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Send correspondence to:
Stephen Swallow
Department of Resource Economics
304 Lippitt Hall
The University of Rhode Island
Kingston, Rhode Island 02881-0814

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INTRA-SEASON REGULATION AND ECONOMIC EFFICIENCY IN RECREATIONAL FISHERIES: AN APPLICATION TO PACIFIC SALMON

By

Stephen K. Swallow

Assistant Professor, Department of Resource

Economics, The University of Rhode Island

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ABSTRACT

This paper focuses on efficient regulation of the within season harvest process for recreational fisheries. Efficient allocation within a season can improve economic benefits, even though political or biological objectives determine the season's quota. The paper includes simulation results for setting creel limits in a hypothetical Pacific salmon fishery.

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I. Introduction.

Although the Fishery Conservation and Management Act (FCMA) of 1976 emphasizes "optimum social yield" as a goal of public management, in practice economists have provided a small - usually negligible - contribution to management decisions. While exceptions exist, the frequent failure of FCMA Councils to solicit economic analysis or to apply economic principles has motivated a lively debate among economists (i.e., Adams).

Managers and Council members often ignore economic principles due to the disciplinary paradigms of professional biologists or the political motives of their commercial and recreational constituents (Bell 1988, Huppert). Some of the concerns of managers motivate the analysis in this paper. The paper treats major management decisions as given. For example, through some exogenous process, managers promulgate a harvest target or quota for the upcoming recreational fishing season. The paper suggests that economists can determine (more) efficient regulations for how anglers actually harvest the quota and that such regulations usually remain consistent with the biological or political motives for the initial quota decision.

To a certain extent, this papers adopts a second best view which cedes the between-year management decision to an exogenous, primarily non-economic process. However, this view is one of short-term convenience rather than a long-term limitation. Stated heuristically, the paper approaches economic efficiency in fisheries management from the "bottom up" rather than from the "top down." Unfortunately, because managers are often not part of the congregation, let alone members of the choir, the economist's sermons fall on deaf ears. Yet by working from the bottom up, economists can stimulate efficiency gains and simultaneously lay the foundation for progressively more comprehensive, economic management programs.

More precisely, the paper considers the potential to efficiently allocate a pre-determined harvest quota. Since the quota addresses many of the managers' major concerns, economic allocation or control of the quota usually will remain consistent with managers' objectives. In short, analysis of a within-season optimization model can improve efficiency in the short-term, under current management policies, while the within-season model provides a foundation for first-best, "top-down" analyses.

The literature has recognized the foregoing points. Notably, Clark analyses the within-season implications of common regulatory measures in commercial fishing. Also, Kellog, Easley, and Johnson consider the optimal date to open a commercial scallop season. Furthermore, Bockstael and Opaluch recognize the complexity of bioeconomic optimization models and, therefore, they de-emphasize economic efficiency and develop a "satisficing" approach to fishery management. The current paper retains the focus on economic efficiency, but limits the scope to efficiency within the season. Furthermore, the paper develops an analysis for the recreational sector. However, extension to cases with multiple user groups is a logical and straightforward "next step" as analyses moves up from the bottom.

Section two develops a theoretical analysis of the within-season allocation problem in a recreational fishery with two subseasons. Section three applies this theoretical framework to a hypothetical Pacific Salmon fishery. The primary objectives are to develop a framework for a within-season allocation model and to demonstrate its implications for harvest regulations. Section four provides concluding remarks.

II. Theory.

For any particular recreational fishery, the within-season harvest allocation problem may include four (or more) interrelated dimensions, i.e.:

1. the harvest target set by managers;
2. seasonal variation in the fish stock;
3. angler's assessment of fishing quality;
4. seasonal variation in angler's demand for recreation.

Seasonality in the stock (e.g., Andrews and Wilen, Sutinen) depends on whether the species migrates and may be more relevant to marine pelagic species than, for example, some shellfish. A number of factors may influence recreational quality (cf. Bell 1989, Johnson and Adams), but this paper follows common practice since Stevens and assumes success rate (fish caught per day) determines quality. Angler's tastes and preferences may induce seasonality in demand, regardless of any seasonal pattern in fishing quality. For example, angler's may prefer fishing during good weather (cf. Cameron and James). For clarity, the current analysis ignores interactions between congestion and the above factors (see Anderson, Smith). While managers in many fisheries choose regulations to achieve some harvest target, the relevance of the remaining three dimensions depends on the characteristics of any actual fishery.

This paper assumes a fishery manager attempts to which maximize net benefits from recreation, subject to the harvest constraint. For analytical simplicity, the season consists of two periods or subseasons and the manager chooses creel limits, L_i, $i = 1, 2$:

$$
\begin{aligned}
(1)\quad \max \underline{L} &= B_1(L_1,L_2,S_1,S_2) + B_2(L_2,L_1,S_2,S_1) && \text{(benefits)}\\
&+ \theta\,[H - E_1(L_1,L_2,S_1,S_2)\cdot N_1(S_1,L_1) - E_2(L_1,L_2,S_1,S_2)\cdot N_2(S_2,L_2)] && \text{(harvest constraint)}\\
&+ \mu\,[s(S_1,L_1) - S_2] && \text{(quality constraint)}
\end{aligned}
$$

where, for subperiod i, $B_i(\cdot)$ represents the aggregate benefits, L_i is the creel limit, S_i measures fishing quality, $E_i(\cdot)$ is the number of angler-days, $N_i(\cdot)$ is the expected catch per average angler-day, $E_i(\cdot) \bullet N_i(\cdot)$ is the expected harvest; $s(\cdot)$ determines S_2 while S_1 remains exogenous; and θ and μ are Lagrangian multipliers. Presently, the model ignores the discrete nature of a creel limit, an assumption dropped in the empirical model. The quality constraint captures the potential impact of harvest (creel limit) and quality in period 1 on quality in period 2. Equation (1) explicitly retains the quality constraint for interpretive convenience. Then the manager's chooses L_1, L_2, and S_2 in order to maximize objective (1).

The aggregate benefit functions, $B_i(\cdot)$, derive from individual angler's choices, where each angler maximizes his or her utility from angling-days in each subperiod subject to fishing costs and personal expectations regarding the S_i and the L_i; then $B_i(\cdot) = B_i(E_i(L_1,L_2,S_1,S_2))$. For example, Anderson provides some detail on the microfoundations of aggregate demand. The analysis assumes that higher quality fishing and a higher creel limit increase demand for angling-days ($\delta E_i/\delta L_i$ and $\delta E_i/\delta S_i$ so $\delta B_i/\delta L_i>0$, $\delta B_i/\delta S_i>0$, $\delta^2 B_i/\delta L_i \delta S_i>0$), while diminishing marginal returns apply (so $\delta^2 B_i/\delta L_i^2<0$, $\delta^2 B_i/\delta S_i^2<0$, since $\delta B_i/\delta E_i<0$ and $\delta^2 E_i/\delta S_i^2$, $\delta^2 E_i/\delta L_i^2>0$). Furthermore, an increase in quality or creel limit in one period is assumed to reduce demand in the other period ($\delta E_i/\delta L_j<0$ and $\delta E_i/\delta S_j<0$ so $\delta^2 B_i/\delta L_i \delta S_j<0$, $\delta^2 B_i/\delta S_i \delta S_j<0$, for $i <> j$). Furthermore, marginal increases in quality or creel limit increase the harvest in each subperiod, either through increasing angler-days, $E_i(\cdot)$, or through increasing the expected harvest per angler-day ($\delta N_i/\delta L_i>0$, $\delta N_i/\delta S_i>0$; also, $\delta^2 N_i/\delta L_i^2<0$, $\delta^2 N_i/\delta S_i^2<0$). Finally, increasing harvest in period 1 may decrease quality in period 2 (so $\delta s/\delta L_1 < 0$).

With these assumptions the necessary conditions derived from (1) are sufficient. The first order condition on fishing quality in period 2 defines the shadow value of increasing S_2:

(2) $\mu = (\delta B_1/\delta S_2 + \delta B_2/\delta S_2) - \Theta\ [(\delta E_1/\delta S_2)\cdot N_1 + \delta(E_2N_2)/\delta S_2]$.

The manager sets quality in period 2 so the marginal benefit of an increase in S_2 just equals the additional angling benefits (including a decline in period 1 benefits) net of the marginal opportunity cost of supplying additional fish in period 2, where the discussion below interprets Θ as the opportunity cost of fish. Fishery managers only control this quality variable indirectly through the creel limit in the first period, where L_1 maximizes (1) if:

(3) $(\delta B_1/\delta L_1 + \delta B_2/\delta L_1) - \Theta[\delta(E_1N_1)/\delta L_1 + (\delta E_2/\delta L_1)\cdot N_2] + \Theta(\delta s/\delta L_1) = 0$ for $L_1 > 0$

≤ 0 for $L_1 = 0$.

The efficiency condition for L_2 is similar:

(4) $(\delta B_1/\delta L_2 + \delta B_2/\delta L_2) - \Theta\ [(\delta E_1/\delta L_2)\cdot N_1 + \delta(E_2N_2)/\delta L_2] = 0$ for $L_2 > 0$

≤ 0 for $L_2 = 0$.

For an interior solution ($L_i>0$, $i=1,2$), conditions (3) and (4) require the marginal benefit from increasing the creel limit in one period to equal the marginal opportunity cost of the implicit increase in harvest allocated to that subseason. In both cases, the effect of L_i on B_j and E_jN_j is included in estimating marginal benefits and opportunity costs. However, (3) includes an additional decrease in net marginal benefits in period 1 due to $\delta s/\delta L_1$.

One has difficulty confirming intuitive hypotheses even in the special case where explicit links between periods are negligible:

(5) $\delta B_i/\delta L_j = \delta B_i/\delta L_j = \delta E_i/\delta L_j = \delta E_i/\delta S_j = \delta s/\delta L_1 = \delta s/\delta S_1 = 0$.

Note that (5) implies S_2 is now exogenous, so (2) no longer applies. Then (3) and (4) confirm that setting the marginal benefit of an increase in the creel limit equal to the marginal opportunity cost of the implicit harvest allocation for that subseason also implies that the demand price for a fish in either subseason equals to the constant supply price (i.e., opportunity cost):

(6) $(\delta B_i/\delta L_i)/[\delta(E_iN_i)/\delta L_i] = \Theta$, $i = 1, 2$,

where the left hand term quantifies the marginal value of increasing the recreational harvest during subperiod i.

Unfortunately, comparative statics analysis yields few additional insights. An increase in S_i on either L_i, L_j, or Θ yields ambiguous results:

(7a) $dL_i/dS_i < > 0$; $dL_j/dS_i > < 0$; $\delta\Theta/\delta S_i < > 0$, $i = 1,2$, j not =i,

(7b) as $[\delta^2 B_i/(\delta L_i \delta S_i) - \Theta\delta^2(E_iN_i)/(\delta L_i \delta S_i)] > < 0$.

The signs in (7a) depend on whether S_i raises marginal recreation benefits from the contemporary creel limit, L_i, at a rate faster than the additional harvest pressure in subseason i (through E_i) raises the marginal opportunity cost of harvest during i.

The impact of angler's fishery-independent pattern of demand also remains ambiguous. To show this, assume the peak demand is during i and the parameter Γ measures the strength of this peak demand, so $\delta B_i/\delta\Gamma > 0$. Comparative statics reveal that:

(8a) $dLi/d\Gamma < > 0$, $dLj/d\Gamma > < 0$, and $d\Theta/d\Gamma < > 0$, i not =j,

(8b) as $[\delta^2 B_i/(\delta L_i \delta\Gamma) - \Theta\delta^2(E_iN_i)/(\delta L_i \delta\Gamma)] > < 0$.

The signs in (8a) depend on whether an increase in the strength of the peak demand increases marginal benefits of the creel limit in the peak period faster than Γ feeds back (through E_i) to marginal the opportunity cost of the subperiod's harvest allocation.

Little consolation derives from noting that the impact of S_i or Γ on L_i is intuitively consistent (i.e., opposite) the impact on L_j. Of course, relaxing the harvest constraint does lower Θ and raise the creel limits:

(9) $\delta\Theta/\delta H < 0$, $\delta L_i/\delta H > 0$.

Important insight regarding the efficient choice of creel limits will rely on empirical work.

III. A Hypothetical Salmon Fishery.

Published results (Andrews and Wilen, Cameron) from studies of recreational Pacific salmon fisheries enable a preliminary empirical investigation of within season regulations. The work of Cameron and of Andrews and Wilen focuses on substantially different issues than the current study. Therefore, the forthcoming results cannot be interpreted definitively.

In particular, the empirical equations (see below) delineate a very flat objective function, which severely restricts the ability to quantify welfare improvements in the hypothetical fishery. Furthermore, results from Andrews and Wilen do not support a model with $\delta E/\delta L$ explicitly greater than zero. However, the empirical model does exhibit an seasonal patterns exogenous quality factors and exogenous seasonality in angler's demand.

With these caveats in mind, results from Andrews and Wilen (AW) conform reasonably well to a model with (5) in force. Using weekly data, AW estimated aggregate harvest as a function of aggregate angler-days and a proxy for the exogenous migratory patterns in mixed stocks of coho and chinook salmon:

$$(10) \quad h(t) = A\ E(t)^{\alpha} \exp(g(t)),$$

where h(t) is aggregate recreational harvest during week t and g(t) proxies for the migratory patterns of salmon. In addition, AW estimate anglers' response to expected fishing success:

$$(11) \quad E(t) = B\ S(t-1)^{\beta} \exp(m(t)),$$

where S(t-1) proxies for fishing quality and m(t) proxies for exogenous patterns in angler's demand for recreation. The AW data derive from 1976 to 1978 when the California salmon fishery was open from weeks mid-February to mid-November (weeks 7 to 46) and anglers faced a constant creel limit of 3 fish. Cameron estimates the willingness to pay for a marginal day of fishing:

(12) $P = C\ N^K$,

where P is willingness to pay for the marginal fishing day and N is the actual number of fish which the angler caught. Parameter estimates for (10)-(12) are available in Cameron and in Andrews and Wilen. (The components of C (see Cameron) are set to their sample means, except NONRES is set to zero. The dummy variables in Andrews and Wilen, (D77, D78), are set to (0, 0.48) for simulations EUK1 and (0, 0) for EUK2 in Table 1.)

From these data, recreational benefits during one subseason equal willingness to pay function times aggregate angler-days for each week:

(13) $B(t,\cdot) = P\cdot E = C\ N^K\cdot B\ S(t-1)^{\beta}\exp(m(t))$.

Initially, one might assume - incorrectly - that AW's quality variable, S, is equivalent to Cameron's N. However, S is <u>more</u> accurately interpreted as an exogenous measure of fishing quality because (10) was estimated under a constant regulatory regime.

Therefore, this paper uses N, the average angler's expected catch, as a measure of the quality of a fishing day which is influenced by both exogenous factors (through S) and endogenous factors (through L). For simplicity, the analysis models the time between "arrivals" of fish in an average angler's creel as an iid random variable. As an initial approximation, this assumption corresponds to a Poisson process with parameter σ, where the probability of an angler catching n fish is (Meyer, pp. 159-170):

(14) $\Pr(x = n) = \exp(-\sigma)\ \sigma^n/n!$.

Given a creel limit, the expectation of n, N(L), is:

(15a) $N(L,\sigma)$: $\Sigma_{x=0,L}\ x\ \Pr(x=n) + L\ (1 - \Sigma_{x=0,L}\ \Pr(x=n))$.

In the absence of a catch limit, σ equals the expectation of n (i.e., $N(L=\infty) =$

σ). The present model estimates σ numerically from the (15a) with L=3,

(15b) σ: $N(3,\sigma) = S(t)$,

as was the case during 1976-78 in the fisheries studied by DW.

The empirical representation of (1) is then to maximize (13) subject to the harvest constraint:

(16) $\max \underline{L} = \Sigma_t\ C\ N^K \cdot B\ S(t-1)^{\beta} \exp(m(t))$ subject to

$H \geq \Sigma_t\ E(t) \cdot N(L(t))$

where (10) with (11) determines E(t) and S(t), while (15b) determines N.

This model was solved by a dynamic program (Haith, pp. 254-255) using Cameron's parameters and two Ports (Eureka and San Francisco) modelled by Andrews and Wilen. The elasticity of marginal willingness to pay with respect to expected harvest is K=0.092 (Cameron) while the elasticity of effort with respect to S is β=1.24 and β=1.38 for EUR and SAN versions of (13) (see Andrews and Wilen). In addition, the exogenous pattern in quality of the SAN fishery, m(t), reaches its only peak at week 34 while week 27 coincides with the peak in demand ($g_{max} = g(27)$). By contrast, in EUK data, the exogenous pattern in fishery quality, m(t), is U-shaped, reaching a minimum at week 38, while peak demand occurs in week 31.

These parameters permit an empirical analysis of the trade-offs implicit in setting a creel limit: i.e., maximizing recreation benefits during periods (weeks) when the fishery's exogenous quality is high versus benefits during peak demand periods. The feasible solutions include a creel limit of zero (L(t) = 0), which creates a subseason closure to promote escapement.

Results are summarized in Table 1. Due to the limitations of the data and the current version of the dynamic program, rounding error becomes significant for creel limits above 3. For this reason, creel limits of 4 and

5 are considered equivalent to L = 3+. This simplication reduces the objective function on the order of 0.1%. or less.

Three types of simulations were run. Simulations labelled SAN (Table 1) correspond to an "average" year for a large fishing port. Results labelled EUR1 correspond to a "poor" year for salmon runs near a small port, while EUR2 simulates a "good" year. Results from the SAN and EUR2 simulations suggest that when the harvest quota is set at the level actually predicted for a constant creel limit of 3 (H = 826 and H = 140, respectively; Table 1), the efficient pattern of creel limits is nearly identical to the status quo. However, in a similar analysis for EUR2 (H = 276), the efficient allocation lowers the creel limit during the beginning and ending weeks.

When H is reduced to 802 in the hypothetical SAN fishery (Table 1), the creel limit is held around 2 during the mid-season approach to the peak demand period. However, L is set at 3+ during the opening two months, when exogenous quality is relatively low, and L = 3+ again after the peak in demand and into the period of peak quality. A similar result obtains for SAN when H = 740. Note that a constant quota of L = 2 would produce a harvest of 800.

For EUR1 with H = 271, the period during which L = 3+ incorporates both the minimum in exogenous quality and the peak period of demand. For a severely restricted fishery during a "poor" year (EUK2, H = 105), the efficient creel limits imply a closed season early, when fishing quality is at a local maximum, followed by a significant subseason of with L = 1, and a short 2-weeks with L = 3+ before the season closes again for the second local maximum in fishery quality.

IV. CONCLUDING REMARKS.

The paper develops a model of within-season harvest allocations which maximize economicly efficient use of a resource where the season's harvest quota may be set according to non-economic criteria. Discussion focused on the implications of exogenous influences on fishery quality and the implications of peak and off-peak patterns in recreational demand. Simulation results confirm that a priori expectations surrounding the efficient pattern of creel limits (and subseason closures) must be confirmed through empirical work.

The analysis conceptually identifies no conflicts with political or biological objectives. However, fishery management professionals might identify additional constraints to the model. For example, nothing currently prevents a cyclical pattern in creel limits, a result which may prove politically tenuous. In principal, the dynamic programing model may easily be constrained to choose a single creel limit for several weeks at a time. Of course, in some fisheries a cyclical pattern in creel limits is acceptable. For example, recent salmon regulations alternate the creel limit between zero (closed season) on Thursday through early Sunday, and a positive limit on other days.

This paper suggests that such within-season harvest regulations could be set based on economic criteria while remaining perfectly consistent with biological or political objectives apparent in many fisheries.

Table 1. Creel limits (L(t)) for simulated salmon fisheries.

	SAN			EUK1		EUK2		
Quota, H:	826	802	740	276	271	140	126	105
week (t)								
7	3	3	3					
8	3	3	3					
9	3	3	3					
10	3	3	3					
11	3	3	3					
12	3	3	3		n/a			
13	3	3	3					
14	3	3	3					
15	3	3	2					
16	3	2	2					
17	3[a]	2	1					
18	3	2	1	2	1	3	1	0
19	3	2	1	2	1	3	1	0
20	3	2	1	2	2	3	2	0
21	3	2	1	2	2	3	1	0
22	3	2	1	3	2	3	1	0
23	3	1	1	3	2	3	1	0
24	3	2	1	3	3	3	1	1
25	3	2	1	3	3	3	1	1
26	3	2	1	3	3	3	1	1
27	3[b]	2	1	3	3	3	1	1
28	3	2	1	3	3	3	1	1
29	3	2	2	3	3	3	1	1
30	3	2	3	3	3	3	3	1
31	3	3	3	3[a]	3	3[a]	3	1
32	3	3	3	3	3	3	3	1
33	3	3	3	3	3	3	3	1
34	3	3	3	3	3	3	3	1
35	3	3	3	3	3	3	3	1
36	3	3	3	3	3	3	3	1
37	3	3	3	3	3	3	3	1
38	3	3	3	3[c]	3	3[c]	3	1
39	3	3	3	3	3	3	3	3
40	3	3	3	3	3	3	3	3
41	3	3	3	1	3	3	3	0
42	3	3	3					
43	3	3	3					
44	3	3	3		n/a			
45	3	3	3					
46	3	2	3					

[a] Peak in demand occurs in this fishery through g(t).
[b] Peak in exogenous quality occurs for this fishery through m(t).
[c] Minimum in exogenous quality occurs for this fishery through m(t).

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