Backgrounder:
Understanding Rebuilding Analyses

Rebuilding analyses are the middle step in a three-step process beginning with a stock assessment and resulting in a rebuilding plan.

The role of stock assessments

A stock assessment is a scientific assessment of the status and well-being of a fish population. Among other things, it provides estimates of stock size, life history, and productivity. If the stock assessment reveals the stock is overfished, scientists then conduct a rebuilding analysis. The rebuilding analysis uses information from the stock assessment to calculate the tradeoff between the time needed to rebuild the stock and the amount of fish that may be caught. The rebuilding plan describes a fishery policy based on a tradeoff between rebuilding time and the allowed catch level recommended by the Council.

Probability and Monte Carlo simulations

Rebuilding analyses can be difficult to understand, because they describe rebuilding in terms of probability, or the likelihood something will occur. Probability is also a measure of risk. If a particular course of action is less likely to produce the desired outcome, it may be considered riskier.

The Pacific Fishery Management Council's rebuilding analyses usually use a statistical technique called a "Monte Carlo simulation." This technique is used to calculate the probability a stock will rebuild within a given time period under a particular harvest strategy (or level of annual harvest).

Using information from the latest stock assessment, Monte Carlo simulation involves repeating many times a forecast—or simulation—of how the fish population may grow over time, if some level of fishing (or catch rate) is occurring. We'll call any one of these simulations a "case." With each case, the inputs used to simulate population growth are slightly different.

In the rebuilding analysis, this method is used to look at uncertainty in future recruitment. Recruits are young fish that survive to enter the pool of fish vulnerable to fishing. Because they are small or live in a different habitat, very young fish are rarely caught with commonly used fishing gear. Once they reach

Definitions

Rebuilding plan	Describes policy measures that will be used to rebuild the fish stock.
Rebuilding analysis	Uses biological information to describe the probability that a stock will rebuild within a given timeframe under a particular management regime.

a certain size, or move into the proper habitat, they become recruits to the fishery. In practice, recruitment is the total number of fish at a particular young age (usually reported as age 0 recruits in assessment models). The models then take into account the increasing contribution of these fish to the fishery and spawning biomass as they grow older. Recruitment is also a measure of productivity: if adult females produce more offspring and more of them survive, the population will grow at a faster rate. Recruitment can vary tremendously from one year to the next. This is what makes it hard to predict how quickly a fish population will rebuild and why the rebuilding analyses present their results in terms of probability.

In a rebuilding analysis, Monte Carlo simulations are carried out for different levels of fishing. In other words, for each case in a simulation, the fishing mortality rate is set to some pre-determined value. (The fishing mortality rate relates to the *fraction* of the population harvested, rather than the absolute harvest; as a population grows, the catch will increase with a constant fishing mortality rate.)

Figure 1.

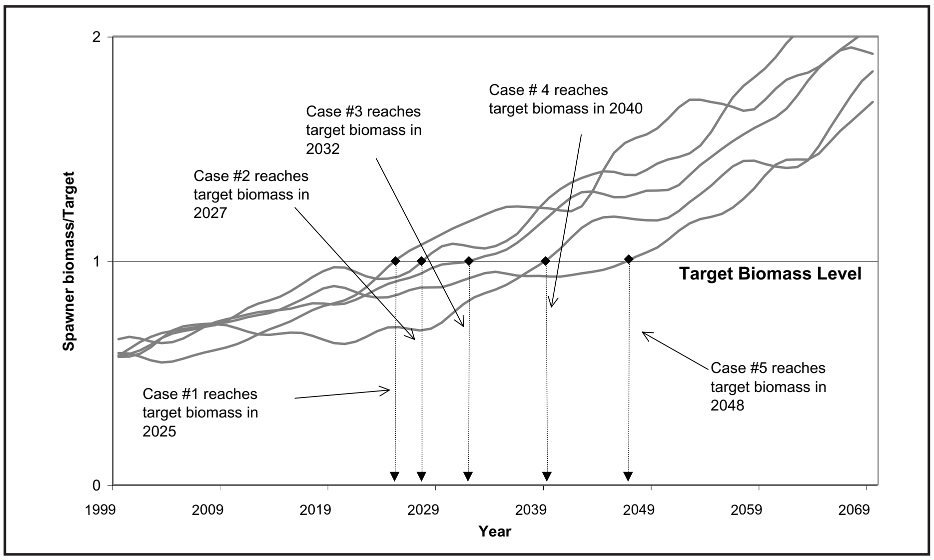
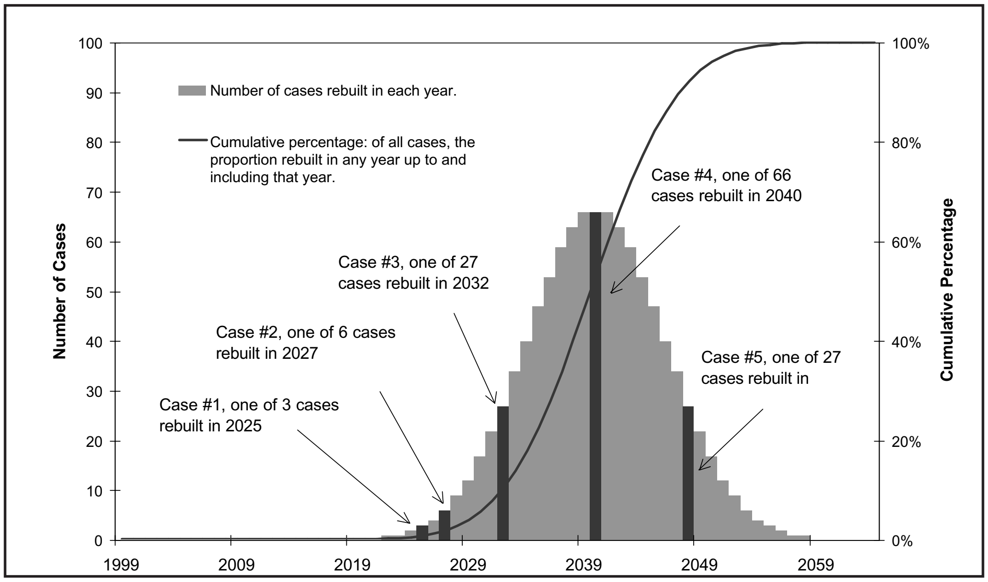


Figure 1 shows five cases from a Monte Carlo simulation, given some harvest rate. The vertical axis represents stock size, expressed as a proportion of the "target biomass," which is the size of the population once it is rebuilt. The horizontal line across the middle of the graph represents this target biomass level. The horizontal axis represents years, in this example from 1999 to 2069. Five cases are represented by the squiggly lines on the graph. (These are a small fraction of the hundreds or thousands of cases constituting a Monte Carlo simulation.) It can be seen that the population increases steadily in each case, but at a different rate because of differences in the number of recruits in each future year for each case. Case #1 reaches the target biomass soonest, in 2025, while case #5 takes the longest, reaching the target in 2048.

The year in which each case reaches the target biomass can then be summarized in Figure 2. Here, a bar graph is used to show the number of cases that reached the target biomass in each year. The five cases shown in Figure 1 are plotted along with the other 995 cases that are part of the Monte Carlo simulation. The years in which the five cases in the previous figure reached the target biomass are highlighted in Figure 2. Case #3, for example, and 26 other cases (that weren't plotted in the first figure), make up the bar tallying the number of cases rebuilt in 2032.

The key to understanding rebuilding analyses is found in the ascending line in Figure 2. This is the cumulative percentage of cases rebuilt by any one year. For example, in 2009 none of the 1,000 cases have reached the target biomass, so the cumulative percentage is 0%. In 2039, we could add up the number of cases represented by

Figure 2.



the vertical bars along the base of the chart that have rebuilt in that year and all the years before it, and divide by 1,000, which is the total number of cases in this simulation. Since 466 cases reached the target biomass in the years up to and including 2039, the cumulative percentage is about 47%. This calculation has been made for each year in the graph and is represented by the ascending line.

This cumulative percentage forms the basis for calculating rebuilding probabilities, which are one of the variables policy makers use in deciding the tradeoff between rebuilding rate and fishing levels. For example, another way of expressing the cumulative percentage is to say, for example, that there is a 47% chance that the fish stock will rebuild by 2039, given the fishing rate used in this Monte Carlo simulation, since we know that 466 out of a 1,000 cases reached the target biomass by this date.

Balancing tradeoffs

In finding a balance between rebuilding and fishing, the Council is limited by the biology of the stock and by national policy. The rebuilding analysis determines the rebuilding timeframe by first determining the shortest amount of time within which a stock could rebuild. All other things being equal, a stock will rebuild fastest if there is no fishing at all. The rebuilding analysis determines this date in probabilistic terms, using the Monte Carlo simulation technique just described. The fishing rate is set to zero, and the year in which half the cases have reached the target biomass is determined. Expressed in another way, there is a 50% probability of recovery by this year, which is considered the most likely year to rebuild under this scenario. Figure 3 shows the cumulative probability distribution from a Monte Carlo simulation where the fishing rate has been set to zero. In this figure, 50% of the cases are rebuilt after 15 years. By choosing the year in which 50% of the cases are rebuilt, we're saying the odds of recovery are evenly balanced in this year. (The simulation begins projecting population growth without fishing beginning when the fish stock was declared overfished. For example, if the stock were declared overfished in 1999, then the simulation assumes that no fishing has occurred since that time and predicts that the earliest the stock could be rebuilt, given even odds, would be 2014.) This lower boundary is called T_{MIN}, or the minimum time period by which we expect the stock to rebuild.

In Figure 3, this minimum time period is greater than ten years, so we calculate the maximum time period (referred to as T_{MAX}) using mean generation time. One mean generation time is how long it takes, on average, for a sexually mature female fish to be replaced by offspring with the same spawning capacity. In the example shown in Figure 3, biologists have computed a mean generation time of 17 years for this fish population. We

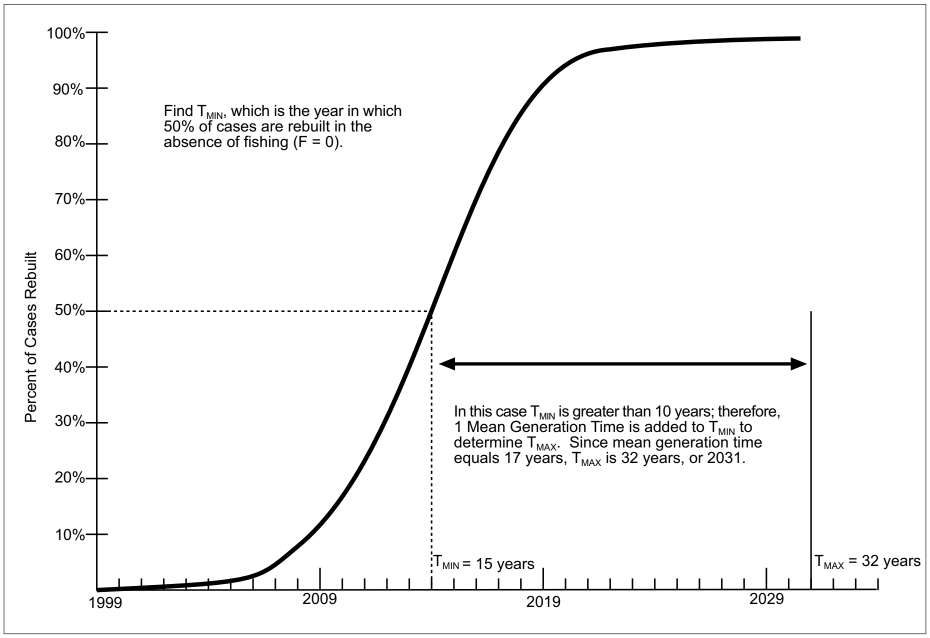


Figure 3.

add 17 years to T_{MIN} to arrive at the maximum time period allowed by national policy (T_{MAX}): in this example 32 years.

Once we have calculated our T_{MAX} goalpost, we are ready to run a series of Monte Carlo simulations, varying the fishing mortality rate or proportion of the population that is harvested (F). By incrementally varying this level of fishing, we can determine the relationship between fishing rates and the probability of the stock being rebuilt by T_{MAX} (in terms of the percent of cases in that simulation that are rebuilt by that year). In Figure 4, we see the results of three such simulations: one with a fishing mortality rate resulting in a 90% probability of the stock being rebuilt by T_{MAX}, one with a 70% probability, and one with a 50% probability. The 50% probability, even odds, represents the simulation with our upper bound of fishing mortality. In most instances, we are not allowed to consider fishing rates that would result in a probability less than 50%.2/ The probability of rebuilding by T_{MAX} is denoted as P_{MAX}. The higher the P_{MAX} probability, the lower the fishing mortality rate. In other words, we are expressing our tradeoff between fishery harvests and rebuilding speed in probabilistic terms. As we reduce fishing, the likelihood the stock will recover in this maximum time period increases.

According to the Magnuson-Stevens Act, federal fishery managers have to identify a year when they think the fish stock will be rebuilt. This target year (or T_{TARGET}) can be computed for any level of fishing or related P_{MAX} value. It is defined as the year in which half the cases in a simulation have rebuilt. In Figure 4 we show how this is computed for the three plotted fishing rates and corresponding P_{MAX} probabilities. As expected, if we apply the lowest of the three plotted fishing mortality rates (in other words, limit fishing the most), we will rebuild the fastest. Our T_{TARGET} for this lowest fishing mortality is 25 years. (To determine the actual target year, we add this value to the year in which the stock was declared overfished. Continuing with the example above, if the stock was declared overfished in 1999, then the target year is 2024.) Not surpris-

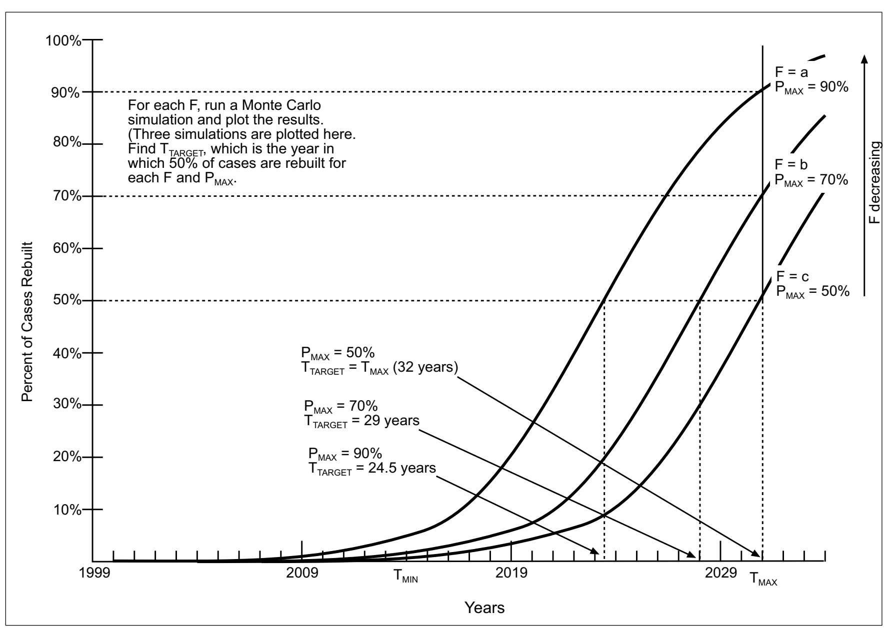


Figure 4.

ingly, this strategy also gives us the greatest chance of rebuilding in the maximum allowed time (T_{MAX})—or a P_{MAX} equal to 90%. The fishing mortality rate associated with the 70% P_{MAX} value gives a later target year: 2028. Finally, T_{TARGET} equals T_{MAX} for the highest allowable fishing since the P_{MAX} value—50%—is the same probability used to determine T_{TARGET}.

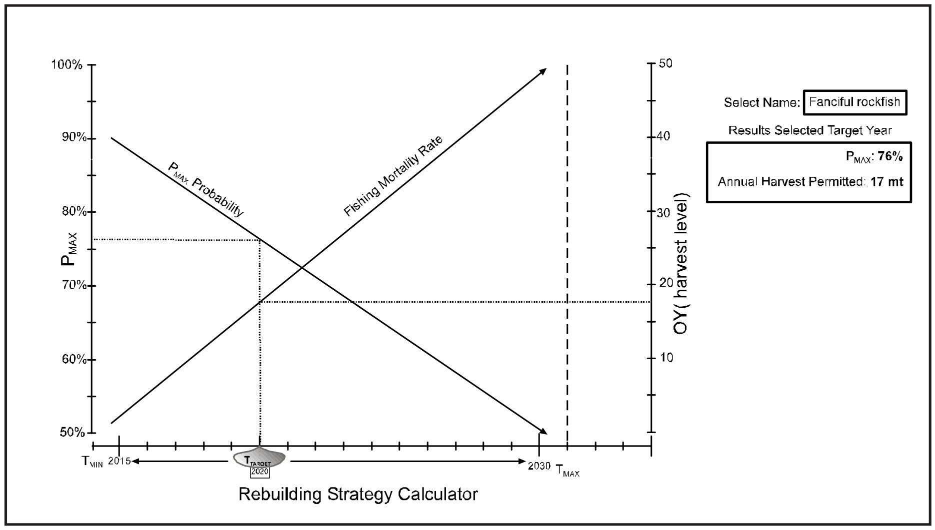


Figure 5.

Policy implications

As mentioned above, rebuilding analyses are used by the Council to draft rebuilding plans. These documents explain how the Council will manage groundfish fisheries so overfished species can recover. Rebuilding plans identify the strategy the Council plans to follow. The basis for any such strategy is the level of fishing that will be allowed, expressed as an annual "optimum yield." The Council then develops management measures, such as catch limits and closed areas, so fishermen won't catch any more than the optimum yield in a year.

It is important to recognize that some of the terms introduced and described above represent policy decisions at the national level and the Council does not have a choice in setting their values. The dates for our "goal-posts"—T_{MIN} and T_{MAX}—are determined based on guidelines established at the national level. Mean generation time is a biological characteristic that cannot be chosen by policymakers. Thus, the Council can't choose these values.

The Council is able to choose a fishing mortality rate and corresponding annual level of fishing. This does represent a Council choice, because we have the means to limit the amount of fish that are caught through the enforcement of management regulations. However, when rebuilding overfished species, it's possible to think about how to set these fishing limits in different ways. The Council could base its management strategy on either

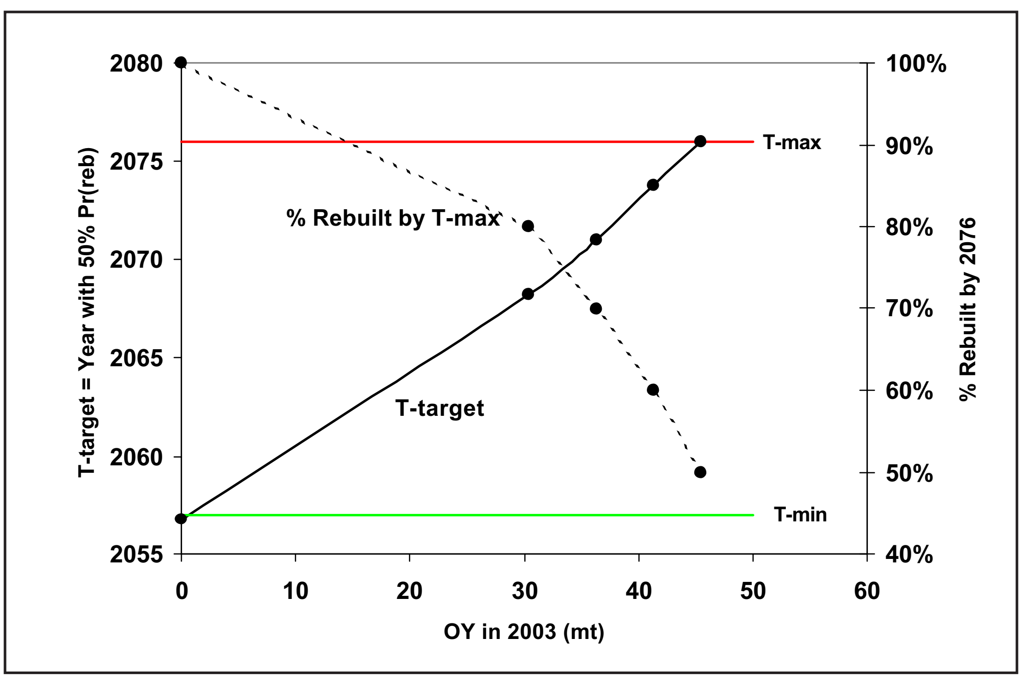


Figure 6.

the value of T_{TARGET}, P_{MAX}, or the fishing mortality rate, keeping in mind these three values cannot be chosen independently of one another. However, T_{TARGET} must be the management target even if its value is calculated based on choosing a P_{MAX} or F value.

Using the "Rebuilding Strategy Calculator" to determine tradeoffs

Figure 5 shows a hypothetical "rebuilding strategy calculator," which helps explain how the three policy variables (T_{TARGET}, P_{MAX}, and the fishing rate) are related. In the middle is a sliding knob, like one you might use to calibrate a machine tool. Each increment the knob can be set to represent a target year between T_{MIN} and T_{MAX}. As you slide the knob to the right, the fishing mortality rate goes up (meaning bigger harvests) and P_{MAX} goes down (meaning less assurance the stock will rebuild by T_{MAX}). Conversely, as the knob is moved to the left, the fishing mortality rate goes down and P_{MAX} goes up, since we're trying to rebuild the stock faster. We can imagine our calculator computes and displays the P_{MAX} value and annual harvest level, or optimum yield (based on the fishing mortality rate), each time the knob is moved to a new position, or target year. Of course, the operator first has to choose which species to focus on, since the results will differ depending on the characteristics of that species. Thus, in our illustration, there is a box in the upper right where the operator enters the name of the overfished species being rebuilt. Below that is a box with the calculated results for the selected target year.

Although a Monte Carlo rebuilding analysis is more complex than the rebuilding calculator, actual rebuilding analyses include a plot that uses the same concepts, showing the relationship between any optimum yield level in the current year, P_{MAX} and T_{TARGET}. This plot from a recent rebuilding analysis for canary rockfish is shown in Figure 6. The dotted line shows the P_{MAX} value, and the solid line shows T_{TARGET} for different harvest levels.

Before we can use our hypothetical rebuilding calculator, it has to be programmed by the stock assessment scientists, so when we slide the target year knob the other two variables change by the right amount. This raises a final very important point: the calculator is likely to get reprogrammed once scientists complete a new stock assessment. Fishery scientists working with the Council redo the stock assessment for a particular species about every two to four years. Each new assessment gives us more information to work with, and scientists often think of new and better ways to evaluate the status of the stock. The rebuilding analysis has to be done again too, and things can change. For example, the assessment may show that mature females are producing more or less offspring than previously thought, or the maximum possible size of the population—the unfished biomass level our targets are based on—is different than previously thought. By the same token, the relationship between the fishing rate, P_{MAX} and T_{TARGET} can change. Thus, once our calculator is reprogrammed, sliding the target year knob will vary our results—P_{MAX} and the annual harvest level—by a different amount. The Council can stick to its target rebuilding year, as long as it's still between T_{MIN} and T_{MAX}, and P_{MAX} is greater than 50%, but our fishing mortality rate and P_{MAX} value will now be different. If the fishing mortality rate is lower, the Council would have to also reduce the annual harvest level, or optimum level, for the species in question.

Simulations have also shown that frequent changes in fishing mortality rates and rebuilding targets can lessen the chance of actually achieving the targets in the long term. Maintaining stability in harvest rates (to the extent practicable) tends to reduce the overall time to rebuild. This is because models change from year to year, usually suggesting values slightly above or slightly below what the true "optimal" harvest rate might be for meeting a management objective. Stability in harvest rates likely leads to more stability in the fishery and in the management system as well.

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