Harvest Strategies: 21st Century Fisheries Management

Well-designed systems can ensure long-term health of fisheries

Overview

Traditional fisheries management is a two-step process: First, scientists conduct stock assessments, and then fishery managers negotiate measures, such as quotas or time-area closures, to make sure that the resource—the targeted fish—is being used optimally and sustainably. While this seems simple enough, the current approach is anything but.

With imperfect knowledge about fish biology, incomplete fishery data, natural variability, and the inherent challenge in using models to count fish in a population, stock assessments can contain significant uncertainty. As a result, scientific advice can be vague or include a wide range of management options. Most fishery management bodies have committed to following scientific advice and the precautionary approach, but without a clear framework for making management decisions, negotiations often become contentious, reactive, and focused on short-term performance.

An alternative approach, known as "harvest strategies" or "management procedures," is emerging as the next innovation in fisheries management. Harvest strategies are pre-agreed frameworks for making fisheries management decisions, such as setting quotas. They are akin to agreeing to the rules before playing the game and shift the perspective from short-term reactive decision-making to longer-term objectives. Although different management bodies name and define them slightly differently, all harvest strategies include these basic elements: management objectives; a monitoring program; indicators of the fishery's status and population health, with associated reference points; a method to assess those indicators; and harvest control rules (HCRs) that set fishing opportunities, which could include catch limits and size limits, depending on the value of key indicators relative to the reference points. While most bodies view harvest strategy and management procedure as synonymous terms, some consider a management procedure to be part of the harvest strategy—namely, the harvest control rule together with the data and stock status estimation method used to apply the HCR. Robust harvest strategies are tested through a process called management strategy evaluation (MSE) before they are implemented.

One of the features that makes harvest strategies effective is the feedback loop. Specific data are collected to assess the fishery's status and to evaluate how it is doing relative to established reference points and management objectives. The results feed into the HCR, which defines what modifications to management measures are needed to ensure that the harvest strategy's management objectives are met. The cycle then begins again with the monitoring program recording the effects of the new measures and collecting new data.

Robust and precautionary harvest strategies benefit both the fish and fishermen. Paired with an effective compliance regime, harvest strategies can account for scientific uncertainty and variability, including that associated with climate change, and replace short-term, reactive decision-making. This process helps overfished stocks recover or maintains populations and fisheries at their targets. Sound harvest strategies increase transparency and predictability of fisheries management, which promotes industry stability. They also improve market access, given that some sustainable seafood certification programs, including the Marine Stewardship Council, require that fisheries have harvest strategies in place.

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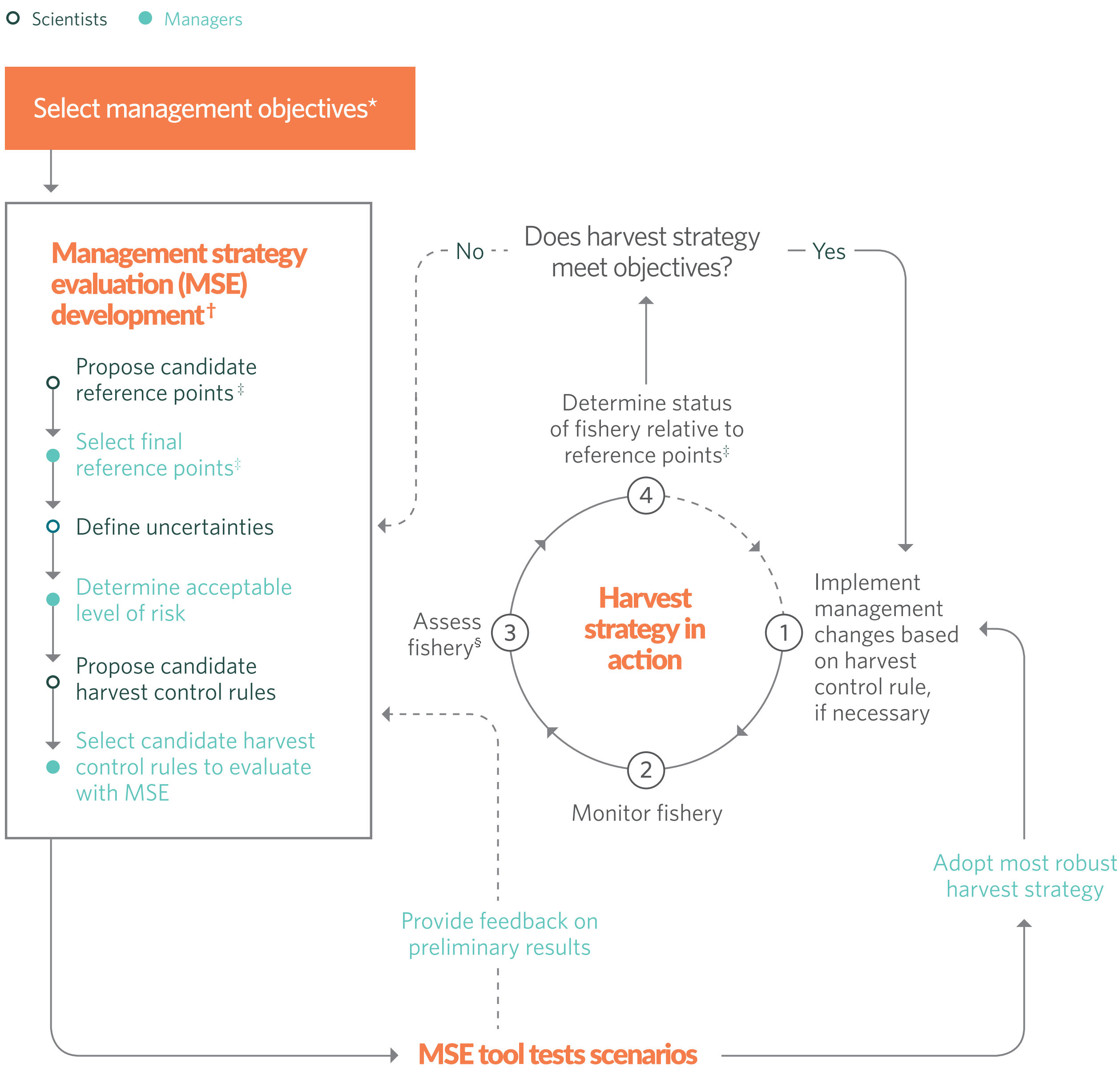
Figure 1

Harvest Strategies: Understanding How the Process Works



* Objectives can be modified as part of long-term reviews (e.g., every 10 years) to ensure they are still applicable.

† Order shown here is provided as an example and can be tailored to the needs of the fishery.

‡ Or other fishery indicators.

§ Through full statistical assessment model or simpler approach (e.g., one or more catch per unit effort indices).

Components of harvest strategies

Management objectives

Setting management objectives is the critical first step in developing a harvest strategy. They set the vision for the fishery and provide mechanisms for measuring the strategy's long-term success. Management objectives can be modified, but if the harvest strategy is going to be effective, it's critical that modifications occur only if the vision for the fishery truly changes, rather than as a means to justify a desired short-term outcome.

While legislative or convention objectives for fisheries are often expressed in general terms related to optimizing catch, management objectives that form the basis for a harvest strategy must be more specific and measurable, with associated timelines and acceptable levels of risk (e.g., a 5 percent risk of breaching the limit reference point or a 75 percent chance of rebuilding a stock to the target reference point within 10 years). Terms that are undefined, such as "high probability" or "in as short a time as possible," are subject to interpretation and lead to a lack of clarity that complicates management negotiations.

Fisheries often have more than one management objective. For example, a single stock could be managed to simultaneously maximize catch, stability in year-to-year catches, profit, the speed of rebuilding the stock, and the likelihood that the population is around a target abundance level and well above any limit.

Where there are multiple management objectives, some may conflict with others—for example, maximizing catch and minimizing the chance of breaching the biomass limit. That means managers may have to weigh objectives differently and consider trade-offs when selecting the final harvest strategy. While fisheries provide food, employment, and economic benefits for many, these benefits are sustained in the long term only if biological productivity and the health of the resource are maintained. Consequently, management objectives should be weighted to ensure a very high probability of achieving the status and safety objectives for a fishery. (See box.)

Typical Categories of Management Objectives

- Status: To maximize the probability of maintaining the stock in a healthy state (i.e., not overfished, no overfishing).
- Safety: To minimize the probability that the stock will fall below the biomass limit reference point.
- Yield: To maximize catch and/or catch rates across regions and/or fishing gears.
- Stability: To maximize stability in catches from year to year to make the industry more predictable.

Reference points

Reference points are benchmarks used to compare the current status of a fishery management system against a desirable (or undesirable) state. When matched to the management objectives for a fishery, they can be used to assess progress toward meeting those objectives. There are two main types of reference points: limit reference points (LRPs, or B_{lim} and F_{lim}), and target reference points (TRPs, or B_{TARGET} and F_{TARGET}), which are typically based on fishing mortality rate (F-based) or population abundance (B-based).

Limit reference points should define the danger zone, the point beyond which fishing is no longer considered sustainable. In a well-managed fishery, managers take precautions to ensure that there is a high probability that they will avoid this zone 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.

Target reference points define the desired 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 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). 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, also called threshold reference points, which are typically set between the TRP and LRP to prompt an additional management response via a harvest control rule to help ensure that the fishery remains close to the target or avoids breaching the limit.

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 to reduce the risk of breaching the limit.

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."

Table 1

Review of Commonly Used Reference Points

Reference point	Description	Pros	Cons
$X\%B_0$ or $X\%SB_{current, F=0}$	X% of the stock's biomass before fishing began, or spawning biomass that would be expected in the 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 (B_0) depend on a number of assumptions and may be unreliable.
$F_{X\%}$ 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) that 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.
$X\%{*}B_{MSY}$, $X\%{*}SB_{MSY}$	Biomass, or spawning biomass (SB),* that is needed to sustain X%* MSY (maximum sustainable yield).	Considers both recruitment overfishing and growth overfishing.†	Difficult to estimate, cannot manage all stocks in multistock fisheries exactly to MSY; sensitive to uncertainty about recruitment and selectivity; not a stationary target.‡
$F_{0.1}$	The F at which the marginal increase in equilibrium yield has dropped to one-tenth of its value when the stock was first exploited. ±	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 level of stock depletion; does not consider recruitment overfishing.
$B_{X\%R0}/B_{X\%RMAX}$	Biomass that will produce X% of virgin/maximum recruitment.	Directly considers recruitment overfishing.	Dependent on estimates of current and historical recruitment.

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

† 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.

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

± Specifically, fishing mortality rate corresponding to 10 percent of the slope of the yield per recruit curve as a function of F when F=0.

Harvest control rules

Also known as decision rules, harvest control rules (HCRs) are the operational component of a harvest strategy, essentially guidelines that determine how much fishing can take place, based on indicators of the targeted stock's status relative to reference points. These indicators come in two categories: empirical and model-based. Sometimes economic or other indicators may serve as triggers instead of, or in addition to, biological reference points.

For empirical harvest control rules, the indicators come from one or more direct measures of stock status, such as an abundance survey or calculations of how much effort it takes to catch a particular amount of fish, known as a catch per unit effort (CPUE) index. For model-based HCRs, an abundance level estimated by a stock assessment model is typically the indicator. In both cases, an HCR should also reflect agreement over how to calculate the stock's status, including how data should be collected. These three components operate together and should not be individually changed. This interdependency is why fully specified harvest strategies are preferable to HCRs.

HCRs range from basic, constant catch strategies—under which catch levels do not change—to complicated, multistep rules that set allowable catch based on triggers. Often the first management action in an HCR is prompted when the population size of a fish species passes a target reference point. By prescribing an automatic management response when the TRP is breached, the HCRs help to ensure that limit reference points are not violated. In other designs, no action would be taken until the fishery reaches a trigger reference point.

Management actions to regulate fishing can be based on catch, effort (e.g., total number of fishing days allowed), or fishing mortality rate (F). HCRs can also require modifications to other controls, such as the length or scale of time-area closures or size limits.

Figure 2

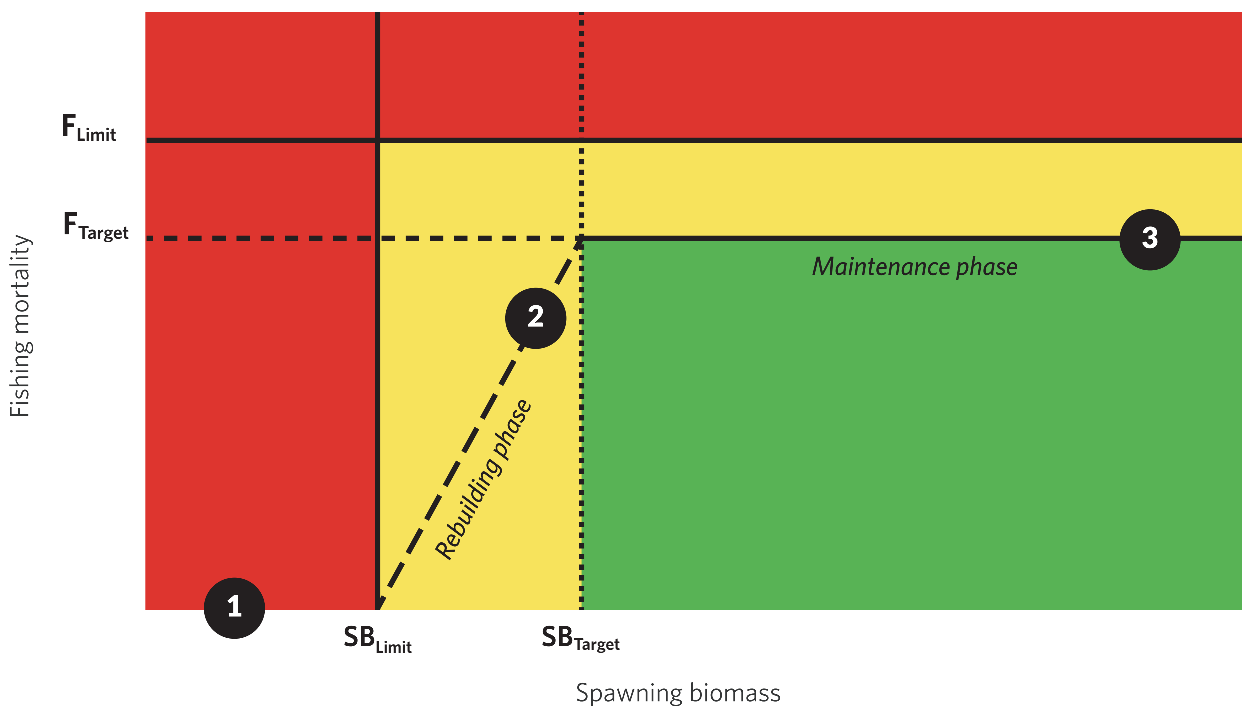
How a Harvest Control Rule Works

The results of a fish stock assessment can be represented graphically by what is known as a Kobe plot. The modified Kobe plot below shows one of many types of HCR. The fishery's ideal state is green, its cautionary state is yellow, and the state to avoid is red. In this example, the indicator for the stock's status is spawning biomass (SB), as estimated by a stock assessment model. The HCR has the following specifications:

1. If SB is below SB_{Limit}, suspend the fishery (i.e., fishing mortality on the left-hand axis = zero) and institute a scientific monitoring quota until the limit is reached or exceeded.

2. If SB is between the limit (SB_{Limit}) and the target (SB_{Target}), reduce fishing mortality in accordance with the rebuilding phase of the HCR (i.e., fishing mortality on the left side reduces from F_{target} when the stock is near SB_{target} to zero as the stock declines toward the SB_{limit}).

3. If SB is greater than or equal to the target (SB_{Target}, i.e., in the green), fish at the target mortality rate (F_{Target}) in accordance with the maintenance phase of the HCR.



Management strategy evaluation

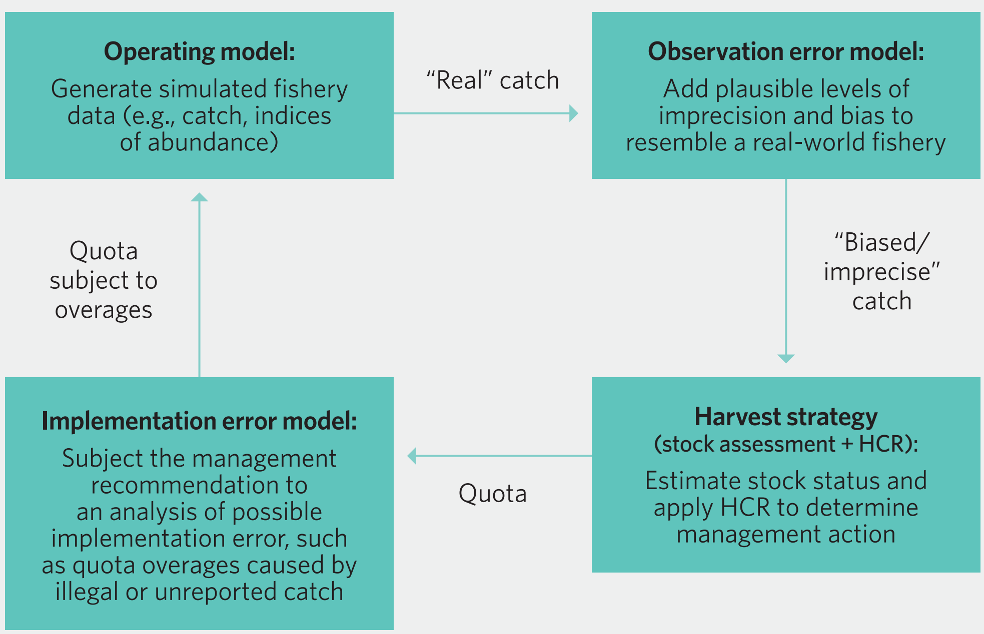
Management strategy evaluation (MSE) is a tool that scientists and managers can use to simulate the workings of a fisheries system and test whether potential harvest strategies can achieve the pre-agreed management objectives. MSE helps to identify the harvest strategy likely to perform best, regardless of uncertainty, and balance trade-offs amid competing management objectives. The MSE is an essential part of the process of developing and agreeing to a harvest strategy.

There are numerous ways to structure the MSE framework, but one or more "operating models" are at the center of the process. These operating models simulate all relevant aspects of the fisheries system and proposed harvest strategy. They include all plausible hypotheses about the biology of the stock, such as recruitment, and aspects of the fishery, such as the level of illegal fishing activity. Because of the many combinations of assumptions, hundreds of scenarios are often tested. The operating models are "conditioned" by fitting available real-world data—such as CPUE data—to them to eliminate implausible scenarios. For example, operating models must be able to mimic what has happened in the past. A "closed-loop simulation" is then used to test the candidate harvest strategies. (See Figure 3.)

Figure 3

Simulation Testing Harvest Strategies

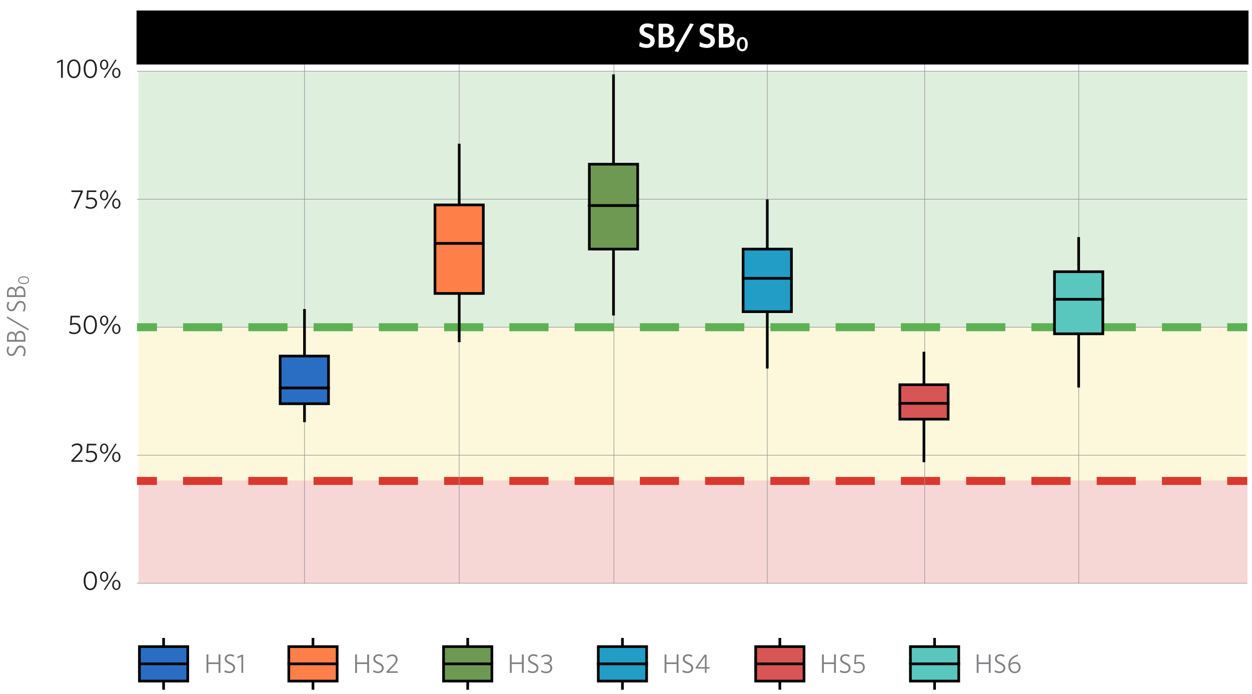
The closed feedback loop of an MSE that simulates the effects of candidate harvest strategies on a stock and fishery into the future, using a catch-based example.



The MSE output gives the likelihood that a candidate HCR will meet a fishery's management objectives (via performance indicators, which are quantitative expressions of the management objectives), either individually or in combination. There are many ways to present the results, including spider plots and box plots. (See Figure 4.) The results can be presented as the percentage likelihood of achieving an objective, such as a 75 percent chance of not being overfished and not being subject to overfishing, or the likelihood of achieving actual numbers, such as a long-term annual catch of 50,000 metric tons, a maximum inter-annual change in allowable catch of 10 percent, or a violation of a limit reference point in 10 of 20 years. When reviewing the results, managers aim to identify the candidate harvest strategy that best meets all objectives, taking into account the trade-offs among sometimes opposing goals, such as maximizing short-term catch and improving stock status.

Figure 4

Sample Boxplot Comparing Performance of Harvest Strategies (HS)



This boxplot shows the performance of six hypothetical harvest strategies against one management objective that establishes a target reference point of 50%SB_0 (green line) and a limit reference point of 20%SB_0 (red line). The horizontal line in each box represents the median, the colored box represents the 25th-75th percentiles, and the thin lines (or whiskers) represent the 5th and 95th percentiles.

Importantly, all elements of the harvest strategy can be updated and the MSE repeated as warranted. After HCRs are selected, they are typically re-evaluated every three to five years and can be modified if they are not performing as expected, if "exceptional circumstances" that were not tested by the MSE occur (e.g., a necessary abundance index is discontinued), or if new knowledge requires a revision of the operating models. Similarly, although MSE and harvest strategies decrease the reliance on traditional stock assessments for informing management actions, benchmark assessments are still typically conducted periodically to ensure that the harvest strategy is performing as expected.

Adopting an untested harvest strategy without going through the full MSE process sacrifices many benefits of this approach and could jeopardize the fishery's performance. When managers consider untested harvest strategies, the process is subject to the same controversial negotiations that have long plagued traditional fisheries management, and decisions can focus more on short-term considerations than achieving long-term objectives.

Conclusion

If designed correctly, harvest strategies benefit both the fish and fishermen. Recognizing the effectiveness of these tools, many international fisheries management bodies are developing or implementing strategies appropriate for their fisheries. Each group can build on and complement the work of the others and benefit from the collective lessons learned along the way.

Developing a sound harvest strategy requires collaboration among a team of scientists, managers, and stakeholders. Although the scientists do the modeling for the MSE, managers must provide extensive input and direction. Managers select the reference points, acceptable levels of risk, and timelines for the harvest strategy. They also outline the candidate HCRs to be tested in the MSE. Once MSE results are ready, managers review them and, based on how they decide to weigh the trade-offs among the different management objectives, select the harvest strategy. In this way, even though the scientists do the bulk of the analytical and modeling work on the MSE, managers, with the guidance of stakeholders, have control over both the front end of the process (setting management objectives) and the back end (selecting the harvest strategy).

While conducting an MSE to select a final harvest strategy requires time and effort, evidence suggests that the initial investments quickly reward stakeholders, exemplified by recent population gains and quota increases for southern bluefin tuna. A well-designed and -tested harvest strategy, paired with an effective compliance regime, can ensure that depleted stocks fully recover and provide long-term, sustainable, and profitable fisheries.

For further information, please visit:
pewtrusts.org/harveststrategies

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