and uncertainty in stock assessments, and in fisheries management in general, one of the benefits of the TRP is that it can create a sufficient buffer zone to help managers ensure that the limit reference point is not breached. The fishery is likely to fluctuate around the target due to natural variability and uncertainty but should not systematically deviate from it (e.g., consistently be below a biomass target or above a fishing mortality target).[1] Unlike in setting a limit reference point, managers and scientists can base the TRP on one or more ecological, social, economic, and/or biological considerations.

Some fisheries also have trigger reference points, which are typically set between the TRP and LRP to prompt additional management response in order to help ensure that the fishery remains close to the target or avoids breaching the limit. It is increasingly common for fisheries managers to formally adopt HCRs that specify a trigger reference point and the resulting management action. Some rules adjust the catch limit in relation to the estimated current stock status and, in effect, give a continuous set of trigger reference points and adjustments. For example, a harvest control rule might continuously decrease allowable fishing mortality as stock status departs from the TRP and moves toward the LRP. However, sometimes the LRP and TRP serve as the only triggers for management action.

Importantly, as uncertainty increases, both target and limit reference points should be set more conservatively. If there is high uncertainty or a less comprehensive monitoring program, the TRP should also be set further from the LRP to create a larger buffer and to reduce the risk of breaching the limit.

Choosing candidate reference points: MSY and beyond

Generally, TRPs and LRPs are divided into two categories: fishing mortality-based (F-based) and biomass-based (B-based). For many decades, reference points have most often been tied to maximum sustainable yield (MSY), defined as the largest average catch that can be taken continuously from a stock under existing environmental conditions. There are two related reference points: F_{MSY} is the fishing mortality rate that eventually results in the largest yield on average (MSY); B_{MSY} is the corresponding average stock size.

One key question that managers face is whether to use F-based and/or B-based reference points when setting targets and limits. Oftentimes, the answer is to use both, because F can be directly managed while B is the critical point to control from an ecological perspective.[2] B-based reference points are also often easier for managers and stakeholders to understand, because biomass is usually expressed as an absolute number that relates physically to the quantity of fish in the water, whereas F is a mortality *rate* that is intangible and cannot be directly observed.

Although MSY is an appropriate basis for reference points in many cases, there are situations in which MSY should not be used, either because it cannot be robustly estimated or because the management objective is unrelated to MSY. In those cases, many other candidate reference points exist to choose from, each with their own strengths and weaknesses. (See Table 1.) Most reference points are calculated from the results of stock assessments, but it is also possible to set empirical, or data-based, reference points that can be directly measured; for example, those related to catch per unit effort (CPUE).

Guidelines for developing and using target and limit reference points are outlined in the United Nations Fish Stocks Agreement (UNFSA) and the Food and Agriculture Organization Code of Conduct for Responsible Fisheries. (See below.) The Marine Stewardship Council also calls on fisheries to be managed with target and limit reference points in order to be certified as sustainable. That guidance can help fisheries choose among the many candidate reference points.

Key Reference Point Principles in the U.N. Fish Stocks Agreement

- LRPs "constrain catches within safe biological limits"; risk of breaching LRP should be "very low"; "if a stock falls below LRP or is at risk of falling below such a reference point, conservation and management action should be initiated to facilitate stock recovery."
- Design management so that TRPs are achieved "on average."
- "Fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points."

MSY: Target or limit?

The concept of maximum sustainable yield originated in the 1930s and became mainstream in fisheries in the 1950s. However, the downsides of MSY-based management manifested within just a couple of decades when it became clear that managing for MSY often leads to unsustainable fisheries and suboptimal economics.[3] As fisheries expert Ray Hilborn wrote in a 2007 study, "The traditional fisheries management objectives of maximizing yield and employment lead to heavily exploited stocks."[4]

By definition, MSY is an average, which is to say there is a 50 percent chance of violating it in any given year. This 50 percent failure potential applies to both B_{MSY} and F_{MSY}. That is, fishing at F_{MSY} only gives a coin flip's chance of being at or above B_{MSY} and is therefore known to lead to fluctuations around B_{MSY} that can be unsustainable.[5] The stock depletion that results can lead to an irreversible loss of genetic diversity and to lower reproductive success as older, more productive individuals are fished out under the structure of traditional fisheries management.[6]

This begs the question: If reference points are based on MSY (or MSY proxies), should the MSY levels be the target or the limit?

Some fisheries experts advocate for MSY-based limits, not targets, at least for fishing mortality, based on the precautionary approach, the UNFSA, and other international agreements.[7] This position is supported by evidence that some fisheries managed for MSY as a target are economically suboptimal and by assertions, such as by Andre Punt and Anthony Smith in 2001, that the only reason MSY has not been "abandoned" in the fisheries management toolbox is that it has changed from a management target to an "upper limit."[8]

Table 1[9]

Review of Commonly Used Reference Points

Reference point	Description	Pros	Cons	Suitability as a target and/or limit
$X\%*B_{MSY}$, $X\%*SSB_{MSY}$	Biomass, or spawning stock biomass (SSB),[a] that is needed to sustain X%*MSY.	Considers both recruitment overfishing[b] and growth overfishing.[c]	Difficult to estimate, cannot manage all stocks in multistock fisheries exactly to MSY; sensitive to uncertainty about recruitment and selectivity.[d]	Limit: B_{MSY} Target: 125-130% B_{MSY}[e] 120% B_{MSY}[f] or Limit: X% B_{MSY} Target: B_{MSY}[g]
$X\%F_{MSY}$	Fishing mortality rate that results in B_{MSY} on average.	Considers both recruitment overfishing and growth overfishing.	Difficult to estimate. Sensitive to recruitment variability and other structural assumptions used in the assessment.	Limit: F_{MSY}[h] Target: 75% F_{MSY}[i]
$F_{0.1}$	Fishing mortality rate corresponding to 10% of the slope of the yield per recruit curve as a function of F when F=0. In other words, the F at which the marginal increase in equilibrium yield has dropped to one-tenth of its value when the stock was first exploited. See Figure 1.	Used as a reference point for growth overfishing; can be calculated with estimate of growth, fishery selectivity, and natural mortality; does not require knowledge of a stock-recruit relationship; possible to estimate even if the yield per recruit curve is flat at the top.	Can be above F_{MSY} so can lead to an undesirably high extent of stock depletion; does not consider recruitment overfishing.	Limit[j] or Target[k]
F_{MAX}	Fishing mortality rate that produces the maximum yield per recruit.	Used as a reference point for growth overfishing; relatively easy to calculate; theoretically maximizes yield for given recruitment.	Does not account for stock-recruit relationship; always at or above F_{MSY} so may lead to an undesirably high extent of depletion; not appropriate to use if the yield per recruit curve is flat at the top as that leads to an infinite value.	Limit
$F_{X\%}$ or $F_{X\%SPR}$	Fishing mortality rate that allows the stock to attain X% of the maximum spawning potential (e.g., egg production, recruits, spawners) which would have been obtained with no fishing.	Used as a reference point for recruitment overfishing; doesn't need stock-recruit relationship or much historical data; can be used if there is reliable fishery and life history data, even if the stock-recruit relationship is unknown.	Does not account for the fact that average recruitment may decrease at lower biomasses; sensitive to changes in selectivity; does not consider optimal yield.	Limit: $F_{20\%}$[l] Target: $F_{40\%}$ ($F_{50\%}$ for lower productivity stocks)[m]
F_{MED}	Fishing mortality rate that can be supported by observed survival rates from spawning to recruitment in 50% of years.	Used as a reference point for recruitment overfishing; based on the historical time series of recruitment.	Does not consider growth overfishing; appropriateness dependent on the stock-recruitment relationship that applies in a particular case.	Target
$B_{X\%R0}$/$B_{X\%RMAX}$	Biomass which will produce X% of virgin/maximum recruitment.	Directly considers recruitment overfishing.	Dependent on estimates of current and historical recruitment.	Limit: $B_{50\%R0}$[n] $B_{75\%R0}$[o]

Reference point	Description	Pros	Cons	Suitability as a target and/or limit
$X\%B_0$ or $X\%SB_{current, F=0}$	X% of biomass of the stock before fishing began, or spawning biomass expected at the present time had there been an absence of fishing.	Can be used for data poor stocks; measures relative abundance in cases where absolute abundance is difficult to estimate.	Pristine biomass estimates depend on a number of assumptions and may be unreliable.	Limit: 20-30%B_0[p] Target: 40%B_0[q] 48%B_0[r] 50%B_0[s]
$F_{SSB-Min}$	F that prevents the SSB from declining below the minimum observed SSB.	Reference point for recruitment overfishing.	Risk-prone; sensitive to time period used in the calculation; does not consider growth overfishing.	Limit
F_{loss}/B_{loss}	F applied over a long time period that would cause the stock biomass to decline to the lowest level observed historically (i.e., B_{loss}).	Reference point for recruitment overfishing; relatively easy to calculate.	Risk-prone because it does not provide any cushion; does not consider growth overfishing; assumes good understanding of the stock-recruitment relationship.	Limit
F_{crash}	Lowest F that would eventually drive the stock to extinction.	Based directly on the stock-recruit relationship so can be easier to calculate.	Extremely risk-prone and, by definition, allows the stock to be on path to extinction.	Limit
Empirical reference point	Expressed in terms of something that can be measured—catch, CPUE, etc.	Can be easier to understand, cheaper to use, and often just as effective.[j]	Can have high rates of failure; hard to ensure it will deliver desired management outcome; challenging to use CPUE as reference point because it assumes constant catchability.	Both limits and targets
50%M	50% of the natural mortality rate.	Can be used in data-poor situations as a fishing mortality reference point.	Possibly too high for longer-lived species.	Limit

a SSB is typically used since it is a measure of reproductive capacity, and having sufficient reproductive capacity to maintain B_{MSY} and avoid recruitment overfishing is a common goal. Furthermore, recent recruitment, and thus total biomass, is difficult to estimate reliably.

b Recruitment overfishing occurs when the adult population is reduced to a level at which the average recruitment is notably lower than for higher abundances.

c Growth overfishing occurs when fish are harvested too young to maximize yield per recruit. It is much more common than recruitment overfishing but not as serious a threat to the stock as recruitment overfishing.

d Selectivity refers to the relative vulnerability of different age or size classes to different fishing gears and fisheries.

e USA National Standard 1 definition of optimum yield.

f As proxy for maximum economic yield (MEY). Nick Rayns, "The Australian Government's Harvest Strategy Policy," ICES Journal of Marine Science 64 (2007): 596-598, doi:10.1093/ icesjms/fsm032; and Pilling et al., *Consideration of Target Reference Points*.

g See, for example, Mark N. Maunder and Richard B. Deriso, Reference Points and Harvest Rate Control Rules (paper presented at Inter-American Tropical Tuna Commission, Scientific Advisory Committee Meeting, La Jolla, California, April 29 to May 3, 2013), http://www.iattc.org/Meetings/Meetings2013/MaySAC/Pdfs/SAC-04-09-Reference-points-and-harvest-control-rules.pdf.

h United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10

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December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks 34 ILM 1542 (1995), http://www.un.org/depts/los/convention_agreements/convention_overview_fish_stocks.htm.

i Restrepo et al., *Technical Guidance*.

j Sainsbury, *Best Practice Reference Points*

k Campbell Davies and Marinelle Basson, *Approaches for Identification of Appropriate Reference Points and Implementation of MSE Within the WCPO* (paper presented at Western and Central Pacific Fisheries *Commission, Scientific Committee, Regular* Session, Port Moresby, Papua New Guinea, Aug. 11-22, 2008), https://www.wcpfc.int/system/files/SC4-GN-WP10%20%5BReference%20Points%20and%20MSE%20Scoping%5D.pdf.

l $F_{20\%}$ as threshold for recruitment overfishing in stocks with at least average resilience; $F_{30\%}$ for less known or less resilient stocks. Pamela M. Mace and Michael P. Sissenwise, "How Much Spawning per Recruit is Enough?" in Risk Evaluation and Biological Reference Points for Fisheries Management, eds. Stephen J. Smith, Joseph J. Hunt, and Dennis Rivard (Ottawa: National Research Council Canada, 1993), http://www.dfo-mpo.gc.ca/Library/149989.pdf.

m $F_{50\%}$ would provide high sustainable yields (more than about 85% of MSY) and maintain biomass above about 25% of unfished biomass for most stocks, while $F_{40\%}$ would similarly be a reasonable target for stocks with a reproductive longevity greater than 5 years. Sainsbury, *Best Practice Reference Points*

n Maunder and Deriso, *Reference Points and Harvest Rate Control Rules.*

o L.T. Kell and J.M. Fromentin, "Evaluation of the Robustness of Maximum Sustainable Yield Based Management Strategies to Variations in Carrying Capacity or Migration of Atlantic Bluefin Tuna (*Thunnus thynnus), Canadian Journal of Fisheries and Aquatic* Sciences 64 (2007): 837–47, doi:10.1139/F07-051.

p X=30% for less productive stocks (and 20% for other stocks) (Sainsbury, *Best Practice Reference Points*) or X=30% for all stocks. Pilling et al., *Consideration of Target Reference Points*.

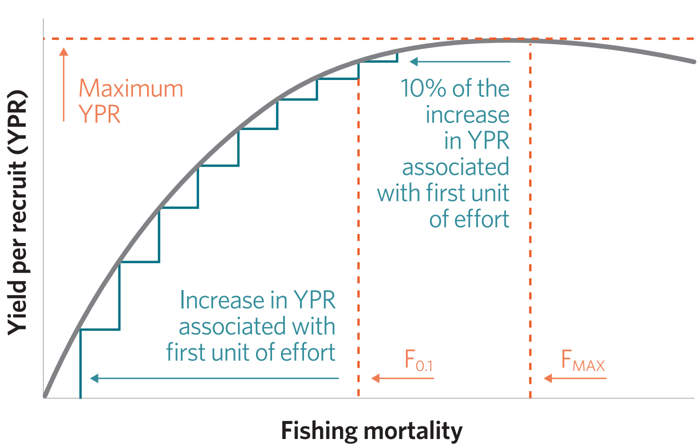
q As a proxy for MEY. Pilling et al., Consideration of Target Reference Points.

r William G. Clark, "F35% Revisited Ten Years Later," *North American Journal of Fisheries Management* 22 (2002): 251-257, doi: 10.1577/1548-8675(2002)022<0251:FRTYL>2.0.CO;2; and Graham M. Pilling et al., *Consideration of Target Reference Points for WCPO Stocks With an Emphasis on Skipjack Tuna* (paper presented at Western and Central Pacific Fisheries Commission, Scientific Committee, Eighth Regular Session, Busan, South Korea, Aug. 7-15, 2012), https://www.wcpfc.int/system/files/MI-WP-02-Target-ref-points-WCPO-Skipjack.pdf.

s Based on a Schaefer stock-production model. Keith J. Sainsbury, Andre E. Punt, and Anthony D.M. Smith, "Design of Operational Management Strategies for Achieving Fishery Ecosystem Objectives," ICES Journal of Marine Science 57 (2000): 731–41, http://dx.doi.org/10.1006/jmsc.2000.0737.

Figure 1

What is $F_{0.1}$?



Note: This reference point, based on yield per recruit, was developed as a more conservative alternative to F_{MAX}. This graphic is provided to further clarify the definition provided in Table 1.

Source: Andrew B. Cooper, *A Guide to Fisheries Stock Assessment: From Data to Recommendations*, New Hampshire Sea Grant College Program, University of New Hampshire (February 2006), https://seagrant.unh.edu/sites/seagrant.unh.edu/files/media/pdfs/stockassessmentguide.pdf.

There is also a growing body of evidence that managing for biomass above B_{MSY} leads to larger fish, similar catch levels, greater economic benefit, and lower adverse ecological impact, providing a compelling case for not breaching B_{MSY}.[10] For example, fishing at 0.75*F_{MSY} was found to result in higher stock size (125%-131% of B_{MSY}) at "the expense of relatively small forgone yields" (94% of MSY or higher).[11] Similarly, Hilborn in 2009 recommended trading MSY for "pretty good yield," defined as the range between 0.8*F_{MSY} and F_{MSY}, and adopting a biomass target of 50%*B_0, finding little expected loss of yield at these reference points.[12] Not only are these targets greater than B_{MSY} good for the stock, but they also help the fishery by reducing fishing costs and increasing stability.

That said, management objectives for many fisheries have traditionally focused on targeting MSY instead of establishing it as the limit. Supporters of continuing that approach argue that MSY-based LRPs are unreasonable given uncertainty in stock assessments and that F_{MSY} won't lead to serious or irreversible fishing impacts as implied by the definition of LRPs.[13]

Proxies for MSY

Many of the alternate reference points presented in Table 1 are comparable to MSY-based reference points, and are therefore sometimes used as MSY reference point proxies when MSY-based reference points are desired but cannot be confidently estimated.

As a proxy for B_{MSY}, fishery managers and scientists can use reference points based on unfished biomass (B_0), with recommended B_{MSY} proxies ranging from 30%[14] to 60% of B_0, with 40%*B_0 as the most common.[15] Scientists recommend the higher percentages for less resilient species.

As a proxy for F_{MSY}, managers and scientists often use reference points based on spawning potential. The recommended range is $F_{30\%}$-$F_{50\%}$, with even higher percentages for low-resilience species.[16] For stocks of average resilience, Wendy Gabriel and Pamela Mace[17] recommend $F_{40\%}$ while Keith Sainsbury[18] recommends $F_{50\%}$.

Other F_{MSY} proxies include $F_{0.1}$, half of the natural mortality rate (50%M), and F_{MAX}, though the latter often overestimates F_{MSY} so it can be risky. For example, $F_{0.1}$ is used by scientists at the International Commission for the Conservation of Atlantic Tunas (ICCAT) as the F_{MSY} proxy reference point for the eastern stock of Atlantic bluefin tuna. An analysis of candidate reference points for this stock found that $F_{0.1}$ was the best proxy for F_{MSY}, while $F_{40\%}$ was also robust.[19] $F_{30\%}$ and F_{MAX} were more biased and less precise, however, so were not deemed by the ICCAT scientists to be suitable proxies.

Conclusion

Selecting robust and risk-averse target and limit reference points is a critical step to ensure sustainable and profitable fisheries in the future. In essence, TRPs protect the economic status of the fishery, while LRPs protect the biological status of the stock. The result is that failure to achieve a TRP usually results in medium-term reductions in the flow of benefits to fishery participants and consumers, while the costs of breaching a LRP are much more serious, ranging from stock decline to collapse, ecosystem destabilization, and/or long-term profit loss (for example, via loss of fishery yield). This is why it is important to use MSE to help select a fishery's harvest strategy, ensuring that the reference points and associated harvest control rule are designed to best meet the fishery's management objectives, including the common requirement to avoid breaching the limit reference point(s).

Endnotes

1 Victor R. Restrepo et al., *Technical Guidance on the Use of Precautionary Approaches to Implementing National Standard 1 of the Magnuson-Stevens Fishery Conservation and Management Act*, NOAA Technical Memorandum NMFS-F/SPO-31, National Marine Fisheries Service (1998), http://www.nmfs.noaa.gov/sfa/NSGtkgd.pdf.

2 Keith Sainsbury, *Best Practice Reference Points for Australian Fisheries,* Australian Fisheries Management Authority (2008), http://www.afma.gov.au/wp-content/uploads/2010/06/R2001-0999.pdf.

3 Peter A. Larkin, "An Epitaph for the Concept of Maximum Sustainable Yield," *Transactions of the American Fisheries Society* 106 (1977): 1–11, doi: 10.1577/1548-8659(1977)106<1:AEFTCO>2.0.CO;2.

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6 Sainsbury, *Best Practice Reference Points.*

7 David J. Die and John F. Caddy, "Sustainable Yield Indicators From Biomass: Are There Appropriate Reference Points for Use in Tropical Fisheries?" *Fisheries Research* 32 (1997): 69–79, doi:10.1016/S0165-7836(97)00029-5; Wendy L. Gabriel and Pamela M. Mace, "A Review of Biological Reference Points in the Context of the Precautionary Approach," *Proceedings, 5th NMFS NSAW, NOAA Technical Memorandum NMFS-F/SPO-40* (1999), https://www.st.nmfs.noaa.gov/Assets/stock/documents/workshops/nsaw_5/gabriel_.pdf; Andre E. Punt and Anthony D.M. Smith, "The Gospel of Maximum Sustainable Yield in Fisheries Management: Birth, Crucifixion and Reincarnation," in *Conservation of Exploited Species,* ed. John D. Reynolds et al. (New York: Cambridge University Press, 2001); Sainsbury, *Best Practice Reference Points*; and Davies and Basson, *Approaches for Identification of Appropriate Reference Points.*

8 Andrew A. Rosenberg and Victor R. Restrepo, *Precautionary Management Reference Points and Management Strategies*, Food and Agriculture Organization (1994), http://www.fao.org/docrep/003/w1238E/W1238E06.htm; and Punt and Smith, "The Gospel of Maximum Sustainable Yield in Fisheries Management."

9 Also reviewed in International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, Pacific Bluefin Tuna Working Group, *Report of the Pacific Bluefin Tuna Working Group Workshop* (2010), https://swfsc.noaa.gov/publications/FED/01046.pdf.

10 Pilling et al., *Consideration of Target Reference Points*.

11 Restrepo et al., *Technical Guidance*.

12 Ray Hilborn, "Pretty Good Yield and Exploited Fishes," *Marine Policy* 34 (2010): 193–96, doi:10.1016/j.marpol.2009.04.013.

13 Maunder and Deriso*, Reference Points and Harvest Rate Control Rules.*

14 Pilling et al., *Consideration of Target Reference Points*.

15 Michael C. Melnychuk, Jeannette A. Banobi, and Ray Hilborn, "Effects of Management Tactics on Meeting Conservation Objectives for Western North American Groundfish Fisheries," *PLoS ONE* 8 (2013): e56684, doi:10.1371/journal.pone.0056684; Restrepo et al., *Technical Guidance*; and Keith J. Sainsbury, Andre E. Punt, and Anthony D.M. Smith, "Design of Operational Management Strategies for Achieving Fishery Ecosystem Objectives," *ICES Journal of Marine Science* 57 (2000): 731 -41, http://dx.doi.org/10.1006/jmsc.2000.0737.

16 Gabriel and Mace, "A Review of Biological Reference Points"; and Restrepo et al., *Technical Guidance*.

17 Gabriel and Mace, "A Review of Biological Reference Points."

18 Sainsbury, *Best Practice Reference Points*

19 Kell and Fromentin, "Evaluation of the Robustness of Maximum Sustainable Yield Based."

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