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A Conditional Constant Catch Policy for Managing the Pacific Halibut Fishery

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Abstract.—Since 1985, the staff of the International Pacific Halibut Commission (IPHC) has used a constant harvest rate policy—currently 20% of exploitable biomass—to estimate the yield currently available from Pacific halibut *Hippoglossus stenolepis* stock. This paper outlines a more stable alternative policy in which yield is held constant at some ceiling level so long as taking that yield would not result in a total exploitation rate exceeding a specified ceiling rate. During any periods of low abundance, the policy would revert to a constant harvest rate policy at the ceiling rate. The ceiling harvest rate would be chosen so as to assure that spawning biomass remained above a specified minimum. A policy of this kind could produce a yield similar to the present 20% constant harvest rate policy but with much less year-to-year variation attributable to changes in stock abundance, assessment methods, and estimated removals by other fisheries.

Since 1985, the staff of the International Pacific Halibut Commission (IPHC) has calculated the available yield of Pacific halibut *Hippoglossus stenolepis* by applying an optimal constant harvest rate to each year's model-based estimate of exploitable biomass. In principle this procedure should have resulted in quite stable yield estimates over time, but in practice the numbers have fluctuated widely because of continual changes in assessment methods that have led to changes in both the estimated optimum harvest rate and the annual biomass estimates. Meanwhile, estimates of long-term potential yield from the stock have not changed since the 1930s. This paper summarizes the evolution of IPHC harvest policy, reviews the various estimates of long-term potential yield, and outlines a conditional constant-catch policy that relies more on the stable long-term potential yield estimate and less on the variable annual estimates of optimal harvest rate and biomass.

Evolution of IPHC Harvest Policy

Annual catch limits have been set for all of IPHC Area 2 and part or all of the present Area 3 (Figure 1) since 1932. Until the 1960s, the catch limits were based on the pioneering work of Thompson and Bell (1934), who showed that the annual surplus production of the Pacific halibut stock (which they variously called ‘‘annual income,’’ ‘‘normal yield,’’ and ‘‘normal catch’’) would be about the same over a wide range of harvest rates. This ‘‘normal catch’’ was estimated to be about 25 million pounds each in Areas 2 and 3 (total 50 million), and catch limits were in fact set very close to those amounts for many years, changing little from year to year. As was sometimes said (e.g., Southward 1968; Hoag and McNaughton 1978), the working policy in those years was to maintain a constant commercial catch per unit of effort (CPUE), raising the quota a bit if CPUE went up and lowering it a bit if CPUE went down; however, that was not the original intent. It is true that if CPUE increased even when the estimated ‘‘normal catch’’ had been taken or exceeded, then the estimate of the normal catch might be increased and hence the catch limit, but the aim of the policy was to maintain a certain yield rather than CPUE (Thompson 1950). The distinction is subtle, however, and may have faded after Thompson himself resigned from the staff in 1937.

Chapman et al. (1962) estimated maximum sustainable yield (MSY) to be somewhat more than the longstanding normal catches: 32 million pounds in Area 2 and 36–38 million in Area 3. Catch limits were accordingly raised in the early 1960s, to a maximum of 28 million pounds in Area 2 and 38 million in Area 3. These increases were driven in part by a requirement under current International North Pacific Fisheries Commission (INPFC) rules to demonstrate ‘‘full utilization’’ of the stock to ward off a directed distant-water fishery (Skud 1972).

During the 1960s, the stock declined as a result of the higher catch limits, the poorly reported bycatch in new distant-water fisheries, and a run of poor recruitments (due in part to bycatch). Commercial CPUE fell steadily, to about half the 1960

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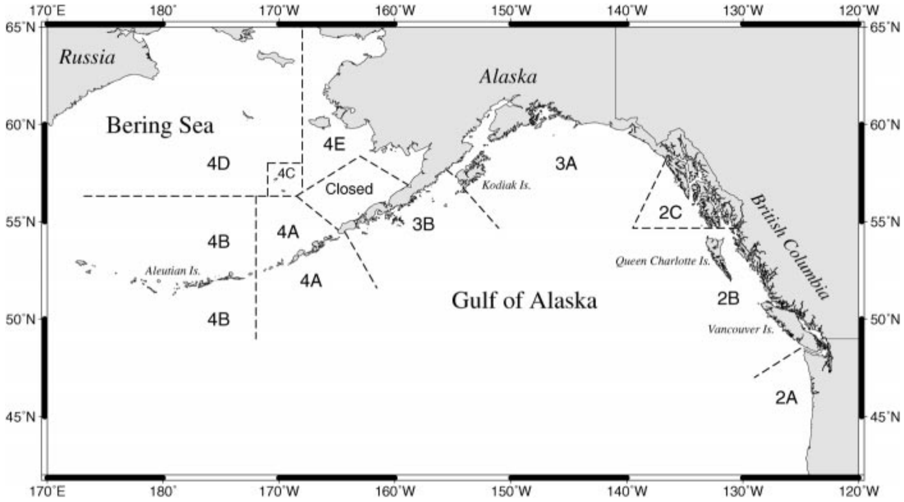

FIGURE 1.—International Pacific Halibut Commission regulatory areas used in managing the fishery.

level, by the early 1970s. Catch limits were lowered gradually in the late 1960s and then reduced drastically in the early 1970s, to 13 million pounds in Area 2 and 12 million in Area 3. The drastic reduction was prompted in part by a reanalysis by Skud (1972) of the effect of longer hook-spacing on commercial CPUE, which suggested that the decline in adjusted CPUE was even greater than previously estimated, although this analysis and its conclusions were disputed by Bell (1981).

Catch limits were reduced still further in the late 1970s, to a minimum of 9 million pounds in Area 2 and 11 million in Area 3. During the early 1980s, Pacific halibut stocks made a rapid recovery. For a few years, a deliberate rebuilding program was pursued, in which catch limits were allowed to rise but still kept below the estimated surplus production so that the stocks would continue to increase. In 1985, the stocks were deemed rebuilt (Hoag et al. 1993).

The Commission did not return to a policy of setting catch limits at the MSY level because by then it was understood that attempting to take MSY every year from any stock would severely deplete the stock if it ever fell below the MSY level of abundance—on of the reasons for the steep decline of the Pacific halibut stock in the 1960s. Instead, the Commission adopted a constant harvest rate policy. Initially, the (full-recruitment) harvest rate (F_{MSY}), the rate that on average yields MSY (Quinn et al. 1985), was set at 35%, at that time the current estimate of the rate. The harvest rate was lowered to 30% in 1993 because the long-term yield at that rate would be almost the same as at 35%, and using the lower rate would almost certainly keep spawning biomass from dropping to the historical minimum levels of the 1970s (Parma 1992), a policy objective the Commission adopted. The harvest rate was further lowered to 20% in 1996, when estimates of recent recruitment were revised sharply upward and indicated less density dependence in the spawner–recruit relationship (Clark et al. 1999).

In principle, a constant harvest rate policy is very robust and quite stable. At the F_{MSY} harvest rate, and across a large range of values around it, average yield is close to the maximum obtainable by any policy (e.g., Sigler and Fujioka 1993). Biomass is maintained because catch limits are automatically set below surplus production if abundance falls below the equilibrium level corresponding to the chosen harvest rate (Figure 2). Similarly, if biomass rises above the equilibrium level, catch limits are automatically set above surplus production, and the stock is fished back down to equilibrium. Catch limits vary smoothly with stock biomass, which in the case of the Pacific halibut stock with many year-classes and a relatively low turnover should produce only small year-to-year differences in catch limits. The policy is even quite robust to climate changes that alter the productivity of the stock (Walters and Parma 1996).

In practice, however, estimates by IPHC staff of current available yield from the Pacific halibut stocks in Areas 2 and 3A have fluctuated sharply from year to year over the last decade, largely because of technical changes in the annual stock

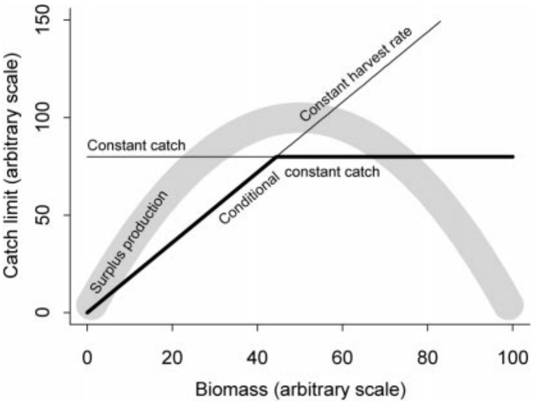

FIGURE 2.—Surplus production as a function of biomass, and catch limits under three harvest policies. The conditional constant catch policy is a hybrid that consists of a constant harvest rate at lower biomass levels and a constant catch at higher biomass levels.

assessment procedures. All of the changes were quite reasonable but resulted in a series of major upward and downward revisions of the current biomass estimates to which the constant exploitation rate was applied; in one case, the constant exploitation rate itself was markedly reduced, from 30% to 20%. As related below, during almost all of this period the estimate of long-term potential was the same (50–70 million pounds), and the expectation was always that the constant harvest rate policy would eventually lead to an equilibrium within that range, such that the policy would then perform as it should; instead, however, the annual estimates tended to jump from one nonequilibrium point to another, and the available yield estimates were often substantially greater or less than the well-established long-term potential. Actual catch limits have been much less variable because the staff and the Commission have not, in fact, followed the abrupt changes indicated by the assessment.

Past and Present Estimates of Long-Term Potential Yield

Over the years, numerous estimates of the potential yield of Pacific halibut have been made, all referring not to the entire stock but to the present Area 2, Area 3A, and in some cases part of Area 3B. (Areas 3B and 4 were only lightly fished before the latter 1990s.) The contribution of Area 3B is relatively small, however, so all of the estimates can be regarded as referring approximately to Areas 2 and 3A. The estimates are as follows:

(1) Thompson and Bell's (1934) ''normal yield,'' totaling about 50 million pounds.
(2) Chapman et al.'s (1962) MSY estimates, based on production modeling and totaling about 70 million pounds.
(3) Quinn et al.'s (1985) estimates of MSY, also based on production modeling, totaling about 60 million pounds.
(4) Parma's (1992) estimates of MSY, based on age-structured simulations of a range of constant harvest rates with three alternative spawner–recruit relationships fitted to historical abundance estimates obtained with the CAGEAN assessment model (Deriso et al. 1985) and totaling 50–60 million pounds.
(5) Sullivan et al.'s (1999) estimates of MSY, similarly determined but with historical estimates obtained with a new assessment model, totaling 50–60 million pounds.
(6) Clark et al.'s (1999) estimates of MSY, similarly determined but with much lower weights at age, reflecting the dramatic drop in growth that occurred during the 1990s and totaling 25–35 million pounds.

Recent analysis (Clark and Hare 2002) has shown that the decline in growth during the 1990s was almost certainly a density-dependent response to high abundance, so that a recovery in weight at age can be expected if and when abundance declines. Their analysis also showed that variations in year-class strength are largely driven by interannual and interdecadal environmental variability, with spawning biomass having little effect over the range of values seen in the historical record (80–300 million pounds). Simulations that incorporate these features and cover a range of exploitation rates keeping spawning biomass above the historical minimum indicate an MSY of about 65 million pounds, which could be taken at harvest rates of 30–40%. The same simulations with no density dependence in growth produce an MSY of about 40 million pounds at harvest rates of 20–25%, similar to the values in Clark et al. (1999).

An important feature of the most recent analyses and simulations is the alternation of climatic regimes, implemented by assuming a shift every 15–30 years. During a favorable regime, average recruitment is more than twice that of a poor regime. During a prolonged favorable regime, MSY would be about 90 million pounds, versus about 50 million during a prolonged unfavorable regime. The difference is less than a factor of two because of the effect of density-dependent growth. The MSY

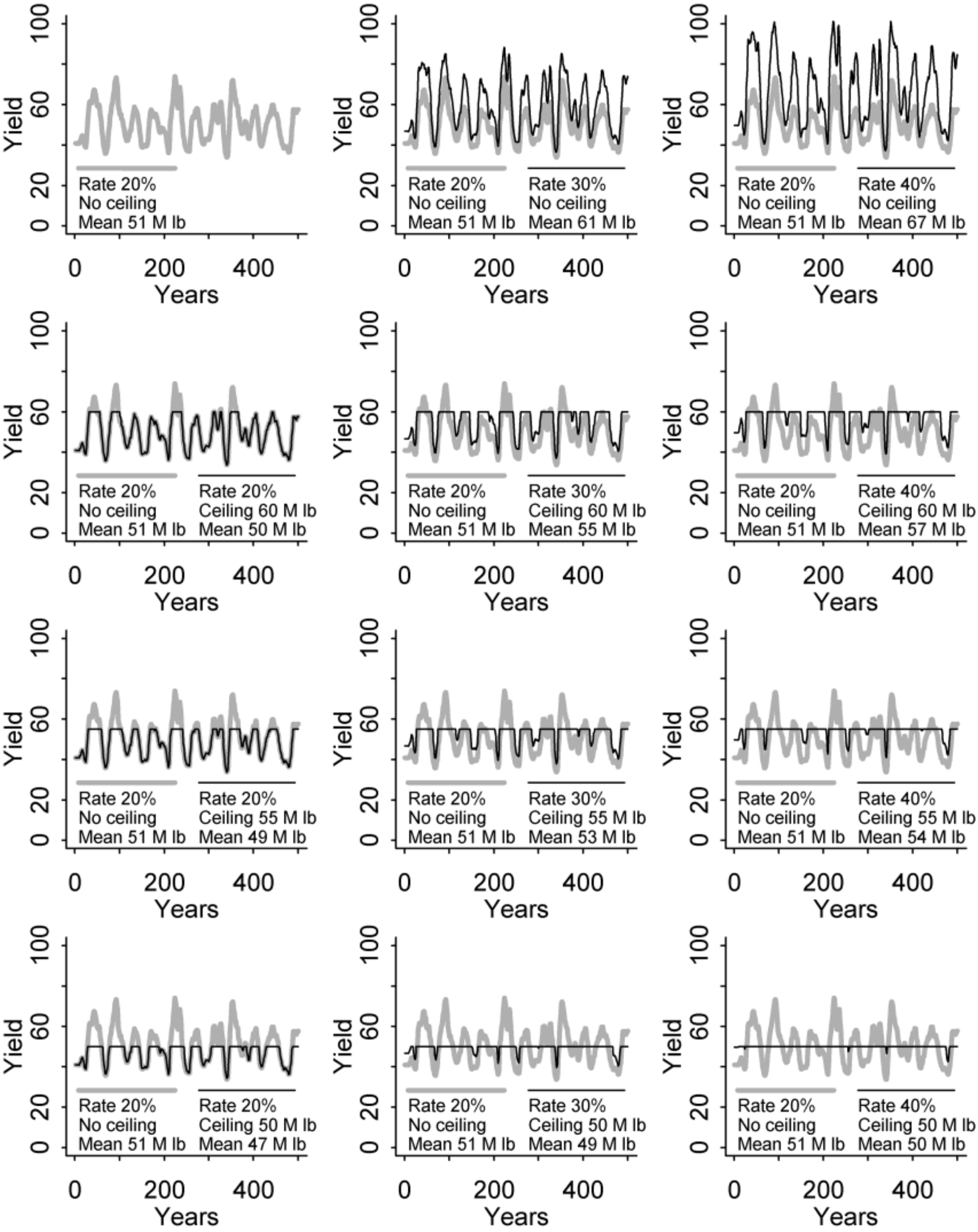

FIGURE 3.—Five hundred–year simulations of yield under alternative conditional constant catch policies for Areas 2 and 3A combined. The thick gray line in every graph is the present 20% harvest policy, with no catch ceiling. The thin black lines are the alternatives. Where no ceiling catch is set (top row), the harvest rate is constant; elsewhere, the harvest rate is a ceiling rate that constrains the catch limit.

of 65 million pounds mentioned above is thus a long-term average of yields under alternating regimes.

Except for the estimates in Clark et al. (1999), which we now consider unrealistic because they do not allow for density-dependent growth, all of the estimates of long-term potential production have fallen in the range of 50–70 million pounds. This is not surprising because all are based on very similar estimates of historical production. Insofar as past production is a reliable indication of what to expect in the future, we regard this range as a reliable estimate of long-term potential.

Simulation Model

Stock dynamics were as reported by Clark and Hare (2002), with recruitment being controlled by environmental conditions over the range of observed spawning biomass levels and growth varying in a density-dependent fashion.

Climate alternated between positive and negative PDO regimes, with the duration (in years) of each successive regime drawn from a uniform (15, 30) distribution. During negative regimes, average recruitment was about half the level in positive regimes. In all regimes, the deviations of log recruitment from the mean had a standard deviation of 0.26 and a serial correlation coefficient of 0.60. Spawning biomass was monitored throughout every simulation to assure that it never dropped below the observed historical minimum of 80 million pounds for any of the harvest rates considered (i.e., up to 40%).

Mean weight at age in survey and commercial catches varied with stock abundance. Specifically, mean weight at age 8 was controlled by smoothed year-class strength (a running mean); annual weight increment thereafter was controlled by the total abundance of fish at age 10+. The values used in the schedules were based on the observed historical variation of growth schedule parameters with abundance.

A Conditional Constant Catch Policy

In retrospect, Thompson's ''normal catch'' policy looks quite attractive, utilizing a constant catch level somewhat less than MSY that can be sustained indefinitely, or at least for long periods. As long as MSY is reasonably well known, this policy can be viewed as simply anticipating the equilibrium to which a constant harvest rate policy would move in the absence of continual technical changes in the annual stock assessment. To guard against a repetition of the depletion that took place in the 1960s, a mechanism must be added to lower the catch limits to be less than any surplus production if,through chance or climate change, the stock should decline to a point where taking the constant catch would impose excessive mortality.

These two features define what we call a conditional constant catch policy, in which yield is held constant at some ceiling catch level for so long as taking that yield would not result in an exploitation rate above some ceiling harvest rate. If such an increase should occur, the yield is limited accordingly, so during periods of low abundance the policy reverts to a constant harvest rate policy at the ceiling rate (Figure 2). The ceiling harvest rate is chosen so as to assure that spawning biomass remains above a specified minimum. Regime shifts complicate the issue in the case of Pacific halibut but they do not make the policy impossible; they only affect its performance as measured by average yield and the frequency of years in which the chosen constant (ceiling) catch can be taken.

For Areas 2 and 3A combined, the ceiling catch would have to be in the range of 50–60 million pounds (or less) to be achievable in most years. The ceiling harvest rate would have to be less than or equal to the MSY harvest rate and, in conjunction with the ceiling catch level, should assure that the spawning biomass remains above the historical minimum (or some other specified level). In light of the most recent analysis and simulations, harvest rates in the range of 20–40% could be considered candidate ceiling values.

Under this policy there is a tradeoff between the magnitude of the ceiling catch and the likelihood of being able to take it. With a very low ceiling catch, stock biomass stays high and the ceiling catch is always below what could be taken at the ceiling harvest rate, so the policy is in effect a pure constant catch policy. With a very high ceiling catch, for example, one well above MSY, the stock biomass stays low and the catch limit is always constrained by the ceiling harvest rate and, again, the policy is in effect a constant harvest rate policy. At intermediate values, the ceiling catch is achievable for longer or shorter periods, alternating with periods when the catch limit is constrained by the ceiling harvest rate.

There is also a tradeoff between the ceiling harvest rate and the likelihood of being able to take the ceiling catch. A higher ceiling harvest rate will clearly constrain the catch limit less often than a lower one. Setting the ceiling harvest rate as high as possible (consistent with the requirement that

TABLE 1.—Effects of adopting different ceiling catch levels at different harvest rates; CC 50, CC 55, and CC 60 represent ceiling catches of 50, 55, and 60 × 10^6 lbs.

Ceiling harvest rate	Annual yield (SD) [$\times 10^6$ lbs]				Spawning biomass ($\times 10^6$ lbs)				Percent years in which constant ceiling catch can be taken			
	CC 50	CC 55	CC 60	No ceiling	CC 50	CC 55	CC 60	No ceiling	CC 50	CC 55	CC 60	No ceiling
0.00	0 (0)	0 (0)	0 (0)	0 (0)	532	532	532	532	0	0	0	NA
0.20	47 (5)	49 (7)	50 (8)	50 (9)	251	241	236	233	58	41	14	NA
0.25	48 (3)	51 (6)	54 (8)	56 (11)	241	226	216	205	74	60	48	NA
0.30	49 (2)	53 (5)	55 (7)	61 (13)	235	218	205	183	86	70	59	NA
0.35	50 (2)	53 (4)	56 (6)	65 (19)	233	212	197	165	92	78	66	NA
0.40	50 (1)	54 (3)	57 (6)	67 (17)	232	209	192	149	95	84	71	NA

spawning biomass remain above the specified minimum) is therefore desirable, both for obtaining a higher yield and for being able to take the ceiling catch, whatever it is, as often as possible.

Figure 2 shows 500-year simulations of yield under alternative policies, all graphed with the present constant 20% harvest policy in the background. The graphs in the top row are pure constant harvest rate policies at 20%, 30%, and 40%. Favorable and unfavorable climate regimes appear clearly, and annual yield varies widely, from 40 to 80 million pounds at 20% and from 40 to 100 million at 40%. The average yield increases from 51 million pounds at 20% to 67 million at 40%.

The lower three rows show the effect of adopting ceiling catch levels of 60, 55, or 50 million pounds, respectively, with a ceiling harvest rate of 20%, 30%, or 40%. Lowering the ceiling catch reduces yield variability by limiting upward movement during favorable periods; the very high yields available at those times are simply forgone. Raising the ceiling harvest rate (above 20%) reduces yield variability by limiting downward movement during unfavorable periods. This occurs because the stock is simply fished harder and yields more at the higher harvest rates.

Average yield is quite similar for all of the conditional policies (47–57 million pounds) and differs little from the average of 51 million pounds expected from the present constant 20% policy (Table 1a). Because total actual removals from Areas 2 and 3A in 2002 were about 57 million pounds, we could shift to one of the conditional policies now with little or no change in the present catch levels or the average size of future catches. Imposing a ceiling catch substantially reduces the variability of catch limits (Table 1b); using higher ceiling harvest rates results in increased average spawning biomass (Table 1c). The percentage of years in which the catch limit is at the ceiling is quite sensitive to the values chosen for the ceiling catch and ceiling harvest rate (Table 1d).

Discussion

A conditional constant catch policy appears to offer some important advantages over the present constant harvest rate policy. Catch limits would be more stable and in fact could be unchanged for long periods. This would simplify the management process and provide more predictability for the industry, which is especially desirable now that quota share systems have been implemented in Canada and Alaska. Except during periods of low abundance, catch limit recommendations would also be insulated from technical changes in stock assessment that altered the estimates of the current biomass. During those periods, the conditional constant catch policy would be the same as the present policy, no better and no worse.

Adopting a policy of this kind requires choosing a ceiling harvest rate, a ceiling catch level, and a minimum spawning biomass. All of the alternatives presented here have a zero probability of resulting in a spawning biomass below the historical minimum of 80 million pounds (which produced good recruitment even during an unfavorable regime in the mid-1970s), but the Commission might not be willing to apply a 40% harvest rate when the biomass was as low as, say, 100 million pounds, and might even decide to raise the minimum.

Once a ceiling harvest rate is set, choosing a ceiling catch level is just a matter of deciding between greater yield and greater stability. At a maximum harvest rate of 30%, for example, a constant catch of 50 million pounds could be taken 90% of the time, 55 million pounds 70% of the time, and 60 million 60% of the time. The higher ceiling catch values also produce somewhat greater average yields.

Most modern fishery management is similar to the present IPHC procedure of applying some kind of harvest rate to an annual model-based estimate of abundance, often with more or less elaborate rules for reducing the harvest rate at lower biomass levels (e.g., Restrepo et al. 1998; Goodman et al. 2002). This policy has several desirable features, the most important being that over quite a range of harvest rates the policy will achieve high yields while maintaining adequate spawning biomass, even when stock dynamics are poorly understood and long-term potential yield is unknown. In our experience, such a policy also has some undesirable features, the main one being instability caused by technical changes in the annual assessment.

In cases like Pacific halibut, where stock dynamics are reasonably well established, attempts to use a pure constant catch policy appear feasible. Although rare in practice, this sort of policy has been used in New Zealand under the name ''maximum constant yield'' (MCY) for some stocks (Annala 1993). We see two drawbacks to attempting the policy in the Pacific halibut fishery. First, the pure constant catch would have to be low to be sustainable indefinitely, although it could perhaps be as much as 50 million pounds, as in Thompson's day, and therefore not far below the yields available with a conditional policy. Second, and more seriously, taking the MCY can occasionally require fishing at a high exploitation rate when stock biomass is lowest. We question whether the Commission would or should do so. The maximum harvest rate parameter of our conditional policy makes this decision explicit.

Parma (2002) has developed and tested a management procedure for the Pacific halibut fishery that maintains a constant harvest rate but eliminates much of the year-to-year variability in biomass estimates. This is achieved by fitting a simple aggregated delay-difference model instead of a detailed age-structured model and thus entirely avoids some of the issues that have caused abrupt changes in biomass estimates in recent years, such as alternative parameterizations of survey selectivity and changes in age-reading practices (Clark and Hare 2003). Other disruptive issues, however, are not avoided, such as the choice of a working value for natural mortality and an apparent change in survey catchability. In practice, one would have to rely on a continuing age-structured assessment for determining an appropriate harvest rate and for detecting weaknesses in the assumptions underlying the delay-difference model (mainly the constant survey catchability). Such a policy would therefore be vulnerable to many (but not all) of the changes in target harvest rate and biomass estimates that have plagued the age-structured assessment.

The conditional constant catch policy outlined above would be less vulnerable to technical changes in the assessment procedures because in most years the catch limit would not depend on a harvest rate or biomass estimate at all. The limit would simply be the ceiling catch, which would be based on our estimate of long-term potential yield. As explained above, the estimate of potential yield is solidly based on the observed historical surplus production of the stock, which is the same regardless of what sort of model is fitted to the historical data, and so is unlikely to change.

Actual implementation of this sort of policy in the Pacific halibut fishery would raise some issues not covered in this paper. What should be the ceiling catch level in each regulatory area? What is a reasonable estimate of long-term potential yield in Areas 3B and 4, where we do not have a long record of production at even moderate levels of exploitation? Should the minimum spawning biomass constraint be global or area-specific? Should there be a biomass threshold somewhere above the minimum at which the harvest rate should be reduced? These issues could be handled in different ways within the general framework of the policy.

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