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BETTER SALMON MANAGEMENT IN THE PACIFIC NORTHWEST BY COMBINING TECHNICAL AND INSTITUTIONAL INNOVATIONS

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Better Salmon Management in the Pacific Northwest
by Combining Technical and Institutional Innovations

William K. Jaeger
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ABSTRACT. The restoration of depleted wild salmon stocks in the Northwestern U.S. could be advanced with the re-introduction of in-river fixed gear techniques such as fishwheels, which offer substantial economic, biological, and stock assessment advantages. A dynamic simulation model is used to demonstrate that fishwheels could reduce costs and increase net economic benefits to commercial fishers by a factor of five. Additional simulations indicates that the potentially adverse income and employment consequences that often accompany policy or technological changes can be avoided with appropriate institutions and sequenced policy implementation. The analysis confirms the feasibility of a transition path to more sustainable salmon management that protects and improves the economic interests of current commercial fishers while at the same time restoring wild salmon stocks.

* Assistant Professor of Economics, Williams College. Research for this paper was undertaken while a visitor at the School of Marine Affairs, University of Washington. The author is grateful to Michael Link, Ray Hilborn, James Crutchfield, James Karr, Claribel Coronado, Gordon Winston, Douglas Gollin, and Elizabeth Brainerd for comments and advice.
I. The problem

The seven native salmon species in the Northwestern U.S. have disappeared from about 40 percent of their historical breeding ranges during this century (Huntington, Nehlsen and Bowers, 1996; National Research Council 1996), and the abundance of the remaining wild stocks has been severely reduced. Nehlson et al. (1991) identified 214 stocks at high to moderate risk of extinction. In addition, annual returns of salmon to the Columbia River Basin have decreased from an estimated 12-16 million fish before the 1930s to 2.5 million fish in the 1980s, including those produced in hatcheries. While catch rates in some commercial fisheries have not declined significantly, most runs that appear plentiful today are composed largely of fish produced in hatcheries. Depletion of native salmon has led to extended restrictions or outright bans on recreational and commercial fishing for several species, and several stocks have been designated as endangered or threatened under the Endangered Species Act.

The decline of salmon in the Pacific Northwest has been caused by numerous interacting activities, such as agriculture, forestry, grazing, industrial activities, urbanization, dams, interactions between wild and hatchery salmon, and fishing. Salmon are particularly vulnerable to this wide range of human influences because of their anadromous life cycle whereby they spawn in freshwater, migrate to sea, and return to their natal streams several years later to reproduce and subsequently die.

Among these factors contributing to the decline of salmon, this analysis focuses primarily on two, the roles of commercial harvesting and the reliance on hatchery-reared fish. Salmon have long been important economically and culturally to commercial and sport fishers,
to Indian treaty fishers, and to the communities that depend directly and indirectly on those fishing activities. They are also of cultural and symbolic importance in the Pacific Northwest, where a high "non-use" or existence value is placed on maintaining healthy native salmon stocks (Olsen, Richards, and Scott 1991). While commercial harvest levels in some areas have been maintained into the early 1990s -- in part through increased hatchery production -- both commercial and sport fisheries have been severely disrupted beginning in 1994 by widespread harvest bans put in place to protect several native stocks at risk of extinction as called for under the Endangered Species Act.

Even prior to these recent restrictions, the commercial salmon fisheries in Washington and Oregon suffered low net economic benefits due to the excessive size of fishing fleets and low harvest per vessel which have given rise to a very inefficient fishing economy. For example, estimates of the net economic value of commercial salmon fisheries in Washington State were negative in all regions for troll fisheries, and negative in three of five zones for gill net fisheries (ICF Technology Incorporated, 1988). Fleets sizes are too large for current stocks due in part to the continued decline in stocks from habitat loss and other degradation of freshwater environments, including spawning grounds. Lower stocks have also been the result of poor ocean survival rates in recent years, attributable to changes in El-Niño climatic conditions in the Pacific. This situation for commercial fishing has only worsened in the 1990s with the widespread restrictions and closures of many of these fisheries. Despite widespread use of "limited entry" permitting systems, restrictions on the number of boats and types of equipment have been unsuccessful in substantially reducing the degree of overcapitalization of the fleets, and thus pressures to allow excessive harvesting have continued.
Hatcheries have been used for more than a century to mitigate the effects of dams and other human activity and to replace declining natural fish populations. As a result, a large proportion of the salmon populations in the Pacific Northwest now consists of artificially reared hatchery fish (National Research Council 1996). For many years people did not recognize the potential for hatchery fish to affect wild fish, but it is now clear that these fish have had substantial adverse demographic, ecological, and genetic effects on native fish populations. Artificially reared salmon are behaviorally, physiologically, and anatomically inferior to wild salmon according to many biologists (White, Karr, and Nehlsen 1995, Meffe 1992). They have reduced genetic diversity within and between salmon populations, increased the effects of mixed-population fisheries on depletion of native populations, altered fish behavior, and caused ecological problems by eliminating the nutritive contributions of carcasses of naturally spawning salmon from streams (National Research Council 1996). Furthermore, hatchery fish compete directly with native stocks for survival in terms of in-stream, estuarine, and ocean capacity constraints; they are increasingly recognized as reducing survival in wild salmon and reducing average fish size presumably as a result of competition for food between wild and hatchery fish.

In addition, because wild and hatchery salmon are intermixed and cannot be distinguished until they are caught, the presence of large numbers of hatchery-reared salmon contributes to the pressures to permit salmon harvests above biologically sustainable levels on the wild fish when both are harvested in "mixed stocks." To protect the genetic diversity and ecological productivity of naturally spawning salmon, precautions have been recommended
that include “an overall decrease in hatchery-fish production and --over the short term--in fishing opportunities” (National Research Council 1996).

II. Identifying a potential solution

Dilemmas of this kind, where multiple and conflicting private interests and public goals create obstacles for social change, are common. In this case, the long-run goal of sustaining native salmon populations is in conflict with the short run exigencies of providing commercial fishers and their communities with harvest levels sufficient to sustain and improve their livelihoods. Although reducing the number of artificially reared salmon would benefit wild salmon populations, it would cause severe economic hardship in the short run on commercial and sport fishing industries and the communities in which they operate. Given the numerous and complex causes of the decline in wild salmon, implementing more efficient and sustainable salmon management policies will require considerable effort and expense, and will likely face enormous obstacles. Even past efforts to “buy out” existing commercial fishers in order to reduce the harvest pressures have had questionable success.

How, then, can a transition be made to a more economic and biologically sustainable path? In the recently literature on “sustainable development,” the notion of a “win-win” opportunity has come to refer to policies or projects that promise both economic and environmental benefit rather than trading off one for the other (World Bank 1992). Most examples of these kinds of “win-win” opportunities refer to cases where existing inefficiencies due to price distortions (such as subsidies for energy or water) could be eliminated resulting in higher economic benefits and lower ecological harms.
In the context of salmon, one technical "innovation," the reintroduction of the fishwheel for commercial salmon fishing in the Pacific Northwest is an example of a “win-win” opportunity. In this case, however, the existing inefficiency takes the form of a prohibition on the use of a mostly forgotten technology that appears to offer at least a partial solution to the dilemma of protecting the commercial fishing industry while at the same time reducing dependency on hatcheries. The fishwheel, a “fixed-gear” harvest technology (as opposed to floating harvest techniques from boats), is a semi-submerged waterwheel that is propelled slowly by a river’s current. As the wheel rotates, netted baskets scoop up fish as they swim under the wheel and lift them out of the river. As the fish are lifted up by the rotation of the wheel, they slide gently out of the basket and into a holding tank.

Fishwheels are not a new invention. Historically, they were used in the region, especially on the Columbia River, with great success. They were banned, however, in the 1920s and 1930s in Oregon and Washington in part because they were so efficient at harvesting salmon that fears were raised that they threatened fishing jobs and the future of the salmon runs. Crude versions of this technology are currently used on the Yukon River in Alaska; and modern versions of the technology have been designed and used recently on the Nass River in British Columbia.

Fishwheels have three distinct advantages over current harvesting techniques such as gill netting, purse seining, or trolling. First, they are a much lower cost technology for harvesting salmon. Second, because the fish are caught unharmed, they can be selectively released to achieve differential catch rates for different species, and in the case of marked hatchery fish, or different stocks, species-selective harvesting allows at-risk species to be
returned to the river unharmed. Third, because stationary fishwheels will tend to catch a fairly constant proportion of the annual returning salmon population, fishwheels can provide a relatively accurate, and hence potentially valuable, stock assessment tool for fishery managers.

A complete, or near-complete conversion to fishwheels is not feasible because the efficacy of the apparatus depends on appropriate depth, width, velocity, and turbidity of the river so that their success will be very site specific (Link and English, 1996). Fishwheels have been used successfully on large systems in the Pacific Northwest including the Columbia, Fraser, Skeena, and Nass rivers, and in Alaska on the Yukon. Many of the historically successful fishwheel sites on the Columbia have since been eliminated by the hydroelectric dams which have transformed the mainstem of the Columbia into a series of slackwater reservoirs (Donaldson and Cramer 1971). Nevertheless, other kinds of fixed gear such as fishtraps or weirs may have potential in locations which prove less amenable to fishwheels.

In the analysis below, we examine the economic, biological, and stock management benefits expected with fishwheels in the Pacific Northwest. Specifically the analysis examines the prospects for a shift toward fishwheels, guided by specific policy and institutional changes, that would restore wild fish, reduce reliance on hatcheries, while at the same time protect the incomes of current commercial fishers. The study concludes in the affirmative: fishwheels offers the possibility of reconciling the competing goals of protecting the short-run interests of fishing families and the long-run sustainability of wild salmon runs.

The remainder of the paper is organized as follows. In section III the economics of alternative harvest technologies are described and incorporated into a bioeconomic simulation

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1 The underlying assumption here is that species-specific or wild stock restrictions on harvesting regulations can be enforced. Currently commercial and sport fisheries in the region appear to be managed relatively effectively in this way with a wide range of species-specific and point of catch restrictions.
model for comparing alternative harvest technologies. Section IV describes the results of a
comparative analysis of both deterministic and stochastic models. In section V, model
simulations are used to verify the feasibility of a transition path to sustainable salmon
management. Some concluding comments are presented in section VI.

III. A bioeconomic simulation model for salmon

For the economic comparisons of alternative harvest technologies, estimates of input
requirements, costs, and productivity of the two most important commercial net harvest
techniques in the Pacific Northwest, gillnets and purse seines, are based on fleet data and
analysis for Washington State where these two techniques account for about 90 percent of the
commercial salmon fishery (ICF Technologies 1988). Prices are adjusted to 1996 levels
where appropriate. State-wide averages for costs and revenues are used for comparisons
between these two net-gear harvesting technologies and the alternative fishwheel technology.
Cost and productivity estimates for fishwheels were made available for modern technology
models designed and operated by LGL Limited for the Nisga’a Tribal Council on the Nass
River in British Columbia, Canada (Michael Link, personal communication; Link and English,
1996; Link, English, and Bocking, 1996).

Table 1 presents cost, revenue and productivity estimates for these three harvest
technologies. The figures show that purse seiners have higher fixed and variable costs than
either gill netters or fishwheels at comparable harvest levels that could be expected with each
type of gear. Gill netters have fixed costs similar to fishwheels, but their harvest rates are

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2 Fishwheels are assumed to catch 3,000-5,000 fish per wheel, although higher rates are possible. The
productivity of a fishwheel will depend on the characteristics of the stream at the point where the fishwheel is
installed. Historically, large variations in productivity were experienced on the Columbia River.
much lower even after adjusting the assumed number of trips per vessel from the actual average of 2.69 to more favorable range of 15 - 20, the catch per gill net boat leaves their average cost per fish higher than fishwheels primarily due to higher variable costs.\footnote{Because of evidence of a large number of “part-time” gill netters among the fleet, the economic comparisons modeled in the analysis below are based on assuming 15 to 20 trips per gill net boat.}

An economic model for a representative fishery in the region is constructed based on the assumptions shown at the bottom of table 1. For the scale of the fish population assumed in the model, alternative fleets of gill netters or purse seiners are assumed to operate in the fishery so as to produce harvest, revenue, and expenditure rates similar to those observed. For the harvest production function

\[ H = qES \]  \hspace{1cm} [1]

where \( H \) is harvest, \( E \) is effort in number of trips made by vessels (or days of fishwheel operation), \( S \) is the fish population or stock, and \( q \) is the “catchability” coefficient. Fleet size and the catchability coefficient are set so that harvest per vessel and harvest per trip correspond to observed values in Washington State. Therefore, harvest per unit of effort (trips by vessels) will vary proportionally with the stock \( S \).

Next, the economic characteristics of these harvesting techniques are combined with a dynamic fisheries population model. Based on a simple Beverton-Holt functional form--one of several well-known fisheries population models--this model describes the major life-stages for coho salmon (\textit{Oncorhynchus kisutch}), emphasizing the density dependent survival from egg to smolt life stages over a three year period (Hilborn and Walters, 1992). The model used is given by
\[ S_{t+2} = k_{t+1} \left( \frac{S_t}{\frac{1}{p} + \frac{1}{c} S_t} \right) - H_{t+2} \]  

where \( S_t \) is the number of adult spawning salmon at time \( t \); \( p \) is the intrinsic growth rate (or density-independent survival rate), \( c \) is the carrying capacity or maximum number of individuals that can be produced. The ocean survival rate, \( k \), is set at 4% and is assumed to be independent of stock density (of this particular stock assumed to be small relative to oceanic capacity), and \( H_t \) is the harvest in year \( t \). Hatchery salmon are also modeled as smolts (2 million per year) that are assumed to have ocean survival rates similar to wild salmon.

The size of the fleets for each gear type is assumed to be fixed for this analysis. For the fish population being modeled, comparisons are made between fleets of 50 gill netters, 12 purse seiners, and 25 fishwheels. These fleet sizes are chosen so that harvest rates and net economic benefits per vessel will be comparable to those observed. Since the comparative analysis below is for relatively stable trends in stocks, the possibility of entry and exit of vessel operators is ignored for this part of the analysis.

Salmon are harvested primarily in mixed-stock groups, meaning that wild and hatchery fish are not separable by net harvesters, except after harvest if hatchery reared salmon are marked. As a result, harvest limits are set to achieve the desired "escapement" (the number of salmon allowed to return upriver to spawn) of wild salmon. Since hatchery populations do not require high escapement levels to maintain the stock size (hatchery managers typically collect

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4 Eggs per spawner is assumed to be constant. Ocean survival, assumed initially to be 4 percent in the deterministic model, is modeled to vary stochastically around 4 percent later on. The capacity, \( P \), is assumed to be 6,000,000; initial survival rate is 50. Number of spawners is initially 24,000 in the deterministic model, 20,000 in the stochastic model.

5 Wild stocks are believed to have higher survival rates, although comparative analysis based on coded-wire tags has not detected differences in ocean survival between hatchery and wild salmon, but this is believed to be due to low tagging data and lower recovery efforts for wild stocks (Coronado 1995).
about 5 percent of the adult population as brood stock), being able to allow higher rates of harvest among hatchery fish than wild fish is a desirable policy goal. Fishery managers are able to achieve a higher harvest rate as a proportion of the hatchery fish than as a proportion of the wild fish by allowing harvests to take place at times and in locations that take account of known differential spatial and temporal densities during their return to spawning grounds. Historical data indicate that with the current mix of gear and management tools, harvest rates of hatchery fish 20 percent higher than wild harvest rates on average are possible, although this will vary considerably depending on many factors, including the relative size of the wild and hatchery runs. When selective harvest is allowed in the model (implying that hatchery fish are marked so they can be identified), fishwheels are assumed to harvest 95 percent of the hatchery catch because all wild fish can be released unharmed.

The deterministic version of the model assumes ocean survival to be constant and the adult stock to be known with certainty. A stochastic version of the model incorporates two features. First, a random variation in ocean survival, \( v_t \), assumed to be normally distributed as a proportion of the ocean survival rate, with mean zero and a standard deviation, \( \sigma_v = 0.6 \). The stochastic model then has the form

\[
S_{t+2} = k_{t+1} \left( \frac{S_t}{1 + \frac{1}{c} S_t} \right) e^{\left( v_{t+1} \frac{\sigma_v^2}{2} \right)} - H_{t+2}
\]

where the exponent’s second term corrects to maintain the characteristics of a normal distribution in proportional terms.

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6 Stock variance estimated from time series data for coastal and inland stocks (Pacific Fisheries Management Council 1995).
The second aspect of the stochastic model is uncertainty. The actual stock is unknown and therefore the predicted stock, $\hat{S}$, is the basis for seasonal harvest decisions. Based on evidence from differences between ex ante and ex post stock assessments, the forecast error, $w_t$, is assumed to be normally distributed with zero mean and standard deviation, $\sigma_w$ so that

$$
\hat{S}_{t+2} = e^{\frac{w_{t+1} - \frac{\sigma_w^2}{2}}{k_{t+1}}} \left( \frac{S_t}{1 + \frac{1}{c} S_t} \right) e^{\frac{\sigma_w^2}{2}}
$$

[4]

Under current management practices and harvest techniques, $\sigma_w$ has been estimated to equal 0.20. This will vary among fishery managers, and the estimate used here is subjective and based on comparisons of ex post and ex ante stock estimates. When fishwheels are employed, however, they tend to capture a consistent proportion of the total stock over the course of the harvest period. This provides a more precise in-stream estimate of fish abundance which can be used to improve management (Link 1995). Because of this advantage, when fishwheels are used the forecast error is assumed to be standard normal with $\sigma_w = 0.05$.

With these descriptions of the basic model, the three advantages of fishwheels can be incorporated into the model to assess how they alter both the economics and the biology of the dynamic simulations. First, the lower cost of fishwheels should increase the net economic benefits of the fishery. Second, the ability to release nearly all wild fish unharmed makes it possible to harvest essentially all surplus hatchery fish while releasing wild salmon to maintain their escapement at desired levels. And third, the consistent harvest rates of fixed fishwheels improves stock estimation, enabling more efficient management of the fishery overall. Results of the comparative analyses are presented in the next section.

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7 Estimate from Brian Edie, Washington Department of Fish and Wildlife, July 18, 1996.
IV. Comparative economic results

The net economic benefits of the three different harvest techniques are compared based on simulations of deterministic and stochastic versions of the model under the three alternative assumptions in the model: a deterministic model with no uncertainty about stock and no harvest selectivity possible between wild and hatchery salmon; a deterministic model allowing harvest catch selectivity which differs between the conventional net gear and fishwheels; and a dynamic stochastic model representing variance in ocean survival rates as well as uncertainty in stock prediction. Results in the first row of Table 2 for a deterministic, non-selective model show that gill nets are currently uneconomic on average with negative net economic benefits of $-3,384 per boat, or $-169,186 for a fleet of 50 vessels.\(^8\) Purse seine boats have a positive net economic benefit of $1,654 per boat (revenues exceed costs by 30 percent). By contrast, for a “fleet” of 25 fishwheels, the net economic benefit is $7,065 per wheel. For the fishery overall, this amounts to nearly $200,000 more than the $19,952 if purse seines were used, or more than 10 times as high.

When differences in the ability of these different gear types to select, or sort, their harvest between wild and hatchery-reared salmon are taken into account, the advantages of fishwheels are expected to be even higher. The reason for this is due to the increased precision in selectivity which means that more (nearly all) of the hatchery fish can be harvested without reducing the escapement of the wild fish below desired levels. Indeed, when selectivity is allowed for in the model, gill netters’ net economic benefits remain negative and

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\(^8\) Negative returns to gill net fishers have been persistent for over a decade given the declining stocks and few opportunities for vessel owners to sell either their boats or their permits. Many of these vessel owners work at other jobs or fish seasonally in Alaska with a second vessel.
purse seine net benefits rise to $10,572 per vessel, but this is still half of the revenue per fishwheel when 25 fishwheels replace the 12 purse seiners. For the entire fishery the advantage of fishwheels over purse seines alone amounts to $386,746, or a four fold increase in net economic benefits.

The most realistic set of comparisons are those from the stochastic model. As expected, the net revenues for all gear types are lower due to efficiency losses under uncertainty and because of the disequilibrium conditions with such large random shocks. Nevertheless, the comparisons under alternative gear types, based on 50 replicates of 30 year simulations of the stochastic model, demonstrate that the advantages of fishwheels are even larger under realistic conditions of uncertainty and variability. The net benefits per year of a fishwheel exceed those of a purse seine boat by $8,793, or slightly less than the $9,972 estimated with the deterministic model. The effect of the introduction of stochasticity, however, reduces net benefits to purse seiners by 43 percent, while fishwheel net benefits are lowered by only 27 percent. Nevertheless, the present value of net benefits of fishwheels for the overall fishery, based on these 30 year simulations, is five times as high as the same fishery operated entirely with purse seine boats, or more than $4 million in additional resource rents from the fishery.

V. A proposed transition path to sustainable salmon management

Despite the prospect of significant social benefits, policy changes often face opposition when there are negative local impacts or when short run costs are concentrated on a small, vulnerable, but influential, group. In this case, concern about the income and employment of
commercial fishers, their families, and their communities, has made it extremely difficult to lower harvest levels and reduce the degree of overcapitalization in these industries. Technological change often carries with it the prospect of reduced employment, and this could certainly be an important issue in the case of a reintroduction of fishwheels.

The analysis here suggests, however, that depending on the numbers of vessels and fishwheels involved, a transition is possible where overall levels of employment in the fishery are maintained at current levels while earnings actually rise for those who operated the fishwheels. Although the estimated wage payments (excluding thenet revenue of vessel owners) from a fishery with only gill netters is higher than for one with only fishwheels, a purse seiners-only fishery would see wage earnings lower than one with fishwheels. Currently in Washington State the shares of salmon harvested by gill netters and purse seiners are about equal. Therefore, the wage implications for a conversion to fishwheels from one that is currently half gill nets and half purse seines would result in little change in wage income, based on the results of the stochastic model. When the net economic benefits retained by the vessel or fishwheel owners are added, however, to wage payments, the total income comparison for the two alternatives are much more favorable to the fishwheel techniques.

Still, commercial fishers are widely believed to be reluctant to abandon their vessels and the traditional boating lifestyle associated with fishing. Proposing that they give up their current way of life in exchange for the right to operate a stationary fishwheel on a riverside will undoubtedly encounter some strong opposition. Furthermore, any reduction in the number of commercial licenses under existing limited entry systems would raise the prospect of some families being forced to abandon fishing as their occupation. Moreover, the
introduction of fishwheels during some transition period could create conflicts between newcomers and established fishing families that may regard their participation in the industry as a *de facto* property right or entitlement.

For illustrative purposes, then, a feasible transition path that is both technological and institutional is described here. The intention is to determine whether a transition to a more sustainable path for salmon management can be devised that takes advantage of these unrealized benefits (from the introduction of fishwheels), but that allocates these benefits and sequences the transition in such a way that no one group is made worse off, and in fact all groups are made better off during and after the transition.\(^9\)

If the net social benefits of the change are substantial, and these resource rents are captured by those who, *ex ante*, may resist the change, then it seems plausible that the resistance could be reduced or eliminated. If fishwheel operators achieve net economic benefits much higher than existing commercial fishers, then one would expect the prospect of a substantial improvement in their economic well-being to be sufficient to induce some current commercial fishers to convert from gill nets or purse seines to fishwheels. Since some may be more attached than others to the traditional forms of harvesting, a mixed fishery including fishwheels, but also some gill netters and purse seiners, may be more socially acceptable than a complete conversion to fishwheels.\(^10\)

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\(^9\) The proposed intervention is calculated in the spirit of the "Kaldor-Hicks" compensation criterion, but going further by using the policy design to translate a potential Pareto-improvement into an actual Pareto-improvement.

\(^10\) In addition to the question of acceptability, a complete conversion to fishwheels is unlikely to be feasible because, as noted above, their efficacy is very site specific, requiring a narrowing of the river, and enough depth, velocity, and turbidity in order to perform well.
With that rationale, a transition can be simulated with the model where, beginning with an existing fishery where one half of the allowed harvest level is caught by gill netters and the other half by purse seiners, the transition would shift permits and the catch toward one where half of the normal harvest is allocated to fishwheels and the other half is split between the remaining gill netters (20 percent) and purse seiners (30 percent). The model simulates a gradual transition over five years where, in terms of numbers, the fishery is initially shared equally between 25 gill net vessels and 6 purse seiners, but where during the five-year transition, boat operators are induced (or coerced) to exchange a boat permit for a fishwheel permit within the existing limits on number of established vessels. For this simulation, it is assumed that over the five year period gill net boats are reduced from 25 to 8, the number of purse seiners remains at 6, and each of these reductions corresponds to an additional fishwheel so that at the end of the transition there are 17 fishwheels in operation, or 31 total “vessels,” the same as at the beginning. Of course, any individual fisher may decide at any time to leave the industry by selling his or her permit. But by allowing current commercial fishers to exchange the rights from one gear type to the other, there exists the possibility that all current owner/operators could continue to fish.

The results of this simulation are shown in figures 1 - 4 from simulations over 30 years based on 100 replicates of the stochastic model. The transition path reflected in figures 1 and 2 indicates that by shifting 50 percent of the commercial fishery over to fishwheels all commercial fishers are made better off. Net economic benefits for the entire fishery rise sharply from nearly $-100,000 to approximately $400,000 per year after a ten year transition period. Perhaps more important from the perspective of the fishers themselves, the net
economic benefits per vessel rise for all groups, with gill netters consistently receiving positive net benefits after 5 years, and purse seiners' net benefits rising from about $6,000 per boat per year to more than $10,000 per boat per year following a ten year transitional period. The average net benefit per fishing unit (vessel or wheel) rises from a negative value $-2,910 to over $11,000 per year. Those owners who switch from gill netting to fishwheels see their annual net benefit rise from $-3,246 to more than $15,000 per year, while those gill netters who continue gill net fishing increase their benefits to $3,514. Those purse seine operators that continue to fish with that particular gear double their net benefits gradually over a ten year period.

The magnitude of these benefits are possible with the introduction of fishwheels for several reasons. First, lower cost of fishwheel harvesting raises the net economic benefit directly for a give level of harvest. Second, because fishwheels are better able to selectively harvest, a larger proportion of the hatchery fish are able to be caught without inadvertently reducing the wild stock escapement below desired levels. Third, the improvement in stock estimation makes it possible to set harvest rates more efficiently, and also strengthen the wild salmon populations. Over time wild stocks recover and the total harvestable number of fish increases, thereby increasing the catch per vessel and lowering the degree of overcapitalization of the boat fleet relative to the size of the harvestable stock. Note in Figure 3 that income to commercial fishers in the form of wage earnings plus profits (resource rents) increases to about $500,000 per year after 8 years of operation.

In addition to these commercial benefits, the advantages that fishwheels offer for selective harvesting and abundance estimation of wild fish enables the stock of wild salmon to
rise gradually from fewer than 30,000 fish to more than 90,000 fish. An alternative scenario that also reduces the level of hatchery production could also be simulated with only marginal reductions in the net economic benefits to commercial fishers.

The effect of a transition to fishwheels on economic benefits and wild stocks will vary considerably from location to location. These results are intended to illustrate the potential for increased efficiency and improved economic well-being of commercial fishers and their families, while at the same time protecting and restoring native stocks of salmonids. The benefits may be lower in some locations for a number of reasons. First, in some locations and for some salmon species the commercial potential for in-river harvesting of salmon is limited because these stocks display metabolic and physiological changes that reduce their commercial value as a food fish. In these cases, for example for chum and pink salmon, or for stocks of chinook salmon that spawn soon after entering their natal river, the commercial potential for fishwheels may be small or non-existent, or the harvested fish may sell at a discount. To allow for this possibility, the analysis above conservatively assumed a 10 percent discounted price for fish caught with fishwheels. However, there is evidence to suggest that in many cases salmon caught by fishwheel (especially coho and sockeye species) may actually sell for a premium above the price of fish caught in commercial net fisheries because the fish can be handled more carefully, refrigerated more quickly, and brought to market in better condition (Michael Link, pers. comm.).

The benefits and costs considered in the scenarios modeled above have been narrowly focused and other, additional benefits have not been captured in the analysis. For example, the analysis may understate the benefits of a transition to fishwheel harvesting to the extent
that the benefits to sport fishing or the non-use value of restoring native salmon stocks is significant. Considerable evidence suggests this is so, given the many expensive and elaborate efforts being made or proposed to restore salmon populations (National Research Council 1996). For example, some of the measures being proposed to restore the wild salmon runs on the Columbia River would cost more than $15 million annually. And to restore salmon on a much smaller river, in 1992 Congress passed legislation clearing the way for the $110 million removal of two dams from the Elwha River. More direct measures of the value of wild salmon include one contingent valuation survey estimating that the non-use and sport fishing benefits from a doubling of the salmon and steelhead runs on the Columbia River are $171 million annually (Olsen, Richards and Scott, 1991).

There are other costs and considerations relevant to the reintroduction of fishwheels that have not been explicitly taken account of in the analysis above. For example, the selective harvesting advantage of fishwheels requires that all hatchery fish be tagged, an activity that involves significant cost, although Washington State hatcheries are already expected to be tagging all hatchery salmon within the near future.11 In addition, productive fishwheel operation requires choosing a location on the river with appropriate characteristics in terms of width, depth, speed of flow, etc. to give rise to adequate catch rates. Some rivers may not be appropriate for fishwheel operation. For example, fishwheels could not operate on the mainstem of the Columbia River where dams have eliminated essentially all free flowing river reaches.12

11Personal communication, Brian Edie, Washington Department of Fish and Wildlife, July 18, 1996.
12Current use of several experimental fishwheels on the Nass River, and commerical use on the upper Yukon River in Alaska suggest that finding appropriate locations for installing fishwheels is not a major obstacle.
Perhaps the most significant dimension in which the analysis above may overstate the case for fishwheels is that it has ignored the very complex jurisdictional and allocation issues that would arise with any significant changes in where and when salmon are harvested. Complex and contentious issues would arise between off-shore, mixed-stock commercial harvesters, Indian fishing rights, and the introduction or exchange of rights between net fishers and in-river fishwheel operators. Because different groups view themselves as having de facto property rights to specific salmon stock, or to sequential priorities in terms of the seasonal migration of the salmon, harvest reallocations—even those confronting current management decisions—raises complex issues similar to the difficult “third-party” effects that constrain transfers of water rights along a river. In addition, fishwheel operators might acquire the right to operate a fishwheel on a particular river, but may not have access to install their wheel without engaging in some form of easement contract with a local land owner.

These obstacles would loom large if the net economic benefits of fishwheels were marginal. However, since the potential net economic gains appear to be so large, it seems reasonable to expect that these institutional obstacles could be overcome through appropriate policies, institutions, and incentives.

VI. Concluding comments

Fishwheels were outlawed in Oregon in 1926 and in Washington in 1934 after a long and contentious political battle. The arguments included concern that these relatively cheap and efficient “dippers” threatened the future of salmon runs on the Columbia River. But the
real reason at the time was an economic fight over salmon, "with the low-cost [fishwheel]
production on the Upper river being particularly irritating to the Lower-river [gill
netters]" (Donaldson and Cramer 1971, p. 113). In today's circumstances, however, the
fishwheel's advantages in economic efficiency and biologically-efficient management offer an
opportunity for a transition from an overcapitalized, inefficient, and largely unsustainable
situation, to one that sustains the biological resource while at the same time improving the
current economic well-being and future prospects of commercial fishing families.

As the model simulations presented above demonstrate, the reintroduction of
fishwheels can in principle be designed and implemented so that the large net economic
benefits are distributed among those individuals who might otherwise suffer a loss of benefits
by changes in existing policies. A sequenced transition of this kind, where current fishers
capture the substantial economic gains of improved harvesting and management efficiency,
could reasonably be expected to have more support among fishers -- and the general public --
than alternatives to reduce harvest levels.

In addition to the several direct, and estimable, benefits that a reintroduction of
fishwheels would provide, fishwheels would give rise to one additional change that may be an
important factor in promoting the long run sustainability of Pacific Northwest salmon. The
decline of salmon reflects all the characteristics and symptoms of a set of complex, interacting
"commons" problems due to a wide range of competing claims for harvesting fish, diverting
water, and altering habitats. These conflicting interests are diverse, dispersed, and often so far
removed from each other spatially and temporally that the identification of individual actions
with cause and effect is virtually impossible. When fish that are returning to dozens of
different streams are caught at sea, the link between a specific asset and the actions that
degrade it are too far separated.

Fishwheels, however, would be operated in a location and at a time where the fish
population, the catch, and the habitat and water resources that support them, are more direct,
observable, and proximate. A fishwheel operator could be expected to take a more active
interest in the protection of all the resources which contribute to a healthy fish stock in the
river where his or her fishwheel is located. Unlike purse seiners, trollers, or even recreational
fishers who may have little knowledge of the streams of origin for their catch, fishwheels
provide a much more direct link, and hence stronger incentive, toward protecting the health
and integrity of these riverine and terrestrial habitats on which the salmon depend.

Evidence from a wide range of case studies and analysis of successful common-pool
resource management regimes suggests that among the most important factors contributing to
successful management of a common pool resource is the direct and observable connection
between the users of the resource and the consequences of their actions (Ostrom 1990). In
the case of salmon, current institutions and interest groups are isolated from one another and
removed from the resources of concern, and they have proven incapable of ensuring the long-
term future of salmon (National Research Council, 1996). It seems plausible, therefore, to
suggest that a transfer of fishing rights from off-shore mixed stock fishers to operators of in-
river fishwheels may alter these incentives significantly and induced evolution toward
institutions that are more consistent with sustainable salmon management.
REFERENCES


Table 1. Economics of salmon harvest by gear type

<table>
<thead>
<tr>
<th></th>
<th>Gill net boat and gear</th>
<th>Purse seine boat and gear</th>
<th>Fishwheels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel/unit asset value</td>
<td>$ 20,000</td>
<td>$ 65,000</td>
<td>$ 20,000</td>
</tr>
<tr>
<td>Fixed cost per vessel</td>
<td>$ 4,415</td>
<td>$ 21,198</td>
<td>$ 3,000</td>
</tr>
<tr>
<td>Annual capital cost (@ 6% of asset value)</td>
<td>$1,200</td>
<td>$3,900</td>
<td>$1,200</td>
</tr>
<tr>
<td>Crew size</td>
<td>2</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Variable cost per trip(^1)</td>
<td>$ 353</td>
<td>$ 1,112</td>
<td>$ 188 (per day)</td>
</tr>
<tr>
<td>Average catch per vessel (no. of fish)</td>
<td>151</td>
<td>4,913</td>
<td>2-5 % of total run</td>
</tr>
<tr>
<td>Average catch per trip</td>
<td>56</td>
<td>521</td>
<td>---</td>
</tr>
<tr>
<td>Average trips per vessel</td>
<td>15-20(^2)</td>
<td>7-10</td>
<td>20 (days)</td>
</tr>
<tr>
<td>Model base case assumptions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of vessels/units</td>
<td>50</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Trips per vessel</td>
<td>≥23</td>
<td>≥10</td>
<td>≥20 days</td>
</tr>
<tr>
<td>Catch per vessel</td>
<td>≥1280</td>
<td>≥5,333</td>
<td>≥2,400-6,000</td>
</tr>
<tr>
<td>Price per fish</td>
<td>$8.63</td>
<td>$8.63</td>
<td>$7.77</td>
</tr>
</tbody>
</table>

Sources: ICF Technologies (1988). Variable and fixed costs for gill netters and purse seiners were adjusted for inflation to 1996 levels. Fish prices and asset costs were not adjusted because current fish prices are at similar nominal levels; and the depressed state of the fishing industry has lowered fleet values in real terms. Fishwheel data and specifications were obtained from LGL (LGL Limited 1994) and from Michael Link of LGL Limited (personal communication).

\(^1\) Work hours per trip are 16 for gill nets and 60 for purse seiners. Fishwheel crews are assumed to work eight hours per day for 20 days and variable costs per trip are assumed not to change with the size of the catch.

\(^2\) The actual average for gill netters of trips per vessel was 2.69 due to the skewed distribution with many part time and semi-active gill net fishers. A figure of 15 - 20 trips per vessel is believed to be representative of more active fishers.

\(^3\) For a representative fishery with a harvest level of 50,000 fish and total stock of about 125,000. Catch per unit effort will be a function of the concentration of the fish stock at time of harvest. To simulate conditions similar to those found in Washington State, for an assumed stock size and harvest rate, the given data on catch per vessel and trips per vessel permit the model to be calibrated by fleet size so as to be representative of the effort per catch rates actually observed. From that baseline stock and assumed productivity, trips per vessel vary in inverse proportion to changes away from the baseline stock.
Table 2. Comparisons of economic benefits of alternative gear types for salmon harvest: simulation results of a bioeconomic model of a representative salmon fishery in Washington State

<table>
<thead>
<tr>
<th>Deterministic model: net economic benefits with no harvest selectivity</th>
<th>Gill nets</th>
<th>Purse seines</th>
<th>Fishwheels</th>
<th>Difference: fishwheel minus purse seines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net annual economic benefits per unit (vessel or wheel)</td>
<td>$-3,384</td>
<td>1,654</td>
<td>8,719</td>
<td>7,065</td>
</tr>
<tr>
<td>Net annual economic benefits for representative fishery</td>
<td>-169,186</td>
<td>19,852</td>
<td>217,752</td>
<td>197,900</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Deterministic model: net economic benefits with harvest selectivity</th>
<th>Gill nets</th>
<th>Purse seines</th>
<th>Fishwheels</th>
<th>Difference: fishwheel minus purse seines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net annual economic benefits per unit (vessel or wheel)</td>
<td>-2,640</td>
<td>10,572</td>
<td>20,544</td>
<td>9,972</td>
</tr>
<tr>
<td>Net annual economic benefits for representative fishery</td>
<td>-132,001</td>
<td>126,862</td>
<td>513,608</td>
<td>386,746</td>
</tr>
<tr>
<td>Annual wage payments</td>
<td>204,342</td>
<td>82,364</td>
<td>137,080</td>
<td>54,716</td>
</tr>
<tr>
<td>Total income (wages and rents) payments</td>
<td>72,341</td>
<td>209,226</td>
<td>650,688</td>
<td>441,462</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynamic, Stochastic Model Results</th>
<th>Gill nets</th>
<th>Purse seines</th>
<th>Fishwheels</th>
<th>Difference: fishwheel minus purse seines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net economic benefit per vessel per year</td>
<td>-3,246</td>
<td>6,007</td>
<td>14,800</td>
<td>8,793</td>
</tr>
<tr>
<td>Net present value of fishery (30 years @ 6%)</td>
<td>-2,243,530</td>
<td>1,034,102</td>
<td>5,185,039</td>
<td>4,150,937</td>
</tr>
<tr>
<td>Present value, wage income plus economic rents of the fishery</td>
<td>-941,116</td>
<td>1,558,355</td>
<td>7,449,306</td>
<td>5,890,951</td>
</tr>
<tr>
<td>Average annual wage payments</td>
<td>186,495</td>
<td>75,069</td>
<td>166,263</td>
<td>91,194</td>
</tr>
<tr>
<td>Average annual wage income plus resource rents</td>
<td>-69,036</td>
<td>109,619</td>
<td>536,275</td>
<td>426,656</td>
</tr>
</tbody>
</table>

Notes: Simulations based on a representative model for a salmon fishery with a native stock of approximately 40,000 adult fish and hatchery production of approximately 80,000 adult fish. Harvest rate is set at 40 percent of native stock. Selective harvesting enables hatchery fish to be harvested at a higher rate of 60 percent for gill netters and purse seine fishers, 90 percent for fishwheels. Alternative fleets are 50 gill net vessels, 12 purse seines, and 25 fishwheels.

In the stochastic model ocean survival (0.04) has a standard deviation of 60 percent. Harvest decisions are based on predicted adult populations returning to spawn. The distribution of the predicted stocks are assumed to be unbiased but with a measurement error with a standard deviation of 20 percent under gill nets or purse seines, 5 percent when fishwheels are employed.
Figure 1. Net economic benefits for a transition from gill nets and purse seines to 50 percent share by fish wheels: results of a stochastic dynamic simulation model (dollars per year)

Note: based on 100 replicates of the stochastic model for transition over 5 years from harvest shares of 50% by gillnets and 50% by purse seines, to 50% fish wheels, 30% purse seins, 20% gill nets.
Figure 2. Per vessel net economic benefits for a transition from gill nets and purse seines to 50 percent share of fish wheels: results of a stochastic dynamic simulation model (dollars per year)

Note: based on 100 replicates of the stochastic model for transition over 5 years from harvest shares of 50% by gillnets and 50% by purse seines, to
Figure 3. Labor income and resource rents for transition to 50% fish wheels: results of a stochastic dynamic simulation model (dollars per year)

Note: based on 100 replicates of the stochastic model for transition over 5 years from harvest shares of 50% by gillnets and 50% by purse seines,
Figure 4. Annual stock of wild salmon for a transition path from gill nets and purse seine harvest to 50 percent fish wheel harvest: results of a stochastic dynamic simulation model.

Note: based on 100 replicates of the stochastic model for transition over 5 years from harvest shares of 50% by gillnets and 50% by purse seines, to 50% fish wheels, 30% purse seines, 20% gill nets.
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