APPROVAL

ABSTRACT

Oncorhynchus nerka

Keywords:

Subject Terms:

ACKNOWLEDGEMENTS

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LIST OF TABLES

1.0 INTRODUCTION

(Ptychocheilus oregonensis),

1.1 A brief history of Cultus Lake

Oncorhynchus mykiss O. clarki   *Salvelinus confluentus*

2.2 Management Objectives

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2.3 Alternative Management Strategies

Table 1 Description of parameters used in the simulation model and definition of scenarios and terms.

Sockeye		
α		
β		
k		
σ		

Northern pikeminnow		
M		
b		

2.5 Model to determine consequences

2.5.1 Model Initialization

2.5.2 Sockeye sub-model

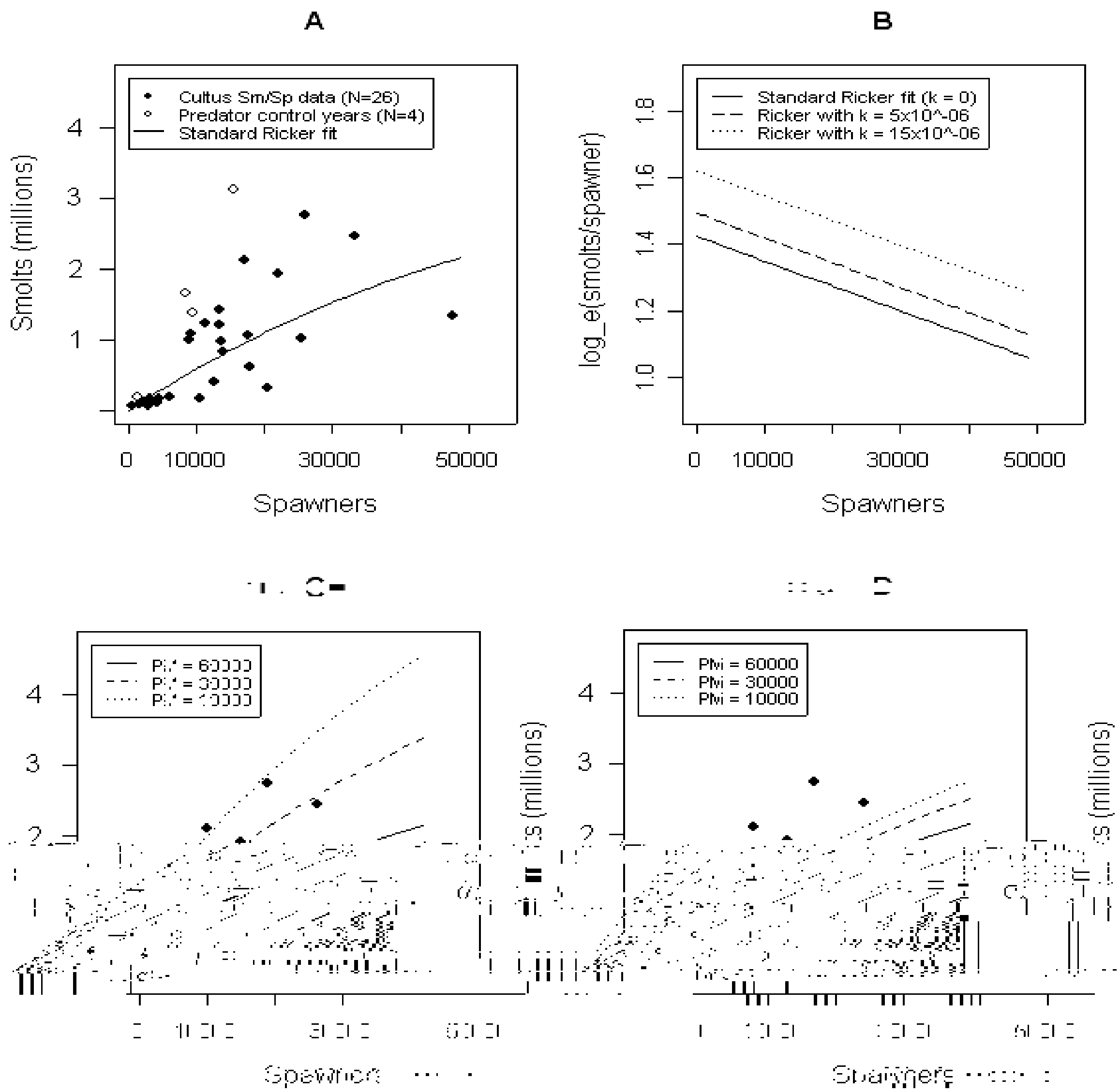


Figure 3 (A) Cultus sockeye smolt and spawner data for years that were not likely affected by either predator control efforts, hatchery operations, or high pre-spawning mortality (solid circles). Years that followed predator control are indicated by open circles. (B) $\mathrm{Log_e}$(Sm/Sp) for standard Ricker model (*k* = 0) and the two alternative models used in this study. (C) Resulting spawner-to-smolt relationships from assuming low *k* (low consumption rate of sockeye smolts per pikeminnow) at three different northern pikeminnow abundances. (D) Spawner-to-smolt relationships assuming high *k* (high consumption rate of sockeye smolts per pikeminnow) at three different northern pikeminnow abundances.

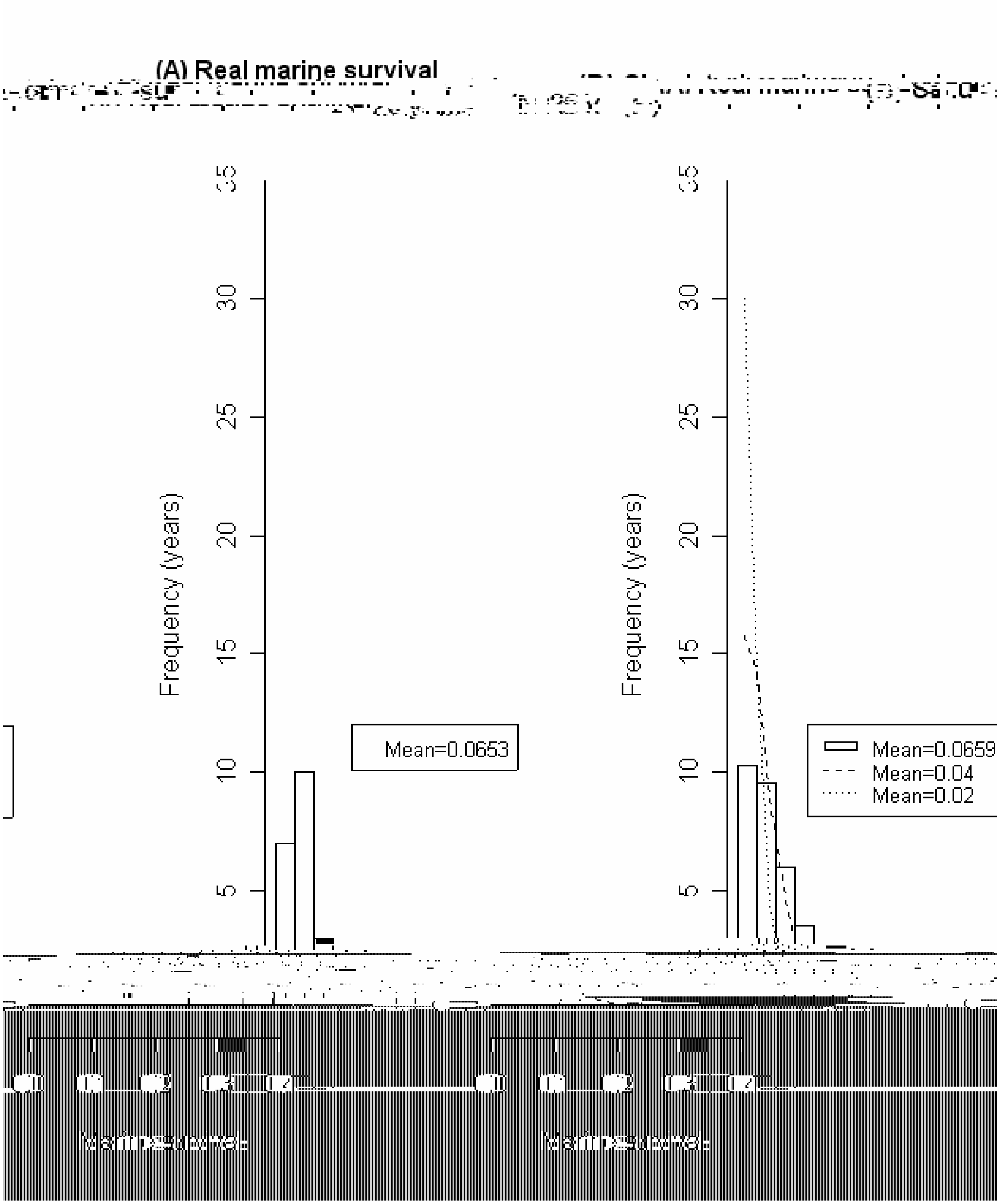
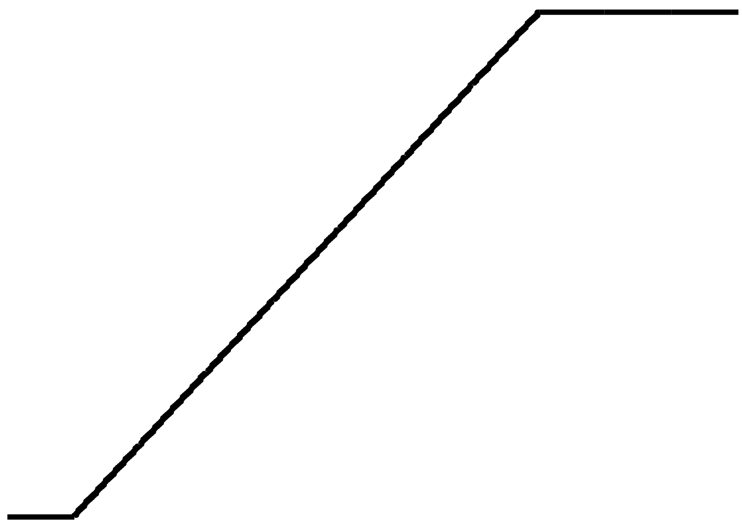


Figure 4 Frequency distributions of marine survival rates for observed Cultus Lake sockeye data (A) and Beta distribution used in Monte Carlo trials for generating annual marine survival rate (B). Bars represent a sample frequency distribution of simulated values with parameters estimated from the historical data; lines represent alternative distributions.



$$(1) \quad Sm_{i,t} \quad * Sp_{i,t-2} * e^{*Sp_{i,t-2} \quad k*PM_t \quad t}$$

$Sm_{i,t}$ i

α β

k k

k

k

α β

k

(5) Sp_t Esc_t $Broodtake_t$

Sp_t t $Broodtake_t$

q F

$$(8) \quad L_a \quad L \; *(1 \quad e^{\,k_{VB}*(a \quad t_{OVB})})$$

L_a a L_∞ k_{VB}

t_{OVB} $t=0$

$$(9) \quad W_a \quad a_w * (L_a * 0.1)^{b_w}$$

W_a a L_a

a b_w

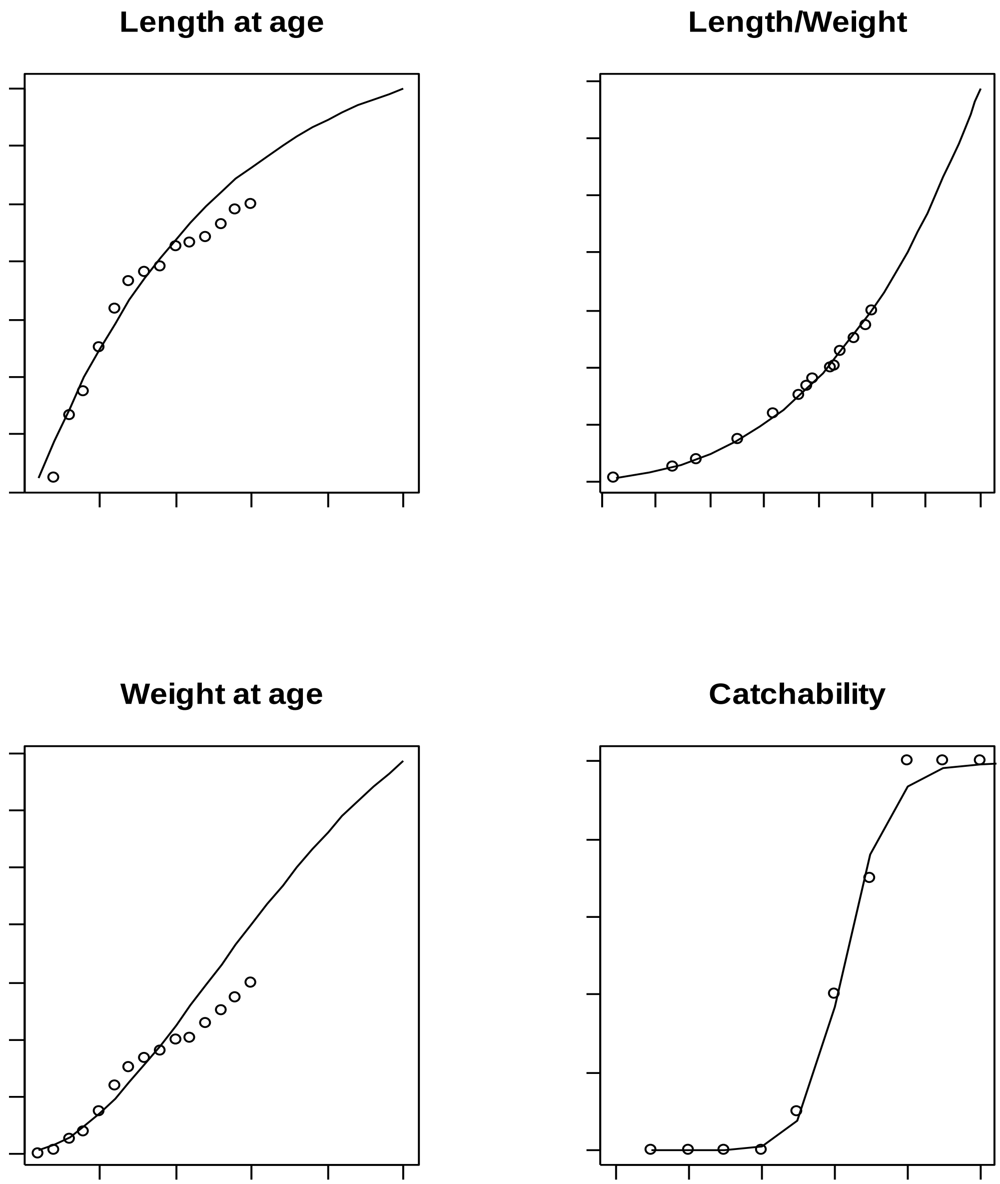
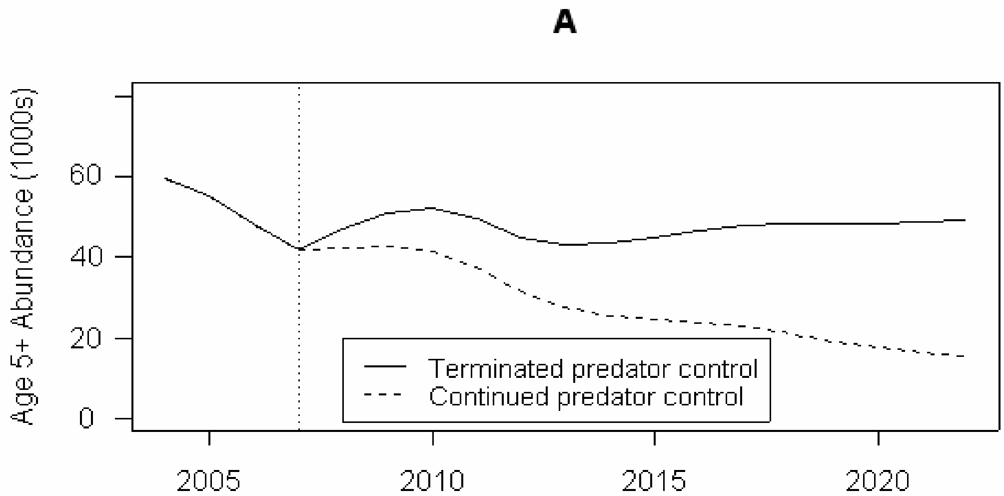


Figure 6 Length-at-age, weight-at-age, and catchability-at-age models (lines) fit to data (circles) and used to simulate the northern pikeminnow population (see text). Parameter values are given in Table 1.

$$(10) \quad q_p \qquad \frac{p^c}{p^c \quad d^c}$$

a *a*

a *b*



[redacted]

Figure 7 Simulated northern pikeminnow abundance under alternative levels of control, with (A) low recruitment compensation, and (B) high recruitment compensation. Notice that all four trajectories begin with the same abundance up to 2007, which represents predator control efforts to date.

3.0 RESULTS

3.1 Survival Objective

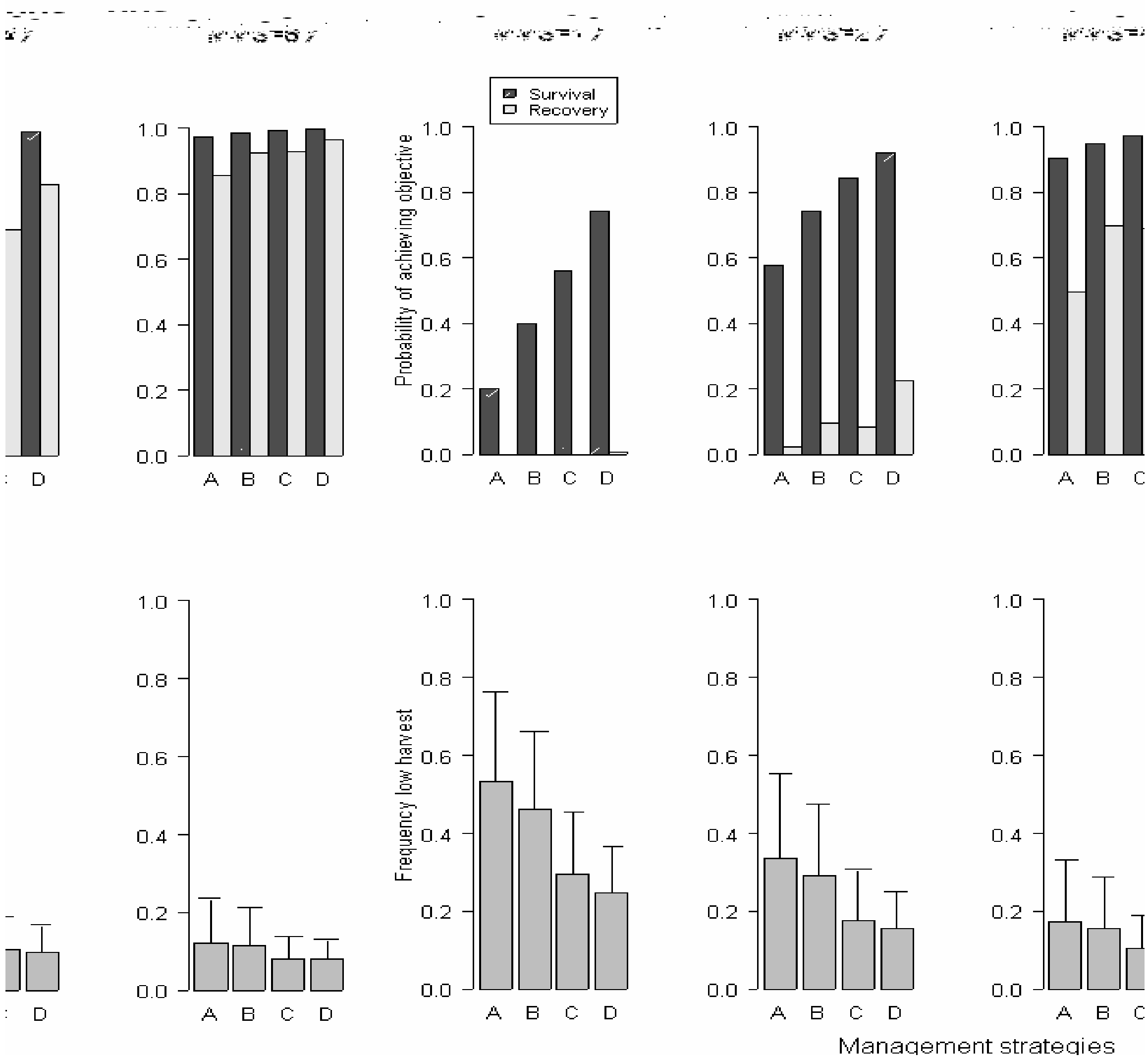


Figure 8 **Simulation results based on Harvest rule 1 (H_{min} = 0.12, H_{max} = 0.50). Top panel shows survival (mean spawners/year ≥ 1000) and recovery (mean spawners/year ≥ 8000) probabilities for four alternative management strategies (A = status quo hatchery operations combined with terminated predator control; B = status quo hatchery operations combined with continued predator control; C = extended hatchery operations combined with terminated predator control; D = extended hatchery operations combined with continued predator control), at four alternative mean marine survival rates (MMS). Bottom panel shows the proportion of simulated years where the harvest rate was set at H_{min} as a result of low Cultus Lake sockeye abundance. Error bars represent two standard deviations.**

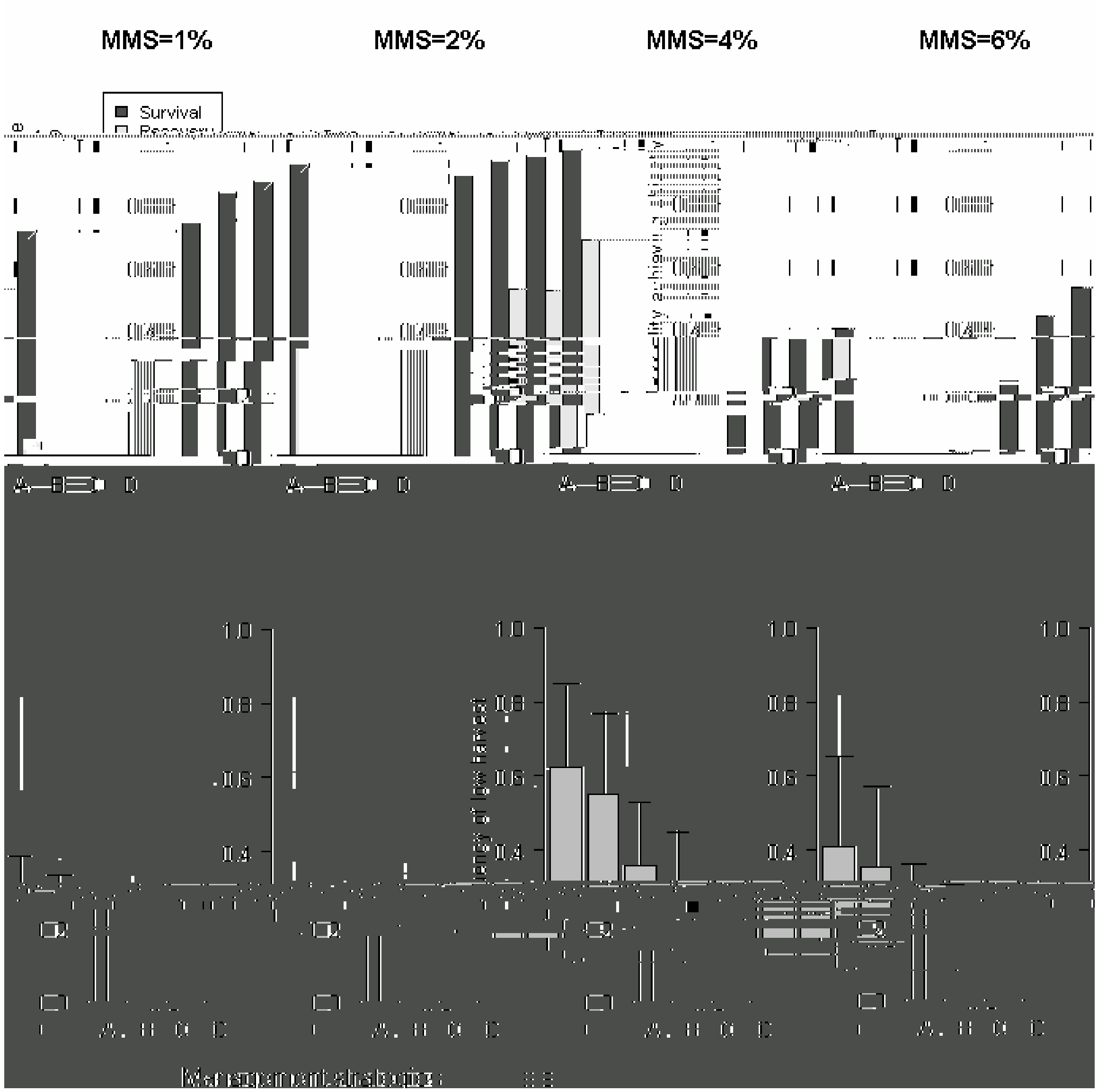


Figure 9 **Same as Figure 8 except results are based on using harvest rule 2 (H_{min} = 0.30, H_{max} = 0.60) as opposed to harvest rule 1.**

RHMS

≥

RHMS

RHMS

≥

k

k

k

A	**sq hatchery and terminate predator control**
B	**sq hatchery and continued predator control**
C	**extend hatchery and terminate predator control**
D	**extend hatchery and continue predator control**

Degree of belief

Survival

	Mean marine survival rate			
P1_RHMS (0.8)	**1%**	**2%**	**4%**	**6%**
0.1	None	None	B/C/D	All
0.2	None	None	B/C/D	All
0.3	None	None	B/C/D	All
0.4	None	D	B/C/D	All
0.5	None	D	All	All
0.6	None	D	All	All
0.7	None	C/D	All	All
0.8	None	C/D	All	All
0.9	D	C/D	All	All

Recovery

	Mean marine survival rate			
P1_RHMS (0.8)	**1%**	**2%**	**4%**	**6%**
0.1	None	None	None	B/C/D
0.2	None	None	None	B/C/D
0.3	None	None	None	B/C/D
0.4	None	None	None	B/C/D
0.5	None	None	None	B/C/D
0.6	None	None	None	B/C/D
0.7	None	None	None	B/C/D
0.8	None	None	None	All
0.9	None	None	D	All

Figure 10 **Prescription tables showing which management strategies (A-D) meet the survival (left) and recovery (right) objectives with at least 90% probability across a range of mean marine survival rates and different degrees of belief for the RHMS of sockeye. Moving down each column mean that greater belief (from 10% to 90%) is placed on high RHMS (0.8) as the true state of nature, rather than RHMS being only 0.2. These results are based on using harvest rule 1 (H_{min}=0.12, H_{max}=0.5).**

A	**sq hatchery and terminate predator control**
B	**sq hatchery and continued predator control**
C	**extend hatchery and terminate predator control**
D	**extend hatchery and continue predator control**

Degree of belief

	1%	**2%**	**4%**	**6%**
0.1	None	None	D	B/C/D
0.2	None	None	D	B/C/D
0.3	None	None	D	B/C/D
0.4	None	None	D	B/C/D
0.5	None	None	D	All
0.6	None	None	D	All
0.7	None	None	C/D	All
0.8	None	None	C/D	All
0.9	None	None	B/C/D	All

Survival

Recovery

A	**sq hatchery and terminate predator control**
B	**sq hatchery and continued predator control**
C	**extend hatchery and terminate predator control**
D	**extend hatchery and continue predator control**

Degree of belief

Survival

	Mean marine survival rate			
P1_k (15x10^-6)	**1%**	**2%**	**4%**	**6%**
0.1	None	D	All	All
0.2	None	D	All	All
0.3	None	D	All	All
0.4	None	D	All	All
0.5	None	D	All	All
0.6	None	D	All	All
0.7	None	D	All	All
0.8	None	D	All	All
0.9	None	D	All	All

Recovery

	Mean marine survival rate			
P1_k (15x10^-6)	**1%**	**2%**	**4%**	**6%**
0.1	None	None	None	B/C/D
0.2	None	None	None	B/C/D
0.3	None	None	None	B/C/D
0.4	None	None	None	B/C/D
0.5	None	None	None	B/C/D
0.6	None	None	None	B/C/D
0.7	None	None	None	B/C/D
0.8	None	None	None	B/C/D
0.9	None	None	None	B/C/D

Figure 12 Prescription tables showing which management strategies meet the survival (left) and recovery (right) objectives with at least 90% probability across a range of mean marine survival rates and different degrees of belief for the impact of Northern pikeminnow on the sockeye Sm/Sp relationship. Moving down each column means that greater belief (from 10% to 90%) is placed on the high *k* value (15 x 10^{-06}) as the true state of nature. These results are based on using harvest rule 1 (H_{min} = 0.12, H_{max} = 0.50).

A	**sq hatchery and terminate predator control**
B	**sq hatchery and continued predator control**
C	**extend hatchery and terminate predator control**
D	**extend hatchery and continue predator control**

Degree of belief

P1_k (	**1%**	**2%**	**4%**	**6%**
0.1	None	None	D	B/C/D
0.2	None	None	D	B/C/D
0.3	None	None	D	B/C/D
0.4	None	None	D	All
0.5	None	None	D	All
0.6	None	None	D	All
0.7	None	None	D	All
0.8	None	None	D	All
0.9	None	None	D	All

Survival

Recovery

4.0 DISCUSSION

4.1 Management Implications

4.1.1 Predator control

Gasterosteus aculeatus

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Richardsonius

balteatus

4.1.2 Hatchery operations

LITERATURE CITED

Ptychocheilus
oregonensis

Ptychocheilus oregonensis

In
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Ptychocheilus oregonensis
Oncorhynchus
nerka

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