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Rivers Inlet Sockeye Salmon: An Experiment in Adaptive Management

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Abstract.—Historically the Rivers Inlet fishery for sockeye salmon *Oncorhynchus nerka* was one of British Columbia's largest salmon fisheries. Suspecting that spawning escapements had declined to far below optimum levels, in 1979 the Canadian Department of Fisheries and Oceans initiated an adaptive management experiment to rebuild spawning runs in hopes of producing larger recruitments. The fishery was essentially closed from 1979 to 1984 and was allowed to increase gradually from 1984 to 1988 in expectation of higher recruitments following the closure. The higher recruitments have apparently not materialized, implying either that the stock was not so badly overfished in the first place, that there has been an unlucky run of poor years for ocean survival, or that the stock has responded but increases have not been detected due to poor spawner enumeration methods. Our inability to distinguish among these alternatives, even after a decade of experimentation, illustrates difficulties in designing effective plans for adaptive management. Industry and government have cooperatively developed a new strategy that they feel represents a better balance between short-term fishing opportunities and long-term information gathering, and that will be less demanding to implement in terms of in-season regulatory tactics.

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There has been much interest in adaptive policies for fisheries management. Adaptive policies involve the deliberate manipulation of management regimes so as to provide direct experimental tests of which regime is best (Walters and Hilborn 1976; Walters 1986). Where there is evidence that the best management regime may lie outside the range of historical experience, an experimental regime represents a "probing for opportunity" to improve the fishery. In theory, adaptive policies generally involve some tradeoff between immediate benefits from (or risks to) the fishery and longer term benefits, such as better information upon which to base decisions. For example, reducing harvest rates in a salmon fishery will mean reduced short-term catch for commercial fishers but may eventually provide data on recruitment rates associated with higher spawning stocks, thereby providing more precise estimates of the optimum spawning stock that will lead to higher catches in the long term.

While adaptive policies are often attractive from a theoretical and scientific viewpoint, there is little documented experience on how well they work in practice. In spite of the best intentions when an adaptive policy is implemented, it may fail for a variety of practical reasons: inadequate monitoring of results, lack of an institutional and political framework for keeping the policy in place in the face of pressures from the fishing industry, and unanticipated ecological changes whose effects cannot be distinguished from the effects of the adaptive policy.

This paper documents 15 years of experience with one of the first adaptive management policies implemented in Canada, on the Rivers Inlet fishery of sockeye salmon *Oncorhynchus nerka* (Figure 1). After the Fraser and Skeena rivers, this fishery was historically the largest sockeye salmon producer in British Columbia. From 1979 to 1984, fishing was drastically reduced in hopes that higher spawning escapements would lead to higher total production. The expected benefits have not materialized, and a more moderate policy was adopted in 1989 to provide a better balance between harvests and informative variation in escapement levels. Here we review the history of the fishery, the reasons for experimenting with it, the results of the experiment, and the rationale for the policy change in 1989.

History of the Rivers Inlet Sockeye Salmon Fishery

Rivers Inlet has been a major sockeye salmon producer (Figure 2) since the turn of the century

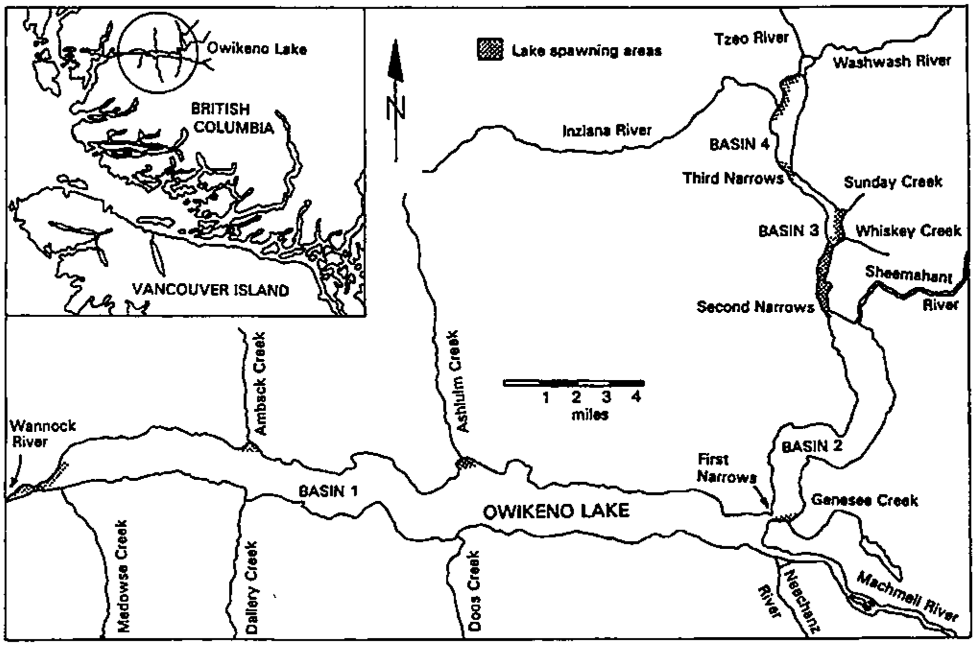

FIGURE 1.—Location of the Rivers Inlet sockeye salmon fishery and production area (Owikeno Lake and surrounding rivers).

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(Wood 1970). Sockeye salmon taken in the fishery are managed as a single stock, though there are actually 12 stocks that spawn in rivers tributary to Owikeno Lake (Figure 1). Maturing sockeye salmon migrate through the Rivers Inlet area mainly in July, with the peak of the run usually occurring around the third week of that month. The bulk of the catches are taken in the 3 weeks surrounding the peak, though a few catches were historically taken as early as June 25. In some years as much as 30% (average, 12%) of the catch is taken in early August, coincidentally with a fishery targeted at that time on pink salmon *O. gorbuscha.*

Table 1 summarizes past escapement estimates for the various streams that contribute to the Owikeno Lake system. The largest spawning run is to the Sheemahant River, a large and glacially turbid stream where spawner enumeration is difficult to impossible. Spawning stocks in the system have been estimated by a variety of methods. In the nonglacial streams, visual counts have been made since 1948 by walking the streams several times each year. In the glacial streams, catches per

TABLE 1.—Spawning escapements to the Owikeno Lake system, 1950–1989. Estimation methods reviewed in text. Average escapements are given in columns 1950–1959, 1960–1969, 1970–1979, and 1980–1989.

Stream	1950–1959	1960–1969	1970–1979	1980	1981	1982	1983
Amback Creek	39,850	32,700	49,250	75,000	180,000	90,000	50,000
Ashlulm Creek	16,130	6,898	8,205	5,000	25,000	15,000	35,000
Dallery Creek	67,750	37,850	19,400	25,000	40,000	60,000	37,500
Genesee Creek	6,040	21,333	17,760	4,500	15,000	8,000	25,000
Inziana River	33,100	42,150	32,500	22,500	18,000	40,000	33,000
Machmell River	0	0	11,438	17,500	20,000	80,000	37,000
Neechanz River	11,400	14,850	25,550	32,500	40,000	50,000	50,000
Owikeno Lake spawners	39,250	9,400	21,000	25,000	10,000	15,000	10,000
Sheemahant River	41,429	68,933	72,850	61,000	200,000	150,000	125,000
Tzeo River	8,656	8,565	13,060	4,000	5,000	55,000	4,000
Wannock River	53,806	91,111	60,000	27,500	150,000	150,000	200,000
Washwash Creek	49,050	56,450	48,850	13,500	50,000	110,000	30,000
Total	316,385	370,695	373,380	313,000	753,000	823,000	636,500

unit effort (CPUE) in beach seine and gill-net sets have been used to provide relative abundances, which have then been inflated by informed guesses of average total abundance. Lake beach spawners are enumerated by drifting over the spawning areas in boats. In 1967 an echo sounding program was initiated at the head of Rivers Inlet (upstream of the fishing area) to provide more direct and immediate assessments of escapement from the fishery (Goruk and Thomson 1988; Winther 1990) and a calibration for the abundance guesses made for glacial streams and beach areas. No clear statistical relationship has been found, however, between the echo sounding index and later escapement counts. This lack of correlation is likely due to variation in fish movement rates through the sounding area, inclusion of other fish species in the sounding counts, and errors in the escapement estimation. Survey methods for years prior to 1980 are poorly documented; since then, an effort to standardize survey methods has resulted in more consistent estimates (Thomson et al. 1988).

Owikeno Lake is very turbid (Secchi depth 1–2 m), and smolts from it are among the smallest in North America (Foerster 1968; Burgner 1987). Most smolts migrate to sea at age 2, spend 2 or 3 years at sea, and return as 4- and 5-year olds (in highly variable proportions). The mix of ages at return has complicated stock assessment because sampling age composition of catches and escapements in order to estimate total production from each spawning brood year becomes necessary. Age compositions have been sampled since 1912 but not in a consistent pattern over the years.

Historical Policies and Fishery Performance

Fishing in Rivers Inlet has been predominantly by gill net. There has never been a limit on the number of boats fishing the area, and in peak weeks as many as 900 boats may congregate in the area if fishing is poor in other areas along the British Columbia coast. The basic management regime by the Canadian Department of Fisheries and Oceans (DFO) has always involved a series of weekly openings, with the number of days open each week set through a combination of preseason planning and in-season adjustments based on day-to-day and cumulative catch rate information.

Prior to the mid-1950s, the fishing area was large (boundaries outside the Inlet proper) and generally

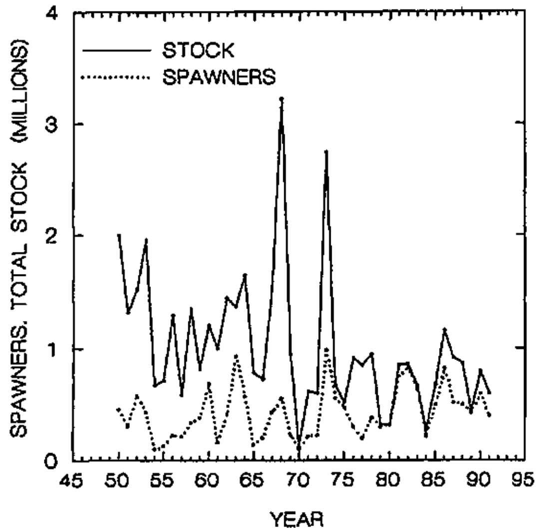

FIGURE 2.—Trends in total stock size and escapement (spawners) for Rivers Inlet sockeye salmon. Catch is the difference between total stock (solid line) and escapement (broken line). Escapements estimated by spawning ground surveys described in the text. The adaptive management experiment in escapement rebuilding began in 1979.

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TABLE 1.—Extended.

Stream	1984	1985	1986	1987	1988	1989	1980–1989
Amback Creek	25,500	52,000	45,000	17,000	40,000	50,000	62,450
Ashlulm Creek	7,000	28,700	47,500	32,000	25,000	12,000	23,220
Dallery Creek	22,000	37,000	30,000	21,500	5,000	2,500	28,050
Genesee Creek	23,000	31,300	30,000	200	500	100	13,760
Inziana River	17,700	20,425	47,500	44,800	20,000	15,000	27,893
Machmell River	5,000	10,000	5,000	1,500	30,000	5,000	21,100
Neechanz River	11,000	35,800	53,000	37,000	53,000	18,000	38,030
Owikeno Lake spawners	1,100	20,000	2,500	2,500	5,000	6,075	9,718
Sheemahant River	25,000	135,000	325,000	100,000	200,000	125,000	144,600
Tzeo River	2,000	10,000	10,000	10,500	9,500	3,500	11,350
Wannock River	45,000	20,000	200,000	200,000	80,000	125,000	119,750
Washwash Creek	30,000	100,000	30,000	54,700	35,000	13,000	46,620
Total	214,300	500,225	825,500	521,700	503,000	375,175	546,540

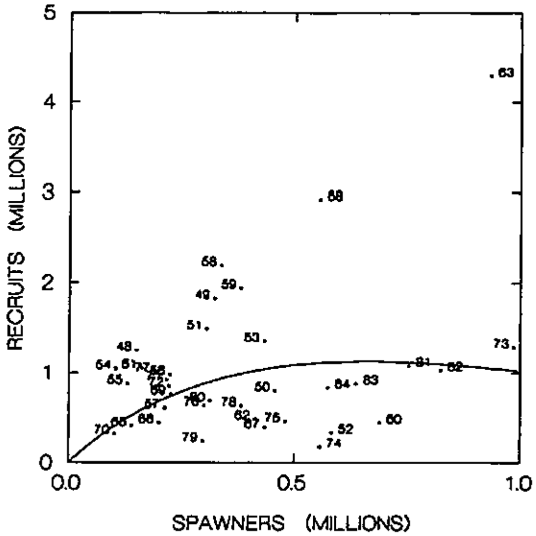

FIGURE 3.—Stock-recruitment pattern for Rivers Inlet sockeye salmon, 1948–1983 spawning years. Ricker curve fitted to data from 1948 to 1973, with Ludwig and Walters' (1981) bias correction for spawning stock errors and Walters' (1985, 1990) bias correction for time series effects. Note agreement between recent recruitments and model predictions.

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open for 4–5 d each week. Catches fluctuated substantially but with no obvious trend (Figure 2). Widespread conversion to nylon gill nets by the late 1950s led to concern about overfishing, and a few alarmingly low escapements were recorded during the late 1950s to mid-1960s. The management response was to reduce the size of the fishing area, from the area the fish migrated through in about 5 d down to the present fishing area by 1985. It now takes fish about 3 d to pass through the fishing area, so that a 1-d opening each week can, at worst, harvest no more than 3/7 (43%) of the migrating fish. Until 1970 it was felt that exploitation rates of around 60–80% per year would provide near optimum escapements averaging 400,000–600,000 spawners.

Suspicions of recruitment overfishing grew especially strong after a weak spawning run in 1965 was followed by the lowest run in history in 1970 (Figure 2). These suspicions were further corroborated in 1974–1975 when very poor returns were seen from the 1970 spawning. By the late 1970s it was feared that the Rivers Inlet stocks might be entering a regime of "cyclic dominance" as seen in Bristol Bay and the Fraser River, where strong spawning runs would continue to produce strong recruitments but weak runs would be held down by fishing, hence producing cyclic gaps in abundance (Eggers and Rogers 1987; Walters and Staley 1987).

The basic reaction to fears of overfishing during the 1970s was to reduce the number of days per week fishing was allowed, especially in the early part of each fishing season. In good years, this reaction resulted in catch-up fishing at the end of the season, with very long openings (six, seven, or even more continuous days) that were inconvenient for fishers and processors.

Design of the Stock Rebuilding Experiment

During the late 1970s, there were several assessments of Rivers Inlet stock and recruitment data (Walters et al. 1982; Wong 1982; R. Hilborn, University of Washington, personal communication) based on fitting stock-recruitment models with data corrected for biases due to errors in spawning stock estimation (Ludwig and Walters 1981; Walters and Ludwig 1981; Walters 1985). These assessments suggested that there had been recruitment overfishing during the 1960s and 1970s, and that the optimum escapement (to maximize average annual catch) might be as large as 1,000,000 spawners. The best fitting stock–recruitment curves indicated optimum escapements of around 400,000 fish (Figure 3), even after correction for known biases due to errors in spawner enumeration (Ludwig and Walters 1981) and time series effects (Walters 1985, 1990), but these stock–recruitment curves were not taken seriously because of poor fit to the data and possible bias in the fitting procedures. In the early 1980s, assessments of gravel spawning areas and lake capacity to produce smolts (DFO, unpublished data) also suggested that spawning runs of 1,500,000 or more might be needed to make full use of habitat capacity. More recent evaluations (1989–1991; K. Hyatt and M. Johannes, DFO, personal communication), however, based on lake carrying capacity, presmolt densities, and typical egg–smolt survival rates for sockeye salmon, suggest that the number of smolts required to adequately seed the lake might be produced by as few as 250,000 spawning adults.

Officials of the DFO were uncertain about how to weigh the broad range of estimates of optimum escapement for Rivers Inlet. The DFO officials recognized, however, a window of opportunity to initiate a new management strategy for the fishery for 1979 and 1980. There was widespread concern about overfishing among both government scientists and commercial fishers, and poor returns were expected due to low escapements in 1975–1977; thus, it was anticipated that there would not be much fishing anyway in 1979–1980 and possibly not until 1984. Also, good runs were expected for other sockeye salmon populations along the British Columbia coast (Fraser and Skeena rivers and enhanced stocks like those in Barkley Sound), and these would provide a buffer for fishers against losses of Rivers Inlet catch.

The DFO decided to capitalize on the window of opportunity by closing the Rivers Inlet sockeye fishery almost entirely for one 5-year cycle beginning in 1979. Fishers were warned that a second cycle of closure might be necessary if the 1979–1984 returns were poor and provided only modest rebuilding of escapements. The DFO explicitly stated that the new long-term escapement target would be 1,000,000 spawners, subject to review when recruits from the 1979–1984 spawnings had begun to add new (and hopefully informative) data points on the stock–recruitment relationship. Thus DFO was explicit about labeling the rebuilding plan and higher escapement target as an adaptive or experimental policy; skeptical fishers warned that the plan might not work but were told that the plan had to be tried for at least 10 years before reliable results could be expected.

The general policy choices and possible outcomes recognized in 1979 can be summarized in a simple decision table (Table 2). Columns of the table show alternative optimum spawning stock sizes (a low stock of 400,000 spawners versus a high one of 1,000,000 spawners), and the rows indicate basic policy choices (continue historical management versus experiment). Reading across each row provides a summary of possible consequences from adopting that row's policy. Note that while the historical policy was expected to continue producing a reasonable catch, the experimental policy was expected to produce a short-term loss followed either by a return to the status quo or to a higher long-term catch. While it is not clear from this table that the experimental choice was superior to a more conservative historical policy, the expected value of catches from the experimental policy (averaged over hypothesized outcomes in the experimental row of Table 2) is higher than for the historical policy if the expected value of catches is summed over many years (i.e., a discount rate less than 7% per year is used in calculation of the present value of the fishery). In other words, a long-term improvement of 20% in average annual catch (to 600,000 from 500,000) does represent a very substantial increase in potential economic value of the fishery, but only if that potential is recognized by using low discounting rates in present value calculations.

TABLE 2.—Hypotheses about stock response, based on optimum spawning stock size, to policy choices for Rivers Inlet sockeye salmon as seen by decision makers in 1979. Historical policy would involve continued high exploitation rates; experimental policy would involve reducing or closing the fishery for some years. Hypotheses about outcome based on analysis of spawner–recruit data available as of 1979.

	Optimum spawning stock	
Policy choice	Low (400,000)	High (1,000,000)
Historical	Average catch 500,000/year	Average catch 500,000/year
Experimental	Reduced catch for 10-15 years, then 500,000/year	Reduced catch for 5–10 years, then 600,000/year

One weakness in planning the experiment was a lack of careful statistical analysis of whether the monitoring system would be adequate to detect responses to increased escapement. No one tried to establish, based on historical variation in recruitment rates, how many years of experimental stock–recruit observations might be necessary to decide with any confidence whether recruitments had increased under the experimental regime. No one looked closely at the escapement monitoring program to determine whether substantial increases in recruitments (particularly to turbid rivers like the Sheemahant) might go undetected. It was assumed that increases in stock size would be dramatic enough to show up clearly in escapement counts, echo sounding surveys, and catches during the very limited commercial fishing openings. Stock sizes of around 1,500,000 fish were forecast to begin in 1985, based on average recruitment rates per spawner in recent years. Such large stock sizes should have resulted in a doubling or tripling of escapements, which it was felt would be clearly visible in spite of known shortcomings with all the monitoring procedures.

Recent Stock Trends and In-Season Management Performance

It is evident from Figure 2 that estimated stock size has not increased since 1984 as expected. In fact, the stock–recruitment observations since that year (representing spawning years 1978–1983) have for the most part been quite close to predicted values from a Ricker stock–recruitment curve fitted without bias corrections to the data for brood

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years 1948–1974 (Wong 1982); for that curve, the estimated optimum escapement was around 400,000 spawners. A relatively poor return was expected in 1980, and the estimated return was even lower than the expectation. Better returns were expected in 1984, but instead the run was one of the lowest on record (partly due to the unexpectedly low escapement in 1980). Estimated runs for 1985–1988 were only about half of the forecast values based on average historical recruits per spawner; the Ricker curve, estimated either with or without various bias corrections, resulted in lower forecasts (which were not made public) because it predicted lower recruits per spawner following the experimental escapement increases that were apparently realized for 1981–1983.

After nearly closing the fishery for 1979–1984 (<3 d open to fishing each year), very limited openings of 1–2 d/week were allowed during the peak of the runs in 1985–1988. When echo sounding indicated a strong and late run in 1988, there was one long opening (11 d) at the end of that season. After the 1988 season, the fishing industry indicated strong distrust of the DFO forecasts and asked for a substantial revision of the fishing policy.

Why the Experimental Policy Failed

From a scientific viewpoint, we might argue that the Rivers Inlet experiment has been a great success. It appears that the predictions of the Ricker recruitment model have been confirmed, and that the optimum escapement is indeed only about 400,000 fish. Some as yet unidentified limiting factor appears to be preventing higher recruitments, in spite of biologists' feelings that there is ample room for more spawners in the rivers. It is precisely this sort of unexpected result that justifies adaptive management experiments in the first place: we dare not trust predictions based on fragmentary analyses of particular life stages or habitat factors.

Yet there are doubts about whether the experiment has even been a scientific success. There are too few years of data from the experimental period, especially considering that there have been 3–4-year runs of relatively poor productivity (poor recruits/spawner, perhaps because of poor marine survival) in the history of the fishery (e.g., 1950–1953 and 1970–1975; see Figure 2). Recent years may just represent another of those runs. It is also possible that recruitments have increased as originally predicted, but that these fish have gone not into catches but rather into spawning rivers like the Sheemahant, where fish cannot be enumerated with any accuracy. Indeed, the 1988 echo sounding data indicate a far stronger escapement than recorded in spawning stream surveys; however, those high acoustic counts can also be explained by the presence of unusually large numbers of pink salmon and walleye pollock *Theragra chalcogramma*.

It was expected that more years of recruitment measurements for high spawning stocks would be available by 1989. The stock sizes in 1979 and 1984 were far lower than expected, making it impossible to achieve high escapements in those years even in the absence of fishing.

The experiment has certainly not been a success from the commercial fishers' viewpoint. They have seen a drastic loss in catch, even allowing for the years (1979–1980, 1984, and 1990–1991) when they would probably not have been allowed much fishing in any case. They have seen a large reduction in the number of days fishing per season, followed by an exhaustingly long opening (11 d) in 1988. In return for these sacrifices, all they have heard is that maybe there has been a run of poor years for marine survival or maybe the runs have improved but the improvement has not been measured accurately.

So in the end we must admit that the experiment will be widely viewed as a failure, unless very high recruitments result from the most recent spawnings (1987–1990). Fishers have been asked to give up too much for too long with inadequate assurance that the results would be unambiguous or accurate enough to insure better management of the fishery in the long term. There is still a good chance that the optimum escapement is as high as originally estimated (1,000,000 spawners), but it will be harder than ever to convince fishers that they should gamble on that optimum by giving up more catch in the short term.

A Balanced Long-Term Strategy

By 1989 there was general agreement between DFO and fishing industry representatives that the original experimental policy should be replaced by a more balanced management strategy that would continue to provide protection for very low runs, provide reasonably steady catches in most years, use only larger runs as opportunities to allow high escapements and hence continue to test for the possibility that such escapements are in fact optimum, and be practical to implement considering uncertainties and constraints associated with the in-season management process. In an effort to design such a strategy, DFO convened a 1-week workshop at Owikeno Lake in May 1989. During this workshop, a group of DFO scientists and industry representatives reached consensus on the strategy described below; this strategy has been in place for four seasons (1989–1992).

A Long-Term Harvest Strategy

It was felt that the basis of the new policy should be a clearly defined harvest strategy rule relating the target exploitation rate for any year to the estimated total stock size for that year (Hilborn 1985, 1986). In general, an optimum feedback policy will involve such a rule (Ruppert et al. 1985; Walters 1986; Hightower and Lenarz 1989). To avoid debate about whether the stock size was above or below some arbitrary threshold for changing from one target harvest rate to another (Hilborn and Luedke 1987), it was decided that the strategy rule should be a smooth curve (harvest rate varying smoothly with stock size). Furthermore, the rule should specify harvest rate to be as low as practicable for stock sizes below 400,000 fish and should specify increasing harvest rates for stock sizes above 400,000 fish; however, there should be an upper limit on harvest rate so as to provide high escapements from very large runs.

To evaluate alternative harvest strategy rules, the Owikeno workshop participants used a combination of hand calculations (of average catches and escapements for different stock sizes) and a simple microcomputer simulation game based on the Ricker stock–recruitment equation but including realistic levels of random variation (estimation and simulation procedures as in Walters 1986, 1990). Copies of the simulation game, which also does stock–recruit curve fitting and spreadsheet data management, are available from D. Radford (DFO, Prince Rupert, British Columbia; IBM PC program "ssa").

After much discussion and simulation of performance for different rules (sample results in Table 3), the workshop participants agreed on the rule curve C in Figure 4. This rule specifies no harvest for stock sizes below 200,000, a minimum harvest rate of 10% for low stock sizes (200,000–400,000), and a harvest rate rising to around 50% for stock sizes near 1,000,000. Simulations indicated that for most years this rule should give escapements near 400,000 but should result in less year-to-year variation in catches than would a rule (curve B, Figure 4) based on always trying to achieve an escapement of 400,000 (see standard deviations in Table 3). Curve C should give somewhat more variable catches than would a simpler fixed-exploitation-rate rule (curve A, Figure 4), but participants were opposed to such a rule because they felt (rightly) that it would tend to perpetuate any cyclic variations that might develop following accidental years of low survival or high harvest (as happened from the mid-1960s through the 1970s).

TABLE 3.—Expected performance of alternative harvest strategies, estimated by averaging results from 100 40-year simulations of a stochastic Ricker stock–recruitment model (model shown in Figure 3; random variation set to give similar pattern to historical data). Catches in thousands of fish. Standard deviation of catch is an index of interannual variation faced by fishers.

Policy option	Mean catch/year	SD of catch	Percent of years with >800 spawners
Observed (1948–1990)	598	544	9.1
Fixed harvest rate	246	246	1.9
Fixed escapement			
Policy B, Figure 4	513	445	0.0
Policy A, Figure 4	482	280	2.6
Policy C, Figure 4	486	364	5.6

Based on historical frequencies of good survival (Figure 2) and the simulation results (Table 3), the adaptive management strategy represented by curve C is expected to result in highly informative "experimental" escapements (exceeding 800,000 spawners) only about once per decade. At this sampling frequency, it would likely take another 60–80 years to gather enough observations to be statistically confident that high escapements do indeed lead to substantially higher recruitments. (In this case, a substantial response would be indicated by mean recruitment exceeding 1,500,000 for spawning stocks of 800,000 or more.) Thus the strategy represented by curve C is adaptive management in only a long-term sense; it provides some opportunity for future generations of fishers and managers to detect the impact of higher spawning runs. Infrequent experimentation is certainly far from optimal in terms of the simple management objectives (e.g., maximization of expected long-term catch) that have previously been included in optimization calculations of adaptive management strategies (Walters 1986); such calculations have generally indicated that quick, harsh experiments are optimal.

Constraints Imposed by In-Season Management

We were also concerned about whether curve C in Figure 4 is practical to implement, considering

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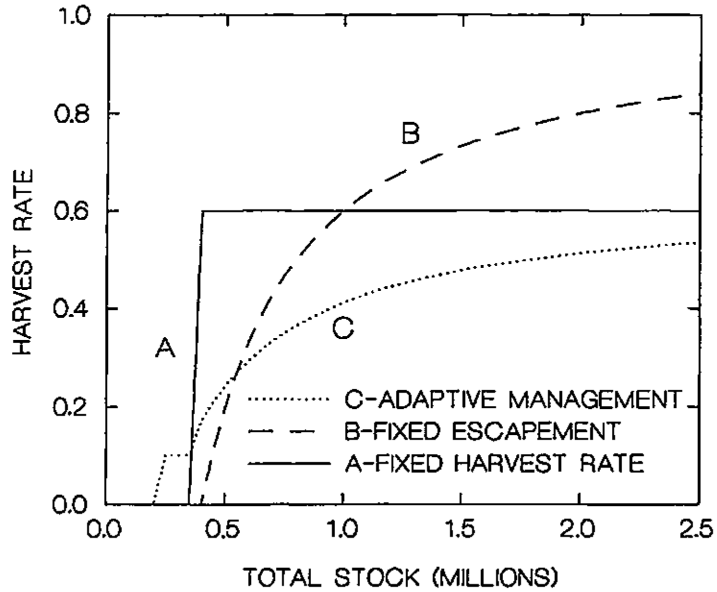

FIGURE 4.—Possible harvest strategy curves relating target harvest rate to stock size. The Rivers Inlet fishery was historically managed with a fixed harvest rate strategy (curve A), but maximum average catch would be expected from a constant escapement strategy (curve B). Curve C represents a balanced policy that should provide relatively stable catches while still permitting informative variation in escapements.

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in-season management procedures. As noted earlier, in-season management involves defining a preseason plan of weekly openings based on forecast run sizes and expected number of fishing boats each week, and then modifying these openings from week to week as catch, CPUE, and echo sounding data provide more information about the actual stock size. Unless fairly long openings (2–4 d) are permitted early in the season, little information about the run size is obtained until well after the peak of migration; by that time it may be too late to catch up if the run turns out to be large (as happened in 1988). On the other hand, fishing harder (for information) early in the season may result in exceeding the target harvest rate specified by curve C if the stock turns out to be smaller than expected.

To obtain a better assessment of what is practical in terms of in-season management, we constructed a simple simulation game of the in-season management process. The simulation uses run-timing curves to generate a daily migration pattern into the fishing area, moves fish through the area, and removes harvests as a function of assumed numbers of boats fishing. To calibrate this model, workshop participants compared its predictions of daily catches, CPUEs, and total catch/escapement ratios to recorded estimates for each year, 1962–1988. Participants then adjusted the run-timing curve and catchability parameters until they felt the model could reproduce historical patterns with reasonable accuracy (i.e., until they felt it was a credible representation of the dynamics of in-season movement and harvest). A nonlinear estimation procedure was also used to see if parameter estimates giving an even better fit to the historical daily catch data for 1960–1989 could be found. This procedure gave essentially the same estimates as the participants had found by trial-and-error gaming and visual comparison of model results to data.

We then used a simple gaming procedure to determine whether the adaptive management strategy (curve C, Figure 4) could be followed in practice. One of the workshop participants acted as "father nature," secretly choosing run size and timing patterns for the simulation. He then started the in-season simulation, pausing each simulated day to give the other participants the latest modeled statistics on catch, CPUE, and escapement echo surveys.

Participants then acted as the Rivers Inlet in-season management committee, analyzing the data to update their run size estimates and openings using the same arguments and procedures as in the actual fishery. After a dozen such gaming trials, we realized that (1) it is not good to use very restrictive openings at the beginning of the season (as a hedge against the risk of a low run) because in most years this strategy would force the use of very long openings near the end of the season and would often lead to total catches well below target; and (2) with longer, more informative openings early in the season, it is generally impossible to keep exploitation rates much below 25–30%, particularly on very low runs. Very low runs, especially if they arrive a week or two earlier than average, are not clearly evident from in-season monitoring indices until about the third week of fishing; by that time, some damage is already done under any in-season plan that provides enough informative early fishing time to avoid continued fishing after the third week.

The Present Compromise

After working back and forth between the long-term population model and the in-season game to test different rule curves for long-term performance as well as practicality for implementation, the Owikeno workshop participants finally reaffirmed curve C (Figure 4). They also concluded that for the policy represented by curve C to be truly effective, given the need for in-season fishing data to estimate run size, fishery openings should follow two rules: (1) openings should be at least 2 d long for the first 2 weeks of the fishery each year, unless the forecast stock size is below 400,000; and (2) if the forecast suggests a very large run, these early openings should be as long as 4 d, depending on the amount of fishing effort in the area. Longer openings should provide even better data for estimating run size early in the fishing season. Such manipulations of the early openings represent a way of improving the in-season adaptive management process so it can better meet long-term adaptive management objectives. In the in-season gaming sessions, we found that participants learned immediately to use the extra early-season information to improve their performance at meeting annual targets; their performance did not continue to improve during longer sessions when they gamed through the management of a sequence of years representing various historical patterns and extremes.

The adaptive management policy is expected to provide more stable catches than the previous fixed escapement policy (see simulated standard deviations of catch, Table 3). Although the policy may result in somewhat more persistent cyclic behavior following unusual low years, the adaptive management policy is expected to make such cyclic variations less likely to occur in the first place, and it should provide for occasional higher escapements. In the very long term (over the next century), these higher escapements will eventually provide tests of the original adaptive management hypothesis that the optimum escapement is at least double the recent historical average. If it turns out that recent escapement estimates have been too high (i.e., if the stocks are in fact more badly depleted than we thought when the experiment was started), then the form of the harvest rule (low harvest rate at low stock sizes, see Figure 4) should allow recovery within 10–15 years, provided the harvest rule is used in conjunction with improved escapement monitoring.

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Conclusions

Has adaptive management really been a failure in the Rivers Inlet case? We believe not. It has proceeded with too much optimism about how quickly clear results could be expected and with perhaps too harsh an immediate impact on commercial fishers. The experimental escapement policy certainly did not produce the increases in recruitment that we expected. But the experience has provided impetus to develop a strategy that appears to provide a better balance of objectives than was achieved historically, and the new strategy will still be an adaptive one. The new strategy is mainly disappointing from a scientific viewpoint; the current generation of biologists will not likely see whether higher escapements can improve production.

Rivers Inlet has provided four major lessons for the design of future adaptive policies. First, it is important to be patient about the acquisition of scientifically useful information; a harsh experimental policy may be more informative and have higher expected value for the long term, but these theoretical benefits may not mean much in the face of pressures placed on the management system once the immediate impacts of the experiment begin to be felt. Second, it is critical before starting large experiments to invest in the modeling and statistical analysis needed to predict how long the experimental program will take to produce useful results, and whether monitoring programs will be up to the task; 10 years into the experiment, after giving up millions of dollars worth of catch, is not the time to make this modest investment. Third, it is important to maintain continued involvement by fishers in the planning, data gathering, and data analysis; by this we mean deep involvement such as the Rivers Inlet fishers had in developing and gaming with the in-season model described above, rather than a few information seminars or discussion sessions. Finally, it is absolutely critical to maintain a clear, consistent set of records on an annual basis, documenting goals, actions, and results, so that future managers can benefit from past experience.

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