STATE OF OREGON
OREGON STATE GAME COMMISSION
1634 S. W. ALDER STREET
P. O. BOX 3503
PORTLAND 8

P.O. Box 1063
Klamath Falls, Oregon 97601
January 7, 1964

Mr. Robert J. Behnke
Zoology-Fisheries
Department of Zoology
University of California
Berkeley 4, California

Dear Mr. Behnke:

There are two streams that were originally part of the Klamath drainage system that would possibly have a pure strain of rainbows. These streams were at one time part of theWilliamson River drainage system but have gone underground. The streams are small and of little importance for fishing and therefore have never been stocked. There names are, Cottonwood Creek, that drains the east slope of Mt. Thielson and Bear Creek, that heads on the east slope of the rim around Crater Lake.

I have never seen any cutthroat trout taken from the Klamath system , but Mr. Fred Locke, of our Portland staff stated that he had observed one taken by indians fishing the Sprague River. Mr. Locke felt that the cutthroat at one time was native to this draingae system.

For many years the rainbow stock for our hatchery at Fort Klamath was obtained from Spencer Creek, a tributary of Klamath River, but because of the difficulties encountered in raising this strain the egg take was discontinued. For the last seven years, all of the rainbows released into the drainage have originated from eggs from Oregon brood stock, California brood stock or eggs from Kamloops trout spawned at Diamond Lake.

The long time residents in this area, that have fished the Klamath system claim that they can tell the difference between a native trout and one originating from hatchery stock, but I have still to learn the method. The local experts say that body shape and coloration are the major identifying characteristics.

They have also insisted that there is a definite spring and fall spawning run out of both Agency and Klamath Lakes, into the Williamson River. These fish are supposed to be of different coloration and body conformity. However, in the time I have worked in this area I have not been able to find these fish on spawning beds. I feel there is some merit to the theory although since in checking anglers on the river during the trout season, the rainbows taken in the early part are small (up to 18 inches) and are bright-silvery fish, like steelhead, and those taken later in the year are big(up to 18 pounds) and are very dark and deep bodied. It is possible that the small fish are residents in the stream and the lunkers come up out of the lake into the cooler water at times when the lakes become quite warm during the hot summer months.

There are many theories on the types of rainbows in Klamath Lake and where there originated and the times of spawning, but I have not had suffecient time or help to do a thorough study of the lakes. I hope some day to be able to spend considerable time on these bodies of water. In the last four years the supply of large trout in Agency and Klamath Lakes have dewindled from large population down to a small one. This was due to the blocking of passage to the major spawning tributaries. To alleviate the problem I have had to go to a large stocking program to bolster the native stock.

I hope I have been of some assistance to you and if you need any further information I will be glad to assist.

Sincerely,

Arthur R. Gerlach

Arthur R. Gerlach
Aquatic Biologist II

BILL TATE, Representing

The Mills Company · SHERIDAN, WYOMING

– Malheur Oregon
Area

– Fish. Biol.

Lawrence E. Bisbee
Ore. St. Game Comm.
Hines, Ore.

POST OFFICE BOX 833 TELEPHONE 674-7473

OSU

OREGON STATE UNIVERSITY
DEPARTMENT OF FISHERIES AND WILDLIFE

CORVALLIS, OREGON 97331

June 10, 1968

Dr. Robert Behnke, Assistant Leader
Colorado Cooperative Fishery Unit
Colorado State University
Fort Collins, Colorado 80521

Dear Bob:

Thank you for your letter of June 4, which outlined the plans for a collecting trip. My student, Pete Bisson, has an Oregon collecting permit.

I could be wrong about the origin of the trout I took from Catlow Valley, but the large specimens that came from Roaring Springs on the east side and Rock Creek on the west side were not typical rainbows. Both the areas have constant water supplies and could have held fish through dry periods. These fish were responsible for my beginning to think that the old trout in these basins were really neither rainbows or cutthroats.

Rock Creek has been poisoned, but whether the headwater areas were treated or not I do not know. The Game Commission saved some trout from the poisoning, but they were typical hatchery stock. It still might be worthwhile to visit Rock Creek and its tributary Willow Creek above the hot springs near Hart Mountain Refuge headquarters.

The Roaring Springs is a good site, and there are trout in Home Creek and Skull Creek.

Kiger Creek would be a good one to try, if you can get to the upper reaches from Fish Lake. Rattlesnake Creek near Harney has trout, and I can find no record that anything but eastern brook were planted there in the 1920's or early 1930's.

I have a set of old planting records that give some assistance, although I know there were many years of unrecorded plants. These records show few plants of trout in the Owyhee drainage, so there might be a possibility of native fish there. Miller Creek in the northern end of the Klamath Basin retained some native fish-- lampsreys and chubs, at least. Perhaps there are native trout there. Be sure to look at some of the trout in the Upper Klamath Sport Fishery.

Pete Bisson might have additional ideas to pass on to you at the time of the trip. I wish you all luck.

Sincerely,

Carl

Carl E. Bond - 753-8315
Professor of Fisheries

CEB:slz

August I,I968

Dr. Robert Behnke
Colorado Cooperative Fishery Unit
Colorado State University
Fort Collins, Colorado 8052I

Dear Bob:

The following is a list of locations and number of specimens (in parentheses) of S. gairdneri from the Harney Basin presently in the O.S.U. collection of fishes:

Scotty Cr. trib. to upper Silvies R. (I5)
Rattlesnake Cr. (4) (7)
Poison Cr. (3)
Devine Cr. trib. to Poison Cr. (6)
Kiger Cr. (I) (6)
Riddle Cr. (I)
Smyth Cr. trib. to Riddle Cr. (4)

In addition, you might also be interested in some early (I924 - 34) stocking records for the same area:

Rainbow-

Bear Cr. trib. to upper Silvies R.
Blitzen R.
Silver Cr.
Poison Cr.
Emigrant Cr. trib. to Silvies R.

Eastern Brook-

Silvies R.
Bear Cr.
Scotty Cr.
Rattlesnake Cr.
Blitzen R.
Fish Lake

I am most anxious to hear how your studies are progressing; in particular, what you have found out about the trout we collected from Catlow Valley and the Harney Basin. Upon rereading Hubbs and Miller's paper, I discovered that they hypothesized an "early pluvial" connection between the two areas. If so, then the "natives" from Threemile(?) and Smyth Creeks might have some important characteristics in common. I've examined what specimens we have of the two undescribed chubs from the Catlow and Alvord valleys, and they appear to be quite different from each other. Catlow chubs are intermediate in both scale and fin ray counts between the strange Alvord form and the typical Columbia one found in several Harney Basin locations. If indeed there was an ancient connection between the Harney and Catlow drainages it probably ceased to exist long before the Harney Basin was sealed off from Malheur R., during a time when the Harney fauna was much more depauperate than present.

If there is any way in which I can be of assistance, please do not hesitate to let me know. If you wish to examine some of the fish from the O.S.U. collection I suggest you write to Dr. Bond, as I will soon be leaving for the Univ. of Michigan.

- copy of thesis

Sincerely yours,

Pete Bisson

Peter Bisson
Dept. of Fisheries and Wildlife

OSU

OREGON STATE UNIVERSITY

DEPARTMENT OF FISHERIES AND WILDLIFE

CORVALLIS, OREGON 97331

November 13, 1968

Dr. Robert Behnke
Assistant Leader
Colorado Cooperative Fishery Unit
Colorado State University
Fort Collins, Colorado 80521

Dear Bob:

I had heard earlier of your success on the Oregon collecting trip from Ray and Pete Bisson. You apparently concur with my contention that the native trouts do exist and that they are not directly assignable to rainbow or cutthroat without careful work. I have taken some criticism, not all of it friendly, from some of my game commission friends on this subject. In January, I am to talk to the local chapter of the A.F.S. on rare and vanishing fishes. Any ammunition you could send me would help in perpetuating these trout stocks.

We have known about the Klamath Basin Dolly Varden for years. Mark Morton, who spends his spare time working on chars (charrs, as he insists) has specimens, and I have a good stockpile. I presume that your Longs Creek is in the Sycan Drainage, and not the tributary to Horse Cr. near Fourmile Lake. We do not have specimens from the latter, as I recall. In 1964, 1965, and 1966, various of my students and I worked over the Klamath Basin in Oregon reasonable well. Dave Vincent (Bob's brother) and I plan to work up a publication on the collection.

Trout in the Guano basin are unlikely but not impossible. No fish were reported from the basin for years - then in 1957 a student found a few dozen winter-killed chubs in Guano Lake. I shared them with Bob Miller. I tried to find fish in Guano Creek, close to the headwaters in 1967 but failed both in the main creek and a spring area. There might be other perennially wet places to try later on.

I am looking forward to your evaluations of the trout.

Sincerely,

Carl

Carl E. Bond
Professor of Fisheries

OREGON STATE UNIVERSITY 1868 1968 CENTENNIAL

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CORVALLIS, OREGON 97331

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OREGON STATE UNIVERSITY

DEPARTMENT OF
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OCT. 1968 – JUNE 1969

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FRANKLIN D. ROOSEVELT
U.S. POSTAGE

Dr. Robert Behnke
Colorado Cooperative Fishery Unit
Colorado State University
Fort Collins, Colorado 80521

trouts

- each basin - disjunct relicts

~~Klamath~~, - Dollies -

- stress Dolly Varden Klamath -

- Rare & vanishing sp.

- basibranchial teeth - some

- range

- coloration - fin markings over

- ~~yellow~~ golden - orange

- nearest as winter

- long head jaw - cutt

-

spotting - intermediate

- rakers -

- scales

- vert. - -

- list waters

making collections

from or authentically

recorded.

OREGON STATE UNIVERSITY
CORVALLIS, OREGON 97331

SCHOOL OF AGRICULTURE and AGRICULTURAL EXPERIMENT STATION

Reply to: THE DEPARTMENT OF FISHERIES AND WILDLIFE

January 20, 1969

Dr. Robert J. Behnke
Colorado Cooperative Fishery Unit
Colorado State University
Fort Collins, Colorado 80521

Dear Bob:

Thanks for sending me the material on native trouts last November. As things developed, the Oregon Chapter of AFS didn't need me to fill in on the program, but nonetheless your information will be of great use to me.

Salvelinus malma is in Annie and Sun creeks in the Wood River drainage. If Dave Vincent has any additional records I will send them later.

Sincerely,

Carl

Carl E. Bond
Professor of Fisheries

CEB:ljb

CORVALLIS, OREGON 97331

OSU

OREGON STATE UNIVERSITY

DEPARTMENT OF
FISHERIES AND WILDLIFE

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CENTENNIAL
OCT. 1968 - JUNE 1969

UNITED STATES 6c

Dr. Robert J. Behnke
Colorado Cooperative Fishery Unit
Colorado State University

Fort Collins, Colorado 80521

July 16, 1984
3463 Chaucer Way
Eugene, Or.97405

Dear Dr. Behnke,

I made another trip into the Alvord Basin during the weekend of July 7-8 to search for the native cutthroat trout.

On Saturday, July 7, I hiked about 3½ - 4 miles up Wilder Creek and fished all the good-looking spots as for as the Sisson Cabin (see map). The creek is from 3 to 6 feet wide in most stretches and appears to contain good habitat for trout ; however, I saw no sign of any fish although I floated flies over and through many nice holes. I'd have liked to have gone another mile or so upstream but lack of time, drinking water and the loss of a boot heel made me decide to go no farther. Besides, the best water was below the cabin. I suppose that it is possible that there could be some trout somewhere up above the cabin but it seems unlikely.

Later that same day I drove up Maggie Creek which is the next drainage to the north. Maggie Creek is very small, rarely more than 2 feet across but nevertheless, it seemed to offer good trout habitat in the few holes. I fished the area immediately above and below the forks in the SE¼SE¼ of Sec 11 T47N R31E. No sign of fish.

The next day, back in Oregon, I drove up Little Whitehorse Creek, across the high divide and descended into Trout Creek. About a mile above the ford, in the SE corner of Sec 8, T41S R38E, I caught a trout which fought and looked much like the trout from Willow Creek just over the hill. This fish has a brassy/pinkish cast to it's coloration and reminded me of the trout I caught last summer from Willow Creek. I know that you found no trace of the native trout when you visited Trout Creek 12 years ago so I thought you might be interested in seeing this one. Enclosed is a 35mm slide showing the fish just after removal from the stream. I killed this specimen and will be sending it to you in a few days.

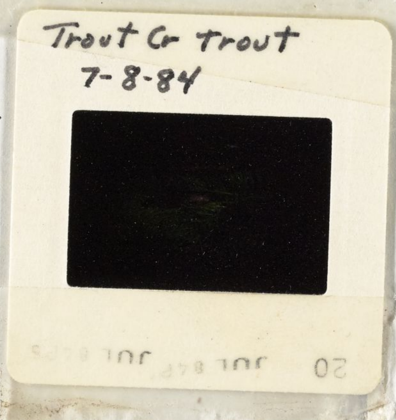
I plan to return to the Alvord area later this year to do more checking - probably in the South Fork of Cottonwood Creek. When you were in the area 12 years ago did you survey the South Fork at all? How far up the main Cottonwood Creek did you get? Do you have any more recommendations?

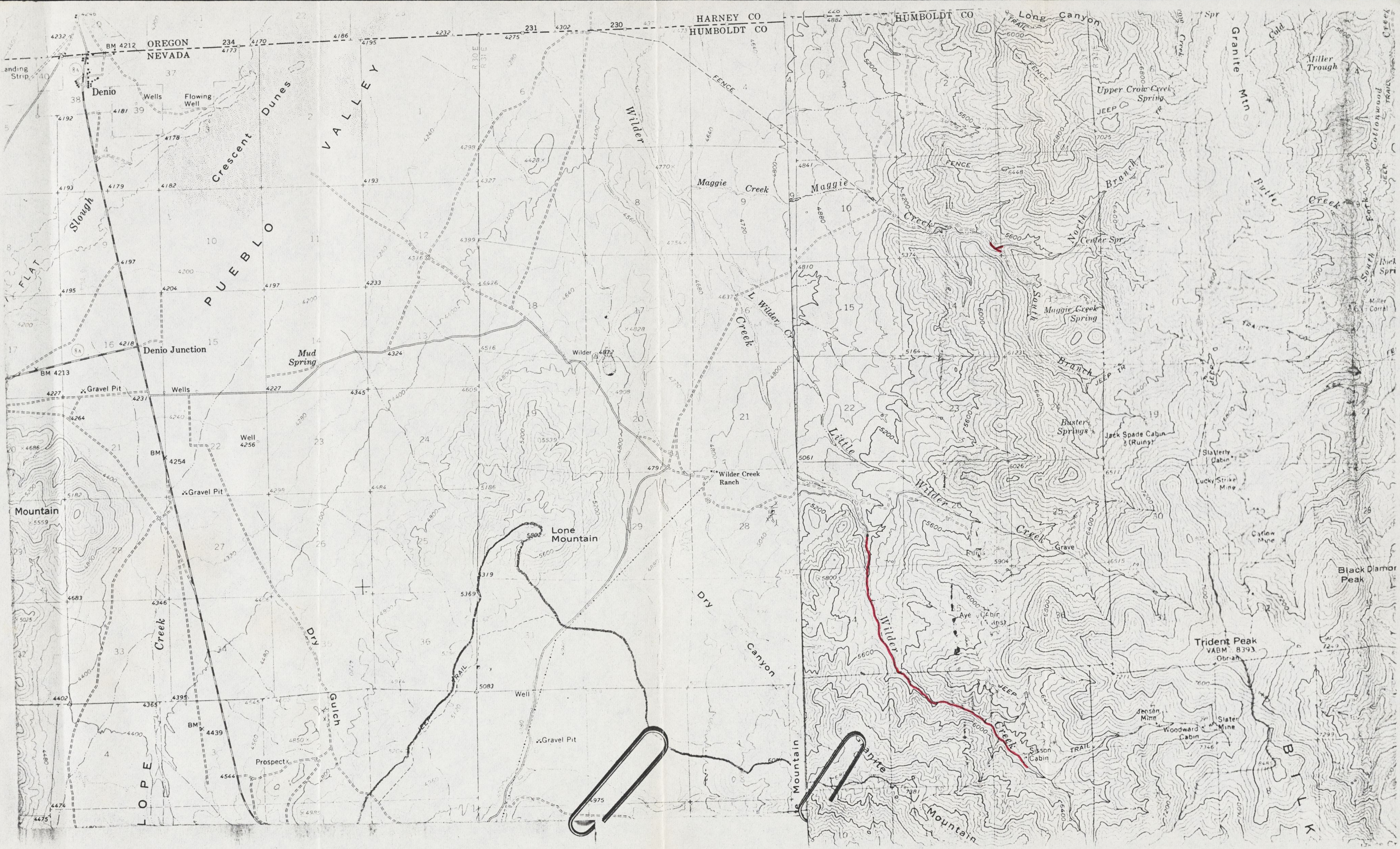
Sincerely,

John L. Perry

John L. Perry

cc : Pat Trotter




HARNEY CO
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HUMBOLDT CO
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NEVADA
Landing Strip
Denio
Wells
Flowing Well
Crescent Dunes
PUEBLO VALLEY
FLAT
Slough
Denio Junction
BM 4213
Gravel Pit
Wells
Mud Spring
Well
Gravel Pit
Mountain
Creek
LOPE
Dry Gulch
Prospect
Lone Mountain
TRAIL
Well
Gravel Pit
Wilder
Maggie Creek
Maggie Creek
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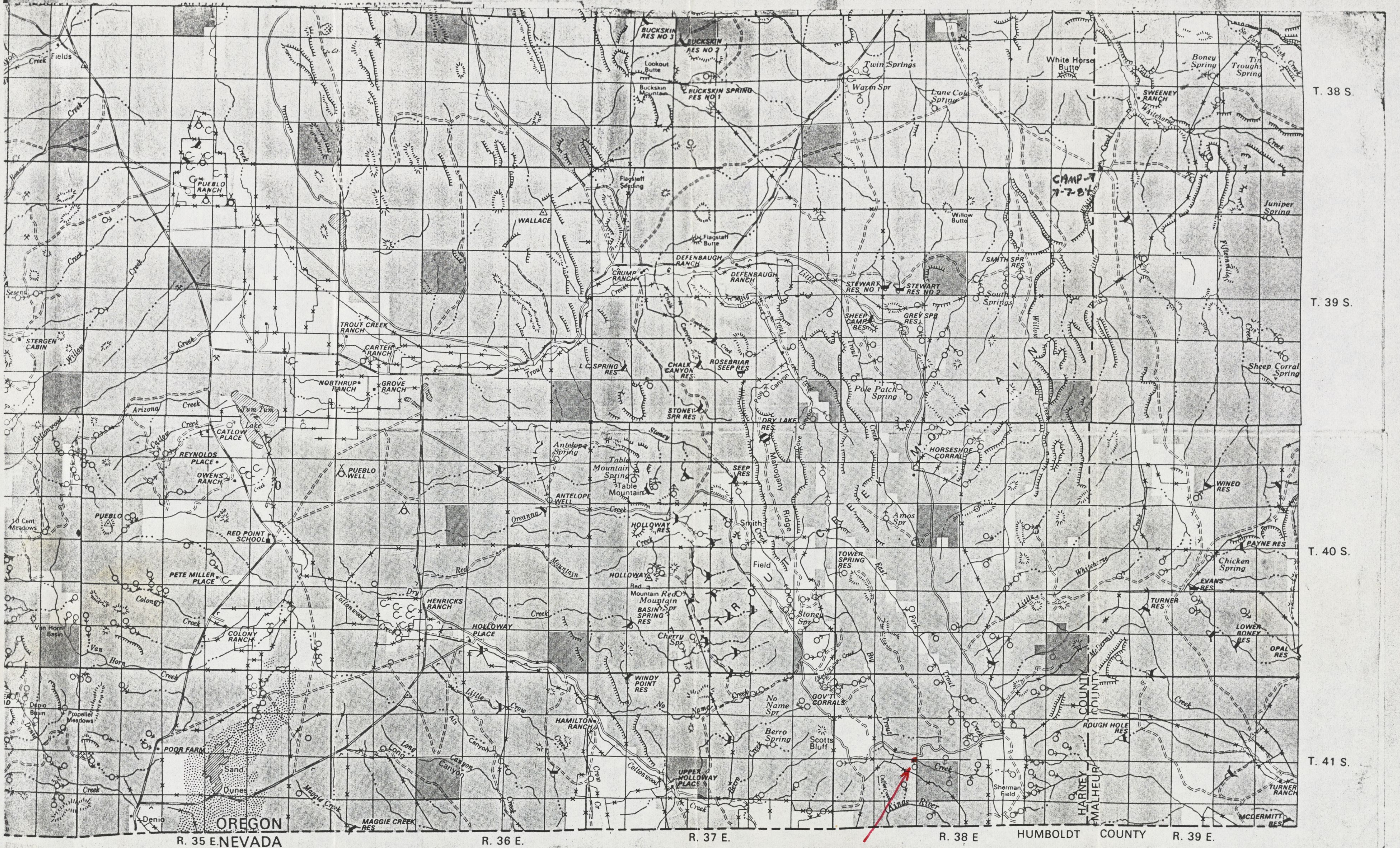
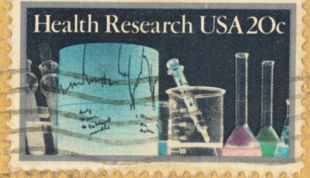
Creek
Wilder Creek Ranch
Dry Canyon
Mountain
Little Wilder Creek
Wilder Creek
Granite Mountain
Sisson Cabin
TRAIL
JEEP
Grave
Long Canyon
Upper Crow Creek Spring
JEEP TR
North Branch
Center Spr
South Branch
Maggie Creek Spring
JEEP TR
Buster Springs
Jack Spade Cabin (Ruins)
Slatterly Cabin
Lucky Strike Mine
Carlow Mine
Black Diamond Peak
Trident Peak
VABM 8393
Jenson Mine
Woodward Cabin
Slater Mine
Granite Mtn
Butte Creek
Miller Trough
Cold
Cottonwood
South Fork
Miller Corral
BILK



SPECIMEN LOCATION

JL PERRY
3463 Chaucer Way
Eugene, Or. 97405



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✓ Cottonwood Valley - Home [illegible] out [illegible] streams
Three Mile Cr - [illegible] redband. and Goose [illegible]

- Swamp Crk. 85°
- Dolly Varden - Bull trout
mig creeks

Slide
predomin[illegible] spotts
AB - but coloration
- Cottonwood Crk. mean scant mine

- Smiths book

Trotter MS

Mike Crouse
Bill Hosford

Dr. Robert J. Behnke
Dept of Fishery & Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523

3463 Chaucer Way
Eugene, Oregon 97405
October 26, 1983

Robert J. Behnke
Dept of Fishery & Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523

Dear Dr. Behnke,

I returned to the Alvord Basin on Oct.13 and decided to take your advice about asking an "old timer" about native trout. The man who pumps gas at the Denio Junction station is about 55-60 and has lived in the area all his life. He told me that there were "natives" in Alder Creek but he wasn't sure what type of trout they might be. He thought they might be brown trout and then went on to tell me about the other type of trout in Alder Creek which have 10-12 small whiskers on their jaw. My optimism about his report diminished at that point.

When I got to Alder Creek Ranch the manager wouldn't give me permission to fish in the creek above the ranch because he was afraid I'd scare his range cattle back up into the mountains and they wanted them to stay nearby the ranch. The manager and his wife insisted that all fish had been washed out into the desert during the spring runoff but they admitted that there had been trout present before, although they didn't know what species they were. I left and went on to the Wilder Creek drainage to see if it might be worth checking. Wilder Creek is a nice looking stream, appears to have enough flow to support trout and is probably worth further investigation. I didn't do much more than look at it as I had no Nevada fishing license, had my bird dog and shotgun and no Nevada hunting license and was afraid of a Nevada game warden finding me up there. To get to the likely appearing water you would have to hike upstream about 2-3 miles. I left Nevada and went back into SE Oregon for a week of bird hunting.

On October 20 I returned to Alder Creek Ranch. Apparently this was a better time to talk and after ½ hour of explaining what I wanted to do the manager granted me permission to use his road to go up the creek. He was concerned that discovery of a rare fish might cause the BLM to reduce his grazing allotment but I think I was able to convince him that the BLM's record with the Willow-White horse Trout showed that he had little to worry about. I fished from the ranch house up and found no fish until I got about 2 miles upstream. There I found numerous fish spawning in the tail-outs of several pools. They were Eastern Brook "trout". I caught 10-12 of them and nothing else. When I returned to the ranch the manager told me that he had seen the same kind of trout in Little Alder Creek and that that made sense as he routinely "switched" the creeks back and forth for irrigation. Based on what you wrote about the Greenback trout and the problem caused by Eastern brook trout, I gather that there would be little likelyhood of finding any native cutthroat in Alder Creek.

I havn't given up on these fish - but I have for the year. Maybe next year I'll get up into Wilder Creek and S.F. Cottonwood Creek. I would like to check some of the tributaries of Virgin Creek also, perhaps re-check Hell Creek and the other major trib - Fish Creek. Fish Creek enters Virgin Creek above Hell Creek and opposite Rock Springs Table Reservoir. With a name like that, it's worth a try. I'll keep you posted on any more looking I do.

Sincerely,
John L. Perry
John L. Perry

cc : Pat Trotter

John L. Perry
3463 Chaucer Way
Eugene, Or 97405

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1983

Dr. Robert J. Behnke
Dept.of Fisheries & Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523

For your info. sjp

Pete Cornacchia
Of the Register-Guard

Bluebacks are back early

FOLKS WHO HAVE spent many summers fishing for sea-run cutthroat, lazily trolling with flashers and worms on the lower ends of coast streams or enticing the trout with flies or crawdad tails under the overhanging brush in upper tidewater and upstream, learned long ago that larger fish on their second or third return from the sea usually will be among the first to show.

These beauties up to 20 inches or more normally will begin to appear around the middle of July, several weeks ahead of the main surge of first-returners averaging 12 to 14 inches. They won't be as abundant as those which come later, of course.

By the time angling pressure builds in August, the catch will consist mainly of cutthroat — AKA bluebacks and harvest trout — which went out to salt water only three months earlier and are returning for the first time.

During that short first tour of sea duty, however, these fish will have grown like mad on a rich diet of shrimp, young perch and herring, sculpin and other goodies. Ranging from nine to 11 inches when they went out, they will be be about three inches longer on their return.

Hardcore fans of the bluebacks also know that whether the fish come back in July or later, they tend to hole up in the estuaries until the fall rains freshen the streams. Most of them will hold in the lower and middle stretches of tidewater.

IN THIS WEIRD YEAR of overheated ocean and crazy weather from El Nino, however, it appears at the moment that the Siuslaw's sea-runs have joined salmon, steelhead and other fish in the goofies.

Far more than the usual numbers have entered the river in the past two weeks and most of them are fish which went out as smolts in early May. Not many of them were expected to come back until next month.

It also appears that many of these early arrivers are pushing upstream at a faster rate than usual, says Jerry MacLeod, district fish biologist. They're being caught throughout tidewater, farther up the main stem, and in Lake Creek.

MacLeod suspects that this departure from normal behavior stems from the Siuslaw's unusually high flow and low temperature for this time, due to the unusually cool and wet weather.

The river is several inches above normal July level and water temperature above tidewater is 68 to 69 degrees, about 10 degrees below normal for now.

IF THIS IS THE Siuslaw, the confused bluebacks may be thinking, it must be September or October and time to be hitting the gravel beds in the creeks.

Since the early 1970's, the Fish and Wildlife Department has been releasing about 45,000 cutthroats in the Siuslaw system each spring. Tagging studies have indicated that the hatchery fish have been accounting for approximately 40 percent of the catch in the river that has become the state's top producer of bluebacks.

Because of disease problems at the Alsea hatchery, only 28,500 cutthroats were released in the Siuslaw this spring. Unlike in the past, when none or only some of the fish were marked, the entire batch was marked by clipped adipose fin.

All were marked as part of a study to assess the number of smolts being caught on their way out in the early part of trout season, as well as their contribution to the tidewater catch in summer and fall.

Random checking this spring indicated that about 65 percent of the trout caught by the relatively few anglers on the river were marked, says MacLeod. Most of those fish were caught at or near known release sites, however. The marked percentage of the catch away from these points was much lower.

Some of the smolts released in early May were being caught by jetty fishermen at the mouth of the river before trout season opened on coast streams, which led the biologist to believe that most of the youngsters moved out rapidly and were gone from freshwater by the opening.

This summer, catch records kept by three marinas and a creel census show that about 60 percent of the bluebacks caught this month were marked.

All the more so in this crazy year, says MacLeod, at this point your guess is as good as his on whether the Siuslaw's run is early and will be below average or the fish will continue to come in their usual waves in August.

RESEARCH ON SEA-RUN cutthroats, including studies on the Siuslaw, Alsea and Nestucca through the latter half of the 1960's, has shown that these fish do very little feeding after returning from the ocean, even though food may be abundant. The sea-runs, it's generally agreed, will hit bait, lures and flies more in reflexive action than in desire for nourishment.

This theory is supported by the fact that fishing will be best in the first several days after a group arrives, then will tail off until the next batch shows.

In this year of El Nino, perhaps you'd better not count too much on the usual fresh batches in August.

SECTION E

Eugene Register-Guard

EUGENE, OREGON, SUNDAY, JULY 17, 1983 ★

Sports

Watson enjoys the carnival with the lead

Boisterous fans, vandals, Stadler's double-bogey spice British Open

By SHAV GLICK
Of the Angeles Times

SOUTHPORT, England — Back before the rn of the century, when Victoria was still Queen England, the Irish Sea lapped the shores of the ncashire coast at Birkdale and the city of Southrt was a bustling seaside resort.

Mysteriously, the sea receeded about the year 00, and the folks in Southport built a mile-long er to chase the water. It was futile. Today it is a er to nowhere, because the Irish Sea is still ceeding and the pier is decaying.

With a pier and no beach, Southport became a ney Island-type carnival town, complete with rris wheels, roller coasters, palmists and forne tellers.

whiffed a 2-inch putt on the 14th hole, giving him a bogey instead of a tap-in par.

• Vandals dug holes and painted slogans on the sixth green in the early morning, causing Royal & Ancient Golf Club officials to shorten the hole 40 yards and create putting "avenues" so players would have a smooth surface to putt across. This served to turn Royal Birkdale's most difficult hole, which had yielded only four birdies (against 121 bogeys) in 36 rounds, to an average par 4 with 13 birdies among 83 players.

• British fans, exhorting local favorite Nick Faldo with football-type rooting, cheered lustily when Watson missed a birdie putt, and supported Faldo with cries of "Go, Nickie, you Bulldog," a Liverpool football (soccer) yell.

With 18 holes to play — barring a playoff Monday — in this 112th rendition of The Open, Watson leads at 205, followed by Stadler, whose double bogey on No. 18 gave him a 72-206. After Graham, Floyd and Faldo at 207 comes Lee Trevino, 73-208, followed by a 209 foursome of Fuzzy Zoeller (67), Mark McNulty (68), Andy Bean (70) and Irwin (72).

It was familiar territory for Watson, reaching the top while sitting down. Last year at Troon he had finished his 72 holes and was watching when Nicki Price collapsed and handed Watson his fourth British Open championship.

"I have mixed emotions about today," Watson said. "I always like to be in the lead, but I struggled with my driver all day and if I expect to have a chance Sunday, I'll have to get the big club

July 25, 1983

Robert H. Behnke
Colorado State University
Fort Collins, Colo.

Dear Dr. Behnke,

I have some good news and some bad news to report. First, the bad news :

On the weekend of July 16 I was able to get away and went to the Alvord Basin to look for native trout. Saturday morning I drove up the Craine Creek valley and wound up on upper Craine Creek in Section 5, T.42N, R27E. The creek was quite small (1 or 2 feet across) but looked as if it could hold fish. The mountain headwaters still had several snow drifts feeding the stream. The stream must get much smaller later in the year. There is a 30' falls in south-center of Sec.5 and I fished all likely looking spots for ¼ mile above and below. No fish caught or seen. The stream channel contains aquatic weeds which provide cover and aspen and cherry trees along the stream provide shade - the creek looks like fish could live there now but in a dry year, who knows?

Next, I drove to the confluence of Craine Cr and Cove Cr and fished about 100 yds down to the start of private (posted) property. No fish caught or seen although here too, the stream looks like good trout habitat but must be much diminished in a dry year. Then I drove upstream along Cove Creek to Cove Meadows. Corral Cr joins Cove Cr here but neither produced any fish. Both are small enough that I doubt if there is any flow in a dry year.

Then I proceeded east across the Quinn River valley and up the BLM access road to Blue Lake. The road climbs Alta Creek canyon and comes out on top in the Theodore Basin, which comprises the headwaters of Little Alder Creek. This is an un-surveyed area but would be in T.44N, R29E (see enclosed map). I started in the Basin area where Little Alder Cr is less than 10" wide and 6" deep. The stream gains size rapidly and gains a tributary in about 200 yards. Gradient is about 5% and there are lots of spots capable of holding fish. About 100 yards below the tributary, the stream drops off the mountain and flows down at a gradient of about 20%. Even in the steep section there are lots of holes and pockets where fish could live. However, I caught or saw none. I fished down to the 6000' level and back up the "south fork" to about 6300'. No fish. I fished my way back up the main creek to Thoedore Basin (7100') and still found no fish, trout or other-wise. The stream looks like good habitat (even had a small size 22 mayfly hatch) but this is a wet year (several snow drifts above Theodore Basin) and in a dry season the creek must be very small.

The next morning I drove on an unmapped jeep road to the edge of Oakley Canyon (trib to Road Canyon) and hiked down to the creek. It is very small and probably is dry in summer, although there could be water farther downstream. However, I decided not to look farther as my time was running out (besides my sealevel lungs just couldn't take much more of that thin air).

I havn't given up on the Alvord cutthroat although my enthusiasm level has dropped some. I think I'll go back to the Pine Forest Range later in the summer when the creeks are at their lowest and maybe a few pools could be located. There I would expect to find the trout, assuming any are left.

Now for some better news:

I am sending (via U.P.S.) sample specimens from three streams in the Coast Range west of Eugene.

Bottle #1 contains 10 fish from Beaver Creek (trib. to Sweet Creek which is trib. to the tidewater section of the Siuslaw River) collected in Sec.4, T19S, R10W about one mile above the impassable Sweet Creek falls. These fish were taken from a 100 yard stretch at the first bridge across Beaver Creek which is about ¼ mile above its confluence with Sweet Creek. The fish are all small and appear to be "natives" although only one or two had obvious cutthroat marks below their jaws. Collected on July 19, 1983 at about 400' elevation. The road up Sweet/Beaver Creeks is open to the public so there is some fishing pressure and people have had homesteads above the falls dating back nearly 100 years.

Bottle #2 contains 10 fish from the headwaters of Whittaker Creek (trib. to the Siuslaw River) taken from Sec.12, T19S, R9W about two miles above an impassable falls. The area was roaded about four years ago but so far fishing pressure is nil. Fish were plentiful but larger than the Sweet Cr/Beaver Cr fish and they all had typical "native" markings. These fish were collected on July 20, 1983 and were from an elevation of about 950'.

Bottle #3 contains 10 fish from the upper North Fork of Smith River (trib. to the lower Umpqua River) taken from Sec.3, T19S, R9W about 3½ miles above a high falls. These fish all appeared to be "natives". There are roads into the area but the bottom land is privately held and gates keep most fishermen away. These fish were collected on July 23, 1983 from an elevation of about 1100'. These fish were also plentiful and larger than the others but were much more difficult to capture due to the low, clear water and open creek banks which made undetected approach difficult.

All three of these streams drain the highest land mass in the central Coast Range, Roman Nose Mountain 2856' (Sweet Creek actually heads up a few miles west in the Goodwin Peak/Mt. Grayback area). With the exception of Sweet Creek, access has been very difficult up until recently and I really doubt if any introductions have ever been made to these streams.

I hope you will find some use for these specimens and if you want more, I would be glad to help. I know of a small stream in Southwest Washington which I used to fish as a kid which has an impassable falls and nativelooking cutthroats above. I could sample that stream (Mosquito Creek) for you next time I visit relatives in the area.

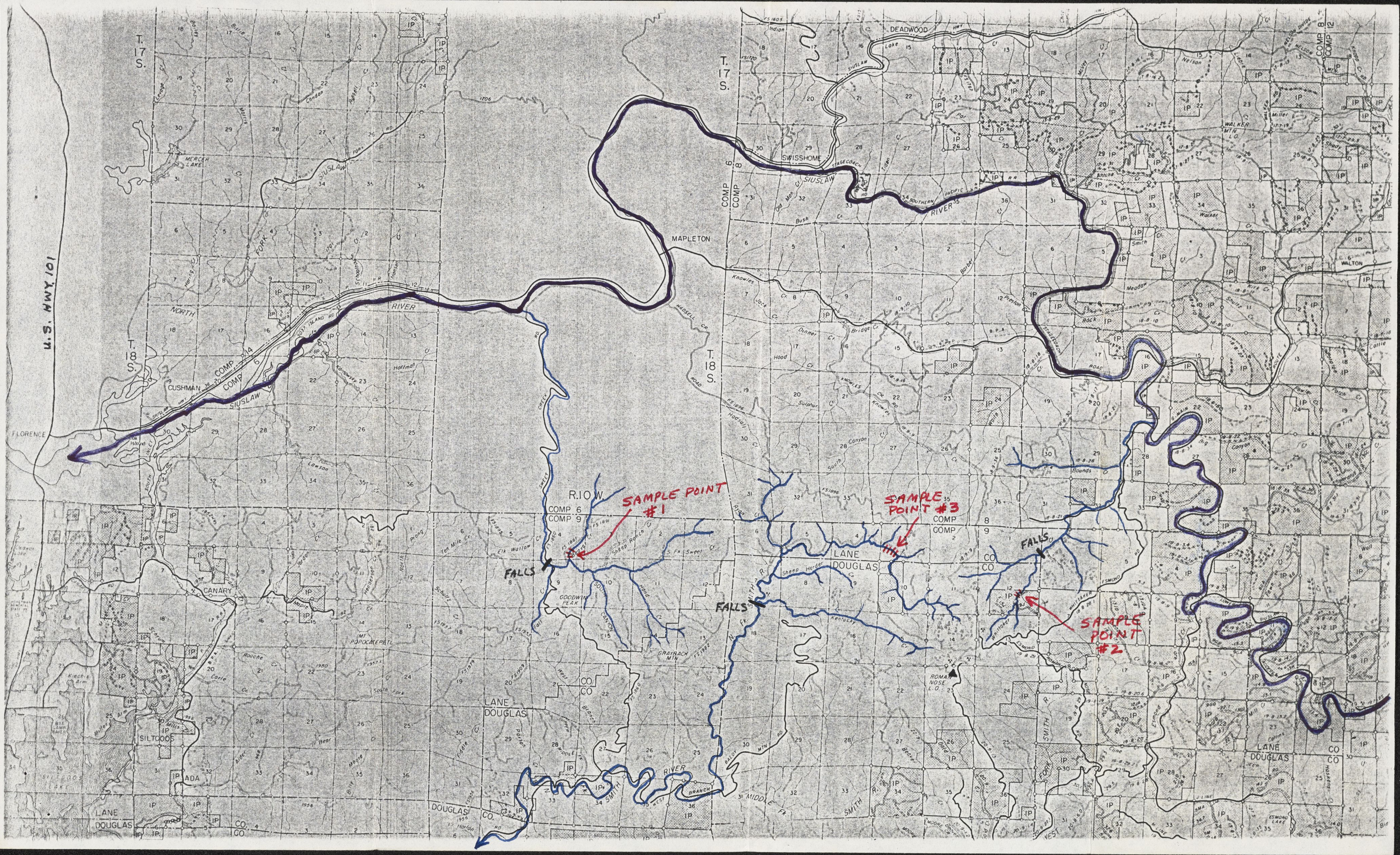
I will write you of my success or lack thereof after I return to the Alvord Basin later this year.

Sincerely,

John L. Perry

John L. Perry
3463 Chaucer Way
Eugene, Oregon 97405

P.S. I kept the first 10 fish caught except for 1 or 2 tiny ones from each stream.
JLP



U.S. HWY. 101
FLORENCE
CUSHMAN
MAPLETON
SWISSHOME
DEADWOOD
WALTON
CANARY
SILTCOOS
ADA
T. 17 S.
T. 18 S.
R.10W.
NORTH FORK
SIUSLAW RIVER
SMITH RIVER
LANE
DOUGLAS
COMP 6
COMP 9
COMP 8
GOODWIN PEAK
GRAYBACK MTN
ROMAN NOSE L.O.
SAMPLE POINT #1
SAMPLE POINT #3
SAMPLE POINT #2
FALLS
FALLS
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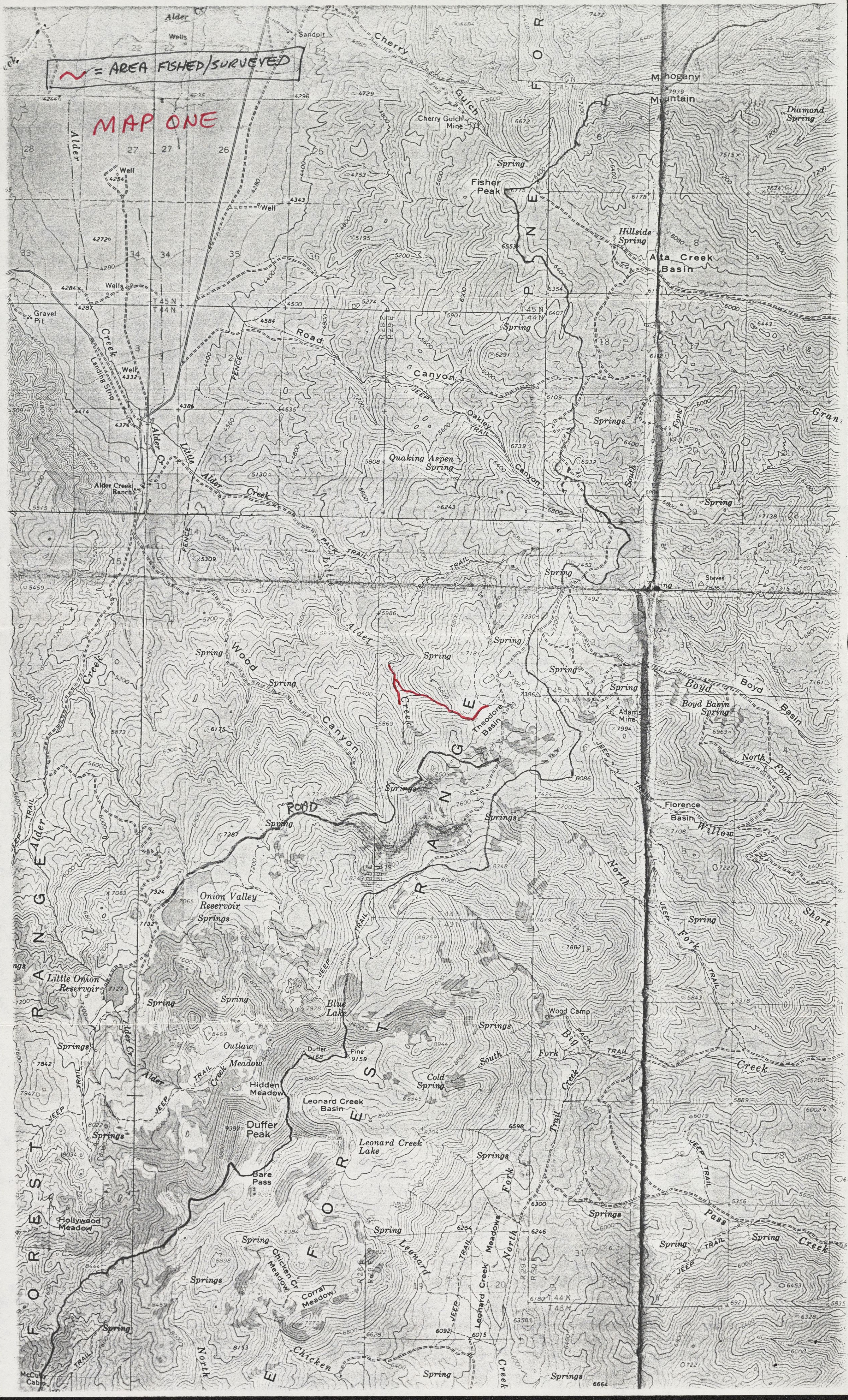
FALLS

VICINITY MAP


= AREA FISHED/SURVEYED
MAP ONE
Alder
Wells
Sandpit
Cherry
Gulch
Cherry Gulch Mine
Fisher Peak
Mahogany Mountain
Diamond Spring
Hillside Spring
Alta Creek Basin
Gravel Pit
Alder Creek
Landing Strip
Road
Canyon
Oakley
Quaking Aspen Spring
Little Alder Creek
Alder Creek Ranch
PACK TRAIL
JEEP TRAIL
Wood Canyon
Spring
Springs
Theodore Basin
Adams Mine
Boyd Basin
Boyd Basin Spring
North Fork
Florence Basin
Willow
Onion Valley Reservoir
Little Onion Reservoir
Blue Lake
Outlaw Creek Meadow
Hidden Meadow
Duffer Peak
Pine
Cold Spring
Leonard Creek Basin
Leonard Creek Lake
Wood Camp
Big Fork
South Fork
Trail Creek
Bare Pass
Hollywood Meadow
Chicken Cr Meadow
Corral Meadow
Leonard Creek
Leonard Creek Meadows
North Fork
Chicken Creek
Pass Creek
Short Creek
Steves
ROAD
FOREST RANGE


MAP TWO
= AREA FISHED/SURVEYED
Landing Strip
Knott Creek Ranch
KNOTT CREEK CHANNEL
Knott Creek Reservoir
Knott
Craine Creek
Cow Creek
Water Tanks
Springs
Cove Camp
Cove Meadows
Gravel Pit
Corral Creek
Willow Spring
Lone Meadow Spring
Craine Spring
McCully Spring
BLACK ROCK RANGE
Center Creek
Bartlett Mine
Bartlett Peak
Josie Pearl Spring
Pearl Camp
Pearl Canyon
Juanita Mine
Columbia Mine
Trail Canyon
Horseshoe Bend
Wheeler Springs
Rock Spring
Prospects
JEEP TRAIL
FENCE

9RB ; cutt

Beaver Crk - Sweet Crk trib. Suislaw R.

coll. Sec. 4 T19S, R10W. 1 mi. above falls

July 19, 83

Whittaker Crk. trib. Suislaw R.

Sec. 12, T19 S, R-9W ca. 2 mi. above falls

July 20, 83

N. Fk. Smith R. trib. Umpqua Sec. 3, T19S, R9W

ca. 3 1/2 mi. above falls.

July 23, 83

John Perry, Eugene OR.

August 2, 1983

Dr Robert Behnke
Colorado State University
Fort Collins, Colorado 80523

Dear Dr. Behnke,

By now you should have received the three samples of fish from the Oregon coastal range area. I hope they arrived in good shape - although I have some doubt about the bottle containing the North Fork Smith River fish as the top had to be enlarged in order for the larger fish to fit.

Yesterday I spoke to Dave Loomis of the Oregon Dept. of Fish & Wildlife. He is in charge of the Dept's Salmon & Trout Enhancement Program (STEP) for the central coast from the Siuslaw to the Alsea. We were discussing the STEP program and in passing he mentioned that one of the techniques used was stocking mature adult Chinook and steelhead above impassable falls. He told me that the Dept. had been "dumping" both species of fish above the Sweet Creek falls for years. That is surprising to me since the falls seems too high for any downstream migrants to survive the plunge. He wasn't sure about Whittaker Cr but didn't think there had been any stocking above it's falls. Loomis had no knowledge of similar activities on the NF Smith (it's not in his area of responsibility).

As I mentioned in my letter of last week, the fish from Beaver (Sweet) Creek didn't appear to be 100% pure (no red marks on lower jaw on some). Perhaps there has been some hybridization between the steelhead and native trout. I suppose it is even possible that some of my samples - the smaller ones anyway - may be juvenile salmon. Now, I'm not sure.

Anyhow, I thought I'd better let you know what I've learned since I wrote my last letter.

Sincerely,

John L. Perry

John L. Perry
3463 Chaucer Way
Eugene, Oregon 97405

steelhead article

Thanks paper clip
coastal cult

Alvord ask
"old timers"

John L.Perry
3463 Chaucer Way
Eugene, Ore.97405

NOTI, OR
AUG
2
PM
1983
97461

Alvord
collections
+ coastal cutts

Dr. Robt. Behnke
Dept.of Fish & Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523

April 24, 1985

Dear Dr. Behnke,

Thanks for your letter of 4-18-85. I was glad to hear the news of the possible discovery of a remnant population of the Alvord cutthroat. In your letter, you mentioned that the trout was found in the headwaters of the Virgin River. My topographic maps of the area show a Virgin Creek which is tributary to Thousand Creek - probably the same water.

Last fall I planned to spend some time exploring the headwaters of the South Fork of Cottonwood Creek. I had planned to go up into that country in mid-October when stream flows would have been at their minimum. Unfortunately, a major weather system moved thru the region on October 14 with snow accumulations on all the higher elevations and rain below - effectively preventing access to the upper watershed within the time I had available.

This year is shaping up to be quite a bit drier than the past two or three with significantly less snowpack in the high mountains. I intend to try to check out the upper S.F.Cottonwood Creek watershed again this year, probably in September.

It seems to me that if the fish the Nevada Dept.of Wildlife biologists found is, in fact, the "lost" Alvord cutthroat, and if an attempt is made to propagate and perpetuate the species, then a second source (genetic base) would be desirable. Maybe that second source exists - maybe not. Regardless, I find the Alvord Basin area intriguing and having something as interesting as a rare trout to look for adds to the interest of the area.

I will keep you informed of any such searches made by me - successful or not. Thanks again for your recent letter. I would very much appreciate further updates on the Alvord cutthroat as events unfold.

Sincerely,

John L Perry

John L. Perry
3463 Chaucer Way
Eugene, OR 97405

J.L.Perry
3463 Chaucer Way
Eugene, OR 97405

VENETA, OR
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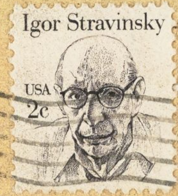

Dr. Robt. Behnke
Dept.of Fishery & Wildlife Biology
Colorado State University
Fort Collins, Colorado 80523

J. Wildl. Mgt. 32(1)
1968

SITE SELECTION AND TIME OF SPAWNING BY TWO GROUPS OF KOKANEE IN ODELL LAKE, OREGON[1]

ROBERT C. AVERETT, Oregon State Game Commission, Corvallis[2]
F. A. ESPINOSA, JR., Oregon State Game Commission, Corvallis[3]

Abstract: The time and area of spawning of two groups of kokanee (*Oncorhynchus nerka*) in Odell Lake, Oregon, were observed in the fall of 1965. The first group was from the 1963 hatchery release (Kootenay Lake, British Columbia stock). They spawned from mid-September until early November in the outlet stream, the main tributary, and along one section of the lake shore. The second group, comprised of the natural-reared kokanee of the lake, spawned from early December until mid-January, apparently along only one section of the lake shore. In addition, females of the two groups were significantly different ($P < 0.05$) in mean length and mean weight. The regressions of egg number on fork length showed no significant difference. Reasons for the selection of spawning sites and the origin of the stock of the second group are suggested.

Odell Lake in the central Cascade Range of Oregon contains an important fishery for kokanee. The lake lies at an elevation of 4,792 ft, covers 3,593 surface acres, and has a maximum depth of 282 ft (Fig. 1). It is fed by two major tributaries, Trapper and Crystal creeks. Odell Creek, the outlet stream, drains the lake and flows 13 stream miles before entering Davis Lake. Trapper and Crystal creeks receive snow melt from higher elevations. Underwater springs are present along the shoreline near the Post Office Lodge.

Since 1950 the Oregon Game Commission has stocked the lake annually with 100,000 to 500,000 kokanee fry and fingerlings. It had been assumed that the fishery was being maintained by the annual stockings but creel census conducted on the fishery in 1964 and 1965 revealed that only 27 and 23 percent of the kokanee catch were of hatchery origin (Campbell 1965, Averett 1966). A study was initiated in the fall of 1965 to determine the location and magnitude of natural spawning. Two distinct spawning groups were subsequently discovered. The first group, primarily of hatchery origin, spawned in two streams and on the lake shore in September and October. The second spawned in December and January along the lake shore only and was composed of wild kokanee. The term "wild" in this report refers to kokanee hatched in Odell Lake.

Sources of eggs for the hatchery fish released in Odell Lake have been Kootenay Lake, British Columbia (Meadow Creek strain), and Flathead Lake, Montana. Kokanee were introduced into Odell Lake before 1950 but the source of eggs and year of initial stocking are not known. All fish stocked between 1962 and 1965 were from Kootenay Lake. Kokanee from Flathead Lake were stocked several times before 1962 and again in 1966. Since 1962, portions of the hatchery fish have been marked by fin removal to assess the hatchery contribution to the sport fishery.

The purpose of this paper is to show the differences in time of spawning and site selection between the natural-reared and hatchery introduced kokanee of Odell Lake.

We wish to thank A. J. Tolmsoff, now at the University of Missouri, for assisting in

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[1] Contribution from Dingell-Johnson Project F-71-R, Oregon.
[2] Present address: Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon.
[3] Present address: Department of Biology, Nevada Southern University, Las Vegas, Nevada.

the field work. Appreciation is also extended to J. Deacon, R. V. Bulkley, H. J. Rayner, and G. D. Holton for reviewing the manuscript and offering suggestions.

METHODS

Mature kokanee were captured with a seine and monofilament gill net at the Post Office shoreline area, with a wire-mesh trap in Trapper Creek, and with a hand-net in Odell Creek. All fish captured in Trapper Creek and at the Post Office shoreline were inspected for marks and measured to the nearest millimeter (fork length), and a representative sample weighed. Eggs were obtained from samples of females for fecundity comparisons. In Odell Creek, kokanee were inspected for marks only.

The number of hatchery kokanee in the spawning areas was estimated by multiplying the number of fin-clipped fish observed in accordance with the ratio of marked to unmarked fish in the liberation. Twenty percent of the fish stocked in 1963 were marked by removing either the right or left pelvic fins. Unfortunately, no evaluation of differential mortality between marked and unmarked hatchery fish has been made. Mortality of the marked fish may be greater than that of unmarked. Consequently, the number of hatchery fish estimated in a given spawning group is minimal.

RESULTS

Kokanee in Odell Lake have been known to spawn in two tributaries, Trapper and Crystal creeks, in Odell Creek, the outlet stream, and along the shoreline near the Post Office Lodge (Campbell 1965). In 1965, spawning occurred at all these sites except Crystal Creek.

For clarity, the two spawning groups of kokanee described in this paper will be designated as Group I (early spawning) and Group II (late spawning).

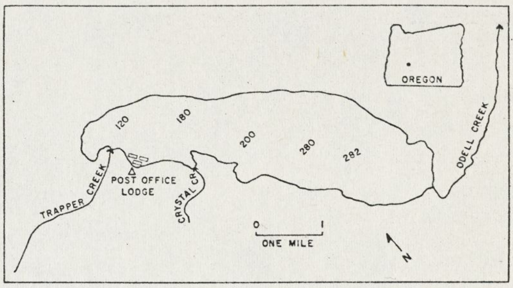

Fig. 1. Map of Odell Lake with selected depths.

Group I

Kokanee from the 1963 hatchery liberation were predominant in Group I; they attained their red spawning coloration as early as August 10, 1965.

In late August they were observed moving along the shoreline of the lake. Eight experimental monofilament gill nets set on the nights of August 25 and 26 captured 385 kokanee of the group, of which 68 were marked fish from the 1963 release. Expanding the marked fish by a factor of five indicated that approximately 340 (88 percent) of the fish were of hatchery origin.

Movement of the group into Odell Creek began on August 22, when approximately 30 kokanee were observed within the first mile of the stream. They began moving into Trapper Creek on September 16 and continued to do so until November 2. Spawning at the Post Office shoreline began on September 18 and continued until November 10.

Table 1 summarizes the number of Group I kokanee examined in the three spawning areas. Of the estimated 1,025 kokanee of hatchery origin, 980 were from the 1963 release (age II+) and 45 were from the 1964 release (age I+).

The three areas in which Group I kokanee spawned differed in direction of

Table 1. Number of Group I kokanee collected at Odell Lake, Oregon, 1965.

Area	Collection Dates	No. of Fish Observed	Marked Fish Observed	Estimated Hatchery Fish	Percent Hatchery Fish
Shoreline net sets around lake periphery	August 25–26	385	68	340	88
Trapper Creek	September 16–November 2	620	94	470	76
Odell Creek	September 28–October 14	215	34	170	79
Post Office shoreline	October 15–25	45	9	45	100
Totals		1,265	205	1,025	81

water currents (inlet stream, outlet stream, and lakeshore). In addition, there was a marked difference in water temperature between the two streams used for spawning (Fig. 2). Throughout the spawning period Trapper Creek had a mean mid-morning temperature of 39.9 F. The mean mid-morning temperature of Odell Creek was 57.3 F.

Stream-spawning kokanee selected the slower-flowing riffle areas near the stream margins. Preferred gravel size in the streams ranged from ½ to ¾ inch in diameter, but site selection may have been a result of other environmental factors. At the Post Office shoreline, gravel size ranged from ⅛ to 1 inch in diameter. A small stream enters the lake at this site and some underwater springs are present. Kokanee were attracted to this site to the exclusion of other shoreline areas.

As spawning progressed, Group I kokanee were observed in the entire length (13 miles) of Odell Creek but the greatest spawning concentration was in the upper 2 miles. An impassable falls limits the spawning area in Trapper Creek to the first mile above the lake. The greatest spawning concentration in Trapper Creek was in the first riffle, approximately 300 ft from the lake.

The actual number of spawning Group I kokanee was determined only at Trapper Creek. We observed that more fish spawned in Odell Creek than in Trapper Creek and that fewer fish spawned at the Post Office shoreline.

In Trapper Creek, 602 kokanee entered the trap between September 17 and October 19 (Fig. 3). Thereafter, a few fish entered the trap at 2- to 4-day intervals until November 2, when movement ceased. Throughout the spawning period, a total of 620 fish, of which 326 were females and 294 were males, entered the trap. Movement into the trap began at the first hour of darkness and was usually complete by 10:00 PM. Daytime movement occurred only once, on an overcast day in late afternoon.

Group II

Kokanee of Group II were first observed in a dense school off the boat docks near the Post Office shoreline on October 28. At this time they were about 100 ft offshore. Between October 28 and November 8, 315 were captured with a monofilament gill net and a 200-ft seine. None possessed the hatchery mark, indicating that they originated from natural spawning in the lake. After being inspected for marks and measured and weighed, each fish was given an upper caudal lobe clip before it was returned to the lake.

Group II kokanee were not fully mature on November 8, as indicated by difficulty in expressing eggs from the females or sperm from the males. An attempt to collect an additional sample on November 10

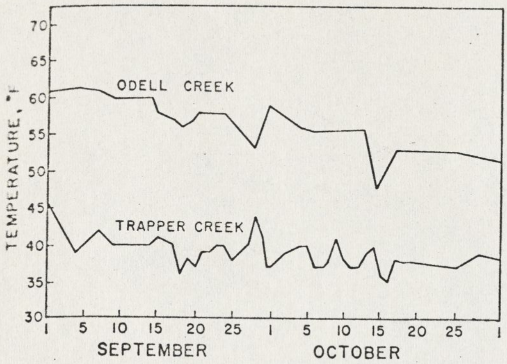

Fig. 2. Mid-morning fall temperatures of Odell Creek and Trapper Creek.

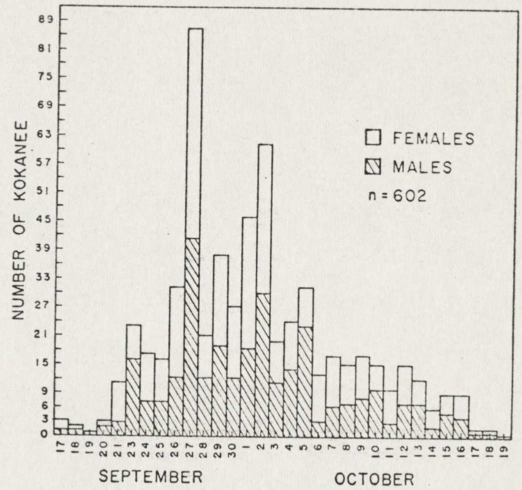

Fig. 3. Frequency of Group I kokanee entering Trapper Creek between September 17 and October 19, 1965.

failed because the fish had left the Post Office area of the lake. An intensive check of the lake shore, the tributaries, and the outlet stream failed to locate them.

On December 6, the school returned to the Post Office shoreline and commenced to spawn. At this time they moved directly into the area where a few members of Group I had spawned a month earlier. Spawning activity was profuse on December 6, and continued into January. Fish bearing the upper caudal lobe clip were easily visible in the spawning school, indicating that this was the same group that had been encountered and sampled earlier in the boat-dock area.

Group II males and females were calico colored and the males possessed a well-developed kype. Group I kokanee were red and the males had a poorly developed kype.

An examination of otoliths from the group indicated that they were in their third year of life (II+), as were most of the kokanee in Group I.

Groups I and II Compared

There was a clear separation of spawning time between the two groups of kokanee (Table 2). Group I spawned from mid-September until November 10, although they entered Odell Creek as early as August 22. Group II spawned from December 6 until mid-January. Except at the Post Office shoreline, there was no overlap of spawning sites. Group II fish did not spawn in any of the streams. An estimated 81 percent of the fish from Group I were of hatchery origin from the 1963 and 1964 releases. Since this estimate is minimal, it is possible that essentially all the fish in Group I were of hatchery origin. None of the Group II fish examined possessed the hatchery mark.

To further compare the two groups, the mean length and weight of females and regression of weight on length were computed (Table 3). Those of Group II averaged 2.5 cm longer and 59.6 g heavier than those of Group I. Group I fish had a length range from 20.8 to 34.4 cm, while Group II ranged from 28.8 to 38.4 cm.

At the 0.05 level, tests for a common line and slopes of weight on length for females of the two groups showed a significant difference.

A test of the regression of egg numbers on fork length within the length range of

Table 2. Area and period of spawning for Group I and Group II kokanee at Odell Lake, Oregon.

Area	Spawning Period	
	Group I	Group II
Odell	Aug. 22–Oct. 28	
Trapper Creek	Sept. 15–Nov. 10	
Post Office	Mid-Sept.–Nov. 10	Dec. 6–Mid-January

Table 3. Sample size, mean length and weight, and regression of weight on length for females of the two groups of Odell Lake kokanee.

Group	No.	Mean Length (cm)	Mean Weight (g)	Regression Formula
I	151	29.7	263.8	$W = -385.08 + 2.1883L$
II	80	32.2	323.4	$W = -542.60 + 2.6910L$

29.1 to 33.4 cm, the range in which females from both groups were represented, showed no significant difference at the 0.05 level.

DISCUSSION

Early-spawning kokanee (Group I) of Odell Lake were progeny of fish from Kootenay Lake (Meadow Creek), British Columbia. Vernon (1957) described three races of kokanee in Kootenay Lake including the Meadow Creek (north end) race. Although he did not precisely determine the dates of peak spawning, he mentioned that all races in the lake spawn in September and October. Seeley and McCammon (1963:8) have associated the early spawning kokanee in California with the British Columbia strain. In California waters, both the early and late spawning kokanee use outlet and inlet streams and suitable lakeshore areas for spawning. In Odell Lake, the British Columbia strain spawned in lesser numbers along the lake shore than in Odell and Trapper creeks.

No direct evidence is available as to the source of the late spawning fish (Group II) in Odell Lake, but it is suspected that they are of Flathead Lake origin. Hanzel (1964) has indicated that in the Flathead Lake drainage kokanee spawn from early October through mid-December in both the lake and the tributaries. A further indication that kokanee from Flathead Lake spawn through at least mid-December was obtained by Averett and Whitney (1959) who reported that the winter catch of kokanee in Georgetown Lake, Montana, which apparently received its kokanee stock from Flathead Lake, dropped from an estimated 850 fish in December to 26 fish in January to no fish in February. They attributed the drop in catch to the completion of the life cycle of the particular age-group that entered the fishery in the fall of 1958.

Rupp and Redmond (1966:257) found that the time of spawning for a stock of American smelt (*Osmerus mordax*) remained unchanged after transfer to a lake where the endemic smelt population spawned much later. This evidence would suggest that the time of spawning is a heritable trait.

In addition to spawning near shore it is possible that Group II kokanee also spawn at other times in the deeper water of Odell Lake, undetected by visual observation. We are certain that their spawning was confined to the lake and did not take place in any of the streams. Of interest are the possible reasons why Group I spawned in three dissimilar areas and Group II only along the shoreline. Group I kokanee had no natal area in Odell Lake because they were reared in the hatchery. Their movement around the shoreline of the lake in late August suggested that they were searching for a suitable spawning site. Lacking a natal site, they finally selected three areas: a tributary stream, the outlet stream, and the shoreline near the Post Office lodge. In contrast, Group II kokanee probably had a natal area at the Post Office shoreline and thus large concentrations of the group would not be expected at other areas. When Group II was originally introduced, individuals of the same stock may have been successful only at the Post Office area. Vernon (1957) found a strong homing tendency among Kootenay Lake kokanee and estimated that straying was less than 3 percent.

Preliminary investigations in the spring of 1966 tend to support the premise of low survival in the streams tributary to Odell Lake. The constant low temperatures of Trapper Creek (mentioned earlier), and evidence of frequent scouring of the stream bottom, suggest low survival to emergence. Low temperatures alone would probably not be the limiting survival factor, for Royce (1959) has shown that sockeye in northern latitudes spawn in streams that approach freezing in the winter. Kimsey (1951) found that kokanee eggs in Donner Lake, California, which had been exposed to occasional freezing still developed successfully when transferred to warmer waters. Water temperatures in Odell Creek are warmer during the winter than in Trapper Creek and the streambed does not show signs of scouring with runoff. Both Trapper and Odell creeks approach maximum annual flow at the time when kokanee emerge.

At the Post Office shoreline, fry emergence was first noted on May 25, 1966, and continued for 4 weeks thereafter. We can only hypothesize at present, but available data suggest that the Odell Lake kokanee fishery is supported primarily by fish hatched in the lake.

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Received for publication June 22, 1967.

Endangered Plants and Animals of Oregon

I. Fishes

Special Report 205
January 1966

Agricultural Experiment Station
Oregon State University
Corvallis

FOREWORD

The publications under this title list and locate plants and animals in Oregon that represent "endangered species" -- ones which can be easily destroyed. They are usually found in relatively small areas. Because they are often rare or unusual, they possess unique scientific value. For this reason alone, their preservation is considered beneficial to man's interest. Moreover, they can be easily eliminated or their numbers seriously reduced through man's manipulation of the environment. Habitat essential to survival, for example, is and can be altered through a number of man's activities, including pesticides, toxic materials, or other pollutants in the environment.

Those responsible for planning and carrying out operations which may destroy or modify natural habitat or pollute it with toxic materials need objective information regarding undesirable or unwanted effects of their activities. Also, there is danger of contaminating high-value natural resources such as the water supply of fish hatcheries or natural breeding areas of fishes which reproduce at specific times in limited areas. The publications grouped under this heading provide additional facts not generally known or available regarding the location of endangered species. Through these publications, it is hoped that the public will select alternatives which will insure the continued preservation of our rare plants and animals.

Thomas G. Scott, Head
Department of Fisheries and Wildlife

I. FISHES

Carl E. Bond
Department of Fisheries and Wildlife
Oregon State University

The following list includes species, subspecies, or races of fish which occupy narrow geographical or ecological ranges in Oregon. Some occur nowhere else; others are represented in other states by the same, or, more likely, different forms. Deterioration of habitat or excessive unnatural mortality could endanger any of those mentioned.

1. Petromyzontidae (Figure 1).

a. Lampetra (Entosphenus) sp. Klamath Brook lamprey. This undescribed species is known from tributaries of Upper Klamath and Agency lakes. It is non-parasitic and does not feed in the adult stage. Ammocoetes are numerous in the ponds of the Oregon State Game Commission Klamath Hatchery on Crooked Creek.

b. Lampetra (Entosphenus) tridentata subsp. Several types of small and dwarf parasitic lampreys apparently referable to L. tridentata may be found in the Klamath and Goose Lake drainages. Preliminary examination indicates that at least two of the races are well-differentiated from the others and might be regarded as subspecies. Systematic studies are needed for the clarification of relationships of the races.

2. Salmonidae (Figure 2).

a. Salmo clarki henshawi Gill and Jordan. Lahontan cutthroat trout. This subspecies is found in the streams flowing north from the Nevada border, south and east of the Alvord Desert. It was once numerous in Trout Creek but has been destroyed there through hybridization with introduced rainbow trout. It possibly has racial characteristics different from the remainder of the subspecies represented by California and Nevada populations.

b. Salmo sp. (gairdneri?) native trout of Catlow Valley. Not enough is known of this fish, which apparently represents the species variously referred to as either cutthroat or rainbow by early explorers. Long-headed, long-jawed, and often small-scaled, it resembles a cutthroat without basibranchial teeth. It is found in Rock Creek and in drainages along the western face of the Steens Mountains.

3. Catostomidae (Figure 3).

a. Chasmistes brevirostris Cope. Shortnosed sucker. This species was formerly abundant in the Klamath Basin of Oregon but now is found mainly in reservoirs along the Klamath River in California. Rough fish control has removed it from Lake of the Woods, Oregon, and unknown causes (probably change in environment) have reduced it in Lost River, Agency Lake, and Upper Klamath Lake. Whether the species actually remains anywhere in Oregon is problematical.

b. *Catostomus warnerensis* Snyder. Warner sucker. This representative of *C. occidentalis* is confined to the Warner Lakes basin and could be endangered by drouth or rough fish control.

4. Cyprinidae (Figure 4).

a. *Hybopsis crameri* Snyder. Oregon chub. This species occupies a fairly wide geographical range in the Willamette and Umpqua drainages but is usually found only in quiet water. Rapid changes in water level can be harmful to the reproduction of this species. In years of good spawning success it can be numerous in some impoundments, but in other years it can be rare in the same area. This is the only Hybopsis native to the Pacific Coast of the United States.

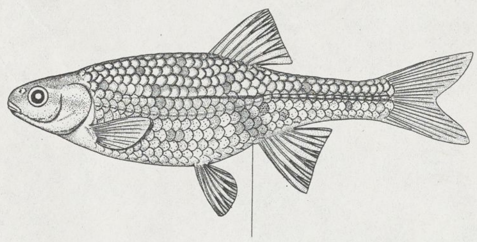

Figure 5. Oregon chub (actual size).

b. Undescribed species, southeastern Oregon. Dr. Carl L. Hubbs of the Scripps Institution of Oceanography has under study a new species of minnow from the Alvord drainage and Catlow Valley. This species may represent an undescribed genus. It is found in many permanent waters of the drainages mentioned.

c. *Rhinichthys osculus* (Girard). Speckled dace. This dace is represented in southeastern Oregon by many races, probably one to each isolated drainage.

5. Cottidae (Figure 6).

a. *Cottus "bendirei"* (Bean). Malheur sculpin. This species was described from Rattlesnake Creek east of Burns. It represents an unprickled form of *Cottus bairdi* and differs from the *bairdi* of most of the Harney Basin. Specimens from the eastern section of the basin - Rattlesnake and Riddle creeks - fit the original description, and those from Upper Silver Creek are quite similar. Attempts to collect the Malheur sculpin from Rattlesnake Creek in 1961 and 1965 disclosed none. Only about a dozen specimens have been preserved from the eastern section of Harney basin.

b. *Cottus pitensis* Bailey and Bond. Pit River sculpin. Although numerous in California, this species may be extinct in Oregon. Specimens were collected from Thomas Creek of the Goose Lake drainage about 10 years ago, but attempts to find the species in 1957 and 1963 failed.

6. Various Lahontan Basin fishes.

In the small section of the Lahontan Basin encompassed by Oregon (McDermitt, Oregon Canyon, Tenmile creeks) some of the fishes typical of that basin are found. These are Catostomus tahoensis Gill and Jordan, Pantosteus lahontan Rutter, Rhinichthys osculus robustus (Rutter), Siphateles bicolor obesus (Girard), and Richardsonius egregius (Girard).

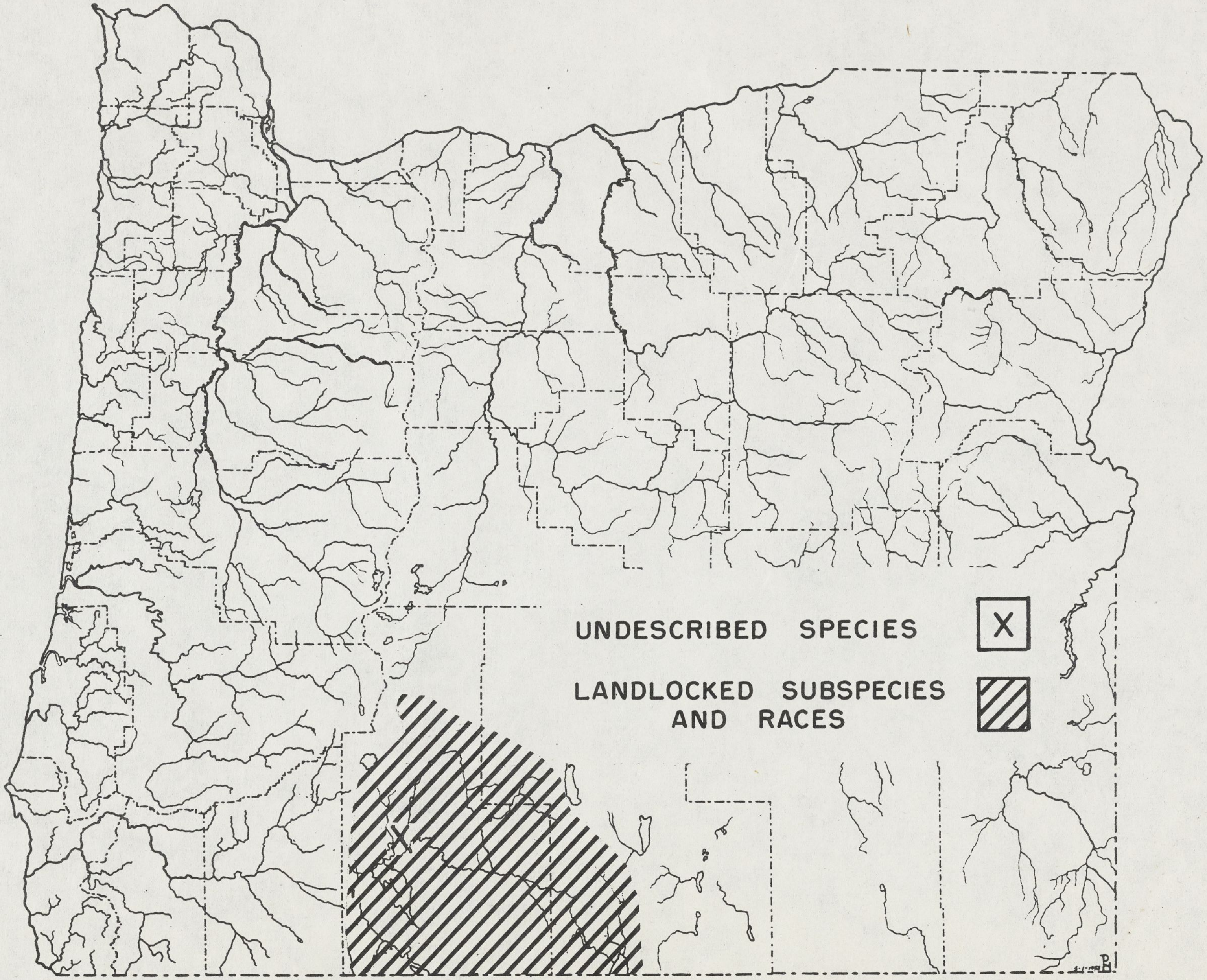

Figure I. Distribution of Klamath brook lamprey Lampetra (Entosphenus) sp.
and others

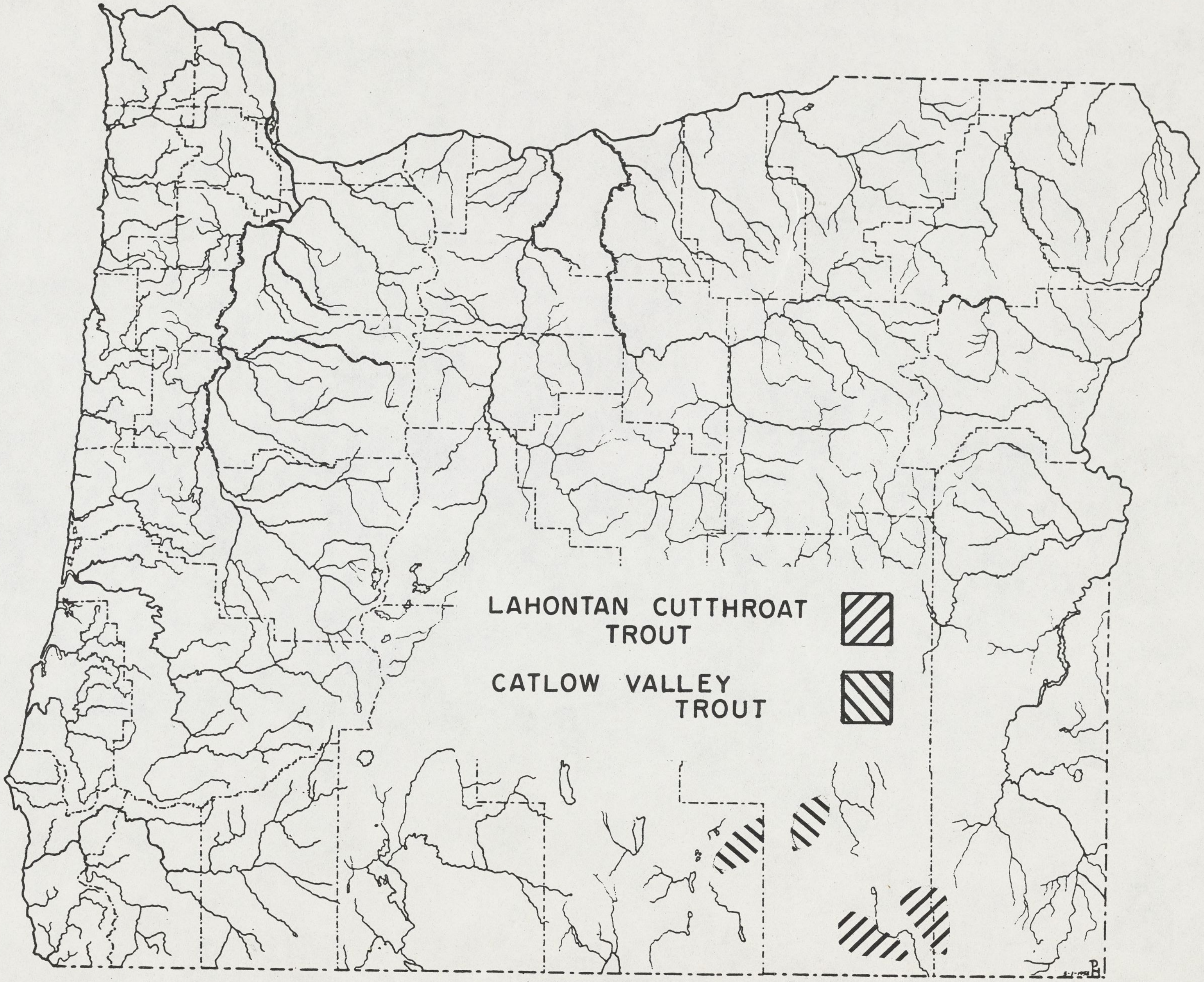

Figure 2. Distribution of Lahontan cutthroat trout (Salmo clarki henshawi) and Catlow Valley trout (Salmo) sp.

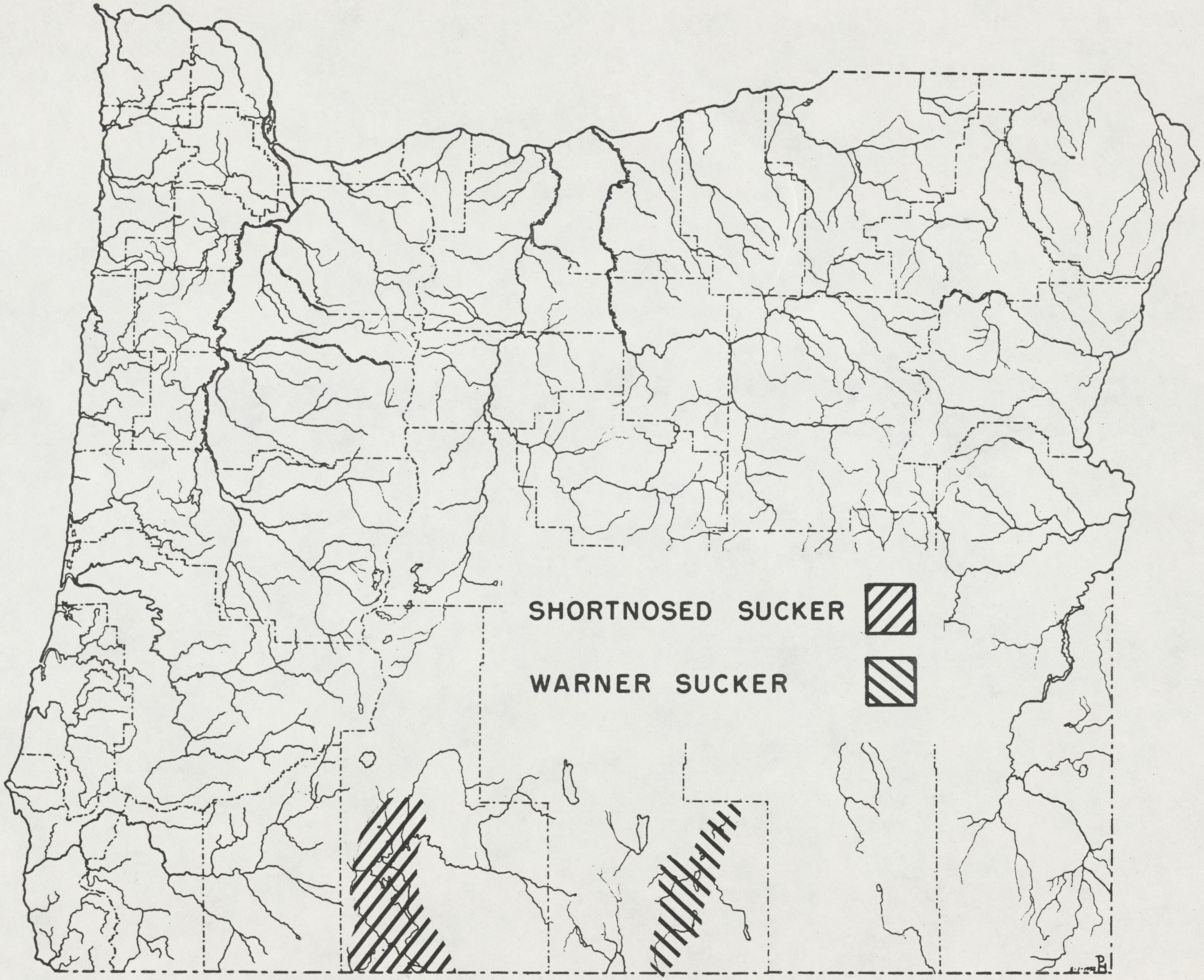

Figure 3. Distribution of shortnose sucker (Chasmistes brevirostris) and Warner sucker (Catostomus warnerensis).

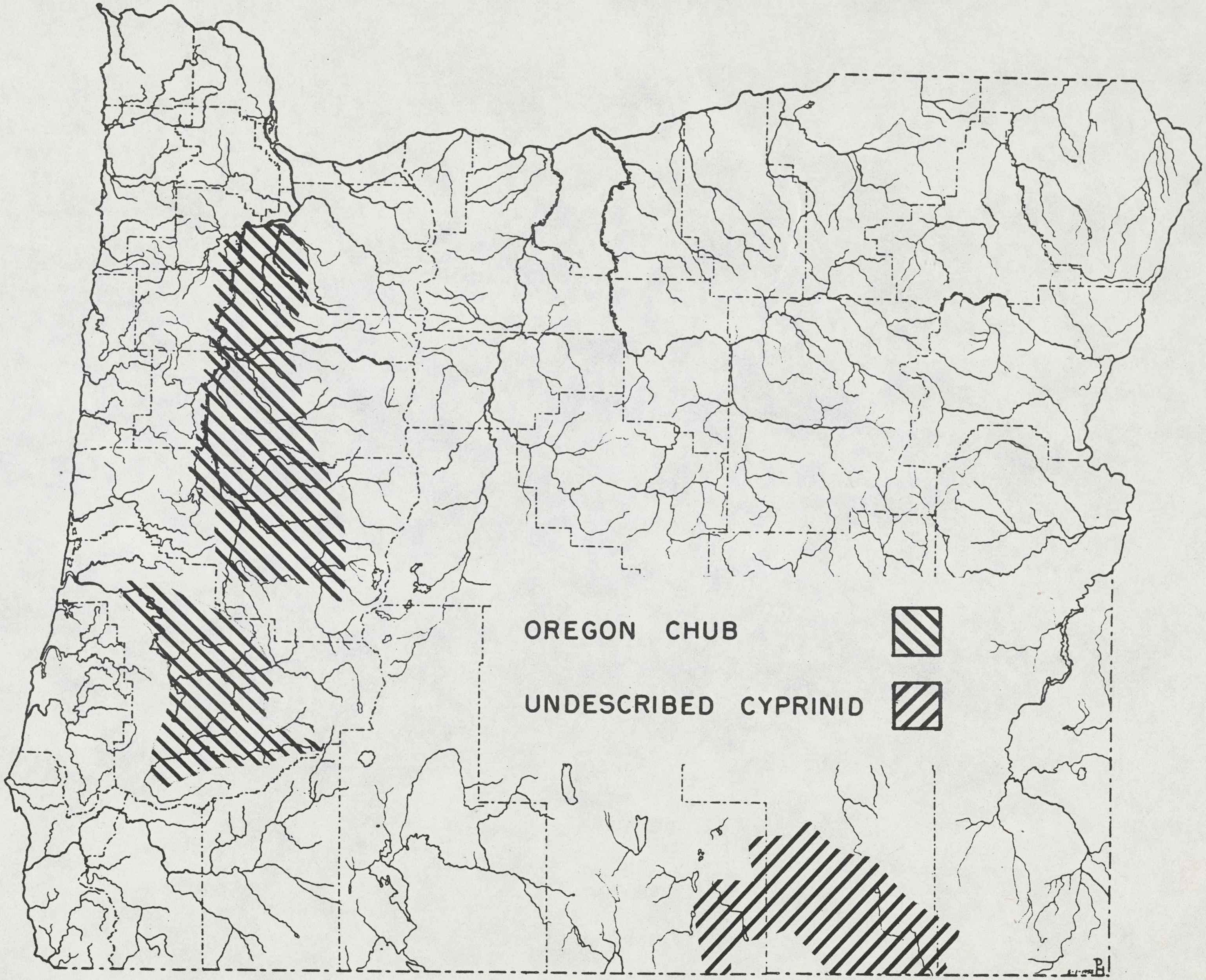

Figure 4. Distribution of Oregon chub (Hybopsis crameri) and undescribed cyprinid.

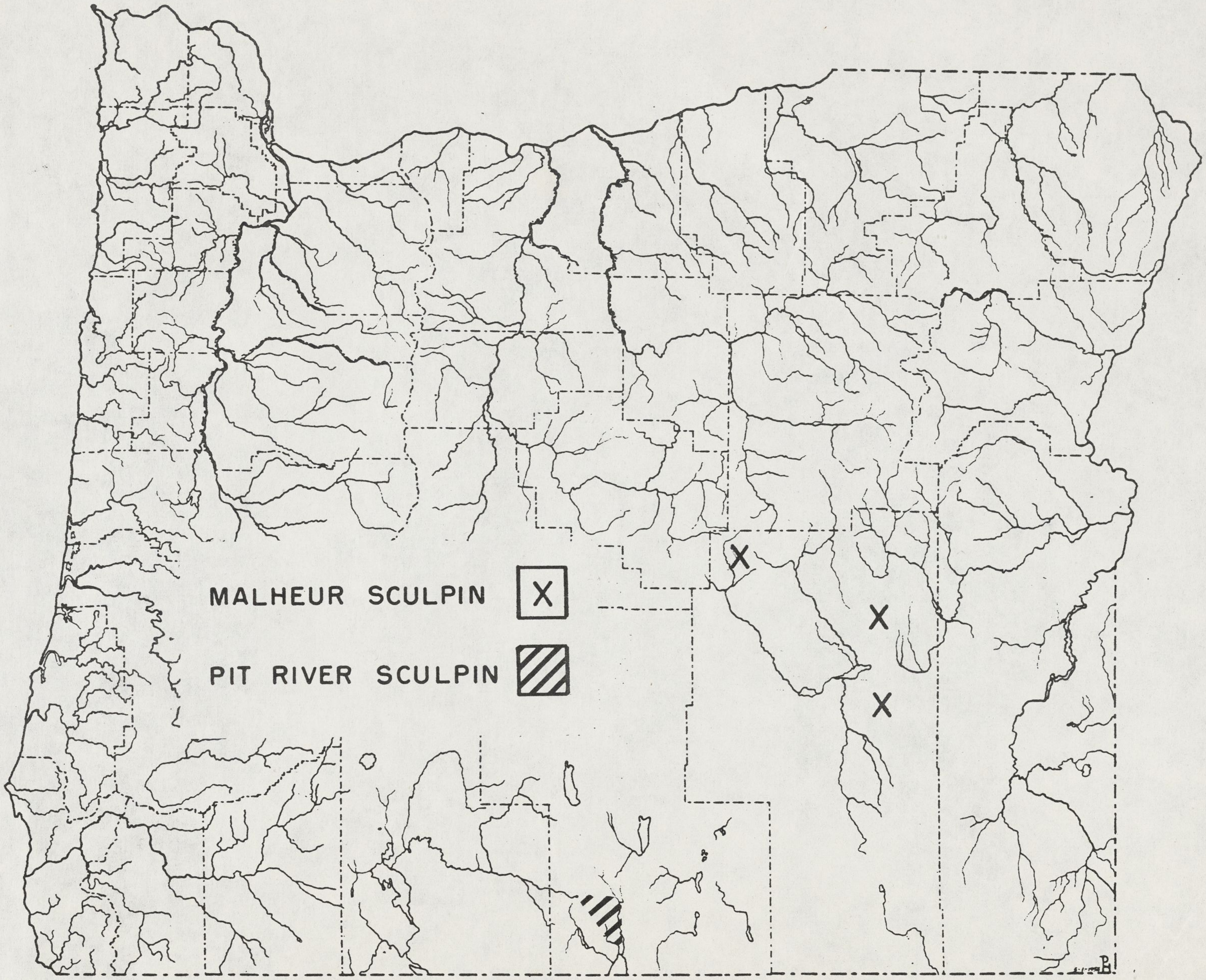

Figure 6. Distribution of Malheur sculpin (Cottus "bendirei") and Pit River sculpin (Cottus pitensis).

FORMULATION AND VALIDATING MODELS OF HABITAT QUALITY FOR CUTTHROAT TROUT (SALMO CLARKI CLARKI) AND COHO SALMON (ONCORHYNCHUS KISUTCH) FOR OREGON'S COASTAL STREAMS

by

Hiram W. Li
Assistant Leader

and

Carl B. Schreck
Leader

Oregon Cooperative Fishery Research Unit
Fisheries and Wildlife Biology
Oregon State University
Corvallis, OR 97331
FTS: 425-4531

Richard A. Tubb
Principal Investigator

Performed for
Western Energy and Land Use Team
Office of Biological Services
Fish and Wildlife Service
U.S. Department of Interior

EXECUTIVE SUMMARY

(1) The best quantitative approach to describing habitat quality was the discriminant analysis approach to classification based on modified Habitat Suitability Index (HSI) model variables.

(2) The non-statistical approach for aggregating individual suitability indicies into an HSI that was the best predictor of standing crop was an Interactive Limiting Factor Model.

(3) Interacting biological factors can change relationships between various physical gradients and fish populations. These relationships are not constant from reach to reach of a stream.

(4) The primary reason relationships between fish populations and physical gradients change in the Nestucca drainage is that competition between species was important in influencing species performances.

INTRODUCTION

This project was aimed at providing data allowing construction of species habitat suitability curves, construction of such curves, and narrative descriptions of life history requirements for select freshwater Pacific coast fishes. This objective was met, and reports on the following species were submitted in 1980: rainbow trout (including steelhead trout) (Salmo gairdneri), golden trout (S. aguabonite), redband trout (S. sp.), coho salmon (Oncorhynchus kisutch), longnose dace (Rhinichthys cataractae), speckled dace (R. osculus), northern squawfish (Ptychocheilus oregonensis), redside shiner (Richardsonius balteatus), Mississipi silverside (Menidia audens), white sturgeon (Acipenser transmontanus), green sturgeon (A. medirostris), prickly sculpin (Cottus asper), and Coastrange sculpin (C. aleuticus).

The above objective was then expanded to test the Habitat Suitability Index models, using coho salmon and cutthroat trout (S. Clarki) as examples, and to expand the predictive power of the model for the Pacific Northwest. The purposes of this document are to provide the information necessary to accomplish this amendment and to serve as a project completion report.

Current Fish and Wildlife Service Habitat Suitability models use quantitative estimates of physical habitat elements or characteristics (e.g. temperature, flow, etc.) as a means of determining habitat quality. They assume a robustness eliminating concern for biological attributes (e.g. competitors, predators, disease organisms, etc.) of habitat. We designed our tests for verification of the models by accounting also for competition as a possible vital element of habitat. Our target species, the coho salmon and the coastal cutthroat trout (S. c. clarki) frequently occur sympatrically with each other and with steelhead trout. It is thus possible that the presence of one species would affect habitat selection by the other species. This eventuality was confirmed by comparing habitat selection by the three species while both allopatric and sympatric in the same stream system. Careful selection of study streams with barriers, such that allopatric populations were located immediately above sympatric populations, allowed us to construct the test models based on identical physical habitat elements by varying in biological characteristics.

but?

OBJECTIVES

The objectives of this study were as follows:

1. To test Suitability Indices (profiles) of selected variables for coho salmon (Oncorhynchus kisutch) and cutthroat trout (Salmo clarki clarki) presented in draft manuscripts of the Habitat Evaluation Program with Habitat Suitability profiles constructed from new data sheets.
2. To build new profiles for variables not incorporated in the current narratives of species requirements by the Habitat Evaluation Program.
3. To compare HSI predictions generated by a geometric mean of Suitability Indices (Average Value Method) with predictions generated by the lowest suitability index and an interactive Limiting Factor approach and application of Discriminant Analysis.

DRAINAGE DESCRIPTIONS

New Suitability Indices (profiles) were constructed from survey data taken from two streams of the Nestucca Drainage: Elk Creek and Bear Creek (R. House, BLM). This drainage is a coastal system in Tillamook County, Oregon. The climate is maritime. The land has been logged for 15 years.

resulting in 50% of the area being logged (House ms). The land is unstable and 42% of the banks of Bear Creek have been classified as being in poor condition (House ms). Both creeks have barriers which inhibit upstream movement of fishes. Below the waterfall in Elk Creek and below the logjam in Bear Creek, cutthroat trout are sympatric with coho salmon and steelhead trout (Salmo gairdneri). Above the waterfall in Elk Creek, coho salmon have been stocked on top of the resident cutthroat trout, but steelhead trout are absent. Above the logjam in Bear Creek, steelhead trout are sympatric with cutthroat trout, but coho salmon are not present.

Models were tested on the Smith, South Coos, and Coquille (Southcentral coastal) drainages using data gathered by Duke and Bond (1981). These drainages are coastal systems of southcentral Oregon. The Smith River area has been logged. It is characterized by a high percentage of bedrock in its substrate (Duke and Bond 1981), one of the outcomes of logging operations in coastal streams when streams were used for logging chutes. Removal of the natural retainers of gravel were eliminated and the substrate was blown out during winter spates (J. Sidell, pers. comm.). Dynamiting to increase pools for coho juveniles was done on Vincent Creek, a tributary of the Smith River.

The South Fork of the Coos River is a high gradient stream system, also characterized by a high percentage of sandstone bedrock (Duke and Bond 1981).

The Coquille system is of low gradient and flows over pasture lands. Many streams are characterized by canopies of deciduous hardwoods and conifers, providing dense shade. Fallen timber is present throughout at least one of the systems, Steele Creek, creating pool habitats (Duke and Bond 1981). Table 1 compares selected variables of the different drainages.

Table 1. Characteristics of test systems (Smith, South Coos, Coquille) drainages and the system used to generate predictive curves (Nestucca drainage). + = presence, - = absence.

Variable	Smith	South Coos	Coquille	Nestucca
pH	5.4-6.6	6.2-6.5	5.8-6.6	7.1-8.9
d.o. (mgl)	4.0-14.0	9.0-12.0	10.0-12.5	9.2-10.6
Temp.(C) (max-min)	21.0-8.5	19.0-13.0	20.0-11.0	27.0-10.0
Average channel width (m)	1.81-9.97	7.52-15.48	2.69-7.52	5.2-6.5
Discharge (m^3/sec)	0.00-0.11	0.05-0.14	0.01-0.04	0.03-0.20
Salmo clarki	+	+	+	+
S. gairdneri	+	+	+	+
Oncorhynchus kisutch	+	+	+	+
O. tshawytscha	-	+	+	-
Ptychocheilus umpquae	+	-	-	-
Richardsonius balteatus	+	+	-	-
Rhinichthys evermanni	+	-	-	-
R. cataractae	-	+	-	-
R. osculus nubilis	+	+	+	-
Gasterosteus aculeatus	-	+	+	-
Catostomus macrocheilus	+	+	-	-
Cottus gulosus	+	+	-	?
C. perplexus	+	+	+	?
C. asper	+	-	-	?
C. aleuticus	-	-	+	?

DATA COLLECTION

The analysis was performed specifically to look at possible impacts of interspecific interactions on the Suitability Index (SI) values. The barriers (logjams and waterfalls) created a natural experiment to look at differences in habitat utilization by the different species when sympatric with a potential competitor or in allopatric situations. In addition, we took precautions to consider the problem of species mixes when predicting habitat quality from the regional model based on the Nestucca system to different drainages of the southcentral Oregon coast.

Data collected by House (BLM ms) and by Duke and Bond (1981) were collected during the summer. One hundred reaches were sampled from the Nestucca and 29 reaches (11 sites, 3 to 4 repeated sampling dates) from the southcentral systems. Both systems used the removal estimate of population inventory. Sections were blocked at the upper and lower ends. The major differences in the studies were in rating instream cover, substrate categories, breakdown of reach types (runs, glides, riffles, pools), the number of sections in which all physical data were taken, and in determination of water velocity. House's measurements are based on surface drift of a neutrally buoyant object; Duke and Bond's measurements are taken 0.4 off the stream bottom with a Gurley Pygmy flow meter. Habitat Suitability Index (HSI) ratings for both studies and differences in the variables measured are listed in appendices 1-4.

COMPARISON OF HABITAT SUITABILITY PROFILES

Tests

1. Compare Suitability Index profiles or curves for selected variables in drafts of species narratives of the Habitat Evaluation Program to curves or profiles of habitat suitability developed from Nestucca drainage data.
2. Each creek of the Nestucca drainage can be compared to the other, forming a second test of general applicability.

Methods

The highest performance in terms of standing crops (fish/m^2) from either Bear Creek or Elk Creek were used to convert values for individual variables into suitability indices, as described under method 1 in U.S. Fish and Wildlife Service (1981). We assumed that combining the data would be acceptable because the two streams were part of the same system. Thus, the highest SI rating of 1.0 will be present only for the creek with the highest standing crop.

The logic used to construct each profile from the survey data is that the extemes are more important than the average performance. Our approach is based on the conceptual framework of Performance Capacities (Schreck 1981). Each datum on each profile results from the response to multiple factors, not just the one independent variate expressed by the graph. The highest point on the graph represents the maximum performance which is realized <u>under a particular set of conditions</u>; the capacity of the species is defined by connecting the maximum performances along the abcissa. The scatter of points below the profile represent individual performances which are limited by a host of interactions not explained by the univariate, graphical treatment.

The HEP draft profiles generated the predicted or expected SI values and were compared with the observed values for the Nestucca drainage. We combined the profiles from both creeks of the Nestucca drainage in order to make comparisons. This step reduced the error between the observed and predicted values by increasing the performance capacities for any specific variable. New Habitat Suitability profiles were constructed to increase the data base for species narratives. Profiles of steelhead trout are presented to examine for possible species interactions among the salmonid guild.

Results and Discussion

The Habitat Suitability curves are not generally applicable to different streams. This is inferred from the lack of correspondence of SI values generated from the HEP draft curves to observed values of the two tributaries and the differences in Habitat Suitability curves describing fish distribution in each creek (Tables 2-6, and graphs 9 and 10). This suggests that there may be different sets of interactions in different systems, resulting in different performances for a given value of an environmental factor of interest. In other words, for a given value of x, there will be different values of y because of different responses to different sets of environmental circumstances interacting together with the factor being examined.

An inspection of Figs. 1-24 reveals patterns that suggest that shifts in habitat utilization by cutthroat trout above the barriers are due to release from competition by two other species of salmonids. The x's denote fish densities above the barriers, and closed circles represent fish densities in the area of sympatry below the barriers. The changes in densities of cutthroat trout do not seem to be entirely attributable to shifts in environmental differences above and below the barriers as the SI values are almost always much higher above the barrier than below it for the same value of the independent variable. The primary differences are that lower Elk Creek has a greater representation of boulders in its substrate composition and that the entire creek has a greater proportion of pools to riffles. Bear Creek has a greater proportion of riffles to pools, and the sections above the logjam are more densely shaded by tree canopy than other sections of either creek. These are factors which can and probably did change the response of fish populations to environmental factors as a set, resulting in different SI profiles for each creek.

Table 2. Comparison between predicted SI values vs. percent riffles for cutthroat trout and those observed from the Nestucca drainage.

	Suitability Index	
Riffles	Predicted	Observed
0	0.50	0.45
2	0.51	0.47
10	0.40	0.60
20	0.80	0.75
25	0.90	0.64
55	1.00	0.65
67	0.90	0.78
80	0.80	0.75

Table 3. Comparison between predicted SI values vs. dominant substrate in riffle sections for cutthroat trout and observed values from the Nestucca drainage. A = mostly boulders and rubble, B = even distribution of boulders, rubble, cobble, gravel, C = bedrock or fines. 55% constitutes dominance.

		Suitability Index		
Substrate	n	Predicted	Observed	± 0.95 interval
		All Reaches		
A	17	1.0	0.32	0.13
B	8	0.25-0.60	0.17	0.26
C	1	0.25	0.08	-
		Reaches Above Barrier		
A	11	1.0	0.45	0.15
B	2	0.25-0.60	.057	-
C	-	-	-	-

Table 4. Comparison between predicted SI values vs. percent fines for cutthroat trout and observed values from Elk Creek and from Bear Creek.

	Suitability Index		
		Observed	
Percent Fines	Predicted	Elk Creek	Bear Creek
15	0.90	0.55	1.00
30	0.60	0.69	0.97
45	0.39	0.38	0.95
60	0.20	0.08	0.59

Table 5. Comparison between predicted SI values vs. percent shade for cutthroat trout and observed values from Elk Creek and from Bear Creek.

Percent Shade	Suitability Index: Predicted	Observed: Elk Creek	Observed: Bear Creek
25	0.65	0.75	0.94
50	1.00	0.52	0.95
75	1.00	0.30	0.99
100	0.40	0.00	0.00

Table 6. Comparison between predicted SI values vs. pool volume for coho salmon and observed values from Elk Creek.

Pool Volume (m^3)	Suitability Index Observed	Suitability Index Predicted
10	0.25	0.65
20	0.48	0.78
30	0.67	0.93
40	0.83	0.99
50	0.93	0.95
60	1.00	0.94

MODEL VALIDATION

Three models were tested: the Average Value Method, the Interactive Limiting Factor approach, and using the Lowest Suitability Index (selecting the most limiting factor). The average value method is described mathematically as follows:

$$H.S.I. = (SI_1 \times SI_2 \times SI_3 \times \ldots \times SI_n)^{1/N}$$

where SI_i = the suitability of the i^{th} environmental factor,

N = the number of environmental factors.

This model tries to obtain an average value of habitat quality without using an additive process. This eliminates the problem of predicting an inhabitable section when one of the factors has an H.S.I. of zero. This has one conceptual drawback, especially considering the way that data for the S.I. profiles are gathered. A value can be obtained which is higher than the most limiting factor, which is illogical. The performance capacity from which the S.I. is obtained is often, as it is in this case, gathered from field data. These data, when transformed on the cartesian axes, are not the result of single factors but a host of factors interacting in unknown ways. The highest performances are <u>the least limited by interaction of other factors</u>.

Using the Lowest Suitability Index is a logical extension of Leibig's Law of the Minimum; that is, the most limited factor defines the upper limit to population density. The assumption is that there are no interactions among variables which further decrease habitat suitability below this level, an assumption which is made using the last approach. The Interactive Limiting Factor Approach is conceptually more conservative than the HEP Average Value Method. This approach is mathematically described as follows:

$$H.S.I. = \prod_{i=i}^{n} SI_i$$

This means that habitat quality can be no higher than the most limited environmental factor. For example, suppose reach A is found to be optimal for 5 factors, but factor 6 has a value of 0.9, and factor 7 has a value of 0.4. The value of HSI is then,

$$H.S.I. = (1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 0.9 \times 0.4)$$

The value would be a fraction lower than the most limited factor, or in this case 0.36. In this theoretical example, the Average Value Method would come out to be 0.60 which is higher than the most limiting value which is 0.4.

Methods

The predictions were made using the SI profiles in the HEP draft manuscripts and from the regionalized data from the Nestucca system. Different sections of the Smith, South Coos, and Coquille system during summer (the same period during which the Nestucca data were gathered) were used as test sections. The predictions are for coho juveniles and cutthroat adults. Both models were adjusted for the effect of competition on cutthroat trout by using sets of curves or profiles (see Figs. 1-17). The set used depended on the presence or absence of coho salmon or steelhead trout when evaluating cutthroat trout habitat quality. Table 7 presents the factors used in the predictions.

Results and Discussion

Overall, none of the three reach-specific approaches performed well (Tables 8,9,10). The results are consistent in that the predictions are not strongly correlated with the observed values in a positive way, in that the Average Value Method always had the highest residual error (cumulative difference between the observed and predicted values, in that the residual error generated by the Lowest Suitability Index Method was intermediate, and in that the lowest residual error was generated from the Interactive Limiting Factor approach.

Better predictions of habitat suitability for cutthroat trout were obtained when one accounted for limitations in performance imposed by competitors (Table 10). The residual errors were reduced from 5.52 to 3.81, from 7.71 to 4.75, and from 14.04 to 8.16 for the Interactive Limiting Factor approach, the Lowest Suitability Index method, and the Average Value Method, respectively. Improvements in the correlation between the observed and predicted values were obtained (Tables 9, 10). The pleasing aspect of the Interactive Limiting Factor Procedure is that it predicted HSI values of 0 when the observed values were 0. It generated an extremely low value that was rounded to 0.00, 2 significant places. In contrast, the Average Value Method predicted very high, positive values from the same set of data (Table 10).

There are several reasons for the low correlation of predicted values by the models to the observed values of HSI from the southcentral Oregon coastal drainages. The Nestucca drainage (from which the regionalized predictive model was made) had better quality habitat than that of the southcentral Oregon coastal drainages, yet the densities of cutthroat trout and of coho salmon were 2.63 to 1.25 greater than the Nestucca. This interesting paradox suggests that the species populations may respond to the entire set of physical and biotic variables in a gestalt fashion, a non-additive manner. Some of the variables measured by the two studies were different, thus several important variables such as gradient and percent canopy were measured by Robert House in the Nestucca drainage, but not by Duke and Bond (1981). It may be that Duke and Bond (1981) interpreted nominal variable differently than House (MS); for instance, rarely are riffle, runs, glides, and pools rigorously defined--these are often subjected to individual biases. Several key variables, as yet unknown, may not have been measured. Several biotic variables such as prey density, endemic diseases, stock differences, or faunal richness are not included in the model. It may be that the performance capacities will not be adequately measured or defined until one has inventoried the best drainage in a region. This will take time to develop. There may be errors in that the best (most precise) measurements of fish densities in the Nestucca were measured in fish/M^2 and in the southcentral drainages in gm/M^2, although HSI standardization removes much of this problem. In addition, we could not logically use the highest measures of performance from the Nestucca to standardize the HSI values for the southcentral drainage because values greater than 1.00 would have resulted; instead, HSI values for the southcentral drainage were made relative to the best performances within that system.

Table 7. Variables used in the calculation of habitat quality by the Limiting Factor and Average Value Methods.

Species	Temperature(C)	Velocity(cm/sec)	% Riffle	% Pool	d.o.	pH	Depth
Cutthroat	X	X	X		X	X	
Coho	X	X		X	X		X

Table 8. Validation tests of coho salmon habitat models. ILF = Interactive Limiting Factors, LSI = Lowest Suitability Index, AVM = Average Value Method, V = number of Variables in the calculation, O = Observed, P = Predicted, r = Pearson's correlation coefficient.

Section	V	ILF	LSI	AVM	Observed Value
Smith	5	0.05	0.20	0.53	0.00
"	4	0.03	0.20	0.43	0.00
"	5	0.02	0.20	0.47	0.00
"	5	0.04	0.20	0.52	0.57
"	4	0.05	0.20	0.47	0.02
"	5	0.04	0.20	0.53	1.00
"	4	0.04	0.20	0.45	0.08
"	4	0.16	0.35	0.63	0.05
"	4	0.07	0.20	0.52	0.00
"	4	0.06	0.20	0.49	0.00
"	5	0.07	0.20	0.58	0.23
"	4	0.04	0.20	0.44	0.03
"	5	0.06	0.20	0.57	0.03
South Coos	4	0.24	0.35	0.70	0.38
"	5	0.25	0.35	0.76	0.43
"	4	0.24	0.35	0.70	0.31
"	5	0.21	0.35	0.73	0.60
"	4	0.07	0.20	0.51	0.90
"	4	0.06	0.20	0.57	0.81
"	4	0.06	0.20	0.49	0.77
"	5	0.05	0.20	0.56	0.53
"	4	0.23	0.35	0.69	0.11
"	4	0.31	0.35	0.79	0.38
"	4	0.27	0.35	0.77	0.14
"	5	0.28	0.35	0.78	0.03
"	4	0.06	0.20	0.57	0.78
"	4	0.06	0.20	0.57	0.93
"	4	0.06	0.20	0.56	0.74
"	5	0.05	0.20	0.55	0.76
Coquille	4	0.28	0.35	0.77	0.04
	5	0.27	0.35	0.77	0.03
	4	0.07	0.20	0.59	0.24
	5	0.06	0.20	0.58	0.29
	4	0.06	0.20	0.58	0.24
	4	0.06	0.20	0.58	0.06

	ILF	LSI	AVM
$\Sigma\|(O-P)\|$ =	9.33	9.88	14.09
r =	-0.19	-0.21	-0.07

Table 9. Validation tests of cutthroat trout habitat models not compensated for competitive effects. ILF = Interactive Limiting Factors, LSI = Lowest Suitability Index, AVM = Average Value Method, V = number Variables in the calculation, O = Observed, P = Predicted, r = Pearson's correlation coefficient.

Drainage	V	ILF	LSI	AVM	Observed Value
Smith	5	0.00	0.00	0.00	0.51
"	3	0.12	0.25	0.50	1.00
"	5	0.04	0.29	0.53	0.49
"	5	0.09	0.29	0.62	0.01
"	3	0.13	0.28	0.51	0.00
"	5	0.08	0.29	0.60	0.00
"	5	0.34	0.42	0.81	0.01
"	3	0.34	0.38	0.69	0.02
"	5	0.10	0.29	0.63	0.00
"	3	0.16	0.27	0.55	0.00
"	5	0.15	0.27	0.68	0.02
South Coos	3	0.27	0.38	0.65	0.00
"	5	0.09	0.30	0.53	0.10
"	3	0.16	0.29	0.55	0.08
"	5	0.10	0.29	0.63	0.03
"	3	0.17	0.31	0.56	0.18
"	5	0.11	0.29	0.64	0.15
"	3	0.15	0.28	0.53	0.10
"	5	0.13	0.28	0.51	0.51
"	3	0.25	0.41	0.63	0.00
"	5	0.22	0.38	0.74	0.51
"	3	0.18	0.30	0.57	0.00
"	5	0.19	0.31	0.72	0.00
"	3	0.16	0.27	0.55	0.00
"	5	0.13	0.26	0.66	0.02
"	3	0.14	0.26	0.52	0.01
"	5	0.13	0.26	0.66	0.00
	$\Sigma\|(O-P)\|$ =	5.52	7.71	14.04	
	r =	-0.30	-0.33	-0.28	

Table 10. Validation tests of cutthroat trout habitat models compensated for competitive effects. ILF = Interactive Limiting Factors, LSI = Lowest Suitability Index, AVM = Average Value Method, V = number of Variables in the calculation, O = Observed, P = Predicted, r = Pearson's correlation coefficients.

Drainage	V	ILF	LSI	AVM	Observed Value
Smith	5	0.00	0.00	0.00	0.51
"	3	0.02	0.09	0.62	1.00
"	5	0.01	0.09	0.62	0.49
"	5	0.02	0.10	0.46	0.01
"	3	0.02	0.10	0.28	0.00
"	5	0.05	0.10	0.55	0.00
"	5	0.05	0.15	0.55	0.01
"	3	0.04	0.15	0.35	0.02
"	5	0.03	0.09	0.50	0.00
"	3	0.02	0.09	0.28	0.00
"	5	0.03	0.09	0.50	0.02
South Coos	3	0.02	0.09	0.28	0.00
"	5	0.01	0.15	0.33	0.10
"	3	0.02	0.15	0.28	0.08
"	5	0.01	0.15	0.40	0.03
"	3	0.03	0.15	0.31	0.18
"	5	0.01	0.15	0.40	0.15
"	3	0.01	0.15	0.22	0.10
"	5	0.02	0.15	0.46	0.51
"	3	0.05	0.15	0.37	0.00
"	5	0.03	0.12	0.50	0.51
"	3	0.01	0.08	0.22	0.00
"	5	0.01	0.15	0.40	0.00
"	3	0.01	0.15	0.22	0.00
"	5	0.00	0.15	0.33	0.02
"	3	0.00	0.15	0.25	0.01
"	5	0.00	0.15	0.33	0.00
	$\Sigma\lvert(O-P)\rvert =$	3.81	4.75	8.16	
	$r =$	-0.11	-0.32	0.09	

DISCRIMINANT ANALYSIS

Testing

The discriminant analysis was conducted to determine which variables contributed most effectively to differentiation of habitat quality for cutthroat trout and coho salmon. The strength of this approach is that interaction among partially correlated variables are incorporated into the analysis. The factors entered into the analysis do not have to be independent. The assumptions of the approach are that the distribution of the population being sampled is multivariate normal, that the components have linear relationships, that the samples are representative, and that all expected covariance matrices of the population sampled are equal (Pimentel and Frey 1978). This is a very robust test as violations of the assumptions do not appear to change the outcome of the test (Pimentel and Frey 1978). We compared differences in classifications for each species between drainages and we compared classifications for each species within drainages when only physical parameters were entered into the analysis in comparison to the classification when both physical and biotic parameters were entered into the system.

Methods

The stepwise discriminant analysis (SPSS, Klecka 1975) using the criterion of minimizing Wilks Lambda was the technique we selected. The following groupings, based on HEP categories, were to be discriminated and classified:

(1) bad habitat (HSI = 0)

(2) marginal habitat (0.1 < HSI < 0.5)

(3) good habitat (HSI $\geq$ 0.5)

The minimum tolerance level needed to proceed to the next step on the stepwise progression was extremely stringent ($P < 0.001$). The output was as follows: (1) a test of consistency of the classification scheme, (2) a listing of variables in order of importance, that form the classification, (3) the functions which discriminate between groups, and (4) the amount each function contributes to the separation of the groups.

Results and Discussion

Good classifications of coho salmon habitat quality were developed (Tables 11 and 12). These classifications were consistent in assigning different stream reaches to the proper category of habitat quality. Classifications developed for cutthroat trout habitats were not as strong as only 56% to 76% of the stream reaches were grouped correctly (Tables 13 and 14).

Two important observations can be made from Tables 15-18. Variables used in the classification scheme of habitat quality for each species are different for each creek. The importance of each variable is listed in stepwise fashion, the most important factor entering in step 1. The second observation is that physical variables are more influential in the classification than the biological factors when both sets of information are entered into the analysis.

The process of predicting group classifications from raw data is determined by substituting the classification function coefficients (Fisher's Linear Discriminant Functions) into the following equation:

$$C_i = c_{ii}V_i + c_{i2}V_2 + \ldots + c_{ip}V_p + c_{i0}$$

where C_i = the classification score of the i^{th} group,

c_{ij} = the classification coefficients,

c_{i0} = constant, and

V_j = the raw scores on the discriminating variables.

As there are 3 groups, there are three equations. The data for the variables of each reach are entered into each of the 3 equations and the reach is assigned to the proper group on the basis of the highest value generated from the set of equations. The coefficients are listed in Tables 15-18.

The amount to which physical factors are responsible for the classification can be determined from the standardized discriminant function coefficients; these are presented in Tables 19-20. The largest value, irrespective of sign, represents the relative contribution of that variable to the discriminant function. The discriminant function is a linear array of variables which separate the groups. In a sense, the functions form borders. Therefore, there are at a maximum, n -1 number of functions, where n = the number of groups. The discriminant function takes the following form:

$$D_i = d_{i1} Z_i + d_{i2} Z_2 + \ldots + d_{ip} Z_p$$

where D_i = the discriminant score for the ith group,

d_{ij} = weighting coefficients, and

Z_j = standardized values of p number of discriminating variables.

One observes from the table of discriminant function coefficients that reach number, which is associated with the distance of the sampling station upstream, is the most important for coho salmon habitat classification (Table 20). The combination of pool area and wetted width of the section are most important factors for coho salmon classification of habitat in Elk Creek (Table 20).

The relative importance of both these variables are associated with the first discriminant function only; but the first discriminant function encompasses 88 to 98% of the variability for classification of habitat for coho salmon irrespective of the creek classified. The first discriminant function accounts for 70 to 84% of the variability in separating the habitats of different quality for cutthroat trout in Elk Creek, so percent pool and percent sand are important variables in Elk Creek (Table 19). The first discriminant function accounts for only 58% of the variability for separating habitat types in Bear Creek; therefore, the second discriminant function is a powerful discriminator and thus most important variables are chosen having high values for both the first and second discriminant function. Both velocity and flow are therefore most important in separating groups in classifying habitats for cutthroat trout in Bear Creek.

The result of the relative importance of the physical factors is that entering biotic variables into the classification scheme did not increase its relative power in classifications of habitat for coho salmon or for cutthroat trout in Bear Creek, and only increased the discriminating ability of habitat classification 7.41% for coho salmon and 1.85% for cutthroat trout. This does not mean that biotic factors are unimportant. We do not have data on food availability, diseases, or on terrestrial predators. Also, recall that Elk Creek and Bear Creek are relatively depauperate in ichthyofauna. Biotic variables in systems of greater species richness may be of greater importance.

Table 11. Discriminant classification of coho salmon habitat in Elk Creek, Oregon. Group 1 = (HSI = 0), Group 2 (0<HSI<0.5), Group 3 = (HSI≥0.5).

Physical Factors Entered Only

CLASSIFICATION RESULTS -

ACTUAL GROUP		NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3
GROUP	1	1	1 100.0	0 0	0 0
GROUP	2	45	5 11.1	37 82.2	3 6.7
GROUP	3	8	0 0	1 12.5	7 87.5

PERCENT OF GROUPED CASES CORRECTLY CLASSIFIED - 83.33

Physical and Biotic Factors Entered

CLASSIFICATION RESULTS -

ACTUAL GROUP		NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3
GROUP	1	1	1 100.0	0 0	0 0
GROUP	2	43 45	3 6.7	41 91.1	1 2.2
GROUP	[illegible]	8	[illegible] 0	1 12.5	7 87.5

PERCENT OF GROUPED CASES CORRECTLY CLASSIFIED - [illegible]

Table 12. Discriminant classification of coho salmon habitat in Bear Creek, Oregon. Group 1 = (HSI = 0), Group 2 = (0<HSI<0.5), Group 3 = (HSI$\geq$0).

Physical Factors Entered Only

CLASSIFICATION RESULTS -

ACTUAL GROUP	NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3
GROUP 1	19	18 94.7	1 5.3	0 [illegible]
GROUP 2	25	1 [illegible]	20 [illegible]	4 16.0
GROUP 3	2	0 0	0 0	2 100.0

PERCENT OF GROUPED CASES CORRECTLY CLASSIFIED - 86.96

Physical and Biotic Factors Entered

CLASSIFICATION RESULTS -

ACTUAL GROUP	NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3
GROUP 1	19	18 [illegible]	1 5.3	0 [illegible]
GROUP [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
GROUP [illegible]	2	[illegible]	[illegible]	2 [illegible]

[illegible]

Table 13. Discriminant classification of cutthroat trout habitat in Bear Creek, Oregon. Group 1 = (HSI = 0), Group 2 = (0<HSI<0.5), Group 3 = (HSI≥0.5).

Physical Factors Entered Only

CLASSIFICATION RESULTS -

ACTUAL GROUP	NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3
GROUP 1	4	4 100.0	0 0	0 0
GROUP 2	36	3 8.3	26 72.2	7 19.4
GROUP 3	6	0 0	1 16.7	5 83.3

PERCENT OF GROUPED CASES CORRECTLY CLASSIFIED - 76.09

Physical and Biotic Factors Entered

CLASSIFICATION RESULTS -

ACTUAL GROUP	NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3
GROUP 1	4	4 100.0	0 0	0 0
GROUP 2	36	3 [illegible]	25 [illegible]	7 [illegible]
GROUP 3	6	0 0	1 16.7	5 83.3

PERCENT OF GROUPED CASES CORRECTLY CLASSIFIED - [illegible]

Table 14. Discriminant classification of cutthroat trout habitat in Elk Creek, Oregon. Group 1 = (HSI = 0), Group 2 = (0<HSI<0.5), Group 3 = (HSI≥0.5).

Physical Factors Entered Only

CLASSIFICATION RESULTS -

ACTUAL GROUP		NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3
GROUP	1	12	9 75.0	2 16.7	1 8.3
GROUP	2	40	15 37.5	19 47.5	6 15.0
GROUP	3	2	0 0	0 0	2 100.0

PERCENT OF GROUPED CASES CORRECTLY CLASSIFIED - 55.56

Physical and Biotic Factors Entered

CLASSIFICATION RESULTS -

ACTUAL GROUP		NO. OF CASES	PREDICTED GROUP MEMBERSHIP 1	2	3
GROUP	1	12	[illegible] 66.7	[illegible] 33.3	[illegible] 0
GROUP	2	40	15 37.5	21 52.5	4 10.0
GROUP	3	2	[illegible] [illegible]	[illegible] [illegible]	2 100.0

PERCENT OF GROUPED CASES CORRECTLY CLASSIFIED - 57.41

Table 15. Classification factors for coho salmon habitats in Elk Creek, Oregon. Group 1 = (HSI = 0), Group 2 = (0<HSI<0.5), Group 3 = (HSI≥0.5), POOLA = Pool Area (m^2), PGRAV = percent gravel (0.25-7.5 cm diam), PRIF = percent riffle, PSAND = percent sand (<0.25 mm diam), PSHAD = percent shade, CUTA = cutthroat trout density (fish $1m^2$), VEL = velocity (cm/sec), GRAD = gradient (%), WETW = wetted perimeter (m), REACA = reach area (m^2), STDA = steelhead trout density (fish/m^2).

Physical Factors Entered Only

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS LAMBDA	SIG.	LABEL
1	POOLA		1	.704411	.0001	
2	PGRAV		2	.614218	.0001	
3	PRIF		3	.557021	.0001	
4	PSAND		4	.496318	.0000	
5	PSHAD		5	.444237	.0000	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER*S LINEAR DISCRIMINANT FUNCTIONS)

HSI =	1	2	3
POOLA	-.1764271E-01	-.8873049E-02	.4097494E-01
PRIF	.1798793	.1652062	.8976250E-01
PGRAV	.9536458E-01	-.5001172E-02	.7867174E-01
PSAND	.4193116	.2989292	.1691138
PSHAD	.3017159E-01	.9107727E-01	.4182216E-01
(CONSTANT)	-16.24723	-10.07474	-8.327023

Physical and Biotic Factors Entered

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS LAMBDA	SIG.	LABEL
1	POOLA		1	.704411	.0001	
2	PGRAV		2	.614218	.0001	
3	PRIF		3	.557021	.0001	
4	PSAND		4	.496318	[illegible]	
5	PSHAD		5	.444237	[illegible]	
6	CUTA		6	.405692	.0000	
7	VEL		7	.379145	.0000	
8	GRAD		8	.343364	.0000	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
10	REACA		10	.306718	.0000	
11	STDA		11	.296877	.0001	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER*S LINEAR DISCRIMINANT FUNCTIONS)

HSI =	1	2	3
GRAD	4.788535	2.493439	.7726576
VEL	-.1341412	-.2888435E-01	-.4948371E-04
POOLA	-.6475417E-01	-.3857303E-01	.2490734E-01
REACA	-.3165023	.1744737E-01	-.7267815
PRIF	.1797688	.1498139	.7635399E-01
PGRAV	.2032602	.6197721E-01	.1689894
PSAND	.6265413	.4271926	.2544377
PSHAD	-.2120051E-01	.3831372E-01	-.3699311E-01
WETW	1.593780	1.355135	[illegible]
CUTA	-411.1193	63.23915	369.4763
STDA	-1[illegible].58195	5.554163	-9.283271

Table 16. Classification factors for coho salmon habitats in Bear Creek, Oregon. Group 1 = (HSI = 0), Group 2 = (0<HSI<0.5), Group 3 = (HSI≥0.5), REACH = stream station, PCOB = percent cobble (15-30 cm diam), FLOW = m^3/sec, PGRAV = percent gravel (0.25-7.5 cm diam), STAG = steelhead all age-groups (fish/m^2).

Physical Factors Entered Only

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS LAMBDA	SIG.	LABEL
1	REACH		1	.265680	.0000	
2	PCOB		2	.229432	.0000	
3	FLOW		3	.201134	.0000	
4	PGRAV		4	.189469	.0000	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER*S LINEAR DISCRIMINANT FUNCTIONS)

HSI =	1	2	3
REACH	2.896550	2.038389	2.300372
FLOW	8.796847	7.672117	7.970734
PCOB	.5977562E-01	.1373231	.1027025
PGRAV	.4459966	.4198163	.4938364
(CONSTANT)	-77.53604	-51.65622	-60.23201

Physical and Biotic Factors Entered

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS LAMBDA	SIG.	LABEL
1	REACH		1	.265680	.0000	
2	PCOB		2	.229432	.0000	
3	FLOW		3	.201134	.0000	
4	PGRAV		4	.189469	.0000	
5	STAG		5	.179496	.0000	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER*S LINEAR DISCRIMINANT FUNCTIONS)

HSI =	1	2	3
REACH	3.236951	[illegible]	2.734135
FLOW	10.37424	9.344346	9.977749
PCOB	-.6001767E-02	.6609110E-01	.1900992E-01
PGRAV	.4772158	.4529125	.5336085
STAG	90.37711	95.81073	114.9923
(CONSTANT)	-89.39975	-64.98335	-79.43821

Table 17. Classification factors for cutthroat trout habitats in Bear Creek, Oregon. Group 1 = (HSI = 0), Group 2 = (0<HSI<0.5), Group 3 = (HSI>0.5), REACH = stream station, PPOOL = percent pool, CHW = channel width (m), VEL = velocity (cm/sec), FLOW = discharge (m^3/sec), PBO = percent boulders (91 cm<), PRIF = percent riffle, GRAD = gradient (%).

Physical Factors Entered Only

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS LAMBDA	SIG.	LABEL
1	REACH		1	.723661	.0010	
2	PPOOL		2	.672459	.0021	
3	CHW		3	.635935	.0042	
4	VEL		4	.599520	.0066	
5	FLOW		5	.539748	[illegible]	
6	PBO		6	.501325	.0057	
7	PRIF		7	.471123	.0078	
8	GRAD		8	.432300	.0075	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER*S LINEAR DISCRIMINANT FUNCTIONS)

HSI =	1	2	3
REACH	1.252200	1.242652	1.441748
GRAD	4.413873	2.997646	3.327703
VEL	-.2047139	-.2169512E-01	-.1101369
FLOW	4.926466	3.671335	4.360979
CHW	1.047911	1.367296	1.094882
PPOOL	.2467299	.2949621	.3316566
PRIF	.3103531	.2553434	.3059169
PBO	-.4831673	-.2058869	-.5058722
(CONSTANT)	-54.45631	-54.47107	-60.23322

Physical and Biotic Factors Entered

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS LAMBDA	SIG.	LABEL
1	REACH		1	.723661	.0010	
2	PPOOL		2	.672459	.0021	
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	
4	VEL		4	.599520	.0066	
5	FLOW		5	.539748	.0048	
6	PBO		6	.501325	.0057	
7	PRIF		7	[illegible]	[illegible]	
8	GRAD		8	.432300	.0075	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER*S LINEAR DISCRIMINANT FUNCTIONS)

HSI =	1	2	3
REACH	1.252200	1.242652	1.441748
GRAD	4.413873	2.997646	3.827703
VEL	-.2047139	-.2169512E-01	-.1101369
FLOW	4.926466	3.671335	4.360979
CHW	1.047911	1.367296	1.094882
PPOOL	.2467299	.2949621	.3316566
PRIF	.3103531	.2553434	.3059169
PBO	-.4831673	-.2058869	-.5058722

Table 18. Classification factors for cutthroat trout habitats in Elk Creek, Oregon. Group 1 = (HSI = 0), Group 2 = (0< HSI<0.5), Group 3 = (HSI$\geq$0.5), PSAND = percent sand (<0.25 mm diam), PBOUD = percent boulders (30-91 cm diam), PPOOL = percent pools, PCOB = percent cobbles (15-30 cm diam).

Physical Factors Entered Only

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS LAMBDA	SIG.	LABEL
1	PSAND		1	.923286	.1306	
2	PBOU		2	.850061	.0844	
3	PPOOL		3	.768871	.0409	
4	PCOB		4	.718888	.0379	

CLASSIFICATION FUNCTION COEFFICIENTS
(FISHER*S LINEAR DISCRIMINANT FUNCTIONS)

HSI =	1	2	3
PPOOL	-.3545563E-01	-.1488970E-01	-.1031930
PBOU	.3198240	.3319991	.6821692
PCOB	.1900890	.2276116	.2642542
PSAND	.3064194	.3363853	.6222125
(CONSTANT)	-6.362928	-8.471948	-17.07265

Physical and Biotic Factors Entered

SUMMARY TABLE

STEP	ACTION ENTERED	ACTION REMOVED	VARS IN	WILKS LAMBDA	SIG.	LABEL
1	PSAND		1	.923286	.1306	
2	PBOU		2	.850061	.0844	
3	PPOOL		3	.768871	.0409	
4	PCOB		4	.718888	.0379	
5	COHOA		5	.6669[illegible]	[illegible]	
6	POOLA		6	.605184	[illegible]	
7	GRAD		7	[illegible]	[illegible]	
8	VEL		8	[illegible]	[illegible]	

CLASSIFICATION FUNCTION COEFFICIENTS
[illegible]

HSI =	1	2	3
GRAD	4.166316	4.315616	[illegible]
VEL	[illegible]	[illegible]	[illegible]
POOLA	-.619[illegible]E-01	[illegible]	[illegible]
PPOOL	[illegible]	[illegible]	[illegible]
PBOU	.3431303	.3750123	[illegible]
PCOB	.1834991	.2254930	.2793199
PSAND	.5349138	.5928597	[illegible]
COHOA	119.7667	131.1375	[illegible]
(CONSTANT)	-16.96520	-20.67998	-43.92655

Table 19. Standardized cannonical discriminant function coefficients for cutthroat trout in Elk and Bear Creeks. PPOOL = percent pool, PBOU = percent boulders (30-91 cm diam), PCOB = percent cobble (15-30 cm diam), PSAND = percent sand (<0.25 mm), GRAD = gradient (%), VEL = velocity (cm/sec), POOLA = pool area (m^2), PPOOL = percent pool, COHOA = coho density (fish/m^2), FLOW = flow (m^3/sec), PBO = percent boulders (91 cm diam<), CHW = channel width (m), PRIF = percent riffle.

Elk Creek

Physical Factors Entered Only

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNC 1	FUNC 2
PPOOL	-.80175	-1.07370
PBOU	.85505	.19933
PCOB	.46436	-.78645
PSAND	1.60703	.01799

Physical and Biotic Factors Entered

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNC 1	FUNC 2
GRAD	-.64726	.12114
VEL	.49330	-.34773
POOLA	1.10950	.14048
PPOOL	.83786	-1.03651
PBOU	-.67364	.07512
PCOB	-.36845	-.81955
PSAND	-1.73115	-.15015
COHOA	-1.15427	-.13623

Bear Creek

Physical Factors Entered Only

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNC 1	FUNC 2
REACH	[illegible]	-1.21[illegible]
GRAD	-.48928	-.42181
VEL	1.09707	.76573
FLOW	-1.07956	-.867[illegible]
CHW	.57471	.753[illegible]
PPOOL	.46071	[illegible]
PRIF	-.49869	-.71105
PBO	[illegible]	[illegible]

Physical and Biotic Factors Entered

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNC 1	FUNC 2
REACH	.06886	-1.21030
GRAD	-.48928	-.42181
VEL	1.09707	.76573
FLOW	-1.07956	-.86700
CHW	.57471	.75300
PPOOL	.46071	-.45037
PRIF	-.49869	-.71105
PBO	.35201	.60644

Table 20. Standardized cannonical discriminant function coefficients for coho salmon in Elk and Bear Creeks. POOLA = pool area (m^2), PRIF = percent riffle, PGRAV = percent gravel (0.25-7.5 cm diam), PSAND = percent sand (<0.25 mm diam), PSHAD = percent shade, GRAD = gradient (%), VEL = velocity (cm/sec), REACA = reach area (m^2), WETW = wetted width (m^2), REACH = reach number, FLOW = flow (m^3/sec), PCOB = percent cobble (15-30 cm), CUTA = cutthroat density (fish/m^2), STDA = steelhead density (fish/m^2), STAG = steelhead density (fish/m^2).

Elk Creek

Physical Factors Entered Only

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNC 1	FUNC 2
POOLA	.99287	.32698
PRIF	-.85156	-.29667
PGRAV	.59945	-.65021
PSAND	-.65492	-.72063
PSHAD	-.42275	.47456

Physical and Biotic Factors Entered

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNC 1	FUNC 2
GRAD	.48973	-.53597
VEL	-.22810	.06529
POOLA	-.96638	.24749
REACA	.81616	.46944
PRIF	.63365	-.15947
PGRAV	-.54488	-.30699
PSAND	.64510	-.64039
PSHAD	.47023	.43357
WETW	-1.13101	-.35225
CUTA	-.43733	.57373
STDA	.29840	.37420

Bear Creek

Physical Factors Entered Only

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNC 1	FUNC 2
REACH	1.55346	-.20914
FLOW	.63891	-.01465
PCOB	-.40665	.21725
PGRAV	.12437	-.95682

Physical and Biotic Factors Entered

STANDARDIZED CANONICAL DISCRIMINANT FUNCTION COEFFICIENTS

	FUNC 1	FUNC 2
REACH	1.50567	.55071
FLOW	.57577	.48567
PCOB	-.38145	-.36225
PGRAV	.11151	.84024
STAG	-.03623	.69654

We believe that the reasons that the population responses to sets of variables is different from reach to reach and from drainage to drainage is due to levels of resource availability, which not only encompasses food and cover, but the presence of predators and competitors which will limit access to these resources. These types of interactions have been discussed by Werner and Hall (1976) and by Werner (1977). Changes in flow and temperature also affect habitat availability. In our unit, Kenneth Rodnick (MS, in prep.) has found that there are dramatic shifts in habitat selection by stream fishes, among them cutthroat trout and redside shiner during different seasons. He can attribute this to changes of flow patterns and temperature which changes the availability of suitable habitat. This corresponds to the concept of thermal niche proposed by Magnuson et al. (1979). We must also be aware that fishes have diel rhythms and may have vastly different requirements at night when data are often not gathered. Rodnick has also found dramatic shifts in microhabitat utilization with respect to velocity, depth, and use of instream cover by cutthroat trout when day and night patterns are compared.

The choice of predictive method is not entirely clear cut. The simple models may be easier for the manager in the field to utilize, if all he needs is an intuitive feel for habitat. In the day and age of hand calculators, the more sophisticated discriminant analysis classification is not beyond the quantitative limits of managers in the field. However, one should be cautioned about applying the results of the classifications presented here to other systems. We have shown creek to creek differences in factors affecting habitat quality. Also discriminant analysis, while robust as far as identification of important variables, may or may not be a good predictive tool if assumptions are violated. This is an epistemological problem as Green (1980) points out, because biologists can seldom avoid violating assumptions of the model despite much care in sampling. Multivariate analysis is a new field and many tests are not yet available to determine whether or not assumptions have been violated. Consequences resulting from departures of the assumptions are presently not understood. However, Frey and Pimentel (1978) state that simulations of data from known distributions indicate that departures do not affect the results of the analysis.

Multiple regression analysis may give a more precise answer than discriminant analysis, but the answers are not necessarily more accurate. Multiple regression analysis has a drawback for stream work; that drawback is the assumption that all the variates do not interact, all the variates are independent and additive. As characteristics of streams are governed by hydrodynamic processes in a geomorphic setting, virtually all the processes are governed by flow or discharge. Flow alone would not explain changes in distribution patterns in the systems studied. Discriminant analysis' great strength is that interacting variates are accounted for in the model. The groupings/clusters are defined by the investigator and are therefore somewhat arbitrary. These models do not demonstrate cause and effect relationships. They are descriptive statistical tools which help to identify good candidates for testing in an experiment or series of experiments to determine cause and effect.

ACKNOWLEDGEMENTS

We thank Ken Rodnick for helpful discussions and statistical consultation, Robert House (BLM) for use of his unpublished data and for exchanges of ideas, and Adrian Hunter for classy typing. We thank Mike Dutchuk for helping to process the data.

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APPENDIX 1. Elk Creek HSI values. Coho = X/.222 fish/m^2, steelhead = X/.391 fish/m^2, cutthroat = X/.036 fish/m^2.

	Coho	Steelhead	Cutthroat		Coho	Steelhead	Cutthroat
47	.55	.21	.08	9	.44	Waterfall	.01
8	.14	.28	.06	80	.27		.06
9	.32	.24	.03	1	.31		.03
50	.32	.16	.06	2	.26		.06
1	.17	.31	.03	3	.45		0
2	.29	.39	.06	4	.18		0
3	.40	.10	.08	5	.23		.14
4	.20	.13	0	6	.29		.06
5	.13	.14	0	7	.79		.17
6	.24	.09	.03	8	.02		.06
7	.31	.29	.03	9	1.00		.06
8	.57	.20	.11	90	.005		.06
9	.44	.18	.06	1	.14		.75
60	.27	.32	.03	2	0		.03
1	.31	.09	.06	3	.15		.28
2	.26	.11	.03	4	.71		.53
3	.91	.03	.06	5	.06		.28
4	.10	.26	0	6	.01		0
5	.39	.20	.11	7	.13		.03
6	.14	.19	.03	8	.50		.44
7	.14	.18	.03	9	.15		.22
8	.53	.27	.06	100	.01		.08
9	.71	.14	.06				
70	.29	.18	0				
1	.45	.14	0				
2	.31	.49	0				
3	.22	1.00	.03				
4	.19	.39	.03				
5	.18	.31	0				
6	.14	.42	0				
7	.21	.36	0				
8	.22	.64	.03				

APPENDIX 2. Bear Creek HSI values. Coho = X/.222 fish/m^2, steelhead = X/.391 fish/m^2, cutthroat = X/.036 fish/m^2.

	Coho	Steelhead	Cutthroat		Coho	Steelhead	Cutthroat
1	.25	.06	0	8	Logjam	.42	.22
2	.17	.06	0	9		.32	.22
3	.09	.04	.02	30		.34	.22
4	.17	.13	.02	1		.21	.11
5	.25	.14	.11	2		.30	.19
6	.22	.18	.02	3		.39	.61
7	.07	.22	.02	4		.31	.61
8	.01	.11	.02	5		.37	.36
9	.13	.43	.02	6		.18	.36
10	.10	.35	.02	7		.22	.52
1	.20	.21	.02	8		.09	.50
2	.13	.38	.02	9		.04	.16
3	.05	.21	.02	40		.03	.94
4	.56	.47	.13	1		.05	.38
5	.43	.25	.02	2		.06	1.00
6	.23	.16	.08	3		.05	.36
7	.09	.31	.05	4		.17	.27
8	.43	.36	.02	5		.05	.44
9	.09	.49	.16	6		.07	.38
20	.23	.71	0				
1	.25	.50	.11				
2	.31	.54	.02				
3	.08	.16	.02				
4	.52	.35	.05				
5	.09	.21	.13				
6	.22	.37	.16				
7	.28	.45	.08				

Appendix 3. HSI values from southcentral Oregon coastal streams, coho = X/2.91 gms/m^2, cutthroat = X/7.81 gms/m^2.

Drainage	Coho	Cutthroat
Smith	0.00	0.51
"	0.00	1.00
"	0.00	0.49
"	0.57	0.01
"	0.02	0.00
"	1.00	0.00
"	0.08	0.01
"	0.05	0.02
"	0.00	-
"	0.00	-
"	0.23	0.00
"	0.03	0.00
"	0.03	0.02
South Coos	0.38	0.00
"	0.43	0.10
"	0.31	0.08
"	0.60	0.03
"	0.90	0.18
"	0.81	0.15
"	0.77	0.10
"	0.53	0.51
"	0.11	0.00
"	0.38	0.51
"	0.14	0.00
"	0.03	0.00
"	0.78	0.00
"	0.93	0.02
"	0.74	0.01
"	0.76	0.00
Coquille	0.04	
"	0.03	
"	0.24	
"	0.29	
"	0.24	
"	0.06	

Appendix 4. Physical factors measured at survey sites from the Nestucca drainage and the southcentral Oregon coastal drainages.

Nestucca	Southcentral coastal drainages
gradient (%)	elevation
velocity (m/sec)	site length
flow (cfs)	average width
channel width (ft)	maximum width
wetted width (ft)	average depth
pool width (ft)	maximum depth
maximum pool depth (ft)	station volume
% pool/riffle/glides/rapids/Cascades	station surface area
% bedrock	flow
% boulders	average velocity
% boulders	maximum temperature
% cobbles	minimum temperature
% rubble	pool/riffle ratio
% coarse gravel	canopy
% fine gravel	shade
% sand	% bedrock
% silt	% mixed substrate
% large organic material	% boulder (30 cm<)
% find organic material	% cobble (15-30 cm)
landform type	% rubble (7.5-15 cm)
landform gradient	% coarse gravel (2-7.5 cm)
riparian width (ft)	% small gravel (0.25-2.5 cm)
% cover	% sand (<0.25)
channel stability	% wood
bank stability	instream cover
air temperature	
water temperature	
average depth	

FIGURE 1. Coho salmon SI vs. gradient (%) for Elk and Bear Creeks.

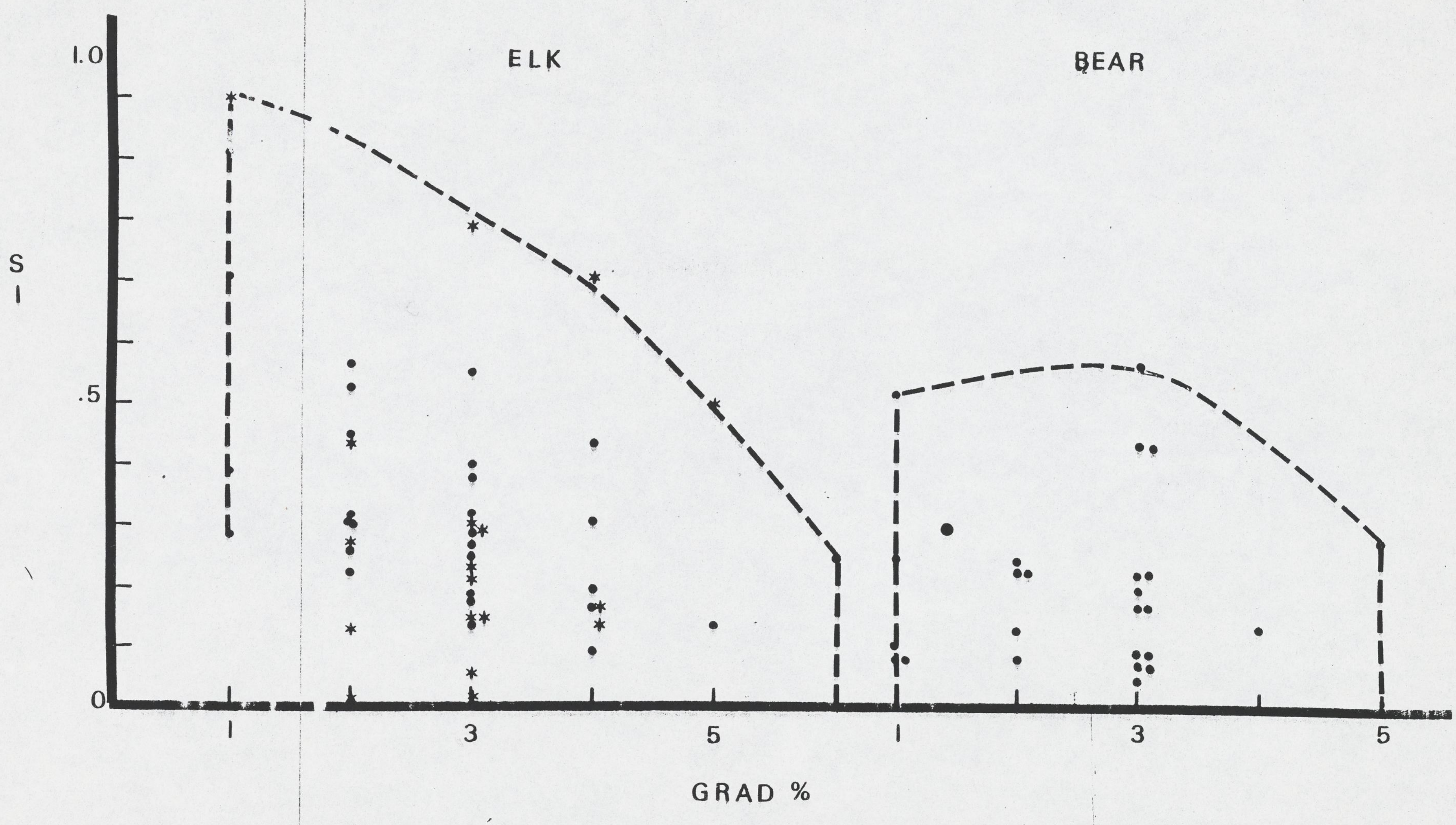


FIGURE 2. Cutthroat trout SI vs. gradient (%) for Elk and Bear Creeks.

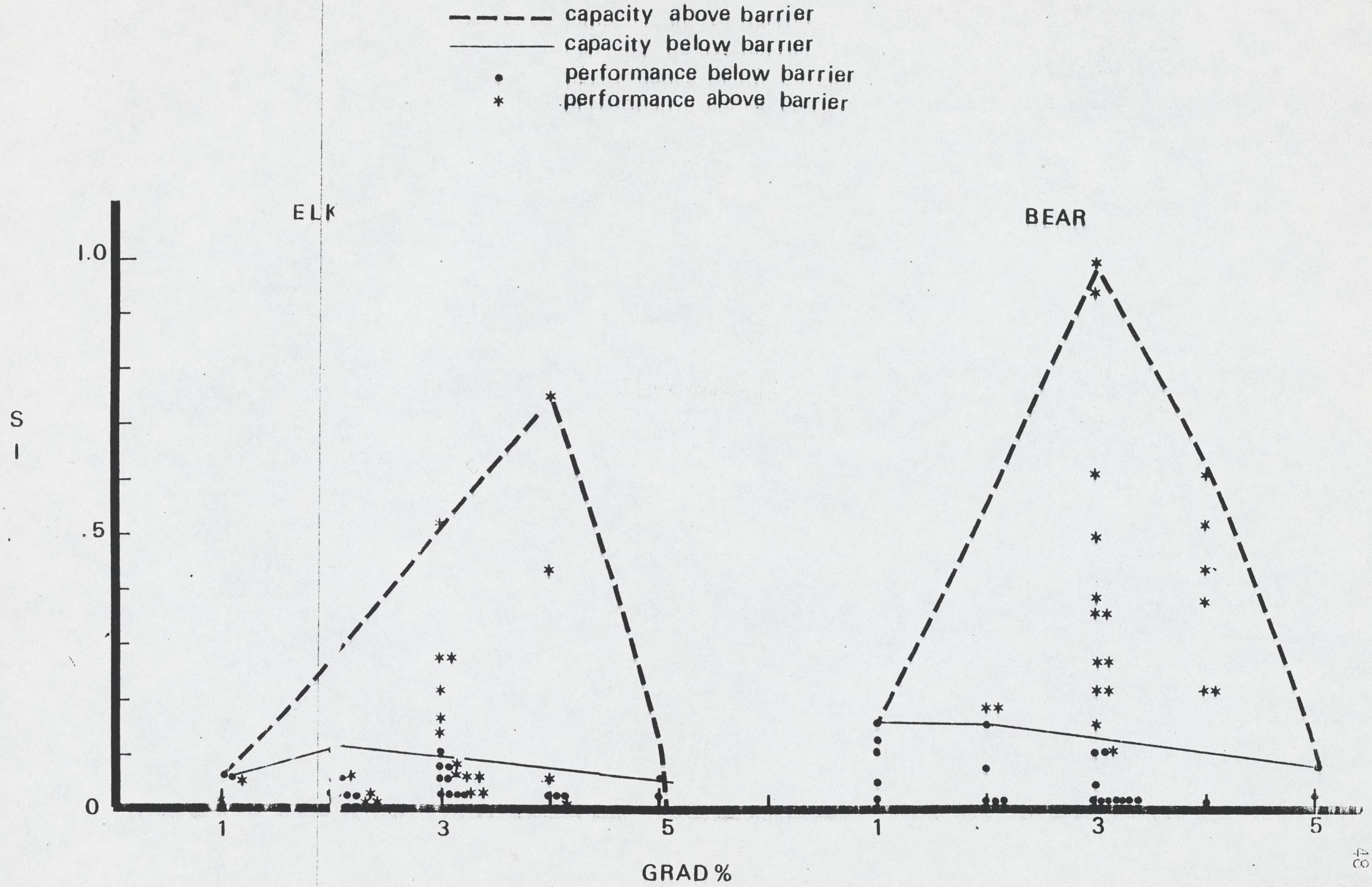
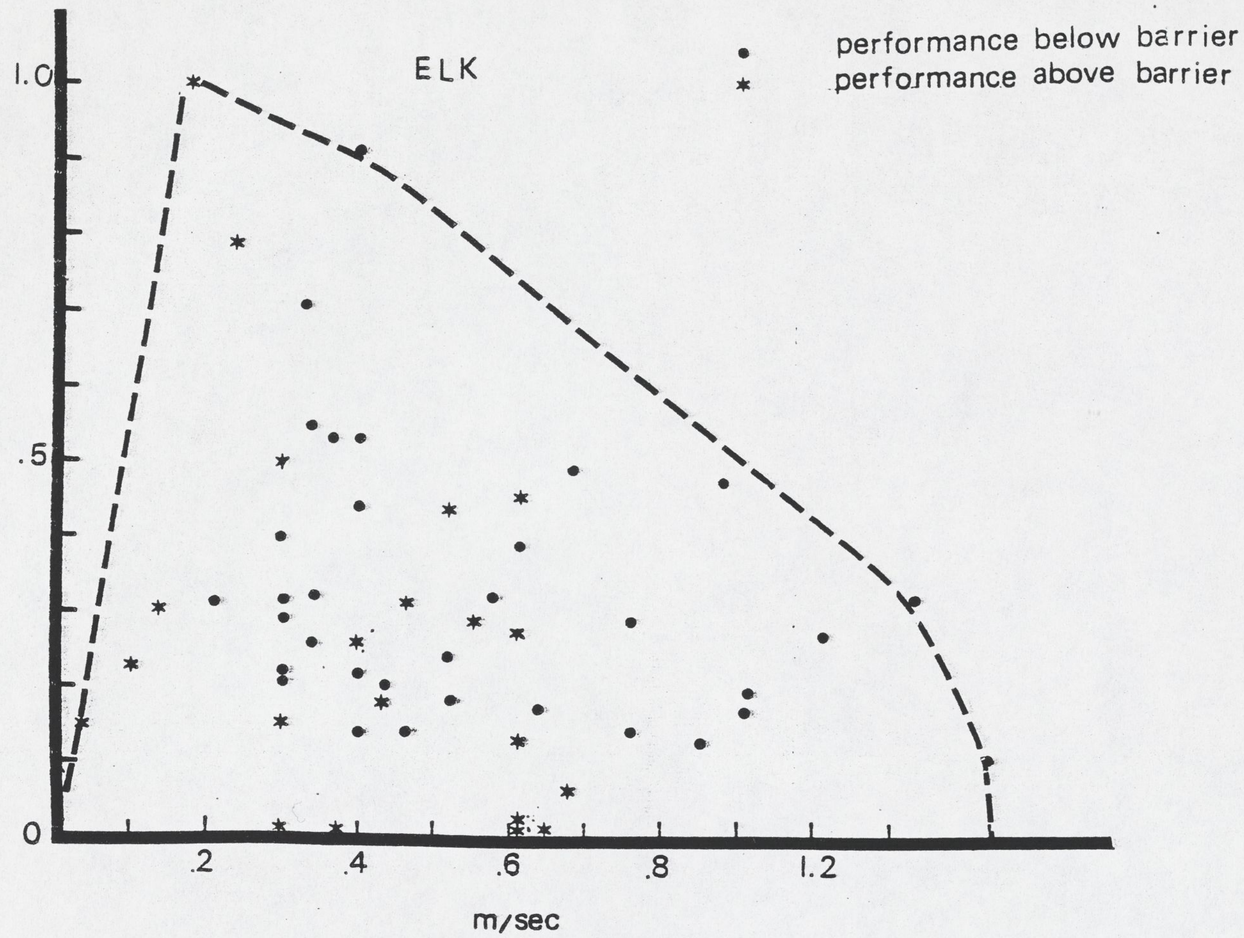


FIGURE 3. Coho salmon SI vs. velocities (m/sec, average for section) for Elk and Bear Creeks.



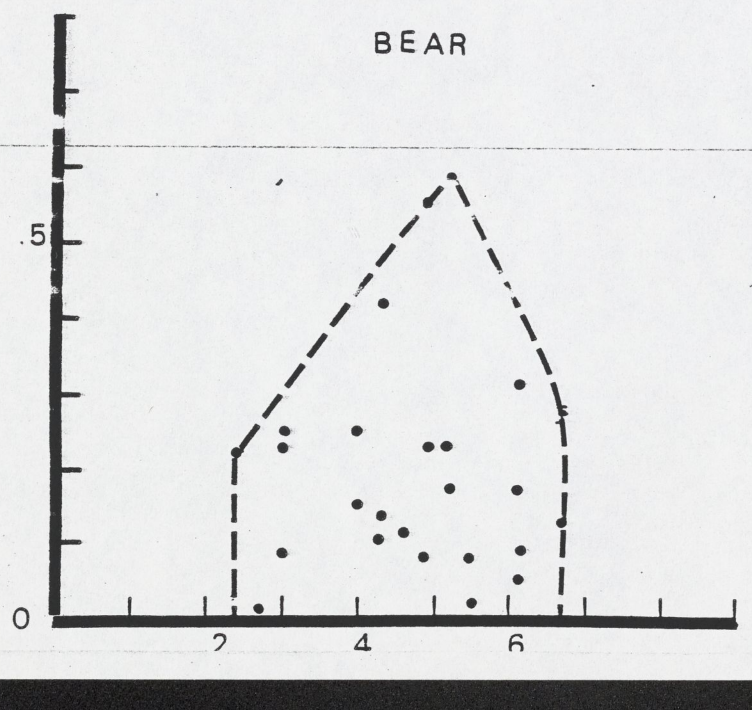


FIGURE 4. Cutthroat trout SI vs. velocities (m/sec, average for section) for Elk and Bear Creeks.

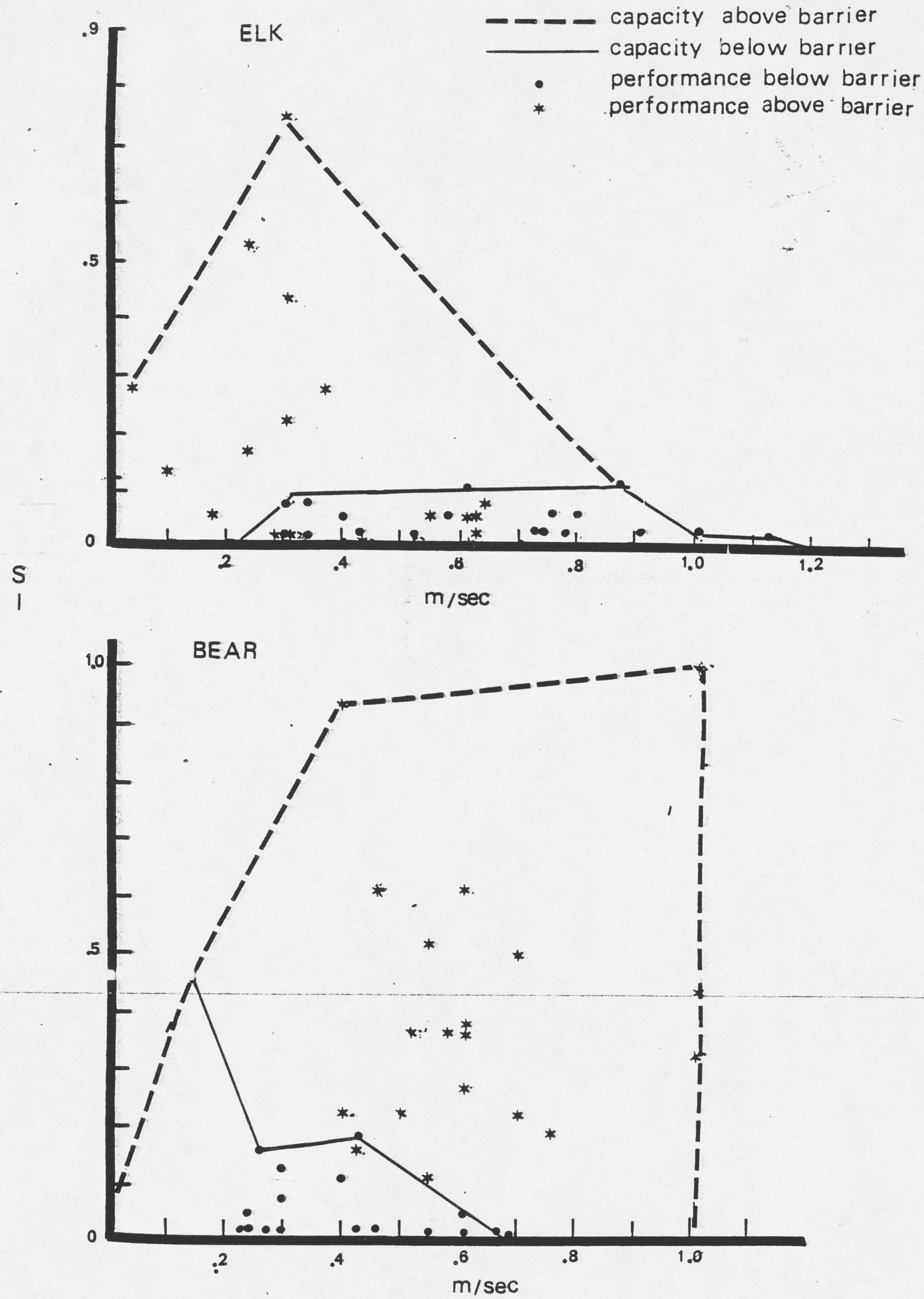


FIGURE 5. Coho salmon SI vs. percent riffle in Elk Creek.

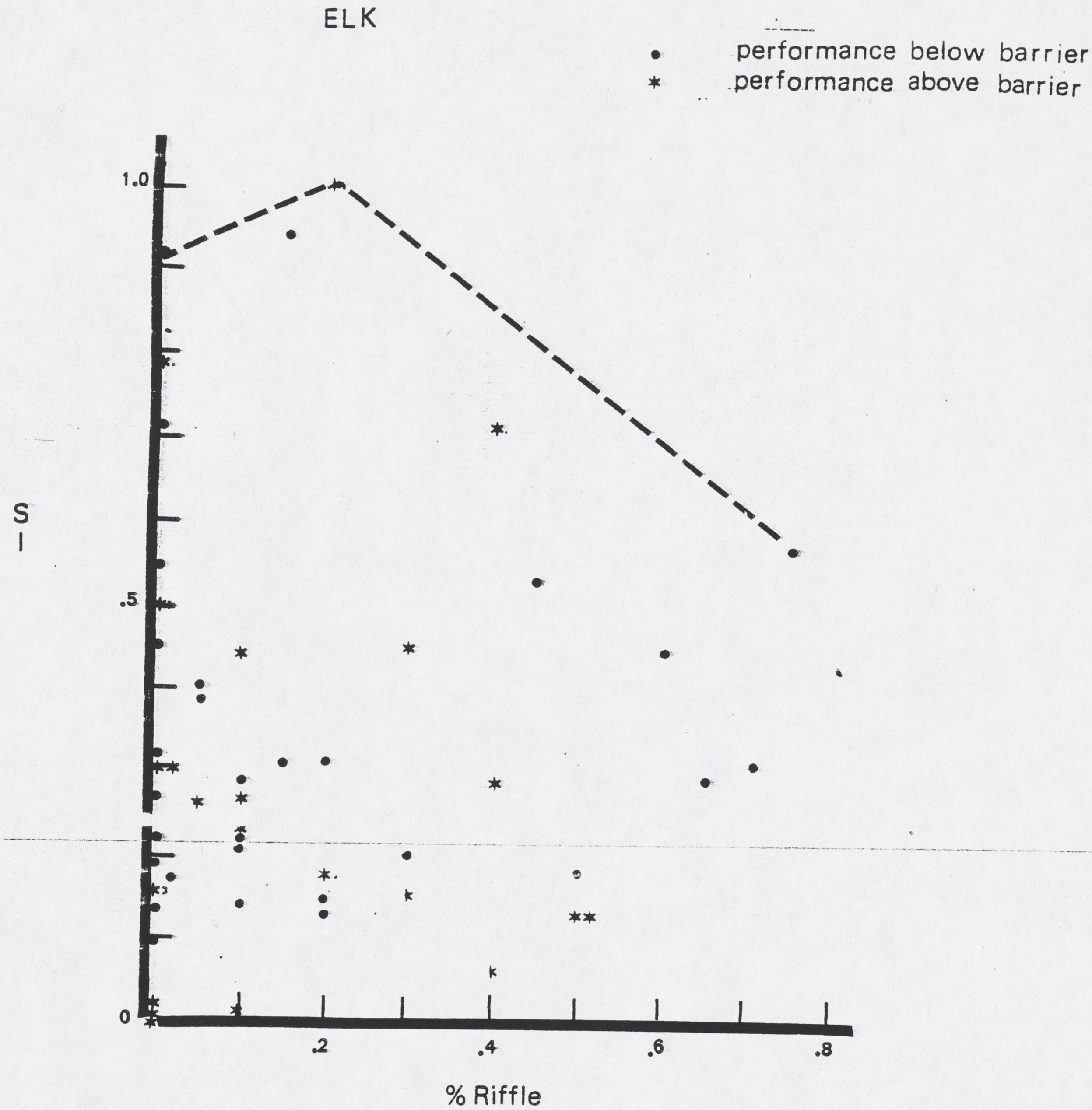


FIGURE 6. Coho salmon SI vs. percent riffle in Bear Creek.

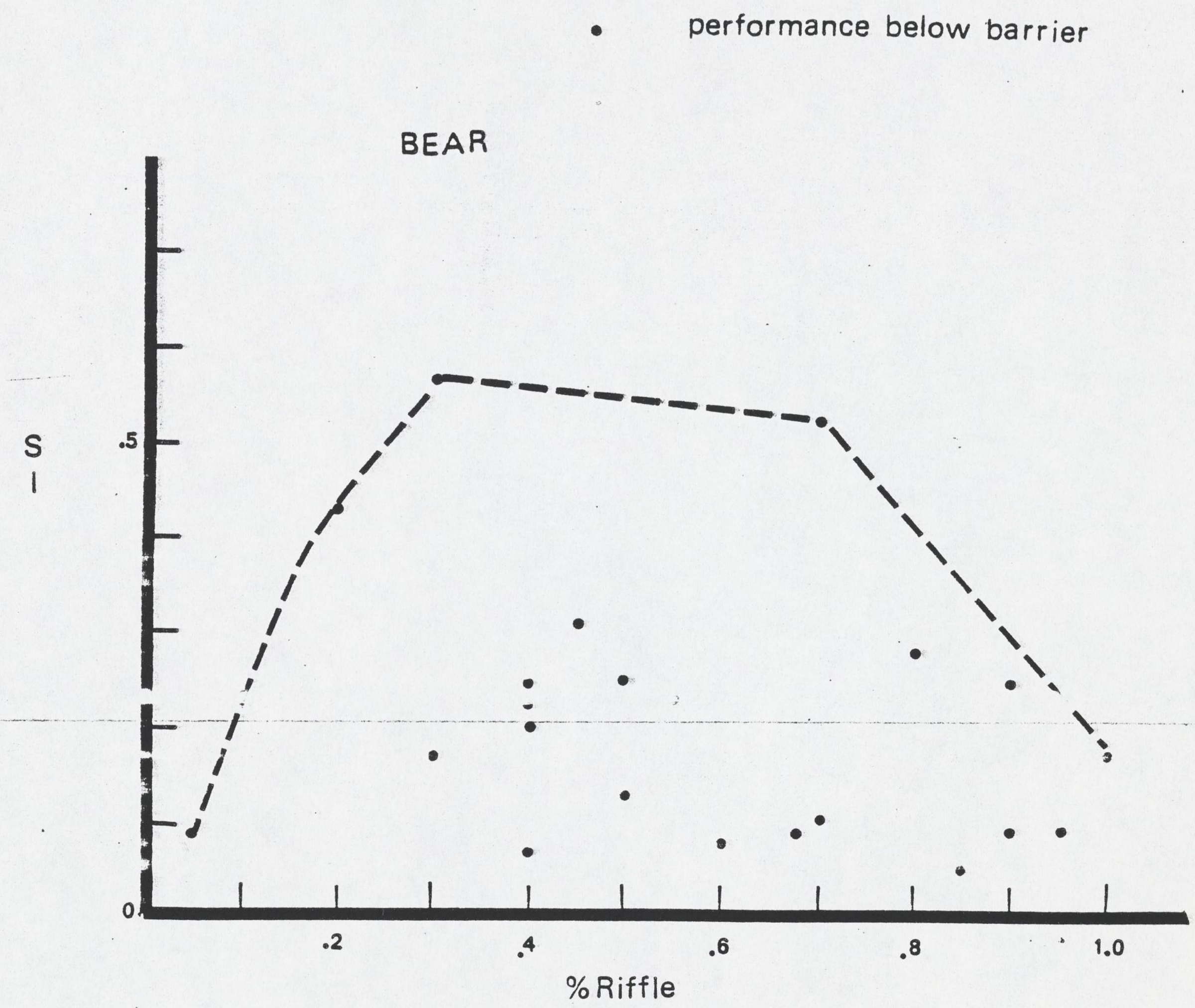


FIGURE 7. Cutthroat trout SI vs. percent riffle in Elk Creek.

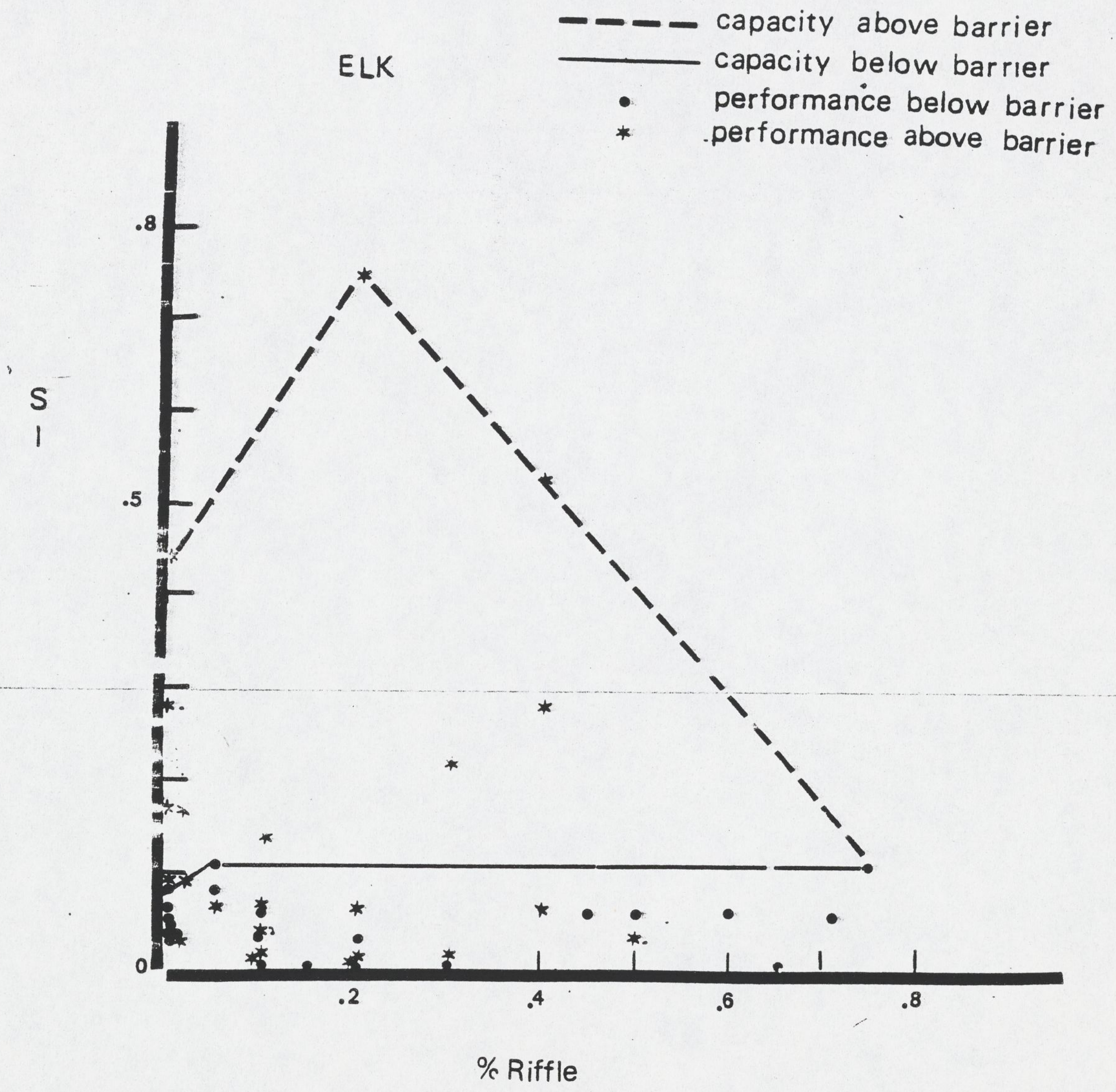


FIGURE 8. Cutthroat trout SI vs. percent riffle in Bear Creek.

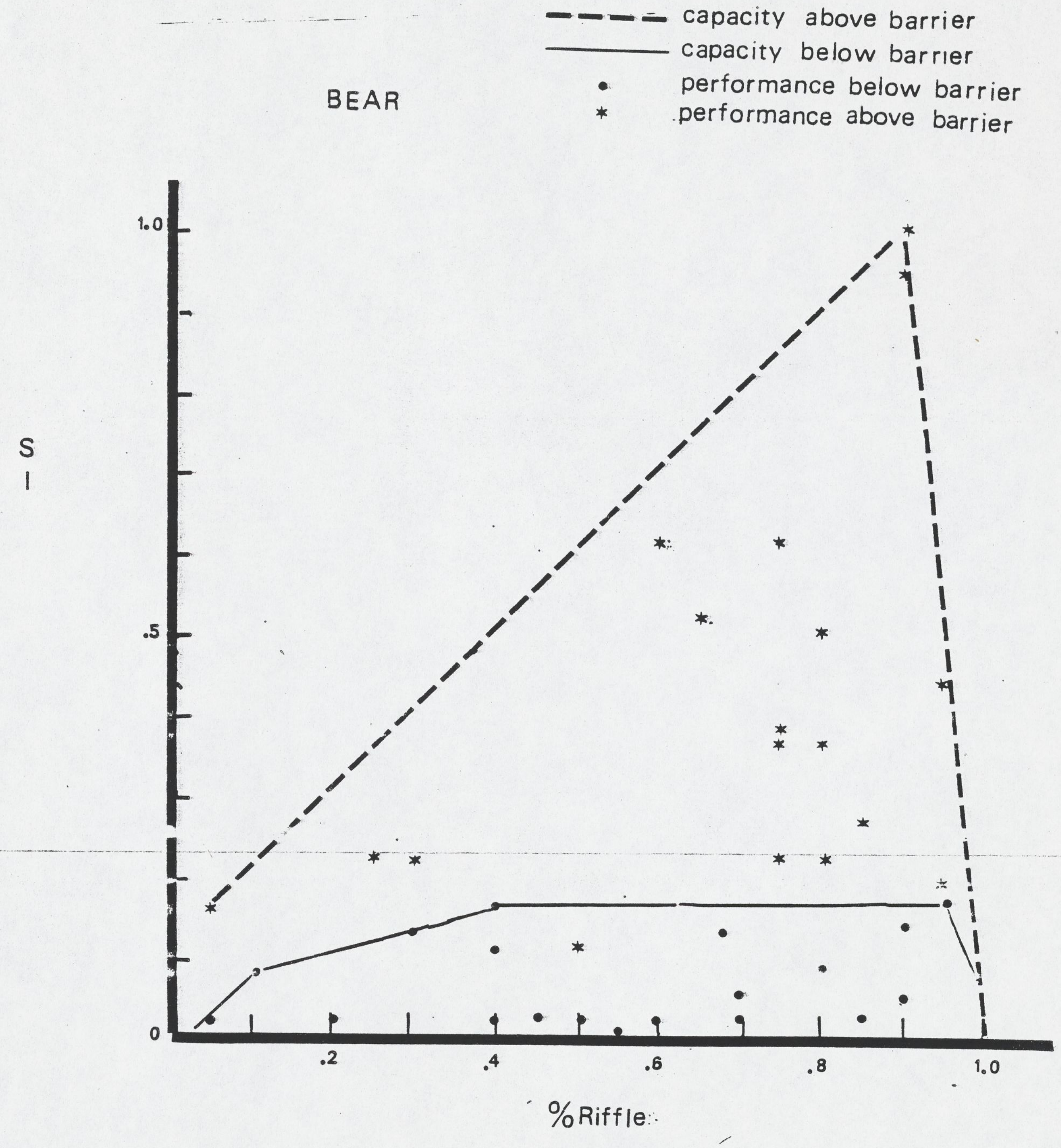


FIGURE 9. Coho salmon SI vs. pool volume (m^3) in Elk Creek.

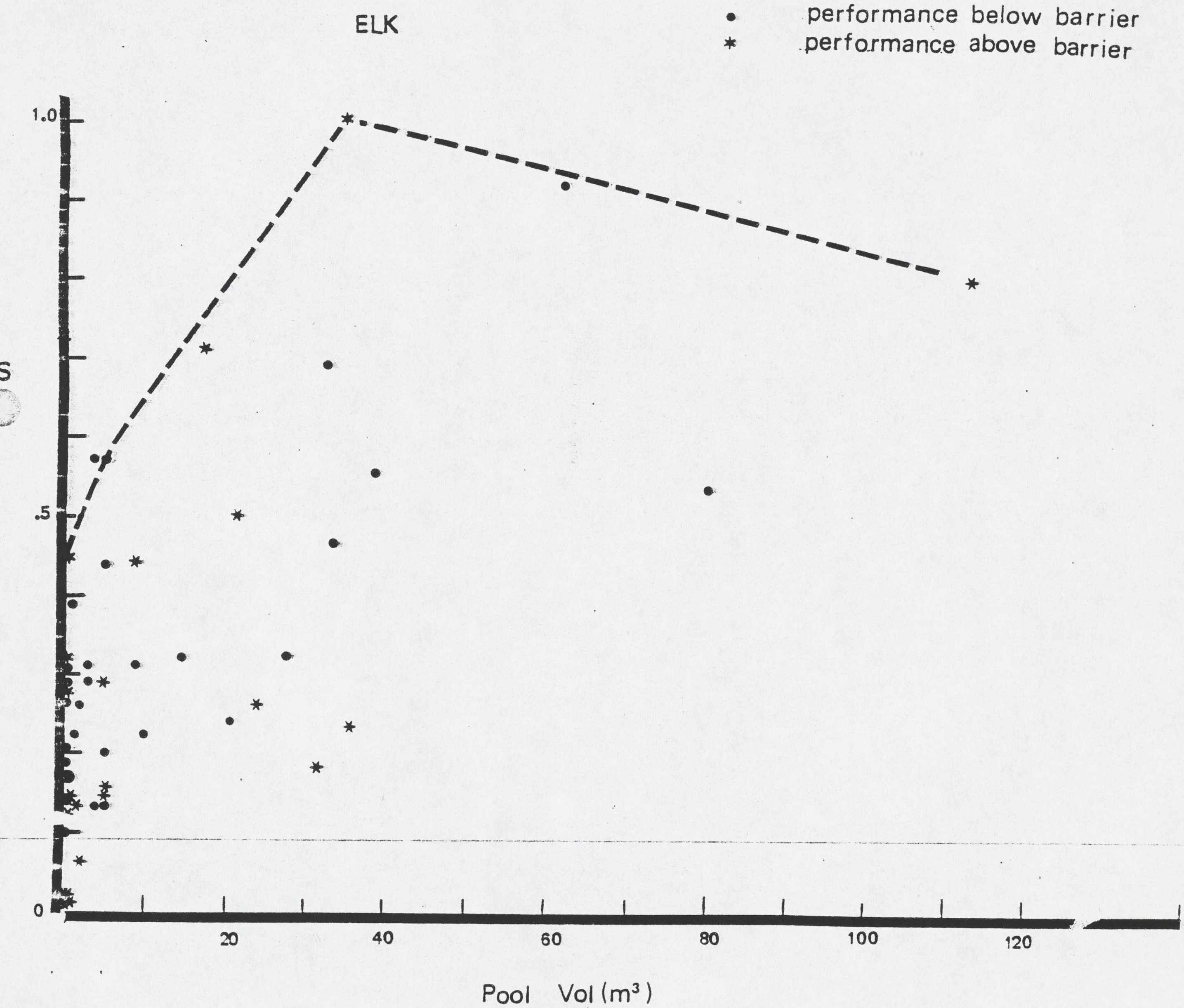


FIGURE 10. Coho salmon SI vs. percent pool in Bear Creek.

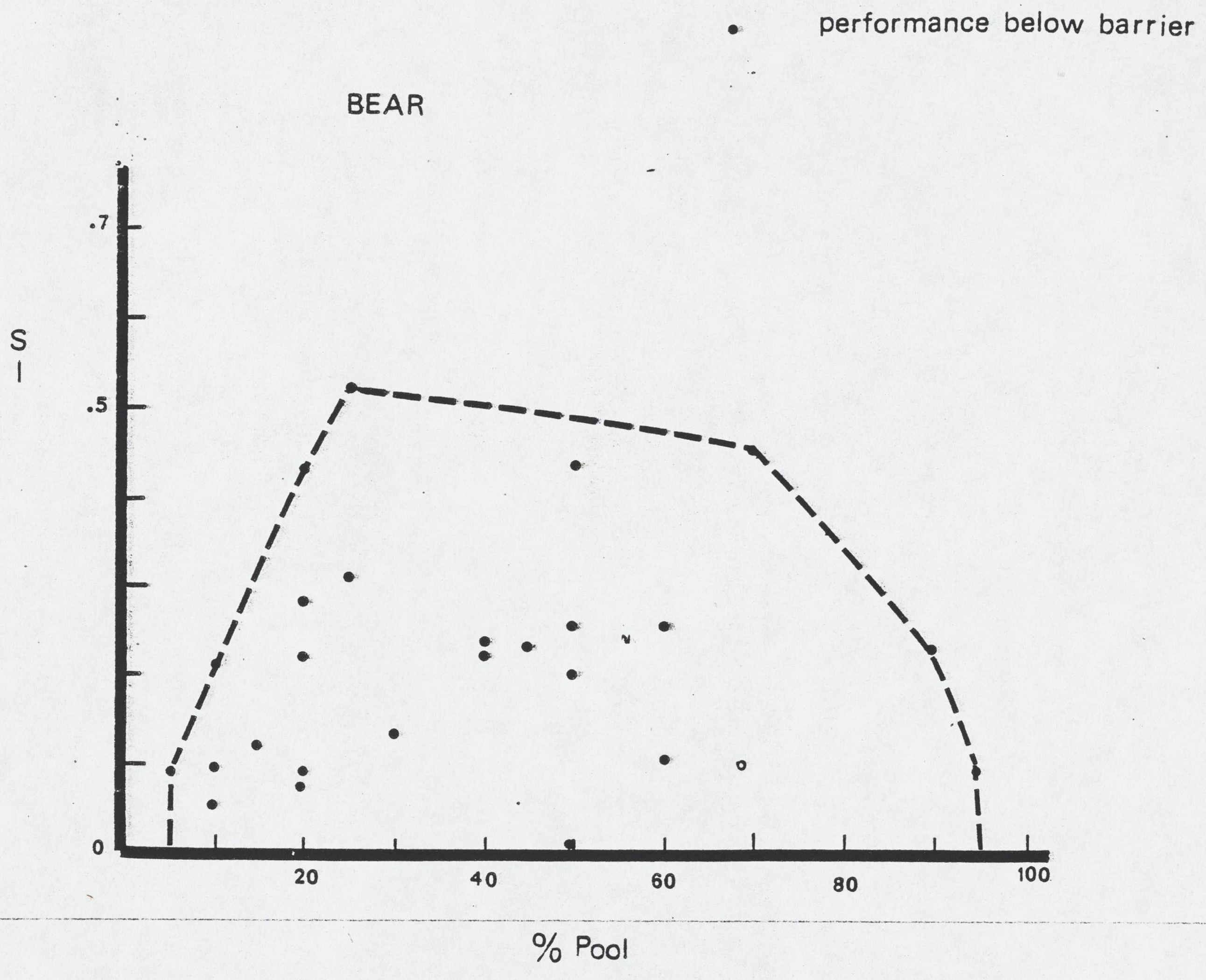


FIGURE 11. Coho salmon SI vs. percent pool in ElkCreek.

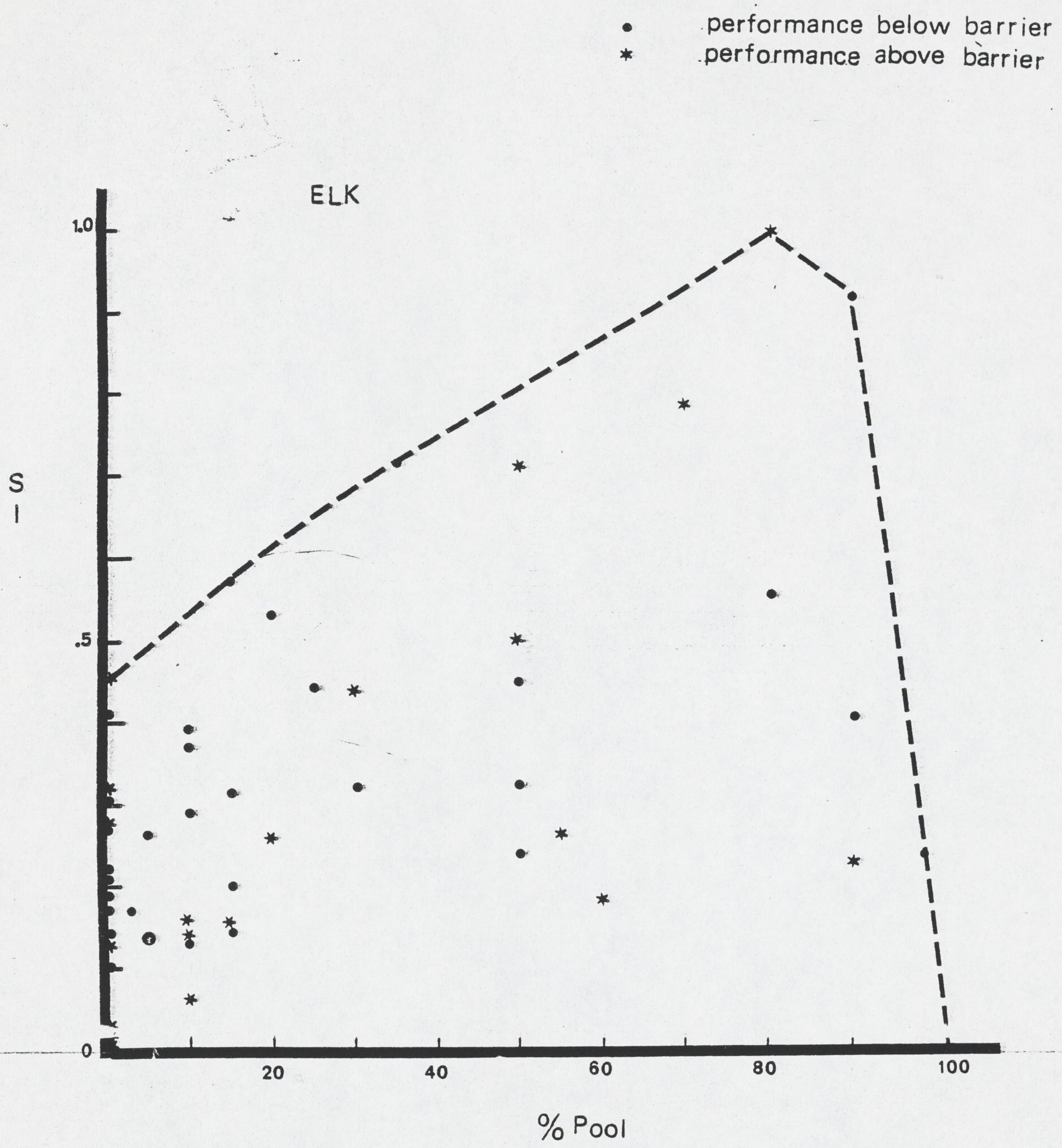


FIGURE 12. Cutthroat trout SI vs. percent pool in Elk Creek.

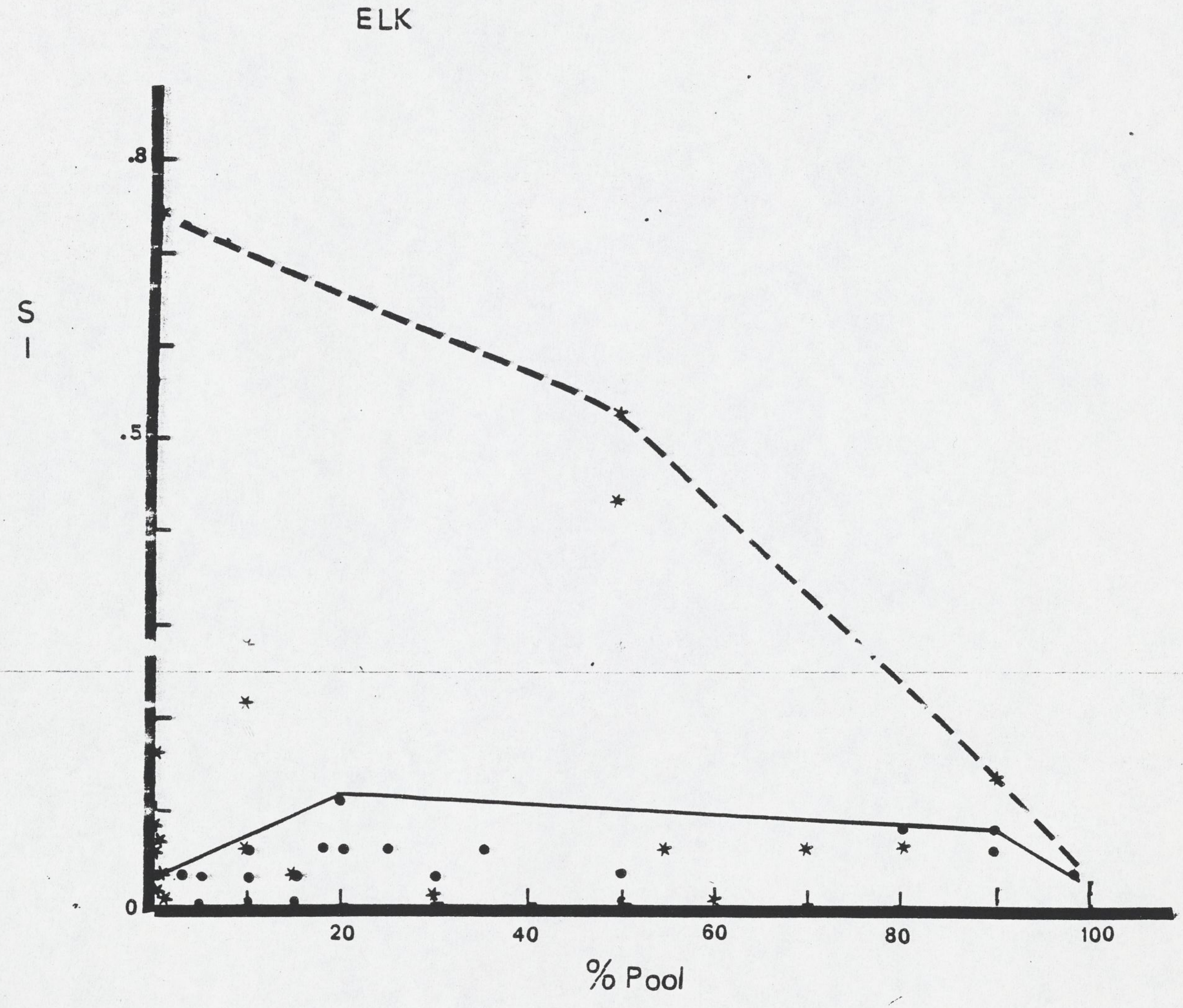


FIGURE 13. Cutthroat trout SI vs. percent pool in Bear Creek.

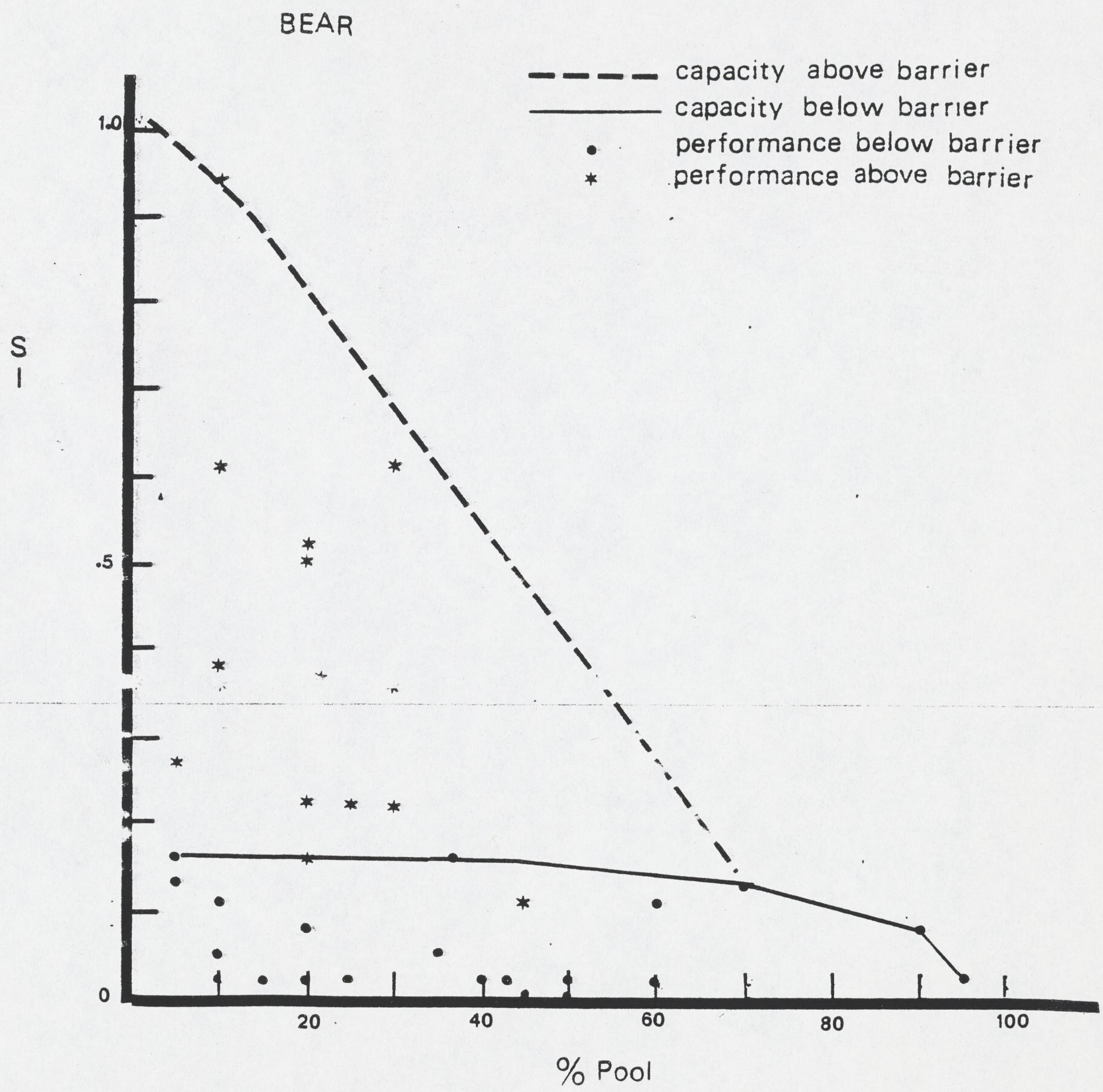
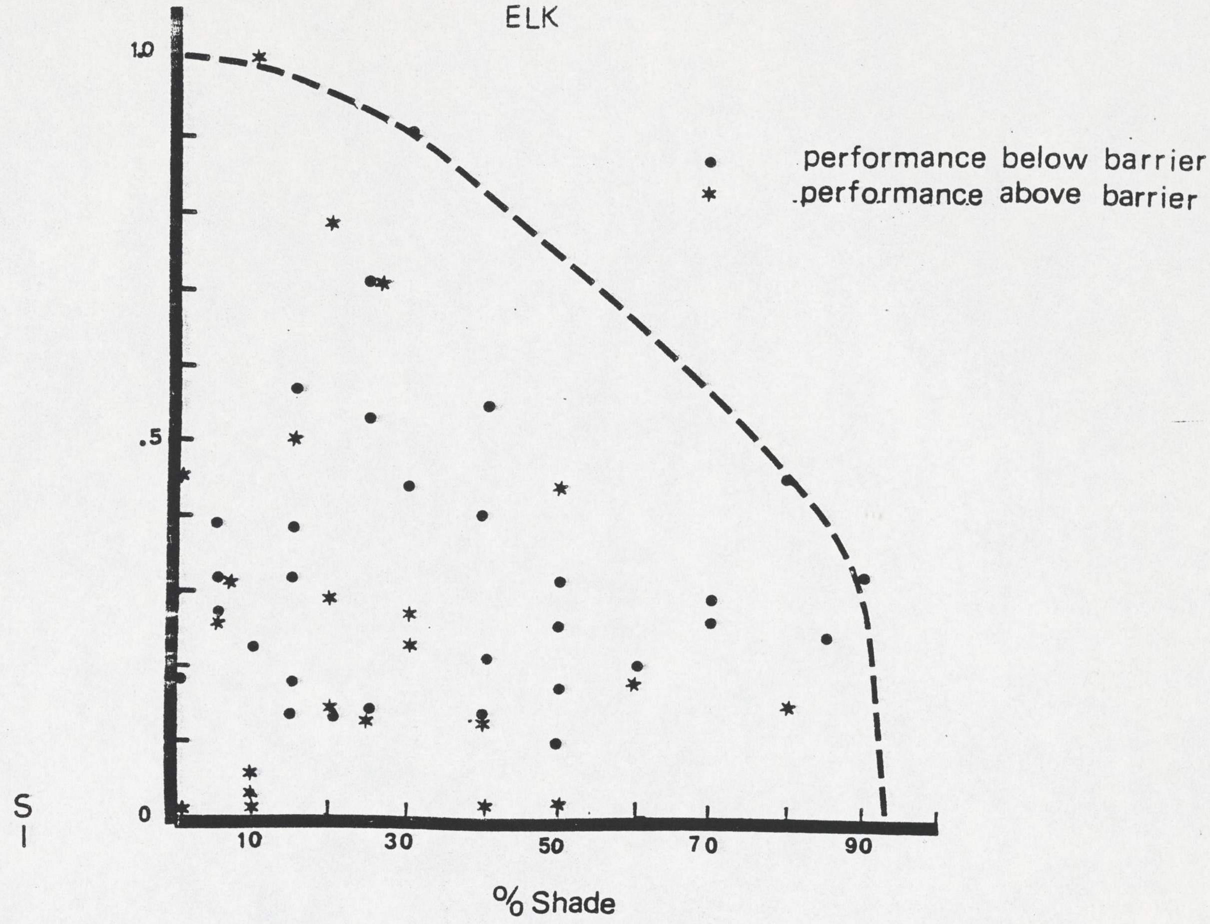


FIGURE 14. Coho salmon SI vs. percent shade in Elk and Bear Creeks.



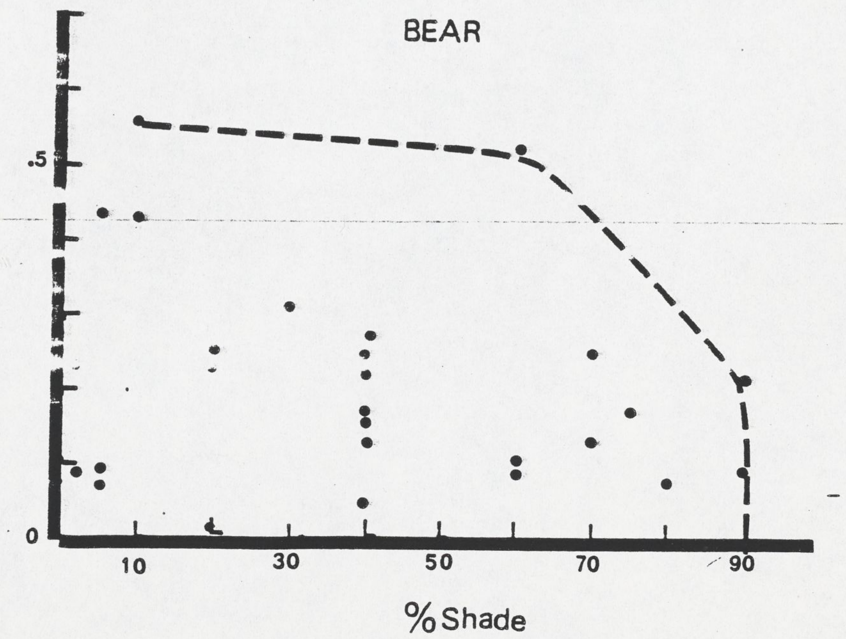


FIGURE 15. Cutthroat trout SI vs. percent shade in Elk and Bear Creeks.

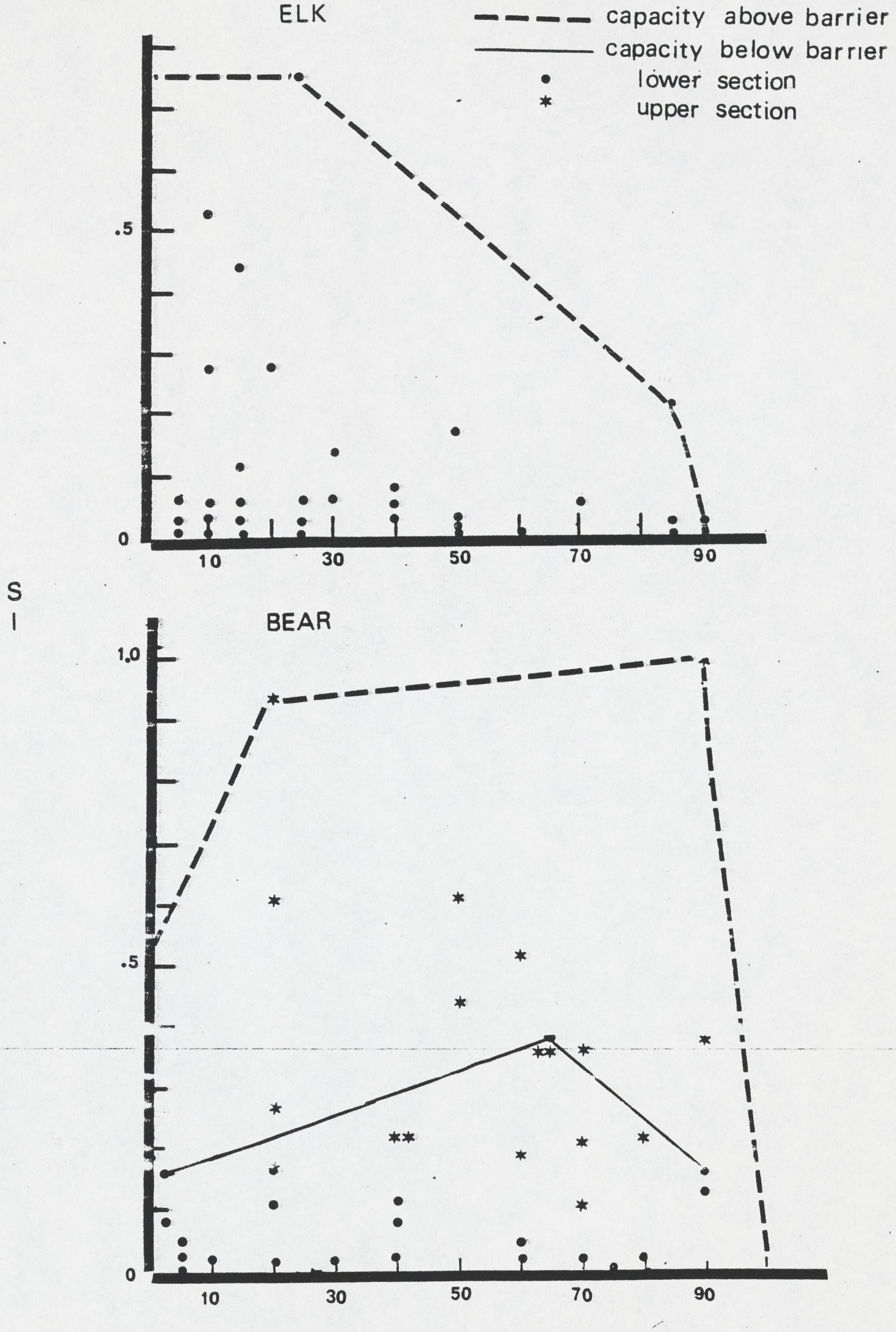


FIGURE 16. Cutthroat trout SI vs. percent fines in Bear Creek.

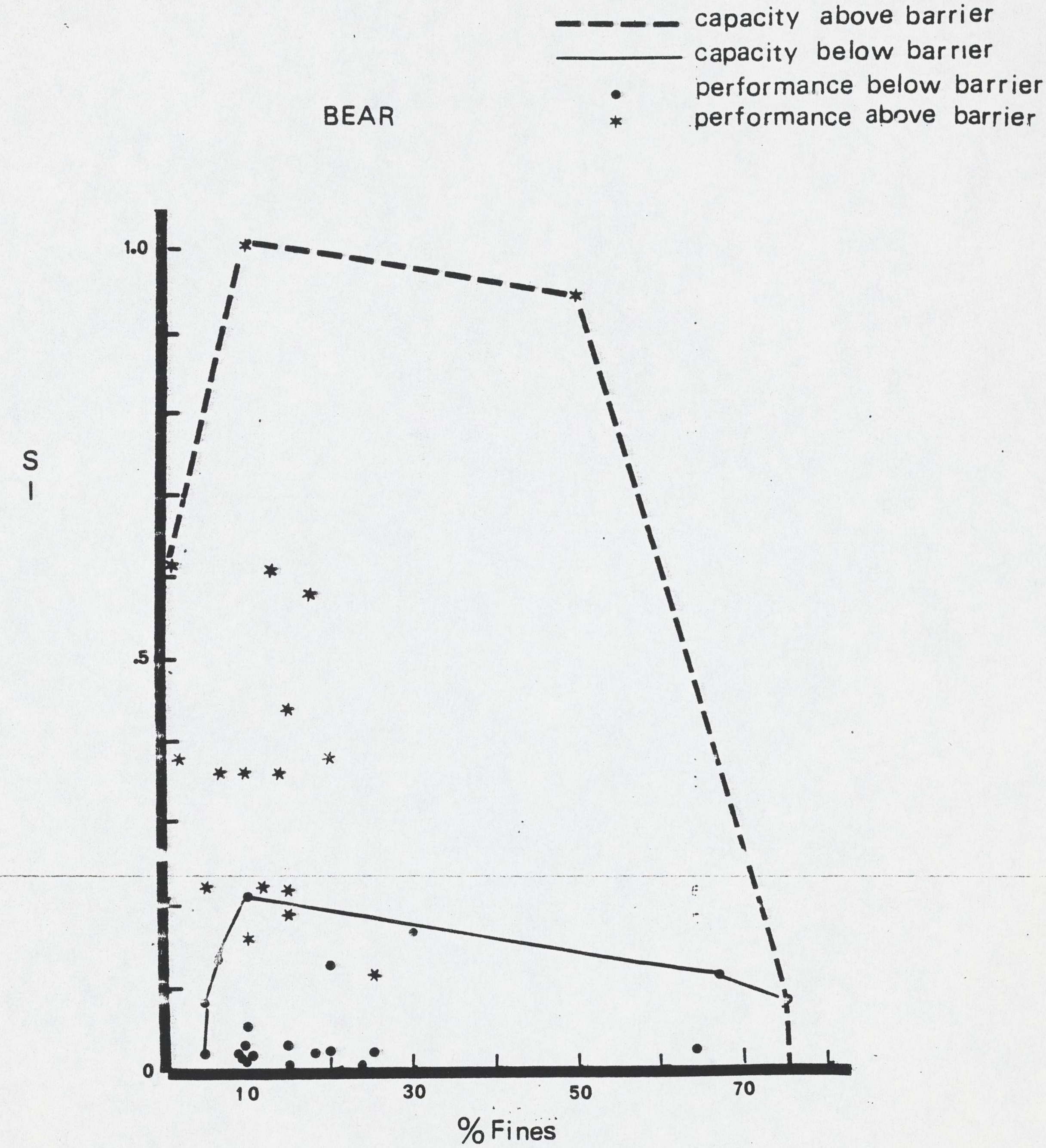
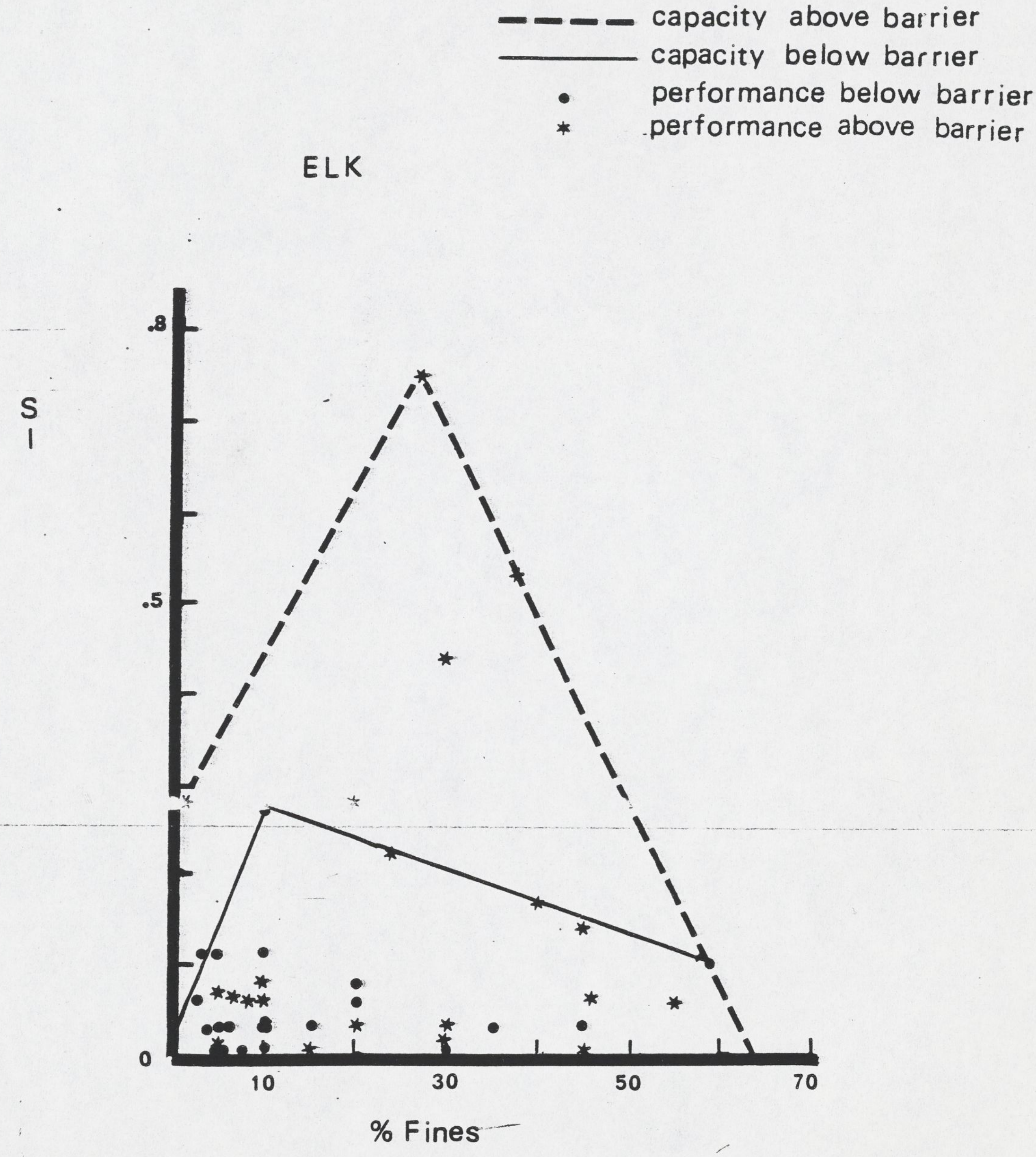


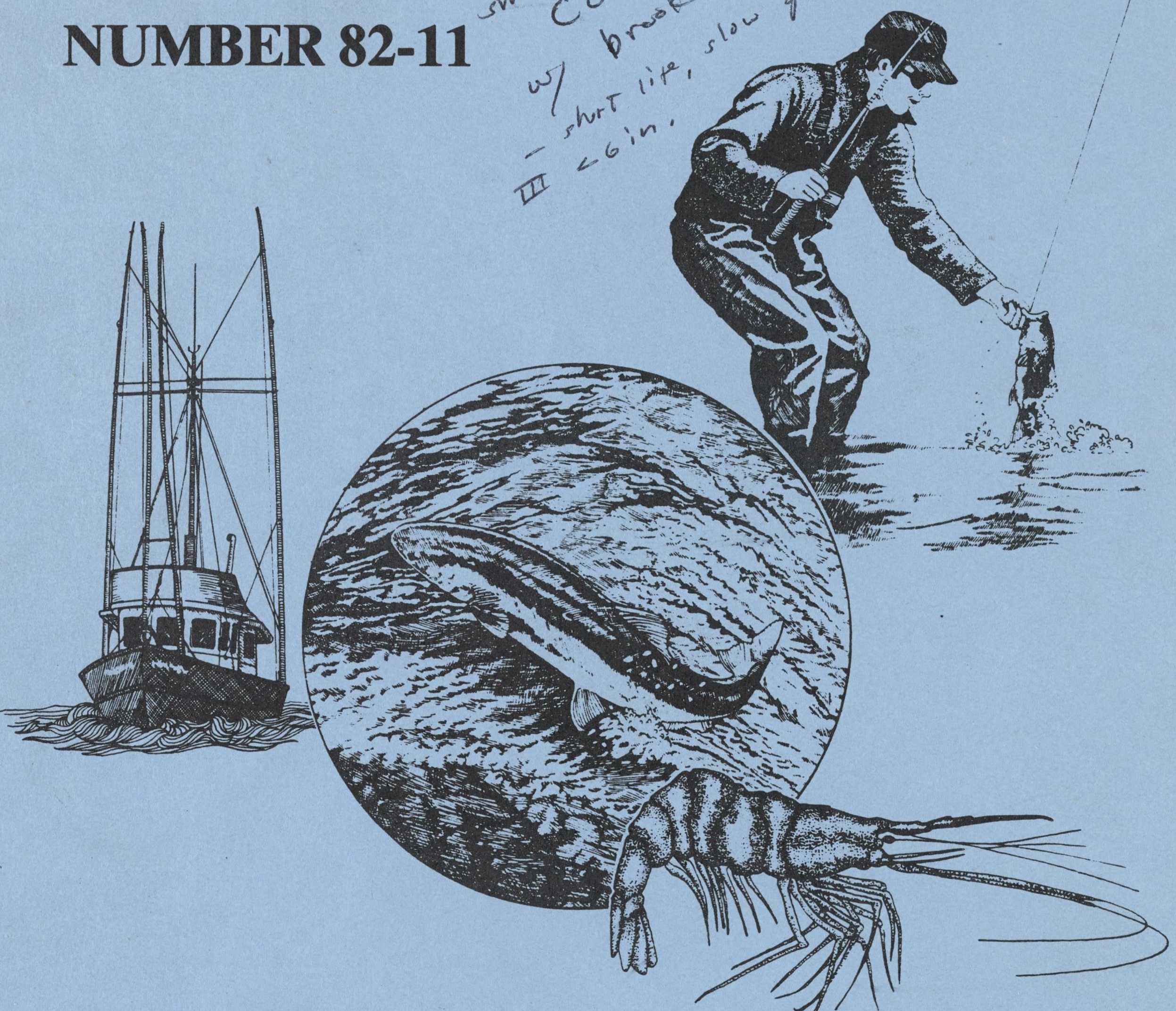
FIGURE 17. Cutthroat trout SI vs. percent fines in Elk Creek.



INFORMATION REPORTS

NUMBER 82-11

small stream
coastal cutt 96%
w/ brook trout 4%
- short life, slow growth
III <6in.



FISH DIVISION

Oregon Department of Fish and Wildlife

A Wild Trout Inventory of the
Parks Creek System

A WILD TROUT INVENTORY

OF

THE PARKS CREEK SYSTEM

By

Joe Wetherbee, District Biologist

and

Wayne Hunt, Crew Leader

Elena Karnaugh-Smith, Seasonal Assistant

Northwest Region

Oregon Department of Fish and Wildlife

October 1982

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INTRODUCTION

The Parks Creek system in eastern Linn County (Fig. 1) was inventoried in the summer of 1981 to assess wild trout populations and their habitat. The system drains about 20 square miles of varied habitat including timber, clearcuts, and meadow. Most of the system is of relatively flat gradient with elevations ranging from 3,360 to 4,000 ft. Ownership is mostly U.S. Forest Service interspersed with some private land. The system is relatively accessible by a network of forest roads.

Parks Creek is a closed stream system as the collective flow goes subsurface into lava fissures. Some 50 surface acres of water may be impounded after the snowmelt in the spring, but this usually recedes to a series of stream channels by early summer.

Stream sections sampled ranged from 6 to 22 ft in width with estimated flows during August and September of 0.2 to 11 cfs (Appendix 1). The system contains both native cutthroat and introduced brook trout. Moderate angling pressure occurs in Parks Creek and the major tributaries.

The system was selected because of the varied habitat, the opportunity to compare cutthroat populations residing at a higher elevation than those examined in a 1980 study on Blowout Creek (Wetherbee and Hunt, 1982), and to assess brook trout in a stream environment.

OBJECTIVES

The wild trout inventory in the Parks Creek system was conducted to:

1. Estimate trout populations by using a systematic sampling approach.

2. Determine the distribution of cutthroat and brook trout.

3. Determine if there is any correlation between habitat and population densities and/or species distribution.

4. Collect data on age and growth of cutthroat and brook trout in a higher elevation environment.

5. Compare population data collected from Parks Creek to that collected in 1980 from Blowout Creek, a tributary of Detroit Reservoir.

METHODS

Sample Area Selection

Sample sections were selected on four tributaries as well as the upper portion of Parks Creek (Fig. 1). Two sample sections were selected on the smaller tributaries (Maude Creek, North Fork Parks Creek, and South Fork Parks Creek) which seemed adequate to represent trout populations and habitat types. Three sample sections were selected on Crescent Creek, the largest tributary, and two sections on main stem Parks Creek. It was not feasible to sample the lower portion of Parks Creek due to large, deep

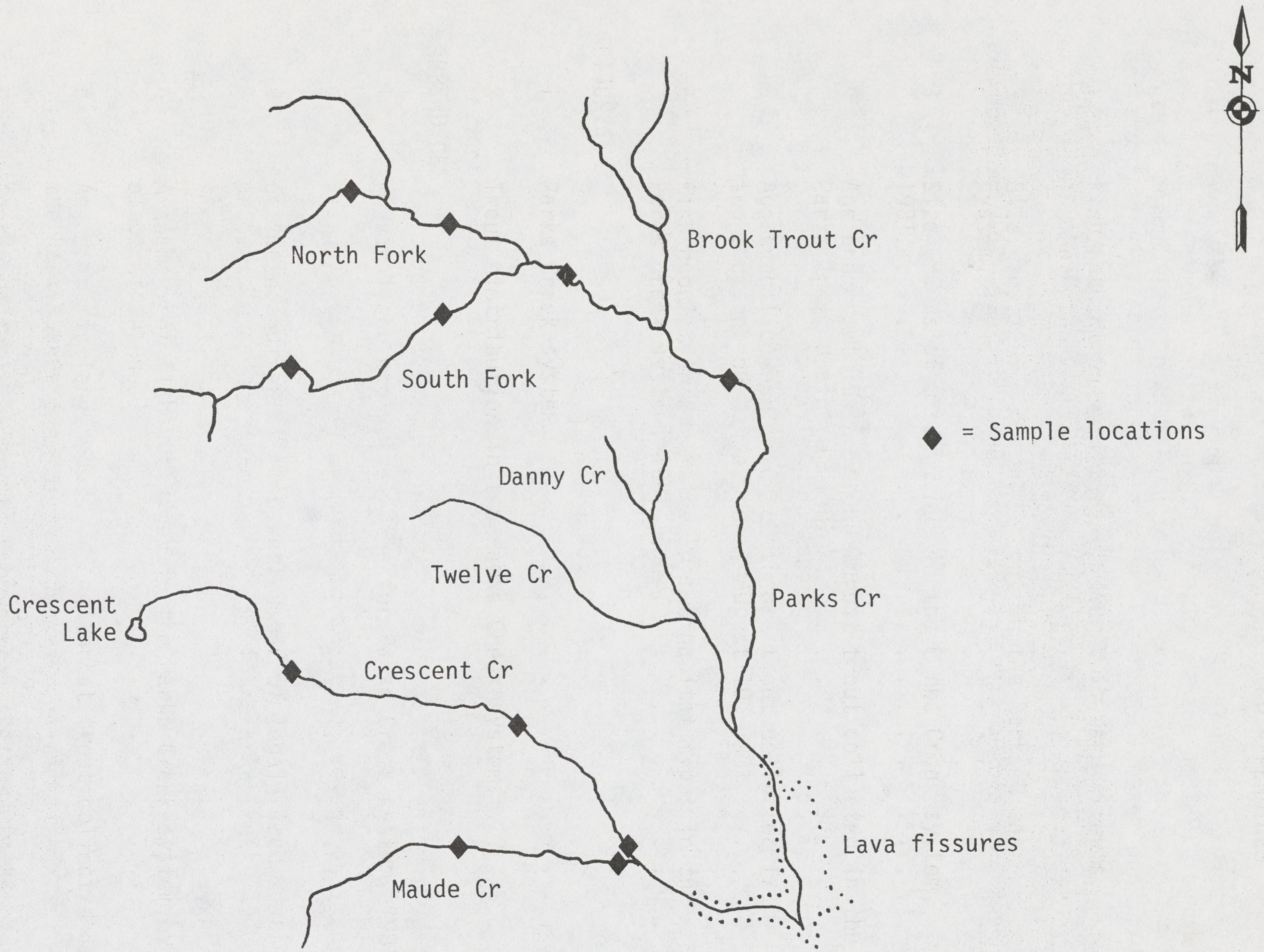


Fig. 1. Parks Creek system.

pools; however, random sampling was conducted to document species present. The length of each sample area was not predetermined, and lengths varied from 139 to 310 ft. In all, 11 stations were sampled in about 11 mi of stream.

Sampling Gear and Techniques

Standard electrofishing techniques were used to capture fish. After each stream section was blocked with seines, two passes were made with a backpack shocker. Fish collected were measured and weighed, and then released below the seine block. Scale samples were collected from each representative size group of fish.

Estimating Fish Populations

The number of fish collected in each section sampled was expanded to determine the average number of fish/mi. This average was then applied to the mileage adjacent to each section to obtain the total estimated fish population for the stream. Total fish population estimates were made on only four tributaries since Parks Creek and two smaller tributaries could not be efficiently sampled.

The upper limit of fish distribution was determined for each stream by walking above the last section sampled until fish were no longer observed.

Recording Data

A form covering each section sampled was completed to record location, length, width, estimated flow, water temperature, description of habitat, and data on each fish recovered (Appendix 2). A detailed drawing of the section surveyed was included on the back of the form. The drawing included measurements of stream length and width, pool depth, and other pertinent physical features.

RESULTS

Fish Populations

Total fish population estimates were made on only four tributaries: Crescent, Maude, South Fork Park, and North Fork Park creeks. Some sampling was conducted on the main stem Parks Creek, but it was inconclusive as the lower portion could not be electrofished efficiently. Estimated total numbers of fish were derived by expanding fish collected in each section to fish/mi and then applying this figure to adjacent mileage between sections (Appendix 3).

We estimated 7,718 trout were in the 9.4 mi of stream in the four tributaries for which estimates were made (Table 1). Of the total, 7,380 (95.6%) were cutthroat and 338 (4.4%) were brook trout. Only 328 (4%) legal-sized fish (6 inches or over in length) were estimated, with no legal fish collected in Maude Creek.

The fish/mi average for the four streams was 821; however, the average number of legal-sized fish/mi was only 35. Similar data collected in the Blowout Creek system in 1980 was 1,084 fish/mi and 102 legal-sized fish/mi.

Table 1. Fish population estimates of four tributary streams in the Parks Creek system, 1981.

Stream	Miles of fish prod.	Number of fish a/ CT	BT	Total	Number Legal-sized
Crescent Creek	3.6	2,719	0	2,719	92
Maude Creek	1.9	1,876	0	1,876	0
South Fork Parks Creek	2.0	1,386	229	1,615	109
North Fork Parks Creek	1.9	1,399	109	1,508	127
Total	9.4	7,380	338	7,718	328

a/ CT = cutthroat trout; BT = brook trout.

Three hundred and seventy-six cutthroat and 29 brook trout were measured. Size distribution, in 1-inch size groups, is shown in Tables 2 and 3. As was observed in Blowout Creek, yearling cutthroat (2 to 4-inch), comprised the largest (61%) size group. Logically, fish of the year (fry) should comprise the largest size group; however, their small size apparently makes them less vulnerable to electrical current and few were captured. This same situation was also experienced in collections in Blowout Creek.

Only 12 cutthroat (3.2%) of the 376 measured were legal size, while 4 (13.8%) of the 29 brook trout were legal size. Brook trout averaged larger in size than cutthroat. This seems logical as brook trout are fall spawners and their eggs would presumably hatch earlier than the spring spawning cutthroat.

A summary of fish collected in each sample section is shown in Appendix 4.

Fish Distribution

The distribution of cutthroat and brook trout is shown in Fig. 2. Brook trout were generally found in habitat sections characterized by flat gradient, deep pools, and adequate in-stream cover. This type of habitat was basically found in the upper part of Parks Creek and the lower sections of the South and North forks. They were also documented in a small tributary (Brook Trout Creek) that was not sampled by electrofishing. Cutthroat were found in stream sections having shallow pools, riffles over boulders, and steeper gradients.

Age and Growth

Scales were analyzed from 131 cutthroat trout, ranging from 2.4 to 8.0 inches long. In the early stages of our field work it was assumed, based on previous work in Cascade streams, that the 2 to 3-inch fish collected were young-of-the-year cutthroat. However, later collections produced a few 1 to 1½-inch fish which were obviously a younger age class. Subsequent aging of scales showed the 2 to 3-inch fish were yearlings.

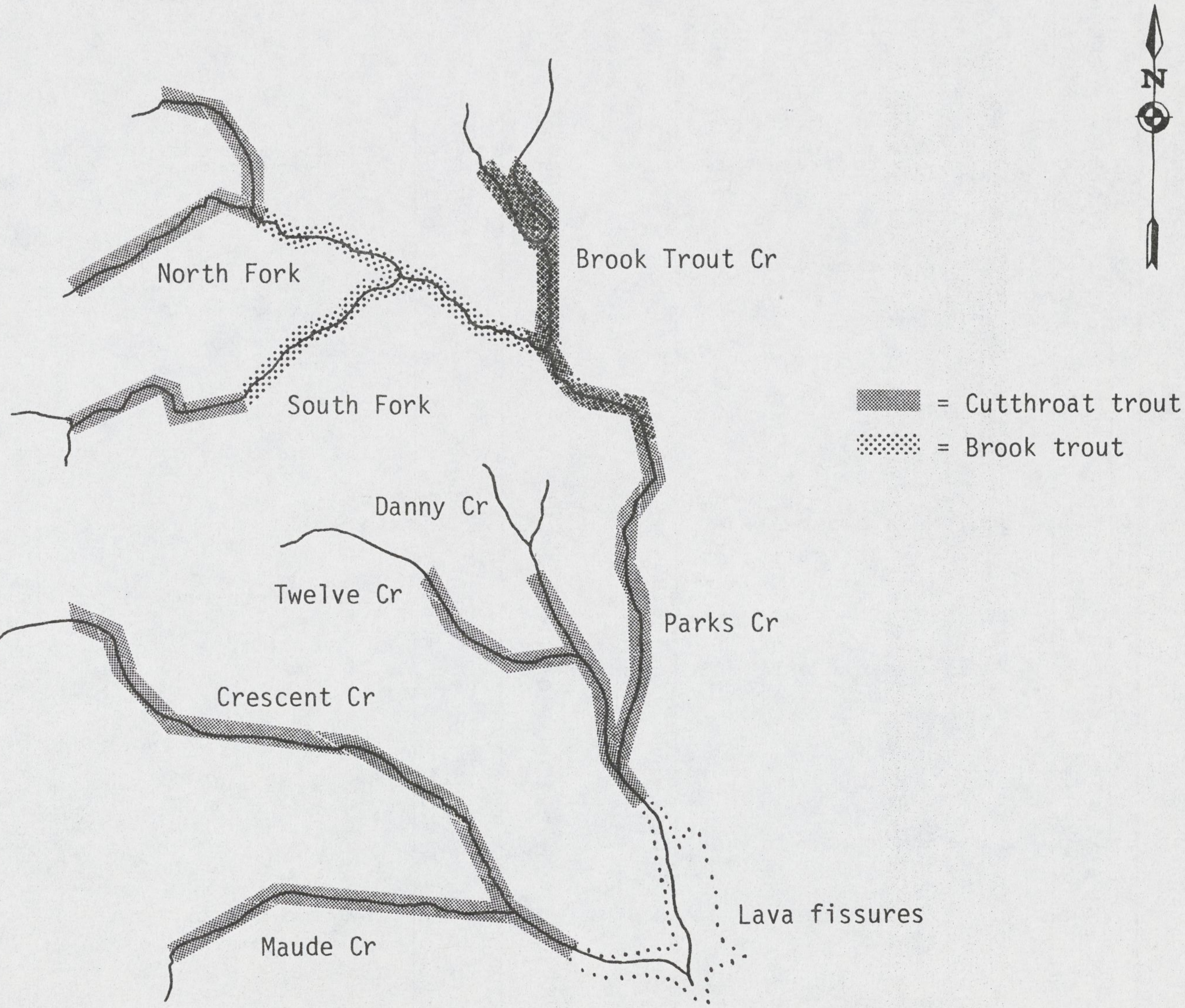


Fig. 2. Trout distribution in the Parks Creek system.

Table 2. Size groups of cutthroat trout in the Parks Creek system, 1981.

Size range (inches)	Streams: Parks Creek a/	Crescent Creek	Maude Creek	South Fork a/	North Fork	Total fish	Percent of total
0-0.9	0	1	0	0	0	1	<1
1-1.9	8	10	0	5	0	23	6
2-2.9	4	6	27	5	12	84	22
3-3.9	4	6	19	3	34	146	39
4-4.9	10	17	15	10	5	57	15
5-5.9	9	18	6	10	10	53	14
6-6.9	0	4	0	2	2	8	2
7-7.9	0	0	0	0	2	2	<1
8-8.9	0	0	0	0	2	2	<1
Total	5	112	67	75	67	376	100

a/ Fish from random sampling included.

Table 3. Size groups of brook trout in the Parks Creek system, 1981.

Size range (inches)	Streams: Parks Creek	South Fork a/	North Fork	Total fish	Percent of total
0-0.9	0	0	0	0	0
1-1.9	0	0	0	0	0
2-2.9	6	2	0	8	28
3-3.9	3	2	0	5	17
4-4.9	0	4	5	9	31
5-5.9	0	3	0	3	>10
6-6.9	0	2	1	3	>10
7-7.9	0	0	0	0	0
8-8.9	0	1	0	1	>3
Total	9	14	6	29	100

a/ Fish from random sampling included.

A comparison of average annual growth increments for Parks and Blowout creeks revealed that Parks Creek fish get off to a slower start and average about 1 inch smaller for each age class. None of the cutthroat collected in the Parks Creek system were older than age III+. Age and growth data (Table 4) show that cutthroat begin to reach legal size after attaining age II and that most become legal size after attaining age III. However, most of the fish collected were from smaller reaches of the system; and our inability to efficiently sample the deeper pools, where growth rates are greater, undoubtedly minimized the average calculated length for each age class. Age specific length data for cutthroat from each stream sampled are shown in Appendix 5.

Average lengths of fish collected on the same date from two different sections on Maude Creek were compared. The areas sampled were about 1 mi apart with an elevation difference of about 250 ft. Water in the upper section was cooler and the flow was estimated to be one-half that in the lower section. Fish collected in the upper section averaged 0.5 inches smaller than those in the lower section for ages I and II (Table 5). Age III fish were not collected in the lower section, thus this age group could not be compared.

Table 4. Age and growth data for cutthroat trout collected in the Parks Creek drainage, 1981.

Age class	No. in sample	Size range (inches)	Mean length (inches)	Avg. annual growth (inches)
I	56	2.4-4.3	3.3	3.3 (1st year)
II	55	3.4-6.7	4.7	1.4 (I to II)
III	20	4.7-8.0	5.9	1.2 (II to III)

Table 5. Age specific length for cutthroat trout collected from two sections on Maude Creek, August 19, 1981.

Sample section	Age class	No. in sample	Size range (inches)	Mean length (inches)
Lower	I	8	2.4-3.9	3.1
	II	7	4.2-5.2	4.5
	III	-	-	-
Upper	I	3	2.4-3.0	2.6
	II	10	3.4-4.5	4.0
	III	4	4.7-5.0	4.9

Condition Factor

Condition factors for the cutthroat and brook trout that were weighed are listed in Appendix 6 by stream and sample section. There was no apparent significant correlation between condition factor and trout densities.

Habitat

The Parks Creek system was selected as a study area partly because of the diversity of habitat. Habitat types include: flat gradients through meadow, timber, and clearcut areas. The upper 2 miles of Parks Creek and the lower sections of the South and North forks were characterized by deep pools with cut banks interspersed with small riffles. Adequate gravel for spawning, primarily lava cinders, occurred in riffle areas. Submerged aquatic vegetation also provided some in-stream cover. Other stream sections were more typical of small Cascade streams with only boulders for cover and some deeper pools.

A description of the habitat in each sample section was recorded on a form which is on file in the ODFW Salem office. Since it is difficult to summarize or tabulate habitat descriptions, photographs of stream sections and habitat types were also taken to better illustrate this segment of the study (Appendix 7).

Physical and biological data were recorded at each sample site (Appendix 1). Flows were estimated and water temperatures were taken only when we sampled. The highest water temperatures recorded (64-67 F) were in Crescent Creek, a stream flowing through a clear-cut area. Elevations given for each sample site show little gradient change except in the upper parts of Crescent Creek and the South Fork of Parks Creek.

Fish population densities were analyzed in two habitat types--clear-cut and timber. As shown in Table 6, the fish/mi average in timbered areas was slightly higher (921) than the average in clear-cut areas (868). We would not judge this to be too conclusive without further analysis of other habitat parameters such as in-stream cover, flows, gradient, etc., that could influence population densities regardless of riparian cover.

Table 6. Fish population densities in two habitat types in the Parks Creek system, 1981.

Stream and sample sections	Number ft sampled	Number of fish collected		Fish/mi
	Clear-cut areas			
Crescent Creek Sec. 1, 2, 3	704	112		840
North Fork Parks Creek Sec. 1	203	34		884
South Fork Parks Creek Sec. 1, 2	498	82		869
Total	1,405	231	(Ave)	868
	Timber areas			
Parks Creek Sec. 1	207	40		1,020
North Fork Parks Creek Sec. 2	278	39		741
Maude Creek Sec. 1, 2	352	67		1,005
Total	837	146	(Ave)	921

SUMMARY

We estimated 7,718 trout were in the 9.4 mi of stream in the four tributaries for which estimates were made. Of the total, 95.6% were cutthroat and 4.4% were brook trout. The fish/mi average for the four streams was 821, and the average number of legal-sized fish/mi was only 35. Averages for the Blowout Creek system in 1980 were 1,084 fish/mi and 102 legal-sized fish/mi.

Cutthroat trout were found throughout the system, while brook trout distribution was closely related to a distinct habitat type consisting of low gradient, deep pools, and some cover.

We were not able to electrofish the main section of Parks Creek because of deep, open pools. Most angling occurs in this section, and there are probably more legal-sized fish available than estimated. In the tributaries sampled, only 4% of the population was legal-size.

Age and growth studies from scale reading concluded cutthroat in Parks Creek were generally 1 inch smaller than cutthroat sampled in Blowout Creek for the same age groups.

Contrary to earlier considerations of increased harvest, the present 5 fish bag limit seems an appropriate regulation in managing the wild trout population in the Parks Creek system.

ACKNOWLEDGMENTS

We wish to thank Merv Wolfer, who assisted in some of the field work, Jim Griggs for his guidance and review of the study, and Larry Korn and Rich Berry for editing the report.

LITERATURE CITED

Wetherbee, J. and W. Hunt. 1982. A wild trout inventory of the Blowout Creek system. Ore. Dept. of Fish and Wildlife, Info. Rept., 82-2. 35 pp.

APPENDICES

Appendix 1. Physical and biological data for Parks Creek system, 1981.

Stream	Date sampled	Stream mile	Estimated flow (cfs)	Average width (ft)	Temperature (F)	Conductivity (micromho)	Elevation (ft)
Parks Creek							
Sec. 1	9-17-81	3.7	4.5	22.3	58	--	3,600
Sec. 2	8- 7-81	5.1	11.0	22.5	55	--	3,640
Crescent Creek							
Sec. 1	8-13-81	1.3	3.0	12.0	64	26	3,360
Sec. 2	8- 6-81	2.5	2.5	11.8	64	26	3,600
Sec. 3	8- 6-81	4.0	1.0	6.2	67	26	4,000
Maude Creek							
Sec. 1	8-19-81	0.1	1.5	10.8	56	23	3,360
Sec. 2	8-19-81	1.1	0.7	9.8	54	--	3,600
South Fork Parks Creek							
Sec. 1	9-16-81	0.6	--	12.8	61	--	3,600
Sec. 2	8-20-81	1.9	2.5	8.5	47	--	4,000
North Fork Parks Creek							
Sec. 1	8- 4-81	0.5	1.5	12.5	49	22	3,600
Sec. 2	9-15-81	1.2	0.2	8.2	58	--	3,780

Appendix 2. Fish inventory data form.

OREGON DEPARTMENT OF FISH AND WILDLIFE

FISH INVENTORY DATA

Stream________________ Tributary to________________ River System________________

Date____________ Surveyor________________ Location: T______ R______ SEC______

Survey Section____

____

________________________ Total Length____________ Average Width____________

Access to Survey Site____

____

Air Temp.________ Water Temp.________ Time________ Conductivity____________

Flow________________ Velocity________________ Gradient________________

Sampling Method____

Description of Survey Section (Dimensions of Successive Pools and Riffles)____________

____

____

Cover: Overhanging Vegetation________________________________

Undercut Banks________________________________

Turbulence________________________________

Instream________________________________

Depth (Extremes and Avg.)________________________________

Canopy________% Bank Cover(Types)________________________________

Bottom Description________________________________

________________________________ Pool________% Riffle________%

Fish Collected:

Pass No.______ (Pool or Riffle)

Species	Length	Weight	Maturity	Scales

Pass No.______ (Pool or Riffle)

Species	Length	Weight	Maturity	Scales

Appendix 2. (Continued)

Pass No._____ (Pool or Riffle)

Species	Length	Weight	Maturity	Scales

Pass No._____ (Pool or Riffle)

Species	Length	Weight	Maturity	Scales

Pass No._____ (Pool or Riffle)

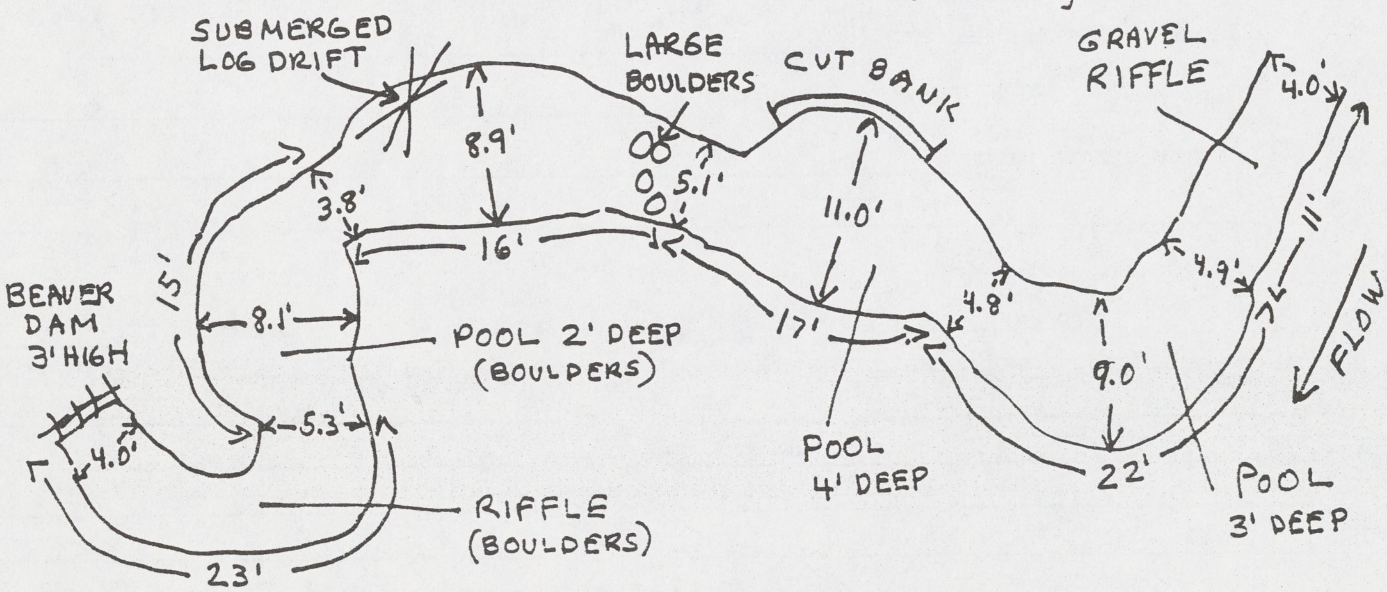
Species	Length	Weight	Maturity	Scales

Pass No._____ (Pool or Riffle)

Species	Length	Weight	Maturity	Scales

Non-Game Species Present____________________________________

Drawing of Survey Section (SAMPLE)



Angler Use: None_______ Light_______ Moderate_______ Heavy_______

General Comments____________________________________

Appendix 3. Estimated number of fish and number of legal-sized fish present in each stream section of four Parks Creek tributaries, 1981.

Stream and Section	Stream mile	Fish/mi	Legals/mi	Adjacent mileage expanded for this section	Total estimated fish for this section expanded	Total estimated legals for this section expanded
Crescent Creek						
Sec. 1	1.3	1,090	52	0.9	981	47
Sec. 2	2.5	645	33	1.35	871	45
Sec. 3	4.0	642	0	1.35	867	0
Total				3.60	2,719	92
Maude Creek						
Sec. 1	0.1	1,140	0	0.6	684	0
Sec. 2	1.1	917	0	1.3	1,192	0
Total				1.9	1,876	0
South Fork Parks Creek						
Sec. 1	0.6	606	59	1.3	788	77
Sec. 2	1.9	1,181	46	0.7	827	32
Total				2.0	1,615	109
North Fork Parks Creek						
Sec. 1	0.5	884	182	0.7	619	127
Sec. 2	1.2	741	0	1.2	889	0
Total				1.9	1,508	127
GRAND TOTAL				9.4	7,718	328

Appendix 4. A summary of fish collected in the Parks Creek system by electrofishing, 1981.

	Section	Pass	Stream mile	Sample Area: Length (ft)	Sample Area: Average width (ft)	Sample Area: Square ft	Fish collected a/: CT	Fish collected a/: BT	Fish collected a/: Total
Parks Creek									
	1	1	3.7	207	22.3	4,616	24	3	27
		2					10	3	13
Total				207		4,616	34	6	40
Crescent Creek									
	1	1	1.3	310	12.1	3,751	36	0	36
		2					28	0	28
Total							64	0	64
	2	1	2.5	213	11.8	2,513	11	0	11
		2					15	0	15
Total							26	0	26
	3	1	4.0	181	6.2	1,122	19	0	19
		2					3	0	3
Total							22	0	22
Total				704		7,386	112	0	112
Maude Creek									
	1	1	0.1	139	10.8	1,501	22	0	22
		2					8	0	8
Total							30	0	30
	2	1	1.1	213	9.8	2,087	24	0	24
		2					13	0	13
Total							37	0	37
Total				352		3,588	67	0	67

Appendix 4. A summary of fish collected in the Parks Creek system by electrofishing, 1981 (continued).

	Section	Pass	Stream mile	Sample Area: Length (ft)	Sample Area: Average width (ft)	Sample Area: Square ft	Fish collected a/: CT	Fish collected a/: BT	Fish collected a/: Total
South Fork Parks Creek									
	1	1	0.6	270	12.8	3,456	10	6	16
		2					12	3	15
Total							22	9	31
	2	1	1.9	228	8.5	1,938	36	0	36
		2					15	0	15
Total							51	0	51
Total				498		5,394	73	9	82
North Fork Parks Creek									
	1	1	0.5	203	12.5	2,538	21	5	26
		2					7	1	8
Total							28	6	34
	2	1	1.2	278	8.2	2,280	22	0	22
		2					5	0	5
		(rotenoned)					12	0	12
Total							39	0	39
Total				481		5,394	67	6	73

a/ CT = cutthroat trout; BT = brook trout.

Appendix 5. Age specific length data for cutthroat trout collected in the Parks Creek system, 1981.

Stream	Age class	No. in sample	Size range (inches)	Mean length (inches)
Parks Creek	I	6	3.4-4.1	3.6
	II	8	4.4-6.7	5.2
Crescent Creek	I	7	3.5-5.0	3.9
	II	7	4.4-6.2	5.1
	III	2	5.6-5.7	5.6
Maude Creek	I	11	2.4-3.9	3.0
	II	17	3.4-5.2	4.2
	III	4	4.7-5.0	4.9
South Fork Parks Creek	I	7	3.1-3.9	3.6
	II	12	3.7-6.5	4.8
	III	4	5.0-6.2	5.6
North Fork Parks Creek	I	24	2.5-3.9	3.1
	II	9	3.9-5.4	4.8
	III	8	5.2-8.0	6.7
Tributary to North Fork	I	1	3.7	3.7
Parks Creek a/	II	2	3.8-4.5	4.1
	III	2	5.3-5.4	5.3

a/ Included in remarks concerning North Fork Parks Creek throughout the text.

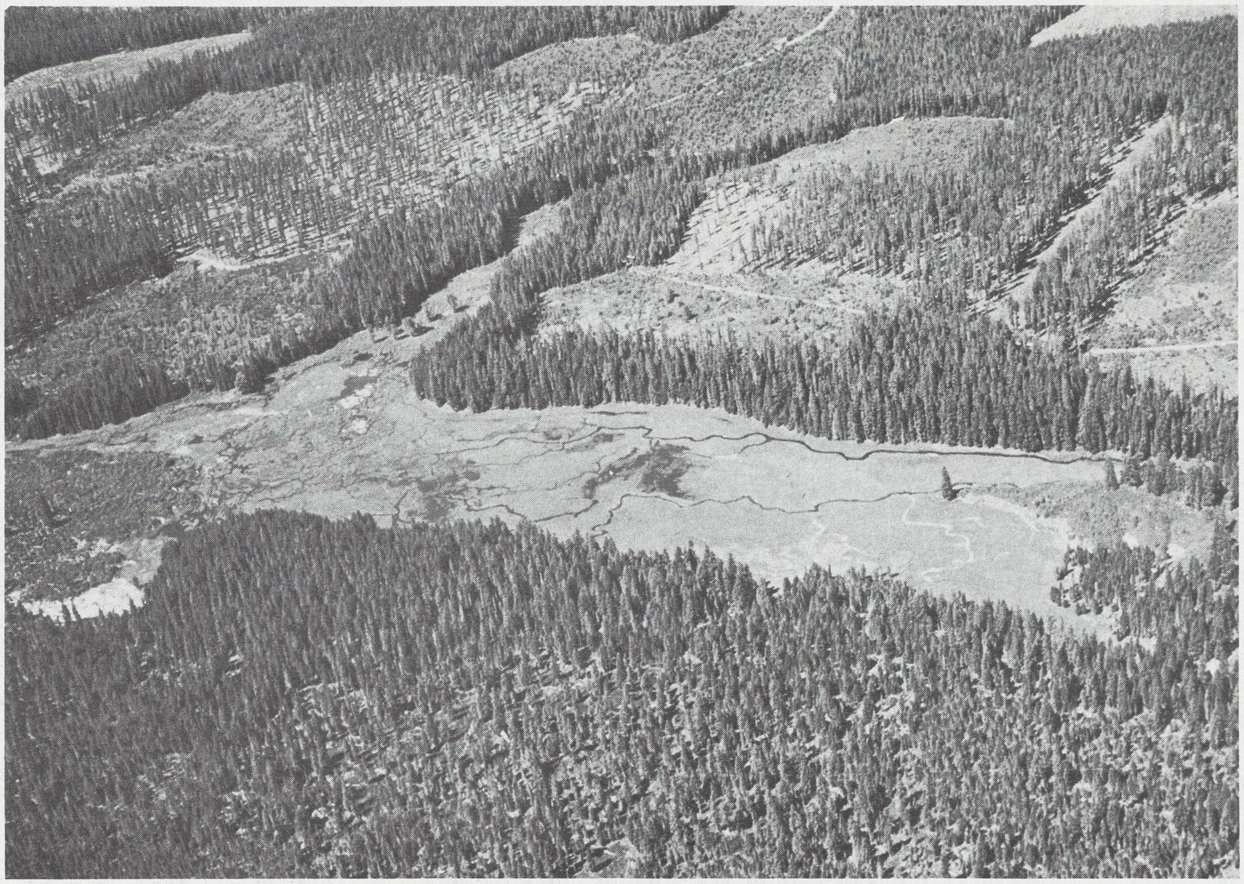
Appendix 6. Condition factors for trout by stream section, Parks Creek system, 1981.

Stream	Stream mile	Trout/yd^2	Species a/	Sample size	Condition factor
Parks Creek					
Sec. 1	3.7	0.077	CT	18	1.20
Sec. 2		--	CT	9	1.06
Random sample	2.1	--	CT	7	1.07
South Fork Parks Creek					
Sec. 1	0.6	0.081	CT	12	1.26
			BT	8	1.55
Sec. 2	1.9	0.237	CT	35	1.29
North Fork Parks Creek					
Sec. 1	0.5	0.121	CT	28	1.39
			BT	6	1.32
Sec. 2	1.2	0.154	CT	32	1.20
Crescent Creek					
Sec. 1	1.3	0.153	CT	55	1.22
Sec. 2	2.5	0.093	CT	26	1.09
Sec. 3	4.0	0.176	CT	19	1.27
Maude Creek					
Sec. 1	0.1	0.179	CT	16	1.17

a/ CT = cutthroat trout; BT = brook trout.

Appendix 7

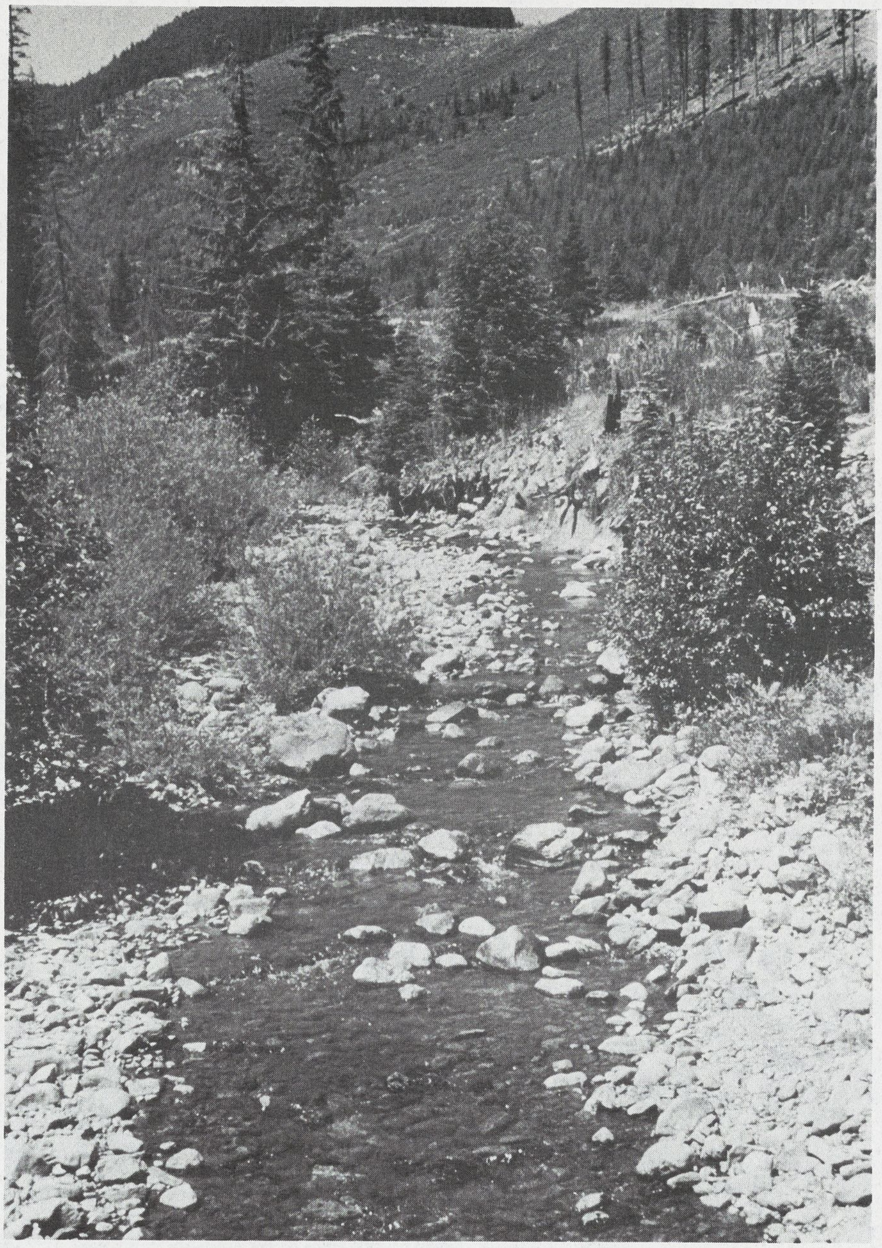
Habitat Photographs



Aerial view of lower Parks Creek

Flat gradient and deep pools

Canopied stream section



Clear cut riffle area

OREGON

Fish & Wildlife

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Portland, Oregon 97208

Interaction for food and space between experimental populations of juvenile coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*Salmo clarki*) in a laboratory stream*

G. J. Glova
Present address: Ministry of Agriculture and Fisheries, Fisheries Research Division, P.O. Box 8324, Riccarton, Christchurch, New Zealand

Keywords: Coho salmon, cutthroat trout, laboratory stream, microdistribution, aggressive behaviour, interaction, segregation

Abstract

Populations of juvenile coho salmon and coastal cutthroat trout frequently cohabit small coastal streams in western North America. The pattern and mechanism of interactions for food and space between experimental populations of underyearlings of these two salmonids were examined at 3, 5 and 13 °C in a laboratory riffe/pool environment simulating winter and summer conditions. When tested separately at 13 °C, their habitat demands were similar and approximately 60–75% of either species occurred in pools. When tested together they segregated, with approximately 75% of coho in pools and up to 63% of cutthroat trout in riffles. In winter, at 3 °C, both species preferred pools and overhead cover, whether tested separately or together. At 5 °C, they partially segregated in a pattern similar to, but far less pronounced than, that in summer. Both species used similar forms of aggressive behaviour, although aggressive displays were more frequently used by coho, while nipping was more frequently used by cutthroat trout. Both salmonids were most aggressive when food was presented, irrespective of season, although coho responded with greater rapidity and intensity to feeding than did cutthroat trout. When tested together in summer, aggressiveness was high for both species, and agonistic interference by coho in pools and cutthroat trout in riffles appeared to largely account for their segregation. At 3 °C, aggression was low and both species weakly defended pools. At 5 °C, their aggression rose considerably and they partially segregated in a pattern resembling that at 13 °C. The mechanism of segregation between these two salmonids is clearly that of Nilsson's interactive type, which presumably functions to attenuate competition when streams are most likely to be resource limiting; typically, that is the late summer period of low flows and relatively high fish population densities.

Introduction

In British Columbia small coastal streams are important nursery areas for juveniles of coho salmon and coastal cutthroat trout. During the late summer period of low stream flows, sympatric populations of these two salmonids broadly overlap in diet but partially segregate spatially, with coho being predominantly in pools and cutthroat trout in riffles (Glova, 1984). Hartman (1965b) reported similar spatial segregation between sympatric populations of juvenile coho salmon and steelhead trout (*Salmo gairdneri*), which he experimentally demonstrated to be of the interactive type (Nilsson, 1956). Such segregation may attenuate interspecific competition for resources in general, and possibly for food in particular, during periods of low streams flows and relatively high fish population densities. Distinct spatial segregation but broadly overlapping diets, as has been observed

*Based on a dissertation in partial fulfillment of the requirements for the degree of Doctor of Philosophy, Institute of Animal Resource Ecology, University of British Columbia, Vancouver, B.C.

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for salmonids, has also been reported for ecologically similar non-salmonid fishes in streams (Gee & Northcote, 1963; Gibbons & Gee, 1972). Some advantages of segregation likely involve greater species growth and survival and, in the case of anadromous salmonids, greater smolt yields to sea.

In this study underyearling coho and coastal cutthroat trout of natural sympatric origin were tested in a stream simulator containing a riffle/pool sequence to determine pattern and mechanism of interaction for food and space at three different temperatures, simulating summer and winter conditions in nature. The null hypotheses tested were that there were no significant interspecific differences in pattern of microdistribution and aggression at different levels of feeding activity, water velocity, and water temperature in the laboratory riffle/pool environment. These were considered to be some of the more important variables affecting the interaction between these two salmonids in nature, which could be readily manipulated in a laboratory stream.

Materials and methods

The test facility

The stream simulator used was the one described by Hartman (1965a), now located at the University of Victoria, B.C. The experimental section was 5 m long × 1.2 m wide × 0.7 m deep. It consisted of a duplicate riffle/pool sequence with an undercut area in each of the pools (Fig. 1). The bottom profile was built of plywood and covered over with a mixture of approximately 5% of fines (silt and sand), 30% gravels, 40% small cobbles, and 25% large cobbles, a composition resembling that of natural streams. Substrate size categories were as per the Wolman (1954) method. The substrates of the sloped surfaces were held in place with an earthen-coloured fiberglass resin. Alder (*Alnus sp.*) logs (0.15 m diam. × 1.5 m long) taken from a natural stream were positioned both within and above each pool as further cover for fish.

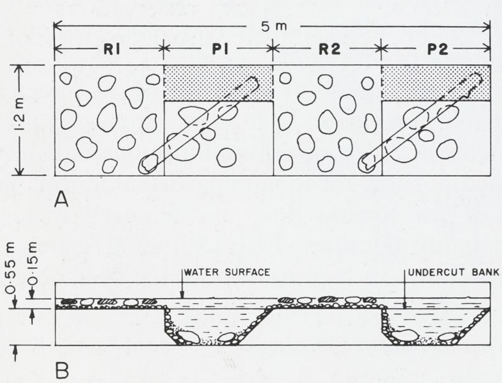

Fig. 1. (A) Plan of experimental section of stream simulator outlining rocks, logs and undercut areas (stippled); riffles – R1, R2; pools – P1, P2. (B) Side view of the experimental section.

The water supply to the simulator was from the City of Victoria, and was dechlorinated by facilities at the University of Victoria. Water in the simulator was continuously renewed at a rate of one complete turn over every two days.

Water temperature was maintained within ±0.5 °C in all experiments by a refrigeration unit situated at the upstream end of the test facility. On-off control of water circulation from the simulator through the refrigeration system was maintained by a thermoregulator and solenoid-hookup to the recirculating pump, and a series of gate valves operated manually. Water which had passed through the refrigeration system re-entered the simulator in the downstream well, after being thoroughly mixed in the return flume by the drive propellor before entering the experimental section.

Natural photoperiod was provided through a set of high windows which was located directly opposite the experimental section. Artificial lights (12, 25W bulbs) with rheostat control were mounted under the ceiling-suspended fluorescent fixtures used by Hartman (1965b), which were gradually turned on at the beginning of each day to augment the available natural light levels. Artificial light intensity measured with a 'Photovolt' model 210 photometer, averaged 250 Lux along the centreline of the experimental section.

A darkened observation corridor of black polyethylene from floor to ceiling along the true right side of the simulator permitted observation into the experimental section without disturbing the fish. A food-dispensing apparatus (Glova, 1978), one for each rifle, provided controlled simulation of drifting food.

The fish

Coho and cutthroat trout fry of sympatric origin were from two small coastal streams situated at the south end of Vancouver Island (approximately 49 °N, 124 °W): the summer fish were from Craigflower Creek (FL range, 35 – 70 mm); the winter fish were from Ayum Creek (FL range, 43 – 95 mm). They were collected with a Smith Roote D.C. shocker, and then transferred to the laboratory in fry cans. The summer fish were collected on the initial day of each experiment. The winter fish were collected in late November to avoid possible difficulty in obtaining the required numbers of fish, particularly cutthroat trout, later in the season. They were held, until needed, at relatively low densities on a diet of fresh-frozen euphausiids in fiberglass tanks (0.7 × 0.5 × 0.5 m) at the Pacific Biological Station, Nanaimo, B.C., under natural photoperiod and water temperature of 5 °C. It is doubtful that the holding of fish had any effect on their behavioural interactions in experiments.

Experimental procedure

Duplicate tests, each lasting one full week, were carried out with coho and cutthroat trout in sympatry (species mixed) and in allopatry (species separate) in both summer and winter. Each test consisted of a total of 40 fish which included six large, 14 medium, and 20 small-sized individuals. The approximate fork length ranges of the size classes of each species in the summer experiments were 35 – 40 mm (small), 50 – 55 mm (medium), and 65 – 70 mm (large); fish in the winter experiments were 45 – 55 mm (small), 70 – 75 mm (medium), and 90 – 95 mm (large) in length. The size compositions were approximately proportional to those which I observed among wild populations of these salmonids in small streams. In sympatry, the number of fish of each species in each of the three size classes was half of that used in allopatry to make up a total of 40 fish. For each of the experiments, fish were anaesthetized with 2-phenoxyethanol and then selected according to fork length. The chosen fish in each of the winter experiments were transferred from the holding facilities in Nanaimo (at their acclimated test temperature) to the test facility at the University of Victoria on the initial day of the experiment.

In each experiment the fish were given a minimum of 2 h to recover from the effects of the anaesthetic and handling while held in aerated water in a 90 – l dark plastic container with a cover. They were then released into the centre of the stream simulator containing still water between 1600 and 1800 h under the available natural light. The flow of low velocity (25 cm s^{-1}) was started up 1 h after their introductuon. In all experiments fish were given two days habituation time to the test facility. Thereafter, observations were made at the low velocity for a period of 2.5 d, followed by observations at the high velocity, which was incrementally stepped-up over a 3-h period, for the remaining 2.5 d. Observations were also made during the initial 2-d period of the sympatric tests in summer.

Both the water temperature and high water velocity levels differed between the two test seasons: summer fish were tested during the period 2 June – 16 September at 13 ± 0.5 °C and a high velocity averaging 43.1 cm s^{-1} in riffles; winter fish were tested during the period 2 December – 27 January at both 3 and 5 ± 0.5 °C and a high velocity averaging 50.7 cm s^{-1}. The increase in velocity allowed for the larger fish used in the winter experiments, based on swimming performance data for juvenile coho salmon reported by Glova & McInerney (1977).

The fish were fed daily in early morning and late afternoon a ration of chopped fresh-frozen euphasiids amounting to 5% of their wet body weight. The food was released as simulated drift in streams by a food-dispensing apparatus (Glova, 1978). Day length was approximately natural with the artificial lighting superimposed from about 0800-2000 h in summer and 0800-1700 h in winter.

The timing of the daily observations of the microdistribution and aggressive interactions of the fish was governed by the imposed feeding cycle: the pre-feeding period was before food was released in the system; the feeding period began 15 min. after initiation of release of drifting foods; the post-feeding period began 30 min. after the release of any drifting food was stopped. The observation schedule was repeated in the morning and late afternoon, usually extending from 0800 to dusk, daily. The approximate horizontal and vertical (upper-, middle- and lower-thirds) positions, size-class, and species of each fish were recorded on outline maps of the stream bottom at each observation period. Each riffle and pool section was observed for a period of 10 min., with the sequence of each of these four sections being chosen randomly in each observation period. The aggressive behaviour of the fish present in each of the riffle and pool sections was recorded on a set of four multiple-key plankton counters by coding the various behavioural components of intra- and interspecific encounters.

The behavioural events recorded included lateral and frontal threat displays (Fabricius, 1953; Kalleberg, 1958; Chapman, 1962); intention movement, drive toward (charge), chase, threat and contact nips, and wig-wag threat display (Hartman, 1965b; Mason, 1969); parallel-swimming, circling and biting (Mason, 1969). In experiments with coho and cutthroat trout together, four types of interaction were recorded: coho-coho, coho-trout, trout-trout, and trout-coho. These were elicited either singly or in a sequence of the behavioural events described above. At the end of each observation period, the information was decoded onto standardized data sheets.

Fish mortality in the experiments ranged from 0–6%, and most often involved small individuals being pinned against the downstream screen at night, particularly during the high velocity tests. The dead fish were accounted for at the beginning of each day, and were removed the following night under dim light conditions to avoid disturbing fish unduly.

At the end of each experiment the tank was drained, with most of the fish retreating into the pools. They were dipnetted out and anaesthetized for determination of species fork length and wet weight.

Data processing

The statistical differences in fish microdistributions between and within species for allopatric and sympatric trials were tested by multiple factorial analysis of variance (ANOVA). Interactions between the test variables were investigated, with the maximum number of variables consisting of habitat type, fish size, feed-period, water velocity, and water temperature. To standardize the data, the numbers of fish present in each habitat were expressed as a percent of the actual number of fish used in each size class, and the data were then transformed by the arcsine transformation) Sokal & Rohlf, 1969).

Individual components of aggression for each species in each observation were summed and adjusted for varying fish densities, providing a comparative measure of rate of aggression within and between species. For each of the test conditions the paired data groups were statistically tested by Wilcoxin's signed-ranks test (Siegel, 1956). Size of fish was not considered in the analyses of aggression as data were available for the allopatric trials only because of the lack of recording equipment necessary to include size in the sympatric tests. The occurrence of the different components of aggression by species is expressed as a percent of the total aggression in each experiment.

Results

General

Partitioning of space in the stream simulator between coho and cutthroat trout fry occurred relatively rapidly in summer. By the end of the first day of an experiment segregation was evident, with coho being more common in pools and cuttroat trout in riffles (Fig. 2). However, within the first two days of any one experiment, individual territories and dominance hierarchies were relatively unstable, and fish of both species moved about considerably within the habitats chosen.

Aggressive activity of both species changed appreciably during the first four days in the summer experiments (Fig. 2). Initially, cutthroat trout actively defended riffles against conspecifics and pools against coho, but as time progressed their aggression declined. On the other hand, aggressiveness in coho markedly increased over time, with coho establishing social dominance and occupying the choice feeding sites in both riffles and pools. From the allopatric trials it was evident that the larger fish of both species contributed most to aggressive activity (Glova, 1978).

In winter, the activity of both species was minimal, particularly at 3 °C, and was largerly restricted to pools. During the non-feeding periods fish of both species tended to cluster in the undercut areas, where water velocity was minimal. For both species, breadth of microhabitat use, degree of movement, and aggressive activity were relatively low in winter. The differences in fish microdistribution

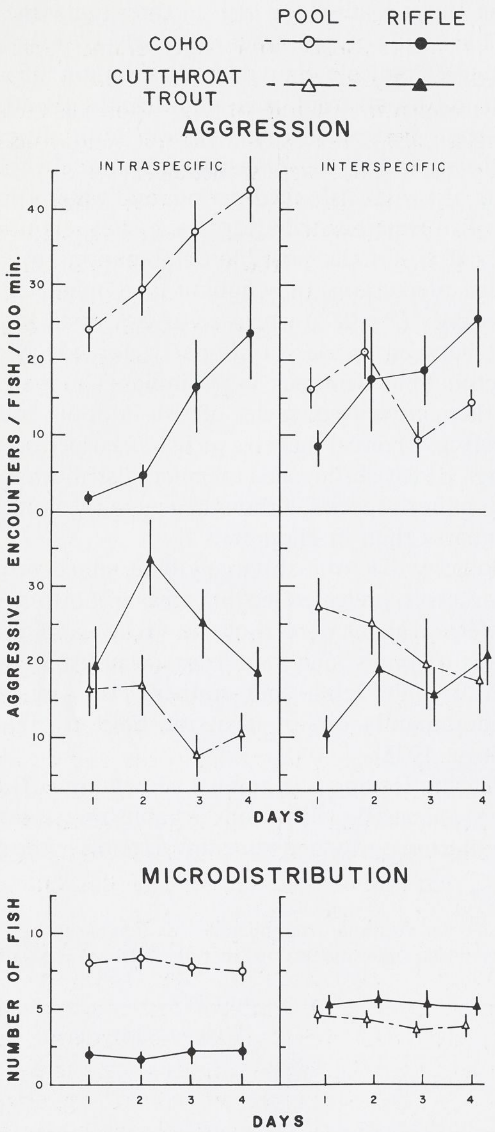

Fig. 2. Summer aggression and microdistribution of sympatric coho and cutthroat trout in pools and riffles during their initial 4 days in the stream simulator at the low velocity. Symbols are means ± SE.

and aggressive activity between the summer and winter experiments are believed to be due, primarily, to the effects of temperature, because at 5 °C the differences between seasons were much reduced.

Coho and cutthroat fry interacted with body postures and movements as described by others for stream-dwelling Salmonidae (Fabricius, 1953; Kalleberg, 1958; Chapman, 1962; Hartman, 1965b; Jenkins, 1969; Mason, 1969). However, in this study there appeared to be some incompatibility between species in lateral threat display. Firstly, such intraspecific encounters generally lasted longer for cutthroat trout than for coho, and frequently involved, either singly or in concert, parallel swimming, circling, and biting of the opponent's peduncular region. Secondly, cutthroat trout possess a brightly-coloured hyoid slash, which is exposed when the basihyal apparatus is lowered in bouts of high intensity lateral threat, and is often accompanied by rapid quivering of the caudal region. Its adaptive significance is uncertain, but both its size and colour intensity may be important in intraspecific aggression. Territorial disputes, particularly in summer, between cutthroat trout closely matched in size, frequently led to prolonged and severe bouts of aggression, occasionally to apparent exhaustion. In an extreme case of interaction, a total of 530 aggressive acts, mostly of high-intensity lateral threat along with intense nipping and biting, were exchanged between two trout at the bottom of a pool over a 12-min. period. In contrast, interspecific lateral threat encounters were generally brief, even in instances when fish were of similar size.

Microdistribution

Summer

The summer microdistribution of coho and cutthroat trout fry was distinctly different when tested in sympatry but not allopatry (Table 1). Pooling the data for the different sizes of fish and feed-periods at low velocity, resulted in approximately 75% of coho in pools and up to 63% of cutthroat trout in riffles. At the high velocity the pattern of habitat use by coho was similar to that at low velocity, whereas that by cutthroat trout differed, primarily due to their increased use of pools and cover. In allopatry, the proportion of fish in pools of each species at low and high velocities was approximately 60% and 70%, respectively.

Submerged areas of cover in riffles and pools were not intensively utilized by both species in summer (Table 1). Both salmonids sought profitable feeding sites, more so than cover. Small fish were the more frequent users of cover sites, often in es-

Table 1. Average percent number of coho and cutthroat trout in the riffle and pool habitats in summer at the two test velocities. Bracketed values refer to the proportion of fish using cover areas in riffles (beneath rocks) and pools (undercut areas).

		Low velocity	High velocity
		Allopatry	
Coho	Riffle	38.2 (0.0)	26.1 (0.0)
	Pool	61.8 (2.4)	73.9 (4.8)
Cutthroat trout	Riffle	39.2 (0.0)	29.7 (0.0)
	Pool	60.8 (10.1)	70.3 (10.5)
		Sympatry	
Coho	Riffle	23.4 (0.0)	25.4 (0.0)
	Pool	76.6 (7.3)	74.6 (8.2)
Cutthroat trout	Riffle	63.2 (1.5)	50.3 (0.0)
	Pool	36.8 (11.9)	49.7 (19.7)

cape from aggressive encounters initiated by larger fish. In riffles, coho were never, and cutthroat trout were rarely found in areas of cover in summer. In pools, the use of undercut areas ranged from 2.4–8.2% by coho and 10.1–19.7% by cutthroat trout, with both species showing slightly higher use during high velocity. In natural streams the use of undercut areas by fish in summer may be higher, because the flow at such sites may provide better opportunities for exploiting a drifting food supply than those available to fish in the simulator.

The results of multi-factorial analysis of variance (Table 2) indicate that microdistribution of coho and cutthroat trout was significantly ($P<0.001$) different between habitat types in both allopatric and sympatric trials. Considered separately, the effects of size of fish, feed-period, and water velocity on fish microdistribution were not significant ($P>0.05$). Of the possible combinations of first-order interactions, only habitat type interacted significantly ($P<0.01$) with size of fish in all but the test between species in allopatry, for which their microhabitat demands were similar. Comparisons of the relative frequencies of fish in pools and riffles (Fig. 3) reveal that size of fish, feed-period, and water velocity influenced the microdistribution pattern of both species, although, generally, more so in sympatry than in allopatry.

Relative size of fish largely determined priority of access to preferred feeding areas of both species. Preferred areas were those in riffles and at the heads of pools, and were least occupied by small fish in all tests, but rather they remained predominantly on, or near, the bottom of pools (Glova, 1978).

During feeding, the number of coho in riffles always increased, with many establishing transient feeding territories and returning to pools in the post-

Table 2. Comparison of F-values from factorial analyses of variance of coho and cutthroat trout microdistribution in summer. Both allopatric and sympatric trials were tested between and within species. The higher-order interactions than those shown were not significantly different.

Variables	df	Between Species: Allopatry	Between Species: Sympatry	Within species: Coho	Within species: Cutthroat Trout
Habitat	7	102.78***	79.88***	131.65***	50.69***
Size of fish	2	3.32	2.33	2.10	2.60
Feed-period	2	0.79	0.06	0.85	1.02
Water velocity	1	0.46	2.25	0.53	0.75
Interactions					
Habitat × size of fish	14	0.73	9.26**	10.30**	9.30**
Habitat × feed-period	14	0.39	0.65	1.29	0.28
Habitat × water velocity	7	0.99	1.16	2.23	0.85
Size of fish × feed-period	4	1.50	1.49	1.13	0.16
Size of fish × water velocity	2	0.06	2.80	1.43	1.68
Feed-period × water velocity	2	0.09	0.27	0.16	0.13

* $F_{0.05\,(1,\infty\,df)} = 3.84$;
** $F_{0.01\,(1,\infty\,df)} = 6.63$;
*** $F_{0.001\,(1,\infty\,df)} = 10.8$

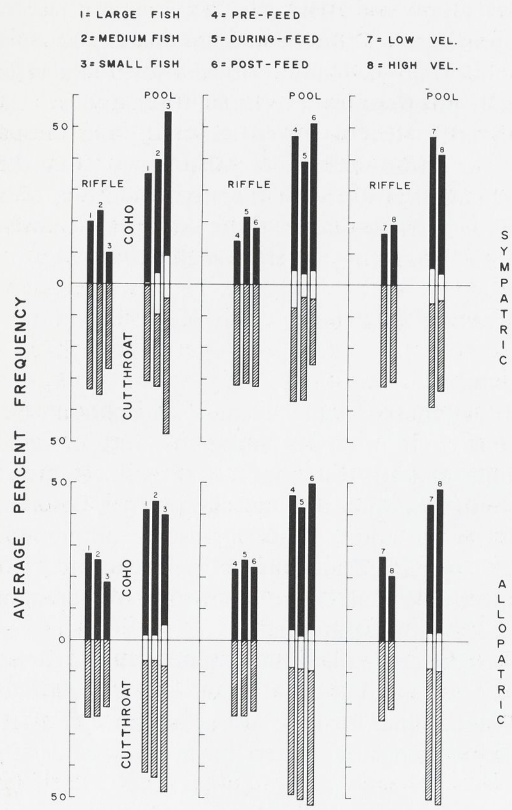

Fig. 3. Relative microdistribution of coho (solid) and cutthroat trout (hatched) in summer in sympatric and allopatric tests at 13 °C in relation to size of fish, feed-period, and test velocity. Open portions of bars refer to fish of both species in undercut areas of pools.

feed period. In contrast, cutthroat trout were slower to respond to the availability of food as indicated by their increased numbers in riffles in the post-feed period rather than during feeding (Fig. 3).

Winter

The winter microdistribution of coho and cutthroat trout fry at 3 °C was similar in allopatric and sympatric tests, with most of the fish occupying pools. When the data were pooled for the different size groups and feed-periods, the proportion of fish in pools ranged from approximately 97–99% for coho and 88–97% for cutthroat trout (Table 3). The high velocity conditions had virtually no effect on the numbers of coho in pools, but slightly increased those of cutthroat trout.

Cutthroat trout used cover more than coho in both habitat types (Table 3). In allopatry, the percentage of coho using the submerged cover areas in riffles and pools ranged from 4.4–11.5% and from 30.9–39.3%, respectively, whereas that of cutthroat trout ranged from 54.8–69.2% and from 49.2–51.2%. Within the depressions beneath rocks in riffles, cutthroat trout were highly territorial, and rarely was there more than one fish at a time under any one rock. Both species showed slightly higher use of cover in pools when in sympatry than in allopatry.

Table 3. Average percent number of coho and cutthroat trout in the riffle and pool habitats in winter at the two test velocities. See Table 1 for further caption details.

		Low velocity	High velocity
		Tested at 3 °C	
		Allopatry	
Coho	Riffle	2.5 (4.4)	2.0 (11.5)
	Pool	97.5 (30.9)	98.0 (39.3)
Cutthroat trout	Riffle	11.3 (69.2)	10.0 (54.8)
	Pool	88.7 (49.2)	90.0 (51.2)
		Sympatry	
Coho	Riffle	1.0 (0.0)	1.0 (0.0)
	Pool	99.0 (41.6)	99.0 (47.5)
Cutthroat trout	Riffle	6.4 (48.9)	3.0 (28.3)
	Pool	93.6 (72.4)	97.0 (69.8)
		Tested at 5 °C	
		Sympatry	
Coho	Riffle	20.8 (0.0)	10.7 (0.0)
	Pool	79.2 (15.7)	89.3 (23.4)
Cutthroat trout	Riffle	26.6 (42.2)	25.0 (28.1)
	Pool	73.4 (54.4)	75.0 (63.7)

Raising the temperature from 3 to 5 °C resulted in a significant ($P < 0.05$) increase in the use of riffles by both species (Table 3). At the low velocity coho in riffles increased by approximately 20%, and cutthroat trout by 15%. At the high velocity, coho use of riffles decreased by approximately 10%, whereas that of cutthroat trout showed no change.

In the winter experiments, habitat type interacted significantly with each of the test variables, except that of feed-period in allopatry, probably because both species used the habitats similarly in relation to the feeding cycle when tested separately. Comparisons of F-values of Table 4 indicate that size of fish, water temperature, and water volocity were of greater importance in the microdistribution of fish than was the feeding cycle. Cover was of prime importance to fish in winter, and its use varied with test conditions. Use of the undercut areas in pools by coho and cutthroat trout decreased with decreasing size of fish, decreasing water velocity, increasing water temperature, and with food drifting in the system (Fig. 4). On the other hand, use of cover in riffles (under rocks) was almost exclusively by small and medium size cutthroat trout. The larger fish of both species occupied the overhead (logs) and undercut cover areas in pools more so than smaller fish (Fig. 4); the latter were mostly on, or near, the bottom of pools, irrespective of test velocity.

The numbers of both species of all size classes increased in the upstream half of the experimental section at the high velocity in all experiments, which probably parallels their upstream movement in nature (Glova, 1978) during increased flows.

Feeding activity of both species was influenced by water temperature. Neither species exploited the food supply in riffles at 3 °C, but at 5 °C their proportions in riffles increased substantially during feeding (Fig. 4). Under critically low temperatures and high velocities, cutthroat trout appear better adapted to feeding in riffles than coho, possibly due to hydromechanical advantages from their closer association with the stream bottom. Coho feeding in riffles under these conditions consisted of brief forays to preferred feeding sites.

Aggressive behaviour

Summer

In allopatry, aggressiveness of coho and cutthroat trout in riffles and pools was reasonably similar at both test velocities (Fig. 5). Aggression of both salmonids declined slightly in riffles at high velocity. In total, coho aggression amounted to 3 225 and 2 022 encounters in pools and riffles, respectively, while that of cutthroat trout amounted to 2 325 and 2 054 events.

In sympatry, coho were generally more aggressive in pools and cutthroat trout in riffles (Fig. 6). When the data for both test velocities were pooled, coho intraspecific aggression in pools and riffles,

Table 4. Comparison of F-values[1] from factorial analyses of variance of coho and cutthroat trout microdistribution in winter. Both allopatric and sympatric trials were tested between and within species. The higher-order interactions than those shown were not significantly different.

Variables	df	Between Species		Within species	
		Allopatry	Sympatry	Coho	Cutthroat trout
Habitat	7	293.69***	311.29***	364.24***	242.43***
Size of fish	2	1.74	8.67**	1.72	6.52*
Feed-period	2	0.14	2.01	0.08	0.78
Water velocity	1	1.15	6.26*	2.17	0.82
Temperature	1		6.13*		
Interactions					
Habitat × size of fish	14	31.03***	28.83***	38.63***	19.04***
Habitat × feed-period	14	3.67	7.90**	6.35*	4.02*
Habitat × water velocity	7	18.44***	21.72***	24.91***	19.36***
Habitat × temperature	7		36.33***		
Size of fish × feed-period	4	0.06	0.63	0.07	0.05
Size of fish × water velocity	2	0.55	0.10	0.53	0.52
Size of fish × temperature	2		0.24		
Feed-period × water velocity	2	0.41	0.47	0.09	0.32
Feed-period × temperature	2		0.33		
Water velocity × temperature	1		0.87		

[1] Critical F-values are as in Table 2.

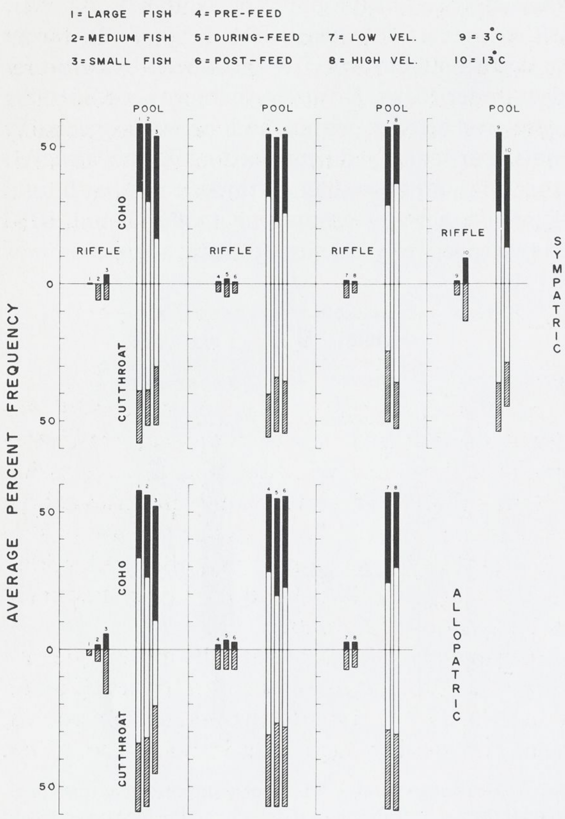

Fig. 4. Relative microdistribution of coho (solid) and cutthroat trout (hatched) in winter in sympatric and allopatric tests in relation to size of fish, feed-period, water velocity, and water temperature. Open portions of bars refer to fish of both species in undercut areas of pools.

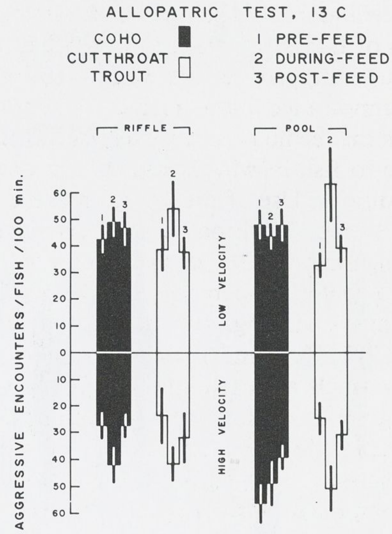

Fig. 5. Mean aggression ± SE of coho and cutthroat trout in allopatric tests at 13 °C in summer in relation to the feeding cycle and water velocity.

respectively, amounted to a total of 2 152 and 515 encounters, while that of cutthroat trout amounted to 242 and 703 events. The pattern of interspecific aggression between pools and riffles was similar, totalling 677 and 477 for coho, and 435 and 618 encounters for cutthroat trout. Coho intra- and interspecific aggressive activity combined were some 30% higher than that of cutthroat trout.

Aggressiveness of coho increased significantly ($P < 0.05$) in pools at the high velocity, paralleling the effects of increased velocity on aggression of Atlantic salmon reported by Kalleberg (1958). However, in riffles, aggression of both species generally decreased at high velocity, although significantly ($P < 0.05$) so only for cutthroat trout intraspecific and coho interspecific interactions.

Aggression of both salmonids was markedly influenced by the feeding cycle in all experiments (Figs 5, 6). Generally, their aggression rose significantly ($P < 0.01$) in riffles and pools during feeding, the outstanding exception being the continued high intraspecific aggressive activity by coho in pools in sympatry at both test velocities (Fig. 6). Interspecific aggression of both species in pools and riffles was substantially higher during feeding than in the non-feeding periods at high velocity. Coho intraspecific aggression in pools was significantly ($P < 0.01$) greater than interspecific activity at both test velocities, whereas the reverse was true for cutthroat trout.

The most frequently used components of aggression by coho and cutthroat trout in both intra- and interspecific encounters were those of chasing, nipping and lateral display (Fig. 6). These comprised more than 80% of the total aggressive acts of each species. Wig-wag displays and frontal threats constituted a small proportion of their aggressive repertoire, the former was more frequently used by coho, and the latter by cutthroat trout. Threat displays and non-contact behaviours were more frequently used by coho, whereas nipping was more frequently used by cutthroat trout. Nipping accounted for 45% of the total aggressive activity by

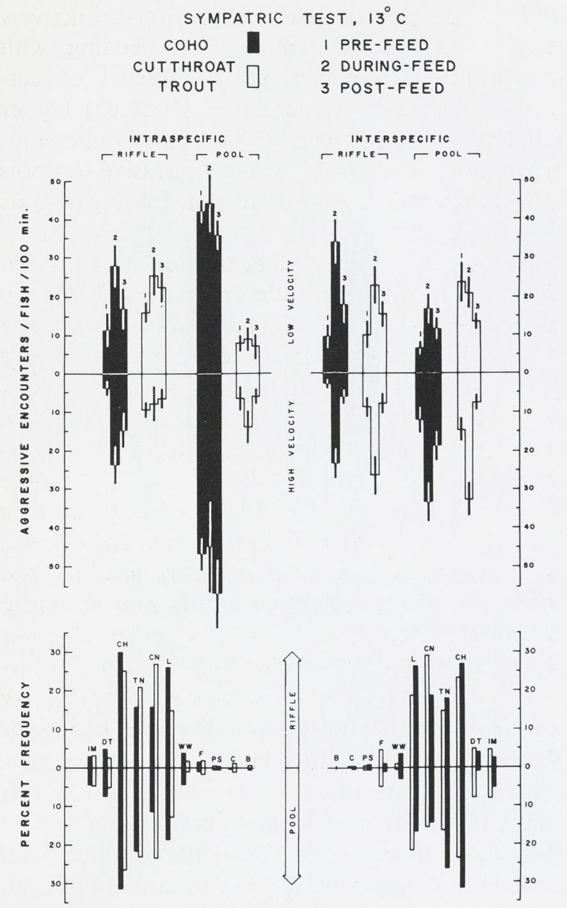

Fig. 6. Upper: Mean aggression ± SE of coho and cutthroat trout in summer in sympatric tests at 13 °C in relation to the feeding cycle and water velocity. Lower: Relative frequency of the components of intra- and interspecific aggression by coho and cutthroat trout. Symbols of aggression are: IM, intention movement; DT, drive toward (charge); CH, chase; TN, threat nip; CN, contact nip; L, lateral display; WW, wig-wag display; F, frontal display; PS, parallel swimming; C, circling; B, biting.

cutthroat trout, and 33% by coho. Neither species showed any obvious differences in the frequencies of the different aggressive components between riffle and pool environments, although Hartman (1963) found that brown trout (*Salmo trutta*) fry used less display than non-display forms of aggression when in fast water.

Winter

The low water temperatures had similar effects on aggressive activity of coho and cutthroat trout whether tested in allopatry or sympatry. At 3 °C, neither species defended riffles (Figs. 7, 8), except for occasional intraspecific encounters by cutthroat trout under rocks. However, there was considerable aggressive activity within and between species in pools, particularly during feeding. Coho attacked other coho more so than cutthroat trout, with total aggressive activity amounting to 2 243 and 1 167 acts, respectively. Cutthroat trout aggression was

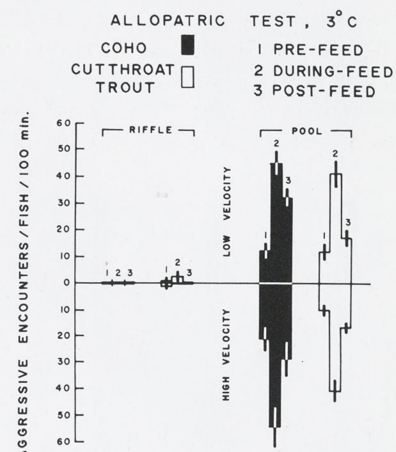

Fig. 7. Mean aggression ± SE of coho and cutthroat trout in allopatric tests at 3 °C in winter in relation to the feeding cycle and water velocity.

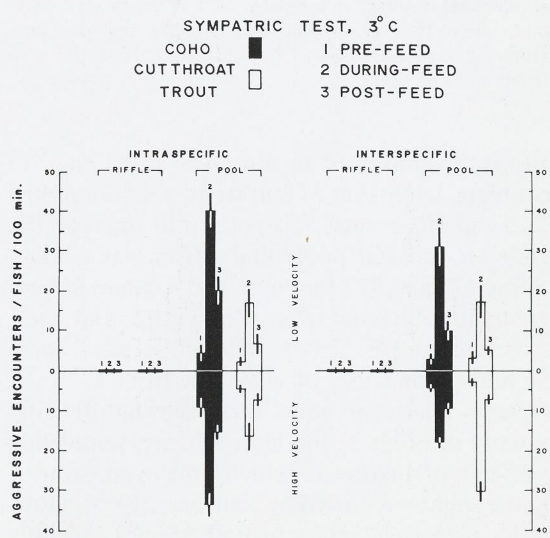

Fig. 8. Mean aggression ± SE of coho and cutthroat trout in sympatric tests at 3 °C in winter in relation to the feeding cycle and water velocity.

more evenly distributed within and between species with a total of 944 and 1 044 encounters, respectively.

Increasing the water velocity had no significant ($0.10 > P > 0.05$) effect on level of aggressiveness of both species at 3 °C in allopatry, but in sympatry interspecific aggression of cutthroat trout increased significantly ($P < 0.05$) during feeding, while that of coho decreased (Figs. 7, 8). The former was largely due to the aggressive activities of large trout. Coho intraspecific aggression was significantly ($P < 0.01$) higher than that of cutthroat trout in the post-feeding period.

Aggression of both species increased markedly when tested at 5 °C in sympatry (Fig. 9). With the

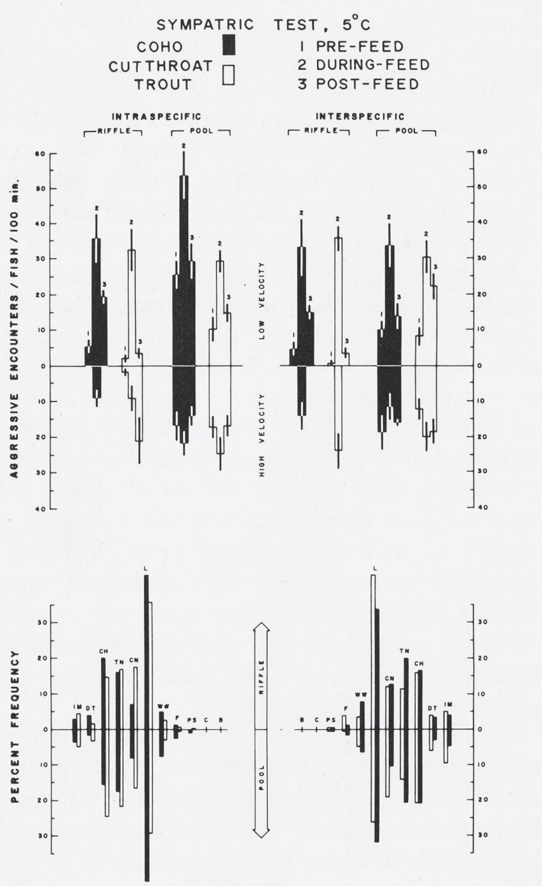

Fig. 9. Upper: Mean aggression ± SE of coho and cutthroat trout in sympatric tests at 5 °C in winter in relation to the feeding cycle and water velocity. Lower: Relative frequency of the components of intra- and interspecific aggression by coho and cutthroat trout. Symbols of aggression are as in Fig. 6.

2 °C rise in water temperature, both species actively defended riffles, particularly during feeding, with both intra- and interspecific aggression of cutthroat trout being significantly ($P < 0.05$) higher than that of coho at high velocity. In all but one instance, both species were more aggressive in pools at 5 °C than at 3 °C during the non-feeding periods (Figs 8, 9).

Changes in intensity of aggression over time in relation to the feeding cycle differed markedly between species (Fig. 10). When tested in sympatry at 5 °C, aggressive activity of coho in pools rose rapidly with the onset of feeding, reaching a peak shortly after initiation of the release of food. The aggressive response in cutthroat trout was much slower and less intense, and did not peak until some 30 min. after that of coho. The coho's strategy gave them priority to preferred feeding sites and allowed them a greater share of the limited food supply. The increased aggressiveness in both species during feeding dispersed fish from their preferred cover sites, and led to a size-related longitudinal and vertical partitioning of space in pools. Typically, the larger fish were positioned near the head and in the

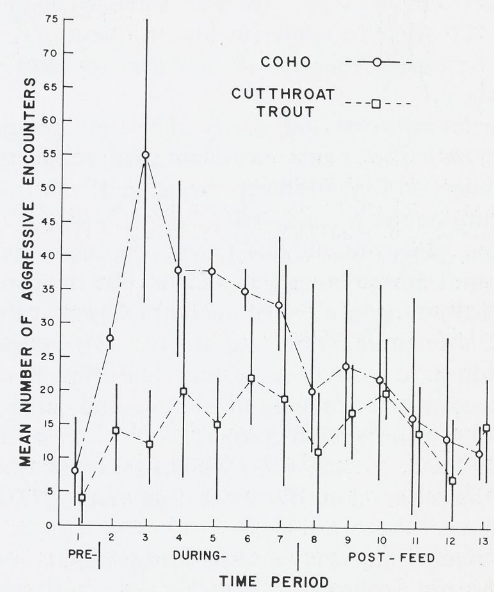

Fig. 10. Aggression (intra- and interspecific combined) of coho and cutthroat trout in pools in winter in relation to the feeding cycle at 5 °C and high test velocity. The fish were observed for a period of 5 min. at each successive 10 min. intervals for a total of 130 min. each day. Vertical lines indicate range.

upper level of pools, with coho, most often, being in front of and above cutthroat trout (Glova, 1978).

The most frequently used components of aggression by both salmonids in winter were those of chasing, nipping, and lateral display (Fig. 9), which together comprised from 80–90% of all their aggressive encounters. Lateral display was more frequently used in winter than in summer by both species, whereas nipping and chasing were generally less frequently used, probably because they are more energy-demanding forms of aggression and are therefore less suitable at low temperatures.

Discussion

In this study evidence has been presented to show pattern and mechanism of interaction for food and space between stream populations of underyearling coho salmon and coastal cutthroat trout. Clearly, segregation between these two salmonids is of the interactive type (Nilsson, 1956, 1967), which differs seasonally as reported by Hartman (1965b) for sympatric coho salmon and steelhead trout. During summer, their high levels of aggression give rise to partial segregation, with coho in pools and cutthroat trout in riffles. However, such segregation does not occur in winter at low temperatures, as their aggression then is low and they co-occur in pools.

Hartman's work (1965b) and this study demonstrate that riffle environments are used extensively by underyearling steelhead trout and cutthroat trout in summer when tested in sympatry with coho salmon. Behavioural differences between these salmonids appear to largely account for such spatial partitioning in streams. In contrast, genetically-based differences rather than interspecific interaction appear to account for resource partitioning between sympatric populations of coho and chinook salmon (*Oncorhynchus tshawytscha*) (Lister & Genoe, 1970; Stein *et al.*, 1972), and of steelhead trout and chinook salmon (Everest & Chapman, 1972) in streams.

Habitat segregation between stream populations of coho and cutthroat trout during seasons of rapid growth presumably reduces interspecific competition for resources. Competition, if and when it occurs, is probably of the exploitative and interference types described by Brian (1956) and Case & Gilpin (1974). Segregation may result from interferance when either species learns from experience that resources are less easily secured in habitats frequented by the other species. Alternatively, segregation may occur when one of the species is more efficient than the other in exploitation of specific resources, such as food and space, as illustrated by Nilsson (1967). Of the two types of competition, I consider the exploitative strategy to be of lesser importance in segregation between sympatric populations of coho salmon and cutthroat trout. Habitat shift by cutthroat trout from pools, their preferred space, to riffles when in sympatry with coho, does not appear to be due to their lesser efficiency than coho in resource exploitation in pools, but rather to their social subdominance. Such reasoning aligns with the dominance theory by Morse (1974), and parallels the niche shift reported by Fausch & White (1981) for brook trout (*Salvelinus fontinalus*) in sympatry with the competitively dominant brown trout in a Michigan stream. Cutthroat trout in allopatry appear equally capable in feeding and in utilizing cover in pools as are coho. In riffles, however, they might be considered a more efficient exploitor of resources than coho, as reflected in their ability to utilize both bottom and drifting foods (Glova, 1984), and to use cover under stones.

In this study, mutual agonistic interference between coho and cutthroat trout appears largely to account for partitioning of stream resources. A similar conclusion was reached by Hartman (1965b) for sympatric populations of juvenile coho and steelhead trout, and by Werner & Hall (1977) for populations of centrarchids in lakes and ponds. The highly aggressive and socially dominant coho is an effective interference competitor against cutthroat trout and steelhead trout in pools and other slow-water habitats. Conversely, the equally aggressive but socially subdominant cutthroat trout and steelhead trout appear to exert a similar interference against coho in riffles and other fast-water habitats.

Interference between sympatric coho and cutthroat trout may, to some extent, be energetically governed. Cutthroat trout may be restricted to microhabitats in which interference is energetically unprofitable to coho. The costs for coho to maintain social dominance over cutthroat trout in fast-water may exceed the benefits they derive from food and shelter in such habitats. Southwood (1977) in a thorough review on the subject of ecological strategies in nature, concluded that each arises from the evolutionary 'trade-offs' of costs versus benefits in the process of adaptation to habitats. In the game of evolutionary 'trade-offs', coho may have evolved as a more specialized 'sit and wait' predator to capture drifting foods in pools, and cutthroat trout as a more generalized 'searching' predator, capable of cropping the drift and grazing the benthos in both fast and slow water habitats.

Structurally complex environments such as riffles, might also decrease the foraging efficiency of a predator as shown for juvenile rainbow trout (Ware, 1972). Pools might permit more efficient feeding by coho, and by salmonids in general, than do riffles. As invertebrate drift comprises a major proportion of the diet of juvenile coho (Mundie, 1969, 1971), the more complex array of submerged cover and higher velocities in riffles than in pools, might reduce their foraging efficiency on drift in riffles. Moreover, Case & Gilpin (1974) emphasize that if the interference competitor is to be able to dominate or exclude the exploitation competitor, it must do so in those habitats in which the carrying capacity is highest for populations of both species. This argument is consistent with my findings that coho socially minimize the cutthroat trout's use of pools, the habitat in which salmonid carrying capacity is typically some threefold higher than in riffles (Glova, 1984).

Factors affecting the microdistribution of coho and cutthroat trout in this study differed seasonally. During summer, relative size of fish had a greater influence on species pattern of habitat use than did the simulated food supply or the water velocity regime. Size-related differences in the use of space have been shown to be of primary importance among other cohabiting populations of salmonids (Everest & Chapman, 1972). However, in winter, temperature appeared to be the primary factor influencing the use of space by fish in this study, with relative size of fish, velocity regime, and the food supply all being of lesser importance.

Coho and cutthroat trout were found to interact minimally over space per se during winter in this study. At 3 °C without food in the system, aggression was virtually non-existent, but increased dramatically with a 2 °C rise in temperature. Hartman (1966) observed similar increases in aggression with temperature in juvenile coho and steelhead trout. Food drifting in the system at dawn and dusk in this study markedly elevated their aggression in pools, but resulted in relatively minor dispersal from their preferred winter habitat. Ther aggressive activity declined rapidly to relatively low levels when food was no longer available. Keenleyside & Yamamoto (1962) also reported reduced levels of aggression in Atlantic salmon (*Salmo salar*) when food was withdrawn.

The influence of low temperatures on the winter microdistribution of sympatric populations of juvenile salmonids in streams has been described by Bustard & Narver (1975a) and Bjornn (1971). As both thermal and hydrological regimes in streams are commonly severe in winter, and drifting foods may be sparse, it is inferred from the present findings that wild sympatric populations of coho and cutthroat trout interact minimally during winter, in spite of their similar microhabitat demands. However, in streams with restricted overwintering cover they may compete for preferred space through mere physical occupancy of specific sites. Bustard & Narver (1975b) found that juveniles of both these salmonids prefer areas with cover rather than without cover when tested under semi-natural conditions in winter.

From the results of this study and others mentioned previously, it appears that juvenile coho salmon and cutthroat trout are generalized exploiters of stream resources, which, accordingly, results in considerable overlap in resource use between them. The partial habitat segregation in summer, but not in winter, most probably functions to attenuate interspecific competition, the season in which small coastal streams are characterised by low flows and relatively high fish population densities.

Acknowledgements

I thank Drs J. C. Mason and T. G. Northcote for their helpful suggestions in this study, Dr J. E. McInerney and Mr R. Scheurle for their kind cooperation during my use of laboratory facilities at the University of Victoria, and Mr F. Nash for computing the multi-factorial analysis of variance statistics. The refereeing of the manuscript by Dr H. W. Li and an anonymous reviewer is greatly appreciated. Logistic support was provided by the Pacific Biological Station, Nanaimo, B.C. Financial support was jointly by the B.C. Fish and Wildlife Branch, NRC grant No. 67-3454 to T.G. Northcote, and NRC Scholarship to the author. Thanks are extended to Mrs C. M. Whaitiri for typing the manuscript.

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OREGON COOPERATIVE
FISHERY RESEARCH UNIT

OREGON
STATE
UNIVERSITY

Department of
Fisheries and Wildlife

Nash Hall 104
Corvallis, Oregon
97331-3803

Telephone
503·737·4531

Fax
503·737·3590

21 Sept. 1993

Dear Bob,

Just a quick note to say "Hi" and to thank you for the issue of Trout. Actually, I had already picked up a copy and circulated it to the Unit students; its a good series of papers and your article was, to use a term I just learned in England, "spot on."

The bad news is, no hat. Jacque & I looked all over our Sunriver place with no success. I'll bet you put it down when we had lunch on the Metolius.

Enclosed is a draft report by Ken that I thought you might enjoy.

Say "hello" to Sally for me please.

Cheers,

Carl

DRAFT

GENETIC VULNERABILITY OF THE YAKIMA FISHERY PROJECT

A RISK ASSESSMENT

by

Kenneth P. Currens
Oregon Cooperative Fishery Research Unit
Nash Hall 104, Oregon State University
Corvallis, Oregon 97331

Carl B. Schreck, Unit Leader

for

Washington Department of Fisheries
P.O. Box 43151
Olympia, Washington 98504-3151

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PREFACE

In the Fall of 1992, I was hired by the Washington Department of Fisheries to produce a genetic risk assessment of the Yakima Fishery Project--a large, complex effort to use artificial propagation to rebuild natural populations of salmon contributing to traditional and commercial fisheries. Genetic risk assessment was required under the Fish and Wildlife Program of the Northwest Power Act. Most managers, regional planning groups, and geneticists, however, were confused about what a genetic risk assessment was, how it should be conducted, and what it could be used for. Although descriptive assessment of a few projects had been completed, no standard for judging their quality existed. No models had been developed. Most terms had not been defined. Biological, historical, and scientific constraints had not been characterized. Assumptions had not been identified.

Out of necessity, I have developed a framework for analyzing genetic vulnerability. Many have hoped that this would be a model that would produce a set of numbers to tell us the probability that genetic harm will occur, or what the acceptable limits are. They will be disappointed. No model can do our job for us. Basing decisions on probability estimates implies that we have such a large number of trials or opportunities available that a low frequencies of failures will not matter. In contrast, I have worked from the fundamental assumption that every single opportunity we have left is too important to be left to chance.

Systematic, policy-oriented research into risk assessment and reduction began over 50 years ago with efforts to forecast and reduce vulnerability to flooding. Since then, research has continued in many other applied sciences. To develop this model, I have relied heavily on lessons learned from risk assessment, risk communications, and risk management of biotechnology, geophysical hazards, chemical and toxic wastes, and nuclear power. Although the technological hazards of natural resource management are different than those of other industries, the principal problems of forecasting harmful events, reducing vulnerability, and resolving conflicting perceptions of risk among the public are fundamentally the same.

This model provides a tool for managers, conservation biologists, and decision makers. Like all tools, it can be improved. It can also be abused. It is designed to be used iteratively as an integral part of monitoring and evaluating obstacles to achieving supplementation. It requires some skill and training for those wishing to use it, but with future refinement it should be accessible to geneticists and non-geneticists alike.

Kenneth P. Currens
31 March 1993

EXECUTIVE SUMMARY

I. Goal

The ultimate goal of this document is the wise use of natural resources through technology. In this document, sciences of population genetics and technology assessment are applied to the wise use of artificial propagation to rebuild or supplement fisheries. Included are two products:

- A model to evaluate vulnerability of Pacific salmon[1] to genetic hazards associated with artificial propagation of fish.

- Evaluation of a proposed artificial propagation project in the Yakima River Basin, Washington.

II. Development of a Model for Genetic Risk Assessment

This model of genetic risk assessment is based on the evaluation of the availability, appropriateness, and sufficiency of control mechanisms to reduce vulnerability to genetic hazards. Vulnerability is the product of risk (the probability of a hazard) and hazards (the adverse losses of genetic structure and function). Genetic hazards are extinction, loss of within-population genetic diversity, loss of among-population genetic diversity, and domestication (or loss of fitness in the wild).

Simply predicting vulnerability of natural resources to management actions does not provide a sound foundation for risk assessment for two reasons. First, the large number of sequential events, complex interactions, and the influence of environmental variation make estimates of risk extremely imprecise. Second, imperfect knowledge leads to different perceptions of hazards.

Assuming that the success of every single supplementation effort is important and that principles and tools of technology assessment can be applied to genetic risks and hazards of artificial propagation, vulnerability can be assessed by examining safeguards for reliability and resilience. This can be divided into four key steps: identification of the structure of the vulnerability system, characterization of sources and endpoints of genetic hazards, inventorying of proximate and ultimate safeguards against hazards, and describing vulnerability and presenting the result. Reliability is a measure of risk associated with protective plans or fail-safe technologies against hazards. Resilience is a measure of the potential rate of recovery from a hazard.

The basic vulnerability system of technological hazards in natural resource-management consists of five components: source of the hazard, proximate safeguards, endpoints, ultimate safeguards, and failures. Brood stock selection, brood stock collection and holding, mating, rearing, release, juvenile migration, and adult migration are the general

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[1] All members of the genus *Oncorhynchus*, including rainbow trout and cutthroat trout.

sources of technological hazards in the life-cycle of Pacific salmon. Endpoints are target populations, non-target populations of the target species within the target area, non-target species within the target area, non-target populations of other target species, and non-target populations of the target species outside the target area. Proximate safeguards are artificial propagation, control of passage, harvest regulation, and habitat management. Ultimate safeguards consist of genetic reserves and adaptive management.

Safeguards include human, physical, and biological components. Human components consist of the quality of the guidelines and ability of technicians to carrying out the guidelines. Physical components are the availability of enough appropriate equipment and plans. Biological components include anticipated variability in fish behavior upon which the guidelines are based and the ability to detect and recognize deviations.

When data have been collecting on the sources, endpoints, and safeguards for genetic hazards, vulnerability can be described using four different possible approaches: genetic and demographic models, comparative vulnerability scores, qualitative description, and probabilistic descriptions. The emphasis of all these approaches is on identifying the components that contribute most to vulnerability and that can be corrected. The primary purpose of using genetic and demographic models is to describe potential genetic hazards simply and quantitatively in terms of loss of genetic structure or function. In contrast, comparative vulnerability scores do not have absolute values but are relative comparisons of reliability and resilience for components of safeguards. Qualitative descriptions are most useful when quantification is not always appropriate or necessary, whereas probabilistic descriptions are intended to be predictive.

III. Genetic Vulnerability of the Yakima Fishery Project

A. Species Examined

Data were available to examine vulnerability of three groups in detail:

- Yakima spring chinook salmon
- Yakima summer steelhead
- Yakima fall chinook salmon.

Hazards associated with supplementation of Yakima summer chinook salmon and coho salmon were described qualititatively.

B. Materials and Methods

The worst-case scenario for this analysis was that supplementation is no different than conventional artificial propagation of salmon. Data for worst-cases scenarios were taken from project planning documents. The relationships between chance extinction and demography in these populations with and without supplementation were examined using the model by Goodman (1987). Evaluation of proximate and ultimate safeguards was based on comparative vulnerability scores.

C. Vulnerability

For every 100 spring chinook salmon taken as brood stock from the upper Yakima River and Naches River, Yakima Fishery Project data indicated that on average only 53 and 66 fish, respectively, will return. Similarly, for every 100 steelhead taken as brood stock in the Yakima River Basin, data suggested that on average only 61 will return. At mean population growth rates sustained by unsupplemented populations of spring chinook and steelhead, probability of extinction in 100 years was less than it was under supplementation. Likewise, at 5% probability of extinction, unsupplemented populations were expected to persist longer than supplemented populations.

The only control mechanism for spring chinook salmon, steelhead, and fall chinook salmon that that had high enough reliability scores to be considered available and appropriate was genetic stock identification. Resilience scores for use of genetic reserves for spring chinook salmon and steelhead were nearly high enough to be considered available and appropriate. Safeguards for fall chinook salmon had the lowest resilience score possible. In general, three major factors contributed to low scores for all three species:

- Operating procedures and protocols for how conservation guidelines will be implemented did not exist, were inconsistent with conservation guidelines, or had only been superficialy developed.
- Very few decision trees had been developed to indicate what the contigency plans are for failure or unanticipated results of a control mechanism.
- Planning documents indicated no intentions to provide appropriate training to avoid technical errors by technicians or biologists.

Data for detailed analysis of risks and hazards of supplementing summer chinook and coho salmon were not available. Qualitative description was provided by Busack (1990) and vulnerability has changed little since then.

IV. Conclusions and Recommendations

Considered together, the results of this analysis suggested that under present plans, supplemented populations may be more vulnerable to extinction and loss of within-population genetic diversity than has been previously recognized. A major potential conflict existed between the use of the Yakima Fishery Project as an experimental opportunity to test supplementation methodologies and the goal of rebuilding natural populations of salmon and steelhead in the Yakima River while maintaining the long-term fitness of the target population, and keeping ecological and genetic impacts on non-target populations within specified biological limits. Experiments must be allowed to fail to gain knowledge. However, supplementation in the Yakima River must not be allowed to fail, if these populations are to be rebuilt and genetic diversity of salmonids within the Columbia River Basin is to be maintained. Considerable effort has gone into development of experimental designs to test supplementation methodologies. Lack of explicit, well-developed operating guidelines, monitoring and evaluation plans, decision trees, and contingency plans, and emphasis on the development of operating guidelines based on statistical needs, however, provided no safeguards against failure of these experiments.

The following actions are recommended to reduce vulnerability in this project:

- Conservation principles analogous to the genetic guidelines for hatcheries should be developed for assessing and guiding management of genetic and ecological impacts during juvenile and adult migration.

- Operating procedures and protocols for how conservation guidelines will be implemented should be fully developed to be consistent with conservation guidelines.

- Decision trees should be developed to indicate what the contingency plans are for failure or unanticipated results of a control mechanism.

- Training programs for managers, field biologists, and technicians should be developed, implemented, and evaluated to help avoid technical errors.

- Monitoring and evaluation efforts must be developed to collect demographic and genetic data to evaluate the vulnerability of the populations as well as the success of different experiments. Project planners need to distinguish between evaluation of supplementation and evaluation of supplementation methodologies.

- Guidelines for designing, designating, and implementing genetic reserves that will include regional as well as local needs need to be developed.

- Genetic vulnerability of the Yakima Fishery Project should be reevaluated when operating guidelines and contingency plans have been developed. Use of the framework and methods presented here would allow evaluation of improvement.

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INTRODUCTION TO THE DOCUMENT

A. The Goal

The ultimate goal of this document is the wise use of natural resources through technology. Technology is applied science. In this document, sciences of population genetics and technology assessment are applied to evaluate artificial propagation as it might be used to rebuild or supplement fisheries. Included are two products:

- A model to evaluate vulnerability of Pacific salmon[1] to genetic hazards associated with artificial propagation of fish

- Evaluation of a proposed artificial propagation project in the Yakima River Basin, Washington.

B. The Problem: Wise Use and Technological Risks

As demand for resources grows so also does need to use technologies that exploit resources more efficiently. Every technological innovation, however, creates risks as well as benefits (Smith 1992). In the Columbia River Basin, for example, technological innovations in harnessing and distributing water support a major enery industry, production of 43% of the United States' supply of aluminum, and irrigation to eight million acres of agricultural lands. But, these same innovations threaten communities and peoples that have traditionally relied on the natural resources that the river once provided (Northwest Power Planning Council 1992).

The wise use of resources through technologies that sustain them -- or conservation (Pinchot 1910) -- depends on identifying resources and choosing appropriate technologies. Three fundamental challenges face assement of technological choices.

- Hazards must be identified, characterized, and forecast.

- Vulnerability to hazards must be reduced.

- Conflicts over perceived risks and benefits of technological choices must be resolved.

These three challenges face the wise use of artificial propagation to rebuild or supplement populations of salmonid fishes. Artificial propagation is an established technology of fishery science (Everhart and Youngs 1981). However, considerable uncertainty exists over the risks and hazards of using artificial propagation to sustain fishery resources (Hindar et al.

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[1] All members of the genus *Oncorhynchus*, including rainbow trout and cutthroat trout.

1991, Hilborn 1992, Meffe 1992). Genetic risk assessment is a process by which genetic hazards, risks, and vulnerabilities may be characterized and managed.

C. Basis for Genetic Risk

Fish are the product of their genes, their environment, and unique interactions between the two. It is the genetic variation within and among populations of fish that determines their capacity to persist in changing environments. Consequently, long-term production of populations or fisheries in changing environments depends on conserving genetic variation. Manipulation of populations and their environments for short-term gains creates genetic risks because genetic diversity may be lost.

Conservation of genetic variation is implied as the genetic objective of supplementation in the Columbia River. Supplementation is the ***use of artificial propagation to maintain or increase natural production while maintaining the long-term fitness of the target population, and keeping ecological and genetic impacts on non-target populations within specified biological limits***. Long-term fitness is used synonymously with long-term performance, which is defined as "the capacity of a population to persist in the face of environmental variability while undergoing natural genetic change" (Regional Assessment of Supplementation Project 1992a).

D. Policy Directives for Genetic Risk Analysis

The Columbia Basin Fish and Wildlife Program, which was established by the Northwest Power Planning Council (NPPC) under Section 4(h) of the Pacific Northwest Electric Power Planning and Conservation Act--Public Law 96-501, makes clear that risk assessment is essential. Section 2.1A(2) states the goal that management programs will pose no appreciable risk to diversity and that the best available assessment tools should be used to evaluate risk before proceeding. Section 6.2C(2) directs fishery managers to prepare risk assessments for proposed supplementation projects. In addition, risk inventory methodology will be necessary for Section 6.2C(13), which provides for independent audits of hatchery performance be conducted to improve, modify, or terminate artificial propagation program. Maintenance of genetic integrity is included as a performance standard in Section 6.2b(7).

E. Overview of Document

This document is divided into three major parts. First is a description of the foundations of genetic risk assessment. This section outlines the boundaries of what risk assessment can and can not do. This includes the following topics:

- Historical, scientific, and biological constraints
- Definitions and key concepts
- Characteristics of an ideal risk assessment model
- Operating assumptions

The second part of the document describes the details of the genetic risk assessment model in four key steps:

- Identifying the structure of vulnerability
- Characterizing the sources and endpoints of genetic hazards
- Evaluating the proximate and ultimate safeguards against hazards
- Describing vulnerability and presenting the results.

The third part of the document is an evaluation of the Yakima Fishery Project using the framework for genetic risk assessment. Three major sections include the following:

- Materials and methods
- Results
- Conclusions and recommendations.

Finally, the appendices contain the summary data used for assessing genetic vulnerability of different aspects of the Yakima Fishery Project.

I. FOUNDATIONS OF GENETIC RISK ASSESSMENT

A. What Are The Important Questions?

We have a problem: How do we rebuild wild populations that contribute to fisheries? We have a potential solution: Use artificial propagation. We know that every technology creates risks as well as benefits. The big question is "How do we assess threats to the resource from artificial propagation?"

Models exist for assessing and managing risks in fields as diverse as biotechnology, geophysical hazards, chemical and toxic wastes, and nuclear power, but not for risks of artificial propagation in natural resource management. To develop a framework for artificial propagation, this section addresses four critical questions.

- What are the biological and social constraints?
- What are the key definitions and concepts?
- What are the characteristics of an ideal model?
- What assumptions do we need to make?

B. What Are The Constraints?

Tools work best if they are designed to work in the environments where they will be used. Identifying biological and social constraints is important because they shape the design, function, and useful of the model. They determine the places where disruptions caused by failure of risky technologies can be identified, measured, rated, or forecast. They also determine the ways in which vulnerability can be reduced.

Four major biological and social parameters constrain the model of genetic vulnerability due to artificial propagation of fish in the Columbia River:

- The history of fishery management
- The relationship between genetic structure and function of the species to be propagated
- The kind, quality, and quantity of available data to describe genetic structure and function of the species to be propagated
- The system of vulnerability

B.1. History of Fishery Management

The most important immediate, historical constraints of fishery management in the Columbia River arise from creation of the Columbia Basin Fish and Wildlife Program, which is administered by the Northwest Power Planning Council under the Power Planning and Conservation Act. These constraints are

- the adoption of adaptive management by NPPC

- the *ad hoc* incorporation of risk assessment and population genetic concepts into fishery management goals and objectives in response to crises, as opposed to well-formulated conservation policy.

Adaptive management is a policy that attempts to improve resource management by designing management actions as experiments that can provide useful information for future actions (Northwest Power Planning Council 1992b). Adaptive management allows for failure if the lessons learned can be applied to better scientific management. Application of adaptive management in recent NPPC (1992b) guidelines has created three environments for genetic risk assessments:

- Initial assessment of individual artificial propagation programs

- Regular audits of hatchery performance

- Cummulative or system-wide assessments of proposed artificial propagation projects.

The *ad hoc* incorporation of risk assessment and population genetic concepts into fishery management goals and objectives, however, has created an environment where debate over the need, uses, and risks of artificial propagation has been hampered by confusing and inconsistent use of common and technical vocabularies. Definitions of important terms and concepts helps determine the environments in which assessment can be successful.

B.2. Relationship Between Genetic Structure and Function

The extent to which genetic structure (organization) is related to genetic function (processes) is important because risk assessment more easily focuses on vulnerability of populations to losing genetic structure or diversity. Measuring function of genetic and ecological systems is difficult in natural populations. Consequently, resource management generally emphasizes protecting structure, which can be more easily estimated (Cairns and Pratt 1986). The goal of maintaining long-term performance or fitness of populations, for example, implies that we wish to manage for function, whereas conservation of biodiversity -- whether at genetic or ecosystem levels -- is protection of structure. A variety of theoretical and empirical research suggests that some measurements of genetic structure are intimately related to function (Allendorf and Leary 1986, Quatro and Vrijenhoek 1989). However, a consequence of focusing on measures of structure that are not closely related to function is that structure may be preserved while function is impaired.

B.3. Kind, Quality, and Quantity of Available Data

The kind, quality, and quantity of available data determine to what extent assessment can produce quantitative estimates of vulnerability. Different kinds of genetic data have different strengths and weaknesses for making inferences about genetic structure or function (Antonovics 1990, Hedrick and Miller 1992). For Pacific salmon in the Columbia River, allozyme data is the most available, reliable genetic data. Demographic data--such as trends in historical abundance and straying patterns and rates--may be useful for investigating functional parameters of possible assessment models. However, these data have usually not been collected systematically or by the same methods and may range in quantity from abundant to imaginary.

B.4. The Vulnerability System

Processes that link sources of potential technological hazards, protective mechanisms and responses, and potential victims are not random. The relationship of these components provides the basic framework for assessing vulnerability. For example, in biotechnology, nuclear power, or toxic waste management, the most common structure is based on confinement and control of the hazard. The source is contained to make it useful, a series of protective, fail-safe mechanisms are placed between the source and the potential victims, and vulnerability is based on the probability that protective mechanism could fail and the potential losses if they do (Wilson 1991). Vulnerability in natural resource management, however, does not follow the "confine-and-control" model because the very resource we wish to protect from harm is also intentionally exposed to the potential hazard. Consequently, fail-safe mechanisms are of limited usefulness.

C. Definitions and Concepts

The *ad hoc* incorporation of risk assessment and population genetic vocabulary into fishery management goals and objectives in response to crisis, as opposed to well-formulated conservation policy, has created a fundamental problem. Lack of shared definitions has resulted in confusing and inconsistent use of common and technical words. This has two serious consequences. First, without defining the hazards or resources, they are unlikely to be brought under control and managed (Wilson 1991). Second, confusion and inconsistency among presumed authorities tends to increase public perception of risk (Smith 1992). The purpose of this section is define key words and concepts associated with risk assessment that have been missused or are potentially confusing. Definitions of genetic vocabulary used here may be found in basic population genetic textbooks (e.g. Falconer 1981, Hartl 1981) or references for fishery managers (e.g. Tave 1986, Kapuscinski and Jacobson 1987).

C.1. Definitions

- *Hazards* are the potentially adverse consequences associated with an event or activity (Smith 1992).

- *Technological hazards* are sequences of events leading from human needs and wants to selections of specific technologies resulting in adverse consequences (Hohenmeser et al. 1983).

- *Genetic hazards* are the potentially adverse losses of genetic structure or function associated with an event or activity.

- *Risk* is the probability that adverse consequences of an event or activity will occur (Smith 1992).

- *Genetic risk* is the probability of genetic hazards.

- *Failure* is the realization of a hazard.

- *Vulnerability* is the value of risk for a given set of consequences.

- *Reliability* is the potential success of protective measures against hazards (Smith 1992).

- *Resilience* is the potential rate of recovery from failure (Smith 1992).

- *Perceived vulnerability* is the value of risk for potential consequences of an event of activity based on imperfect and personalized knowledge.

- *Endpoints* are the biogeographical dimensions where the magnitudes and durations of failure of a technology can be measured, ranked, or assessed.

C.2. Risk

The concept of risk is potentially confusing because in common usage it may include the probability of an event occurring or the adverse consequences associated with an event or activity or some product of the two. For example, in regional planning documents for artificial propagation of fish in the Columbia River, genetic risk has been defined as the probability of failing to meet genetic objectives (Anonymous 1992). It has also been classified into four major types according to the potential losses genetic structure and function (Busack 1990). This ambiguity introduces an element of confusion about the product of genetic risk assessment. Is it estimated probabilities of harmful events? Or is it the kind and quantity of losses that might occur? To reduce this confusion, the meaning of risk is here confined to the definition above and concepts of hazard, failure, and vulnerability are introduced. However, because "risk assessment" has been widely used to describe the process of analyzing vulnerability, both in regional planning documents and the scientific literature, it will also be used for that meaning here.

C.3. Hazards

Hazards can be recognized as potential losses. Following Busack's (1990) classification, four basic hazards need to be recognized.

- Extinction
- Loss of within-population genetic variability
- Loss of between-population genetic variability
- Domestication or the loss of fitness in the wild of fish propagated in an artificial environment.

Hazards have meaning only in an ecological context. Events or phenomena that in some situations might be beneficial or desirable will be hazardous in other situations, depending on human location, needs, and perceptions. For example, inbreeding results in lost heterozygosity and increased expression of homozygous genotypes (Falconer 1981). These often lead to reduced performance (Ryman 1970, Kincaid 1976a, 1976b, 1983, Allendorf and Leary 1986). Consequently, conservation genetic guidelines for artificial propagation of fish to be released into the wild frequently warn against using small breeding populations, which increase the chance of inbreeding and genetic drift (Tave 1986, Gall 1987, Kapuscinski and Miller 1993). In completely different circumstances, however, conservation geneticists have purposefully created small, inbred strains from a few endangered animals to minimize the chance that genetic diversity of the whole species is lost (Templeton et al. 1987). Likewise, inbreeding is often recommended in agricultural programs that wish to increase the contribution of outstanding individuals to a strain.

C.4. Endpoints

Not all losses are equal, however. The value of a hazard or loss is estimated at different endpoints. Because technological hazards in natural resource management arise from complex sequences of events and choices at the interface of natural and human systems, simple cause-and-effect or dose-response relationships rarely occur. Impacts cascade through different levels of biological organization. For example, extinction of a population of predatory fish may be measured as a loss of unique genotypes, loss of diversity within an species, or loss of diversity or function within a community. Resilience may range from nonexistent (the same genotypes are unlikely to reevolve) to rapid (invasion of a different predator in the community). Identification of appropriate critical endpoints is one of the principal uncertainties of vulnerability assessment (Bartell et al. 1992).

C.5. Vulnerability

The concept of vulnerability is necessary because risks and hazards are not always equal. For example, in a given artificial propagation program, risk of domestication may be high, relative to the risk of extinction. However, vulnerability to extinction, if the program fails, may equal or surpass that for domestication because the value of the loss is so much greater. Or, in another case, risk of domestication may be low compared to risk of losing within-population variability when brood stock are collected from the wild. However, vulnerability to domestication may be greater because it accumulates over multiple generations, whereas the vulnerability to the hazard of brood stock collection only occurs once.

The basic relationship between vulnerability (V), risk (r), hazard (L) may be expressed as

$$V = rL \tag{1.1}$$

where L is the value of a hazard measured as a loss (Smith 1992). However, risk of a hazard with value of L results from sequence of N number of independent events. Additionally, perceptions of losses will vary. Consequently, this relationship may be further developed as

$$V = \left(1 - \prod_{i=1}^{N} (1 - r_i)\right) L^x \tag{1.2}$$

where x is a power that depends on perceived vulnerability. The expected value of x is assumed to be 1 with complete, objective estimates of risks and losses (Smith 1992). When x does not equal 1, the difference between vulnerabilities based on different values of x leads to the conflicts over appropriate technologies. Estimating and managing perceived vulnerability is part of the field of risk communications.

The above relationship illustrates why risk analysis is really analysis of vulnerability. Estimating only r or L will not provide fishery managers with enough information to reliably predict how their actions will reduce the value of risk for a given set of hazards. The relationship also indicates that the safest natural resource technologies are those that either reduce the probability that adverse consequences of a management action will occur or those that limit losses from a hazard.

Vulnerability can be managed through reliability and resilience (Smith 1992). Reliability is the measure of risk associated with protective measures or fail-safe technologies against hazards. Resilience is the measure of what happens when fail-safe technologies fail. Where hazards can be contained, reliability is useful. However, when hazards can not be contained, resilience of the system becomes extremely important.

C.6. Perceptions of Vulnerability

Different perceptions of vulnerability are an inevitable part of risk assessment, because imperfect knowledge forces individuals and groups -- scientific and non-scientific -- to simplify and personalize the situation to resolve the dilemma of how they should act (Simon 1956, Kates 1962). When these simplifications meet scientific criteria they are called models. Different models of vulnerability are based on different perceptions of both impending losses and risks.

Perceptions of losses range from well-defined and technical to poorly-understood and complex. For example, scientists generally view potential losses technically by how they can be measured (e.g. mortality, loss of alleles, or loss of spawning grounds). Nonscientists tend to view losses as much more complex, including harms such as social disruption and loss of values and history (Gardner and Gould 1989, Wachbroit 1991). Although technical perceptions of loss may be more quantifiable and repeatable, they are not necessarily neutral (Tversky and Kahneman 1981) or more valid and they tend to underestimate losses (Smith 1992). Even among scientists, different technical approaches may lead to different scientific conclusion about vulnerability. A now-classic example is a debate in *Science* in which a respected ecologist and a respected geneticist use very different scientific models to arrive at very different conclusions about the risks of releasing genetically engineered organisms into the environment (Davis 1987, Sharples 1987). Disagreement among experts increases the perception of vulnerability among non-experts (Smith 1992) and reinforces the complex view of loss.

Different perceptions of risk (probability) also contribute to differences in perceived vulnerability. In risk assessment two major problems are important:

- Interpretation of the probability of occurrence of a single, immediate event (Wachbroit 1991)
- Public acceptance of fallacies about probabilities (Tversky and Kahneman 1974).

For example, what does it mean in the short term (e.g. the Yakima Fishery Project) if experts conclude that the probability of extinction in the next 100 yrs of such a population under proposed supplementation guidelines is 10^{-7}. Such a small risk would probably not be seen as reason to prevent supplementation. However, it is entirely possible and consistent with this probability that the next three populations supplemented might go extinct. A 10^{-7} probability tells us nothing about the frequency of extinction in the short term; it only predicts that in 10^{7} events, extinction is likely to happen once. Consequently, use of long-term frequencies as a basis for policy when every single case is important may not be advisable (Wachbroit 1991). Likewise, an example of a commonly-accepted fallacy is the notion that deviations from random should get corrected (e.g. if you have three sons, odds are greater that the next child will be a girl).

One way to reduce differences in perceived vulnerability is to establish a shared standard. The default standard in risk management is the worst-case scenario (Wilson 1991). Rather than debate probable events and consequences, assessment assumes a worst-case -- that a failure has happened -- and evaluates the consequences. No guidelines exist for choosing the series of probable and improbably events that result in a worst-case. Consequently, analysts need to explicitly define the *de minimus* standard they have choosen (Fiksel and Covello 1986). Evaluation of worst-case scenarios is not neutral, but it can be an objective and responsible standard for convey information about vulnerability (Wachbroit 1991).

C.7. Distinctions Between Assessment and Management

The distinction between risk assessment and risk management is a major source of confusion that needs to be resolved. When risk assessment was first applied to ecological systems, risk assessment was defined as the scientific process of collecting objective, value-free information which could be used by risk management in incorporating values and policy decisions (National Academy of Sciences 1983). For a variety of practical and theoretical reasons, however, most risk assessment usually incorporates evaluation of how well vulnerability can be reduced. This has confused expectations for risk assessment. A classic example exists in planning guidelines for artificial propagation in the Columbia River (Regional Assessment of Supplementation Project 1992b), in which risk assessment is defined to have two parts--estimating risk and managing risk--but several paragraphs later risk assessment is limited to its traditional roll of objective, scientific measurement of risk that does not include decision making.

Review of the scientific literature indicates that although quantitative measures of vulnerability should ideally support management decisions, most assessments in natural, ecological systems will include some decision making and risk management. For example, the National Academy of Sciences (1989) recently offered three criteria for assessing hazards of biotechnology.

- How familiar are we with the organism to be released and the environment?
- Can we confine or control the hazard?
- What are the probable consequences of unintented effects?

Of these, only the last fits the traditional definition of risk assessment.

The distinction between risk assessment and risk management in natural resource systems inappropriate for two reasons. First, this distinction was based on inappropriate models. The most common model was the chemical risk-assessment model (National Academy of Science 1983), which relies on estimates of exposure, dose-response relationships, and predictable rates of entropic dissipation and decay of chemicals to estimate vulnerability. Although some microbiologists have attempted to use similar models (e.g. Fiksel and Covello 1986, Strauss 1991), organisms fundamentally do not behave as chemicals. Because organisms--unlike chemicals or atoms--mutate, adapt, reproduce, and interact with other organisms, the adequacy and usefulness of the chemical risk assessment model has been challenged (Sutor 1985, Cairns and Pratt 1986, Fiksel and Covello 1986, Andow et al. 1987, Tiedje et al. 1989, Naimon 1991, Sharples 1991). Second, risk assessment of natural ecological systems leads to complex perceptions of vulnerability. Developing traditional risk assesssment models for ecosystems is difficult because of the large number of sequential events, complex interactions, and influence of environmental variation (Fiksel and Covello 1986, Bartell et al. 1992). Consequently, assessments made in natural systems have great uncertainties attached to any estimates (Smith 1992) and lack of scientific certainty introduces judgement into the assessment process (Russell and Gruber 1987).

D. What Are The Characteristics of An Ideal Model?

Based on the above considerations, the development of a genetic risk assessment model for artificial propagation should work towards these goals.

- It should provide a systematic method for identifying and evaluating genetic vulnerability.
- Methodology should be well-specified and repeatable.
- Methodology should be capable of using existing data or techniques.
- The model should be based on our best understanding of the structure and function of genetic systems at the appropriate levels of organization.
- Results should be easily understood and fit into decision-making processes, including initial risk assessments during the planning of the program, and subsequent hatchery audits, and monitoring and evaluation.

E. What Are The Assumptions?

The following assumptions, based on examining the constraints and concepts necessary genetic vulnerability assessment, were made to develop the rest of the model.

- The success of every single supplementation project is important.
- Genetic structure is tightly related to genetic function.
- Risk assessment should be based on worst-case scenarios.
- Risk assessment should emphasize the importance of resiliency as well as reliability in determining vulnerability.
- Principles and tools of technology assessment can be applied to genetic hazards and risks of artificial propagation.

II. FOUR STEPS IN GENETIC RISK ASSESSMENT

Genetic risk analysis can be divided into four key steps each of which will be discussed in detailed below:

- Identify the structure of the vulnerability system
- Characterize the sources and endpoints of genetic hazards
- Inventory the proximate and ultimate safeguards against hazards
- Describe vulnerability and present the results.

A. Identify The Vulnerability System

The vulnerability system is the heart of genetic risk assessment and risk management. The system consists of the source of the hazard, control and protective mechanisms, and the endpoints, and the processes that link them. The structure of the system determines how risks, hazards, and vulnerability can described and where managers should focus their efforts to reduce vulnerability. To assess natural resource technologies then, it is essential to understand the system of vulnerability.

The basic vulnerability system of a technological hazard in natural resource-management is illustrated in Figure 1. Five main components make up the system.

- Source of the hazard
- Proximate safeguards
- Endpoints
- Ultimate safeguards
- Failures

The organization of this system is very different from confine-and-control models of other kinds of technological hazards (Figure 2). In confine-and-control situations, source is separated from endpoints by a series of safeguards or control mechanisms that emphasize reliability of control mechanisms in preventing or controlling transfer and exposure to hazards. Vulnerability is reduced by reducing risk. For example, in laboratories using radioactive compounds, vulnerability is controlled by protective measures, such as proper training in handling compounds, wearing protective clothing, confining use to certified areas, and so on. Technicians wear radiation-sensitive safety badges to monitor radioactivity that escapes confinement. This information is then used to determine whether protective measures are

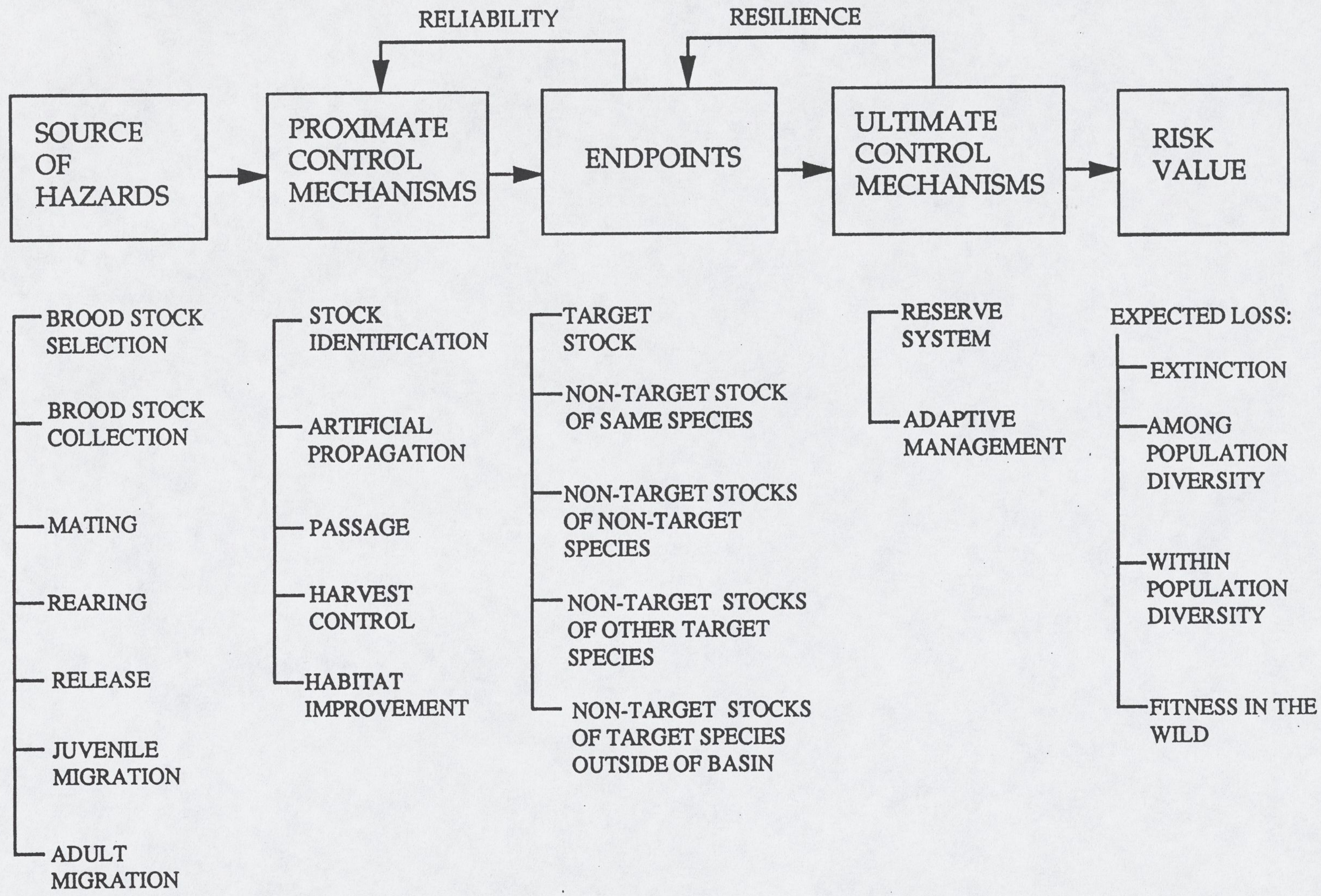

Figure 1. The vulnerability system for technological hazards in natural resource management. Below each component are examples from fishery supplementation projects.

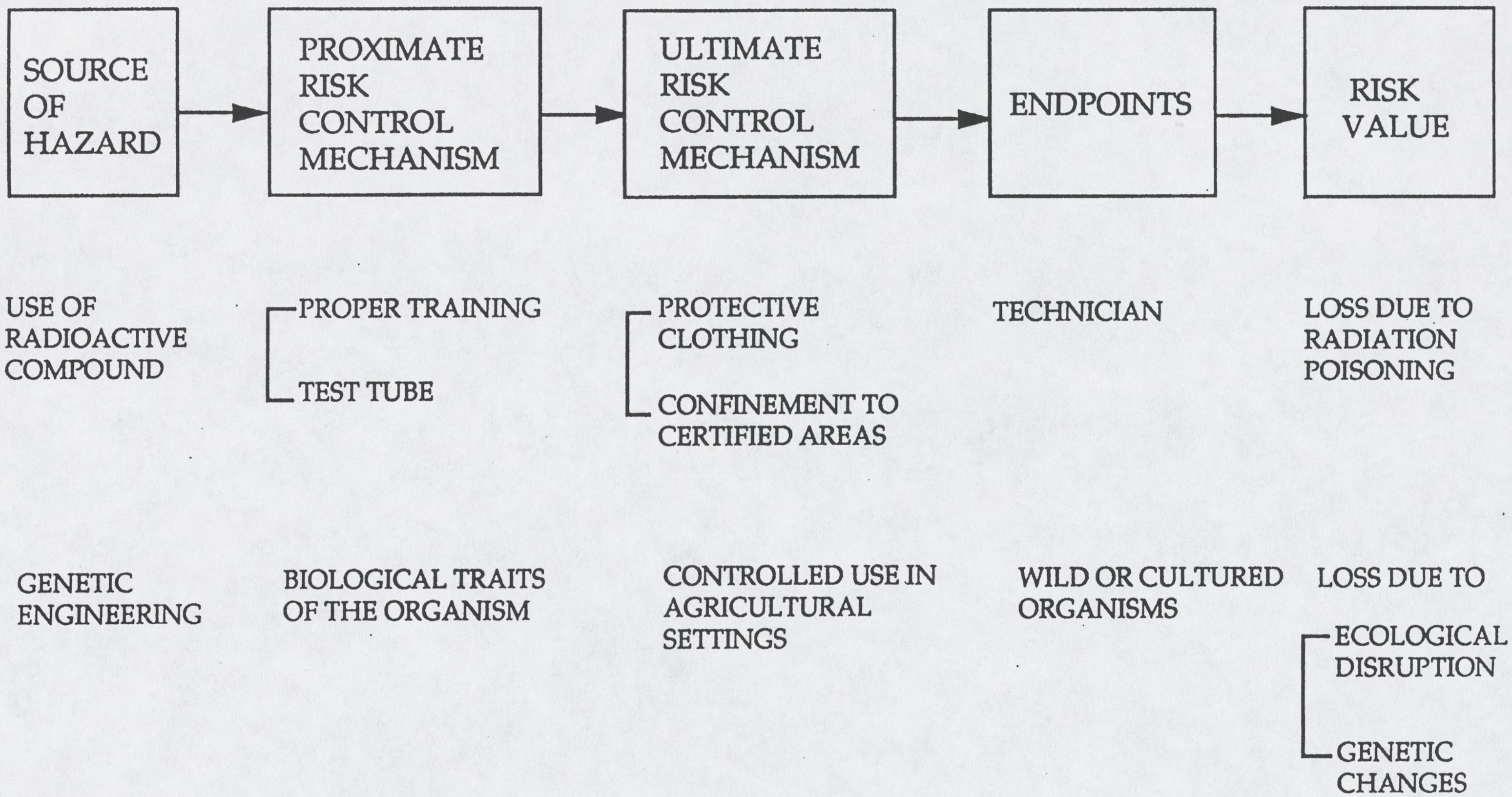

Figure 2. The confine-and-control vulnerability system for technological hazards. Below each component are examples from the use of radioactive compounds in laboratories and the use of genetic engineered organisms.

working or need to be changed. In contrast, emphasizing ways to rehabilitate persons exposed to harmful levels of radiation, rather than confining and controlling the hazards, is not considered part of the system.

The crucial difference between the two systems is that vulnerability in natural resource systems is reduced by limiting loss through resilience provided by ultimate safeguards, as well as by reducing risk through proximate safeguards. Emphasis on reliability of confine-and-control models, which focuses on transfer of a hazard, is clearly not appropriate when artificially-produced fish are intentionally raised and released to have a effect on a wild population. The model of vulnerability for natural resource systems, on the other hand, focuses on the biological capacity for homostasis and heterostasis. Although vulnerability may be reduced by proximate safeguards, such as adherence to genetic hatchery guidelines (e.g. Kapuscinski and Miller 1993), managers must assume that such safe guards will sometimes fail. If proximate safeguards fail, the resource must still be able to respond to the hazard. Consequently, risk assessment for natural resource technologies, such as artificial propagation, must focus on the adequacy of safeguards that emphasize resilience, as well as reliability.

A.1. Sources of Hazard

Sources of hazards are the events or series of events where potentially adverse consequences might occur. The source of the hazards often becomes the focus of management attention rather than the presence or absence of effective safeguards. Seven general sources of hazards in the life-cycle of Pacific salmon from supplemented populations can be identified (Figure 1):

- Brood stock selection
- Brood stock collection and holding
- Mating
- Rearing
- Release
- Juvenile migration
- Adult migration.

Each of these can be divided into two or more specific events with associated hazards and mechanisms. For example, when brood stock are collected from the wild population (the event), non-representative sampling of the population (the mechanism) can result in a loss of within-population genetic diversity (the hazard). Even if the collection is representative, if the mortality in adults before spawning is non-random with respect to genotype (the mechanism), then within-population genetic diversity will be lost (the hazard).

A.2. Description of Endpoints

Hazards are meaningless without endpoints. Because impacts of technological hazards in ecosystems cascade through different levels of biological organization, determination of a single endpoint for risk assessment is not satisfactory (Cairns and Pratt 1986). Genetic risk assessments of supplementation for Pacific salmon have at least five potential endpoints (Figure 1):

- Target population (A)
- Non-target populations of the target species within the target area (B)
- Non-target species within the target area (C)
- Non-target populations of other target species (D)
- Non-target populations of the target species outside the target area (E).

Consider an example where wild steelhead, chinook salmon, and cutthroat trout spawn within several nearby coastal rivers and artificial propagation is intended for steelhead and chinook salmon in one stream (the target area). With the classification above, two different sets of endpoints exist. For steelhead, the target population (A) is the specific spawning aggregation to be supplemented. However, if other genetically differentiated, spawning aggregations of steelhead occur in the river (B), they may be effected by supplementation, as might be the cutthroat trout (C) and the chinook salmon (D). Because steelhead do not spend their entire life-cycle within the river, genetic hazards exist for steelhead in other coastal streams (E) as well. Similar endpoints would be constructed for the chinook salmon as well.

A.3. Proximate Safeguards

Proximate safeguards are components of **reliability** associated with the primary mechanisms by which sources of hazards are controlled to provide benefits to the resource or resource users while limiting vulnerability. Four primary control mechanisms presently exist for supplementation in the Columbia River:

- Artificial propagation
- Control of passage
- Harvest regulation
- Habitat management.

Each of these control mechanisms is associated with one or more hazard sources and represents an opportunity for safeguards.

In most cases, proximate safeguards will include human, physical or logistical, and biological components. For example, Figure 3 illustrates four major components of proximate safeguards. Human components include the quality of the guidelines and ability of technicians to carrying out the guidelines. Guidelines include conservation guidelines, operating guidelines, and decision trees. Conservation guidelines are genetic or ecological guidelines based on first principles (e.g. collect brood fish randomly throughout run; release no more fish than the freshwater carrying capacity for that life-history stage). Operating guidelines are the protocols and procedures that are actually used (e.g. collect every third fish over a weir). Decision trees are flow charts that allow a technician or manager to arrive at an appropriate decisions when unexpected problems arise. Decisions trees are just as needed for managers making conservation decisions as for hatchery biologists raising fish. Technician ability may be divided into having adequate training and skills to complete expected tasks and to make appropriate decisions when the unexpected happens. Logistical components include the availability of enough appropriate equipment and the ability to plan and coordinate the activity. Biological components include the anticipated variability in fish behavior upon which the guidelines are based and the ability to detect and recognize deviations.

A.4. Ultimate Safeguards

Ultimate safeguards are the components of **resilience** in the management of the natural resources. Like proximate safeguards, ultimate safeguards consist of biological and human components:

- Genetic reserves are the biological component.

- Adaptive management is the human component.

The importance of genetic reserves is simply a logical extension of the fundamental genetic objective of supplementation to manage genetic diversity to maintain the capacity of populations to persist in the face of environmental variability using adaptative management (Northwest Power Planning Council 1992b, Regional Assessment of Supplementation Project 1992a). The Columbia Basin Fish and Wildlife Program acknowledges that a supplementation project may fail completely and directs that adaptive management be used encourage resilience. It follows, however, that the potential rate of recovery from failure (i.e. the capacity to persist) depends on the amount and structure of genetic diversity that remains. If proximate safeguards fail or don't exist, genetic reserves provide the most effective resilience, because some of the genetic structure and function that otherwise might have been lost would have been protected.

The link between biological and human components is crucial. Adaptive management increases resilience by providing a means to learn from failures. An often ignored constraint on adaptive management, however, is the availability of future opportunities to apply what has

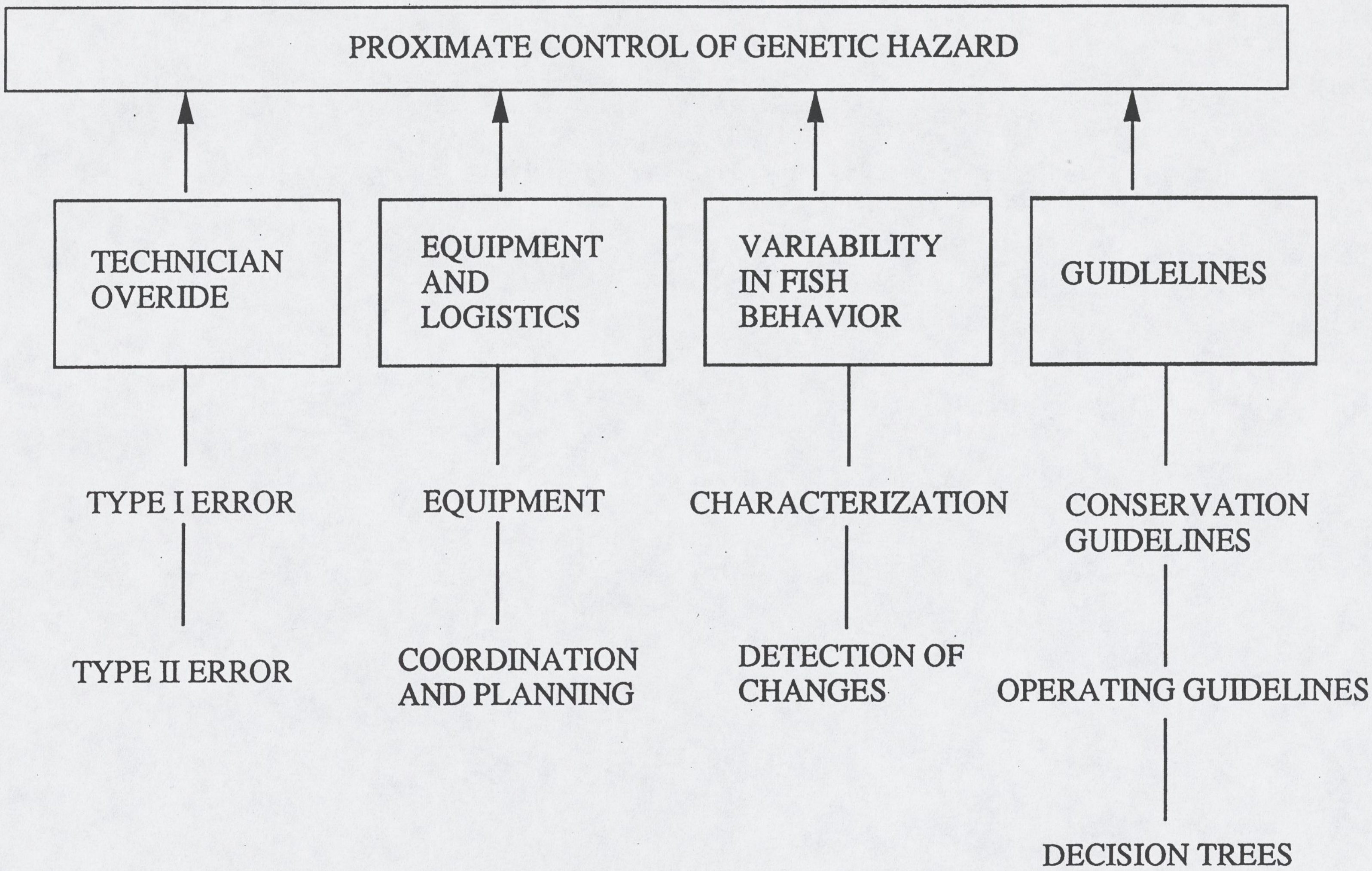

Figure 3. Components of vulnerability control mechanisms in natural resource management.

been learned. Understanding what we should have done is a hollow lesson when we've lost the resource we wanted to manage in the process. Reserves allow adaptive management to work. General principles for creating and managing genetic reserves in the Columbia River have been described by Currens et al. (in review).

B. Inventory Sources, Endpoints, and Safeguards

Once components of the vulnerability system have been identified, the next step is to gather the data for the genetic risk assessment. This has two parts:

- Identification and characterization of each hazard source and its respective endpoints

- Inventory of proximate and ultimate safeguards.

B.1. Identification and Characterization of Sources and Endpoints

Because sources of hazards and endpoints are so intimately related, they may be characterized as part of a single process. This may be done systematically in two steps:

- Identification of sources and mechanisms for each possible hazard-endpoint combination

- Description of the characteristics of the source that potentially create hazards.

One method of systematically organizing the sources and mechanisms of genetic hazards for each endpoint-hazard combination is to construct for each source a matrix of the four types of genetic hazards (see Section I.C.3.a) and the five types endpoints (see Section II.B.2.b) and fill it in with the appropriate genetic or demographic mechanisms. Once the appropriate mechanisms have been identified, data are collected to describe the characteristics of the mechanisms that potentially create hazards, including the types, duration, intensity, and amounts. For example, one cell in the matrix for brood stock collection might describe non-random sampling of spawners as the mechanism resulting in loss of within-population diversity in the target population. To characterize this possible hazard, we would want to gather data on the sampling procedures and variability of the endpoint: How many fish are to be taken? What is the sampling design? What kind of capture technique will be used? What is known about the variability in the wild, donor population?

B.2. Inventory of Safeguards

The second step in gathering data for genetic risk assessment is to inventory and describe the safeguards associated with each hazard source. The key to accomplishing this is to construct a complete diagram of the relationships of the major components of each safeguard. Once components have been identified, they can be characterized, either qualitatively or quantitatively, by descriptions, presence or absence, ratings, or results of empirical testing.

Three tools are often used in risk assessment for identifying and analyzing components of vulnerability:

- Relevance tree analysis
- Fault tree analysis
- Decision trees

In relevance tree analysis, a central component or function is reduced into simpler elements that support it. Relevance trees are well-suited for analyzing hierarchical systems and assessing the relative importance of different components, when it is not critical to capture a dimension of time. Relevance trees are useful for analyzing both proximate and ultimate safeguards. Figure 3 is an example of a relevance tree.

When elements are organized sequentially, as they are in proximate safeguards, fault tree analysis may be more appropriate. Fault tree analysis uses flow charts to display all the possible independent elements that must work if the safeguard is to prevent a failure. Figure 4 is a simple example of a fault tree analysis for collecting brood stock representative of the wild population. Failure of any of the four main components will result in a failure to collect representative brood stock. First the guidelines must be correct. Next, the fish must behave in a way that was anticipated by the guidelines. Even if these two conditions hold, the procedure may fail if the collectors do not have enough available equipment adequate for the task. Finally, the technicians must be able to do the work.

Technician failure can happen in two ways (Wilson 1991). First, they may simply be unable to do the work because of unavailable guidelines, knowledge of the natural variation of the fish, equipment, as well as lack of skill and training (Type I error). Second, if they are aware that one of the previous components may have failed (e.g the seine is unable to capture any portion of what appear to be the largest, oldest fish in a boulder-filled pool), which should lead to failure to accomplish the goal of representative samples, they may choose to overide the system and continue. If, in fact, their decision was correct, no harm was done. If, however, their decision was wrong (Type II error), then they failed to get a representative sample for brood stock.

Decision trees are valuable in analyzing vulnerability associated with making different choices. Decision trees are maps of the choices that lead to specific actions or conclusions. By formalizing judgements of an organization or expert, decision trees allow different individuals to arrive at uniform conclusions or actions. Because of this, future responses to crisis can be anticipated and evaluated. In the example above, for example, a well-developed decision tree might reduce risks of technician overides. Likewise, evaluation of decision trees based on the different proposed management responses to unsuccessful hatchery performances allows risks analysis of how well adaptive management might operate to reduce vulnerability.

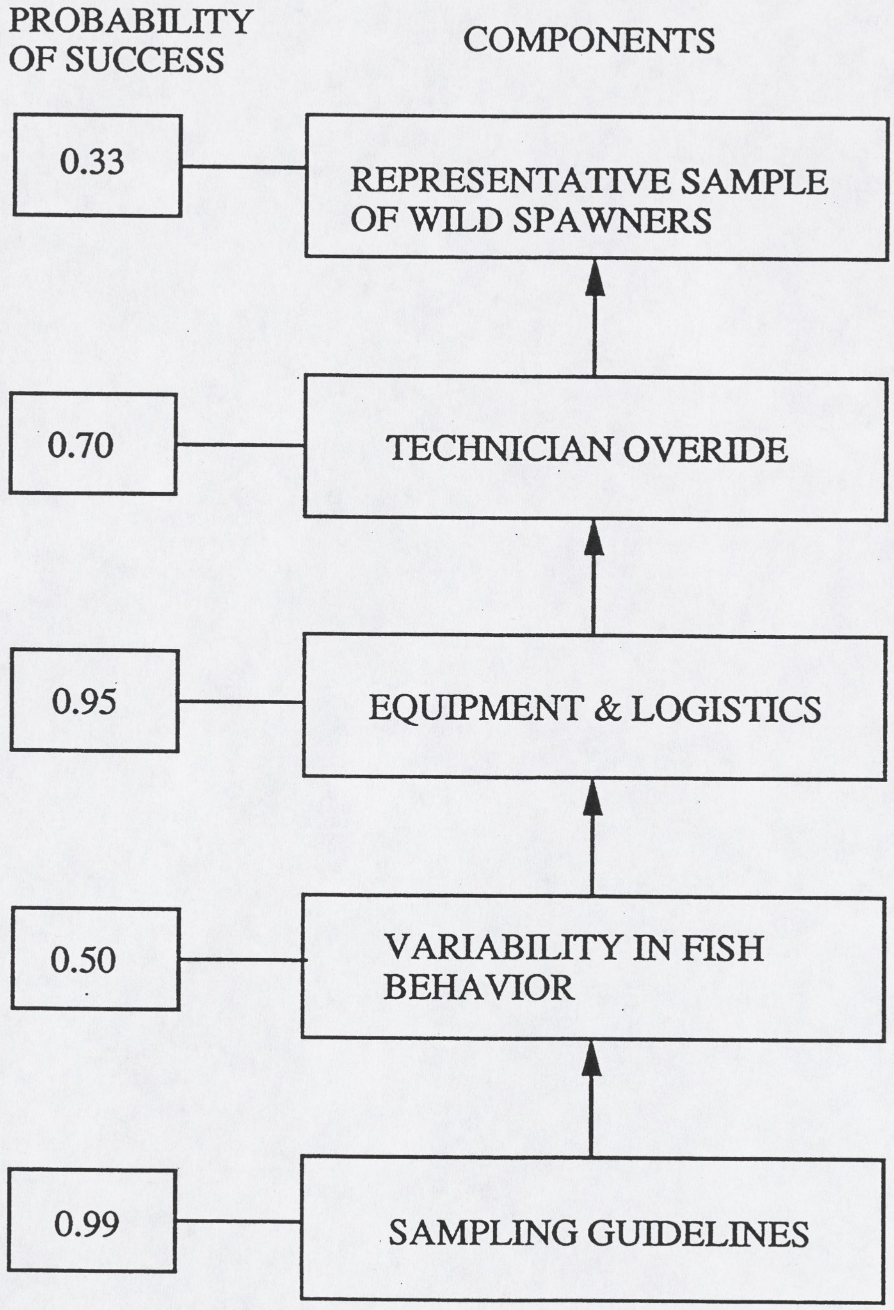

Figure 4. Fault tree analysis of collecting a representative sample brood stock from a wild population of fish.

C. Describe Vulnerability

The last and most challenging step in risk assessment is to describe and present the results. Four different approaches are presented:

- Genetic and demographic models
- Comparative vulnerability scores
- Qualitative description
- Probabilistic descriptions.

The emphasis of all these approaches is on identifying the components that contribute most to vulnerability and that can be corrected rather than on estimating probabilities (risks) that genetic hazards will occur. Probabilistic descriptions are not emphasized for two very important reasons:

- If we can not afford to fail in a supplementation or recovery program, then long-term frequencies are not a sound basis for estimating probability of success for a given project or making policy decisions.

- Prediction relies on statistical theory and large amounts of accurate historical data, which are generally not available for supplementation, if it is to generate a probability that an event will occur that is not completely speculative and unreliable (Fiskel and Covello 1986).

C.1. Genetic and Demographic Models

The primary purpose of using genetic and demographic models is to describe potential genetic hazards simply and quantitatively in terms of loss of genetic structure or function. These analyses can provide an estimate of potential losses and help identify sources of hazards that were otherwise were not obvious. For example, given an estimate of what gene flow might be among large, supplemented populations under different production strategies, it is possible to describe the between-population diversity that might be lost. Likewise, simple birth-and-death demographic models can be used to describe the growth or decline of a population as brood stock are continually taken from the wild and more complex models can be used to describe extinction under a variety of scenarios. The use of genetic and demographic models can be tailored to the specific project, based on availability of data and preliminary qualitative assessment of which aspects of the project are most vulnerable.

C.2. Comparative Vulnerability Scores

The primary purpose of comparative vulnerability scores is to calculate relative values for different components of a supplementation effort that will allow project managers to identify the most vulnerable areas. The analysis is based on the inventories and descriptions of sources, endpoints, and proximate and ultimate safeguards identified in the previous step of risk assessment. In its simplest form, this is the procedure: At each level and for each component identified in relevance tree analyses (Figure 3), the performance of the supplementation project is rated from 1 (poor) to 5 (good) according to predetermined criteria. For example, for brood stock collection, assessment might begin with the guidelines. For each element (conservation guideline, operating guidelines, decision trees), the project is given a score based on whether the elements have been developed, implemented, and how effective they are. Lack of decision trees, for example, might rate a 1, whereas well-developed decision trees might rate a 5. After all the different elements of brood stock collection have been rated, the scores for each component (e.g. all the elements under sampling guidelines) can be normalized (maximum score of 100). The scores have no absolute value, unlike genetic or demographic calculations. However, completed across the whole project, it possible to compare parts of the project and identify the areas that are most vulnerable.

C.3. Qualitative Description

Qualitative descriptions are most useful when quantification is not always appropriate or necessary. When probabilities and losses are poorly understood and precision of the estimates is large, then qualitative descriptions of vulnerability are appropriate. This is especially important when attempts to force the data into a quantitative model would provide an impression of precision that is not warranted. Likewise, when probabilities and losses of specific mechanisms are well understood, but precision is not needed for risk assessment (e.g. vulnerability of eggs to light or desiccation) then hazard descriptions are all that is necessary (Fiksel and Covello 1986).

C.4. Probabilistic Description

Probabilistic descriptions are intended to be predictive. The problems of using probabilities for predicting short-term success were discussed earlier (Section I.C.6). However, fault tree analysis is one method which may be useful both for its predictive and heuristic value.

In fault tree analysis, a probability of success is estimated for each independent component. Because the probability of success of the whole is the product of probabilities of success for each component, probability of failure for the whole process can be calculated. For example, in Figure 4 the probability of successfully collecting a representative sample for brood stock is 0.33 -- or the product of the probabilities that sampling guidelines are correct (0.99), that fish behave as anticipated (0.50), that it is logistically possible to sample the fish (0.95), and that the technicians make all the correct decisions (0.70). If an estimate of loss is available from genetic or demographic descriptions then it is possible to calculate a value of risk using equation 1.2.

The difficulty in using fault tree analyses is in estimating probabilities. Estimates of probabilities generally come from long-term frequencies of failures based on empirical testing or analysis of historical records. Because in ecological systems it may be impossible to obtain accurate estimates of the probabilities for each component, the use of fault tree analyses provides one method of obtaining an upper limit on the probability of success: if one or more components are amenable to empirical or historical assessment, even if others aren't, the overall probability of success has to be lower than any single probability or product of probabilities (Stich 1978). When no historical data or empirical assessments are available, however, estimates can be generated by a Delphi process. The Delphi process attempts to exploit the opinions of a group of experts using a highly structured format that preserves anonymity while allowing feedback to minimize adverse effects of group dynamics (O'Keefe 1982).

In addition to providing a simple method of calculating probability of success, fault tree analysis is extremely useful for identifying the components that contribute most to vulnerability that can be reduced. For example, if the hypothetical estimates in Figure 4 are reasonably accurate, then the analysis clearly indicates that the most likey source of failure is because we don't understand variability in behavior and technicians are likely to make costly errors. Nothing can be done about variable behavior except by collecting more informantion. However, the success of technicians can be improved by proper training and providing them with decision trees. Spending large amounts of time and money on other components may not provide the same benefits.

III. GENETIC VULNERABILITY OF THE YAKIMA FISHERY PROJECT

A. Purpose

The purpose of this part of this report is to apply the fundamentals of genetic risk assessment described above to evaluate genetic vulnerability of the Yakima Fishery Project. Two levels of risk assessment are required for supplementation in the Columbia River Basin (Columbia Basin Fish and Wildlife Authority 1991). Level I risk assessment, which was provided by Busack (1990), identifies genetic risks during the planning and evaluation of production alternatives. Once alternatives have been selected, Level II risk assessment is developed as part of operation plans and includes more quantitative analysis of production measures and the contigency plans to prevent, terminate, and correct undesirable genetic impacts.

This report provides a Level II risk assessment of the Yakima Fishery Project for three groups:

- Yakima spring chinook salmon
- Yakima summer steelhead
- Yakima fall chinook salmon.

Additionally, hazards associated with supplementation of Yakima summer chinook salmon and coho salmon are discussed.

B. Materials and Methods

The worst-case scenario for this analysis is defined as the null hypothesis that supplementation is no different than conventional artificial propagation of salmon. Choosing this level has two important advantages. First, it is based on realistic scenarios. Second, unlike the speculation about what supplementation may accomplish, worst-cases scenarios are described by considerable historical data.

B.1. Sources of Information

- Yakima/Klickitat Production Project Preliminary Design Report & Appendices (Anonymous 1990).
- Yakima/Klickitat Fisheries Project Draft Project Planning Status Report (Yakima Fishery Project Science Team 1992)
- Yakima/Klickitat Fisheries Project Planning Status Report 1992, Vol. 1-8 (Anonymous 1992)

- Yakima Hatchery Experimental Design (Busack et al. 1991)

- Yakima Basin Subbasin Salmon and Steelhead Production Plan (Confederated Tribes and Bands of the Yakima Indian Nation et al. 1990)

- Yakima River Spring Chinook Enhancement Study (Wasserman et al. 1984, Fast et al. 1985, 1986, 1987, 1988, 1989, 1991a, 1991b).

- Yakima Fisheries Project Operations/Procedures Manual (Hagar, In prep.).

- Yakima River Basin Fisheries Project Draft Environmental Impact Statement (Bonneville Power Administration 1992).

B.2. Describing Extinction

The purpose of this analysis was to examine differences in chance extinction of salmon and steelhead in the Yakima River with and without supplementation. It was not intented to provide absolute estimates of extinction probabilities. The relationships between chance extinction and demography were examined using the model by Goodman (1987), which expresses persistence time as a function of mean population growth rate and variance in population growth rate. Supplementation is expected to increase population growth rate, because it decreases the death rate during the early life-history of the fish. However, it will not necessarily change variance in population growth rate.

Mean population growth rates (r) and variances for natural populations of spring chinook salmon and steelhead were calculated from historical trends in numbers of fish and from estimates of age structure of the spawners (Fast et al. 1991, Yakima Fishery Project Science Team 1992). Calculated values of r were assumed to represent the maximum limit of population growth rates expected of these populations under historical fishery management policies and environmental variation. Minimum population growth rates for populations which have persisted in Yakima River at low levels over the last 30 years were set at 1. Growth rates under supplementation were calculated from project estimates of fecundity of brood stock of different ages, prespawning mortality, egg-to-smolt survival, and smolt-to-adult survival of hatchery-reared fish, assuming (1) brood fish were a representative sample of the natural population; (2) mating between wild and hatchery fish was random, (3) values for fitness of the matings of hatchery and wild fish were

wild x wild	= 1.0
wild x hatchery	= 0.8
hatchery x hatchery	= 0.5,

as used by the System Planning Model, (4) no fitness difference existed among hatchery and wild fish in the F_2 generation, and (5) no more than 50% of the wild spawners could be used as brood stock. Variance in mean growth rate was assumed to be 12.08, based on the agreement between observed variances for three different stocks of Yakima spring chinook salmon for which we have the most complete long-term data set (Fast et al. 1991) and Belovsky's (1987) estimate of 7.32r for high environmental variance.

B.3. Comparative Vulnerability Scores

Evaluation of proximate and ultimate safeguards was based on comparative vulnerability scores. Comparative vulnerability scores have no absolute value but rather provide a systematic means of identifying and describing patterns of vulnerability due to flaws in production measures or contingency plans to prevent, terminate, and correct undesirable genetic impacts. The reasons for relying on comparative vulnerability scores, rather than probabilistic or deterministics descriptions are discussed in Part I of this report.

For each of the seven sources of genetic hazards (Fig. 1), potential scenarios that might lead to losses from any of the four kinds of genetic hazards at any of the five possible endpoints were identified. Then, for each source and each kind of hazard, the project was given a rating of 1, 2, 3, or 5 for the availability, appropriateness, and sufficiency of each of the essential components of proximate and ultimate safeguards that increase reliability and resilience and reduce vulnerability (Table 1). A component was appropriate if it was consistent with the principles and actions recommended in the genetic guidelines. A component was sufficient if it was both appropriate for all endpoints and well-enough developed to allow monitoring and evaluation. Criteria for scoring components of proximate and ultimate control mechanisms are given in Table 1 and Table 2, respectively. Reliability or resilience scores (R) were computed as the proportion of the maximum possible score x 100, such that a score of 100 indicated the highest possible reliability and a score of 20 indicated the lowest possible reliability. Thus,

$$R = \frac{\sum_{i=1}^{n} C_i}{5n} 100 \qquad (3.1)$$

where C is the score of each component and n is the number of components in that safeguard. To compare vulnerability of different hazards among different parts of the project, vulnerability was calculated by

$$V = (1-\sum_{i-1}^{N} 0.01R_i)\,L \qquad (3.2)$$

where N is the number of sequential events that combine to realize a loss and L is the value of the loss. Without empirical data to set the relative genetic losses of extinction, loss of within-population diversity, loss of among-population diversity, and domestication, all hazards -- except extinction -- were arbitrarily given a value of 100. Loss due to extinction of a

Table 1. Components and criteria for assessing reliability of proximate control mechanisms in supplementation. Hazards are 1) extinction, 2) loss of within-population genetic diveristy, 3) loss of between-population genetic diversity, and 4) domestication.

COMPONENTS	HAZARD SCORES				
C.. HAZARD:	1	2	3	4	
C.1.. Guidelines					
C.1.a.. Genetic Guidelines					
C.1.b.. Operating Guidelines					
C.1.c.. Decision Trees					
C.2.. Natural Variability					
C.2.a.. Baseline Characterization					
C.2.b.. Detection of Departures from Baseline					
C.3.. Logistics					
C.3.a.. Equipment					
C.3.b.. Coordination					
C.4.. Technician Ability & Judgment					
C.4.a.. Type I Error					
C.4.b.. Type II Error					

1 = component is not available and not indicated in project planning documents.

2 = component is available but not appropriate or sufficient OR component is not available but project documents indicated that an appropriate safeguard is to be developed.

3 = component is available and appropriate but not sufficient.

5 = component is available, appropriate, and sufficient.

Table 2. Components and criteria of assessing reserves as ultimate control mechanisms.

CRITERIA FOR EVALUATING POTENTIAL RESILIENCE FROM RESERVES	SCORE
1. Availability No genetic or ecological reserves identified = 1 Reserve identified but not implemented = 3 Reserve identified and implemented = 5	
2. Appropriateness Scoring: Neither of the criteria below apply = 1 One of the two criteria apply = 3 Both criteria apply = 5 • Genetic structure is template for identifying the reserve. • Reserve represents ecological, aquatic diversity of area targeted for supplementation.	
3. Sufficiency Scoring: None of the criteria below apply = 1 One of the criteria apply = 2 Two or three of the criteria apply = 3 Four criteria apply = 4 All criteria apply = 5 • Probability of extinction of target species in the reserve is less than 5% in 200 years. • Reserve protects genetic and ecological diversity of more than one stock. • Harvest management goals protect reserve. • Management goals (e.g. harvest, interagency agreements about habitat, water flows, migratory corridors, artificial propagation) are defined within a temporal hierarchy, beginning with the goal that the reserve should function for at least 200. • Reserve protects or restores historical complexity of migratory patterns of target species.	

group of populations of the same species was set to 200, or the sum of losses of within-population diversity and among-population diversity. Total vulnerability was calculated as the sum of the vulnerability of the different proximate and ultimate control mechanisms:

$$V_{TOT} = V_{DAP} + V_{IAP} + V_{HB+P} + V_{HV+P} + V_{UCM} \tag{3.3}$$

where

V_{TOT} = total vulnerability
V_{DAP} = vulnerability of artificial propagation due to direct genetic effects
V_{IAP} = vulnerability of artificial propagation due to indirect ecological effects.
V_{HB+P} = vulnerability of habitat and passage management
V_{HV+P} = vulnerability of harvest and passage management
V_{UCM} = vulnerability of reserves.

C. Vulnerability of Yakima River Spring Chinook Salmon

C.1. Special Problems

Two special problems confront management of genetic vulnerability for spring chinook in the Yakima River:

- No practical method is available to avoid collecting American River salmon while collecting Naches River spring chinook for brood stock.

- American River spring chinook will not be supplemented because they have been designated a genetic reserve but low numbers of adult fish returning to this population give it the greatest probability of chance extinction.

C.2. Extinction

For every 100 spring chinook salmon taken as brood stock from the upper Yakima River and Naches River, Yakima Fishery Project data indicate that on the average only 53 and 66 fish, respectively, will return. This rate of return is the product of 80% expected pre-spawning survival of brood stock (Hagar, Yakima Fisheries Project Operations/Procedures Manual), expected mean fecundity of 4084 and 5067 eggs per female from the upper Yakima and Naches rivers, respectively (calculated from age structure and fecundity data in Fast et al. 1991), expected 65% egg-to-smolt survival (Hagar, Yakima Fisheries Project Operations/Procedures Manual), and 0.05% release-to-adult survival (Fast et al. 1991). No data presently support greater returns under supplementation. If population growth of wild-spawning spring chinook salmon isn't far enough above replacement levels to buffer against this loss, supplementation will lead to extinction of the entire population.

Under supplementation, mean growth rate of the population is reduced. Mean growth rates less than 1.0 indicate that numbers of adult salmon returning to reproduce are declining.

From 1962 to 1991, mean growth rate of upper Yakima and Naches river spring chinook salmon was 1.65. Under simple, deterministic conditions of supplementation, mean growth rate of upper Yakima and Naches river chinook salmon populations would be reduced to approximately 1.06 and 1.11, respectively. Assuming replacement of wild fish was 1, mean growth rate of upper Yakima and Naches chinook salmon under supplementation would be 0.71 and 0.75.

Figures 5 and 6 illustrate the relative effect of supplementation at high and low growth rates of the wild spawning fish on frequency of extinction. At mean population growth rates maintained by unsupplemented Yakima River spring chinook salmon over the last 25-30 years, probability of extinction in the next 100 years is consistently less for all population sizes than under supplementation. The smaller the spawning population size, the more pronounced is the difference (Figure 5). Similarly, at 5% probability of extinction, unsupplemented spring chinook salmon populations are expected to persist for more generations than they would under supplementation. When very few spawners return per generation, however, the expected persistence times of the population are so short that differences are meaningless.

C.3. Reliability and Resilience

A reliability or resilience score of 60 or greater for proximate or ultimate control of vulnerability at any given source of genetic hazard indicates that over all, the essential components of that control mechanism were available and appropriate. For spring chinook salmon, the only proximate control mechanism that consistently scored over 60 was genetic stock identification (Table 3, Appendix A). Isolated scores of 100 in Table 3 (e.g. control of extinction during mating) reflect situations where the hazard was considered inappropriate; no control mechanism scored 100 because it was perfect.

Three major factors contributed to low scores for supplementation of spring chinook salmon:

- Operating procedures and protocols for how conservation guidelines will be implemented did not exist, were inconsistent with conservation guidelines, or have only been superficial developed.

- Very few decision trees have been developed to indicate what the contigency plans are for failure or unanticipated results of a control mechanism.

- Planning documents indicated no intentions to provide appropriate training to avoid type I and type II error by technicians or biologists.

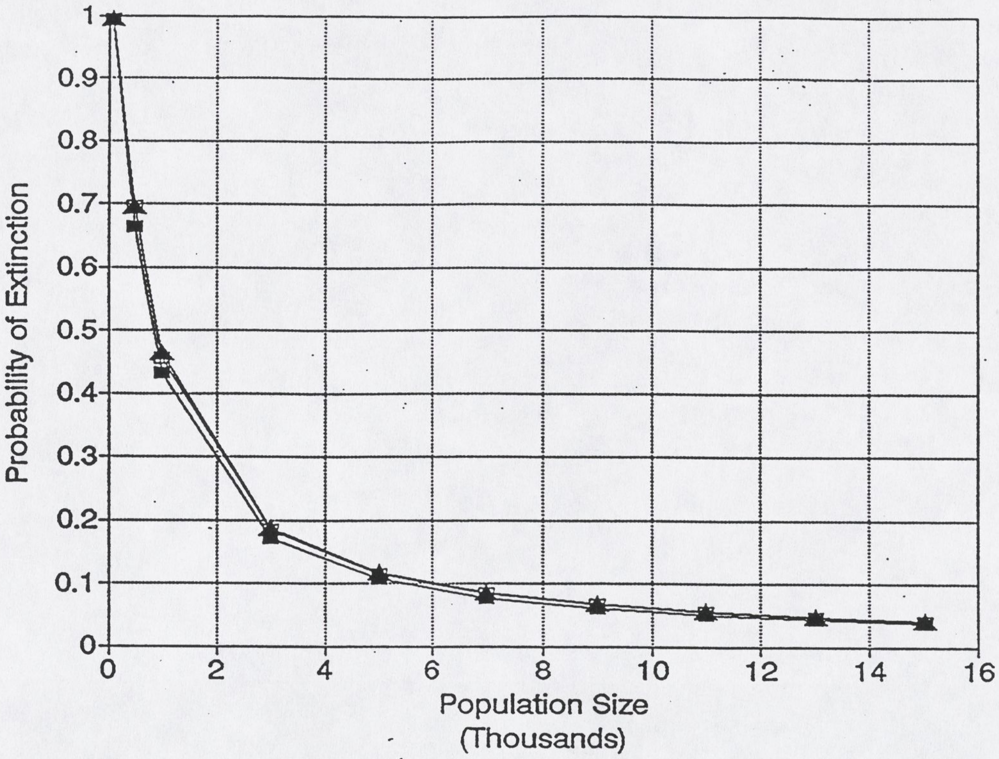

Figure 5. Relative probability of extinction in 100 years for Yakima River spring chinook salmon at different spawning population sizes with and without supplementation. Solid boxes indicate unsupplemented populations at high population growth rate; open boxes show unsupplemented populations at a low population growth rate and supplemented populations at a high population growth rate; triangles are supplemented populations at a low population growth rate.

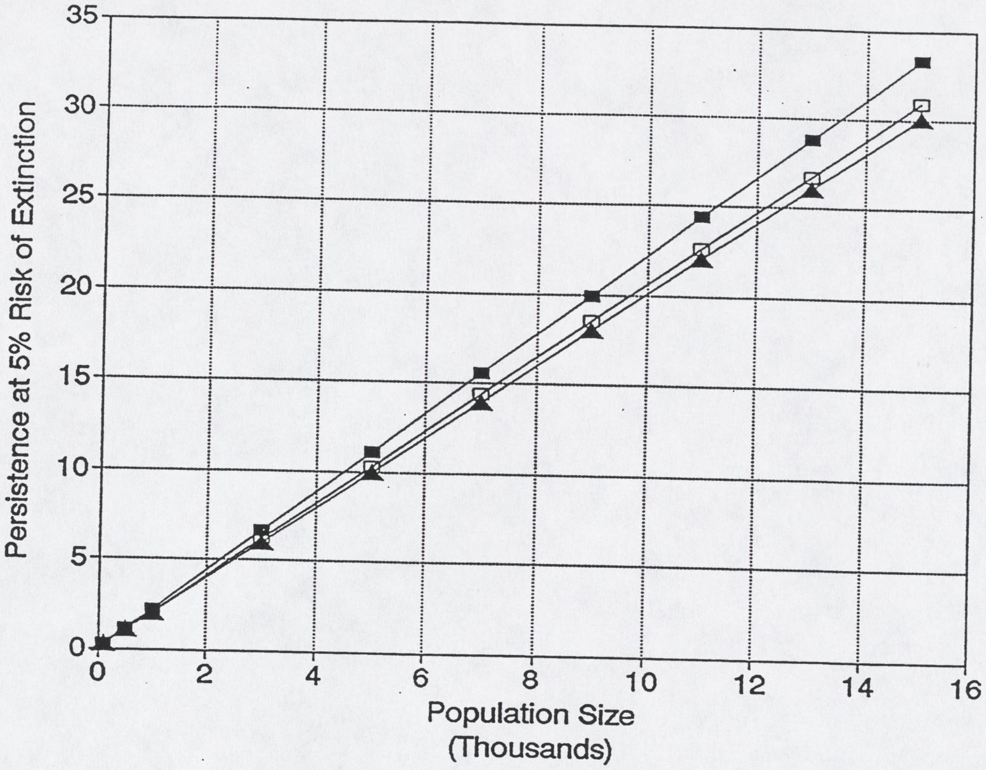

Figure 6. Relative persistence (in generations) at 5% risk of extinction for Yakima River spring chinook salmon at different spawning population sizes with and without supplementation. Solid boxes indicate unsupplemented populations at high population growth rate; open boxes show unsupplemented populations at a low population growth rate and supplemented populations at a high population growth rate; triangles are supplemented populations at a low population growth.

Table 3. Reliability and resilience scores for proposed supplementation of Yakima River spring chinook. A score of 100 indicated high reliability or resilience, whereas a score of 20 indicates low reliability or resilience. Genetic hazards are 1) extinction, 2) loss of within-population genetic diversity, 3) loss of between-population genetic diversity, and 4) domestication.

		Genetic Hazard			
Controls	Source of Hazard	1	2	3	4
Genetic stock identification	Brood stock selection	91	91	91	91
Artificial propagation	Brood stock collection	40	44	53	29
	Mating	100	49	49	44
	Rearing	40	40	40	40
	Release (direct effects)	38	36	36	40
	Percent of maximum reliability score	5.5	2.8	3.4	1.9
	Release (indirect effects)	33	33	33	100
	Percent of maximum reliability score	33.3	33.3	33.3	100
Passage and Habitat	Juvenile migration	33	33	100	100
	Percent of maximum reliability score	33.3	33.3	100	100
Passage and Harvest	Adult migration	53	53	36	100
	Percent of maximum reliability score	53.3	53.3	35.6	100
Genetic reserves	All of the above	53	53	53	53
	Percent of maximum reliability score	53.3	53.3	53.3	53.3

Lack of appropriate training for technicians and biologists was conspicous for every source of genetic hazard. As a new application of artificial propagation, supplementation has such special problems that geneticists have been hired to identify and characterize them. Assuming that technicians and field biologists already have the training to implement this technology correctly is a major weakness. Control mechanisms of each of the potential sources of genetic hazards are discussed in detail below.

C.3.a. Genetic Stock Identification

Selection of brood stock has a direct effect on vulnerability to all four major genetic hazards. Genetic stock identification for spring chinook salmon had the highest reliability score of any control mechanism for any species examined during this project. Every component was judged available, appropriate, and sufficient, except for decision trees and the ability to detect departures from baseline stock identification (Appendix A). Needed are explicit decision rules for how to proceed on selection of the Naches River stock as a brood stock if it continues to be impossible to avoid collecting American river adults with Naches River brood stock.

C.3.b. Artificial Propagation

C.3.b.(1). Brood Stock Collection

For brood stock collection, the greatest weakness was the lack of operating guidelines for how brood stock would be collected and held to assure a representative sample of the upper Yakima River population. For example, no guidelines, decision trees, or monitoring procedures existed to control possible non-random mortality of brood stock while they are being held prior to spawning (Appendix A), yet potential effects of 20% non-random mortality should not be ignored. Likewise, although minimium effective population size (N_e) of natural populations should be at least 500 for genetic reasons (Lande and Barrowclough 1987), no decision rules were available for deciding how to proceed if N_e falls below 500 during supplementation or if more brood fish are being taken for brood stock than return from supplementation.

C.3.b.(2). Mating

Reliability of controls for mating was the greatest of any source of genetic hazard associated with artificial propagation (Table 3), primarily because conservation guidelines were well-developed (Kapuscinski and Miller 1993), operating guidelines were to be consistent with conservation guidelines (Hagar, in prep.), and monitoring procedures were being developed.

C.3.b.(3). Rearing

In contrast, low reliability of controls during rearing (Table 3) reflected two major weaknesses.

- Operating guidelines for rearing fish according to the recommendations in conservations guidelines (Kapuscinski and Miller 1993) were missing.

- Decision trees for how to respond to unexpected emergencies that might either compromise genetic goals or experimental goals have not been developed.

Experimental hypotheses and designs have been formulated for rearing, but without operating guidelines it was difficult to determine what the actual environments of the fish in the hatchery will be and whether they were appropriate or sufficient. Likewise, lack of decision trees here is crucial. For example, if the health of fish in one experimental environment appears to be worsening due to unanticipated direct or indirect effects of the rearing regime, will the regime be changed or will it remain the same? If it is not changed, a large portion of the fish may be lost, resulting in lower overall returns to a natural population from which more brood stock may already be being taken then return from supplementation. This increases vulnerability to extinction and and loss of within-population genetic diversity. However, if rearing is changed, the experiment is jeopardized.

C.3.b.(4). Release

Release of fish is both a direct and indirect source of genetic hazards. Consequently, artificial propagation was judged least reliable in controlling hazards associated with acclimation and release (Table 3). Two components of this safeguard need work.

- Operating guidelines were inconsistent with conservation guidelines or poorly-developed.

- Decision trees have not been developed.

Conservation guidelines recognized the uncertainty associated with time, place, and condition of releasing fish (Kapuscinski and Miller 1993). However, present operating guidelines created several several problems. For example, supplementation of Naches spring chinook salmon called for acclimation facilities on the Little Naches River (Anonymous 1990). Although this site may be appropriate for imprinting Naches River spring chinook salmon, it is also very near the American River. Low levels of straying may occur naturally between neighboring wild chinook salmon in American River and Bumping River (Craig Busack, Washington Department of Fisheries, unpublished data). However, untested acclimation procedures could increase numbers of potential Naches River salmon straying into the American River, resulting in loss of among-population genetic diversity and of a reserve. Likewise, winter migration of wild spring chinook in the Yakima River is an important behavioral trait (Fast et al. 1991), but it was unclear how this will be altered in hatchery-reared salmon by release protocols. Finally, conservation guidelines recommended that the numbers of fish released be based on freshwater carrying capacity. However, actual numbers of fish appeared to be based on sample sizes necessary to detect statistical significance rather than on biological criteria (Anonymous 1992).

No decision trees were available for situations involving release. What will be done with fish that do not choose to leave release facilities? If these fish are forcibly released, how will they be monitored. Very little baseline data existed to determine the reliability of operating guidelines for releasing fish in protecting genetic diversity of non-target species.

C.3.c. Management of Juvenile Migration and Habitat

Reliability of managing juvenile passage and habitat to control genetic hazards was the least of any component of artificial propagation (Table 3). Lack of reliability here is critical because mortality during passage through the Yakima River is a major source of poor smolt-adult survival rates (Fast et al. 1991). Three major weaknesses of this proximate safeguard were the following:

- Conservation guidelines have not been well-developed.
- Operating guidelines were absent or poorly-developed.
- Decision trees were missing.

First principles of conservation genetics and ecology have been applied to most other proximate controls, but specific guidelines are lacking for management of juvenile migration and habitat. Operating guidelines dealing with passage, water flows, and predators are certainly available, but some are inappropriate or untested. For example, one first principle is to protect or restore historical complexity of migratory patterns of target species (Currens et al., in review). Yet, although project returns of target species would increase by improving flows, the Yakima Fishery Project has an operating guideline of not affecting water in the Yakima Basin (Bonneville Power Administration 1992). Similarly, no appropriate proximate controls have been tested that would protect less productive, natural populations of fish from depletion due to increased natural harvest (i.e. predation) because large numbers of predators have been attracted by an abundance of hatchery-reared fish. Finally, contigency plans and decision rules have not been developed for problems associated with juvenile passage and habitat.

C.3.d. Management of Adult Migration and Harvest

Management of adult migration and harvest had relatively greater reliability to protect against extinction and loss of within-population diversity than to protect against loss of among-population diversity (Table 3). The higher scores for extinction and loss of within-population diversity (Appendix A) reflect intentions to use multiple-stock status-indexed harvest management that is based on protecting the less productive stocks (Yakima Fishery Project Science Team 1992). This an unofficial document, however, and scores could change when actual operating guidelines can be evaluated.

A major conspicuous weaknesses of management of adult migration and harvest was the lack of sufficiently well-developed conservation guidelines to judge whether operating guidelines guidelines for harvest are appropriate. For example, although minimum N_e might be 500 for genetic reasons, it is not certain that this is an adequate number of spawners to protect against demographic risks of extinction (Figure 5, 6). American River spring chinook most likely already have an N_e below 500 (Craig Busack, Washington Department of Fisheries, unpubl. data).

Lower scores for loss of among-population diversity reflected the uncertainty and lack of decision trees associated with using a wier or other facility (Anonymous 1992, Yakima Fishery Project Science Team 1992) to prevent strays from entering the American River. Although this may prevent fish of other populations from spawning in the American River, it may also prevent American River salmon from entering the river. This would effectively reduce N_e of the American River and could lead to American River salmon spawning with other populations.

C.3.e. Genetic Reserves

Recognition that genetic reserves are an essential component of reducing vulnerability is a major strength of the Yakima Fishery. The American River has been designated a reserve because it was genetically and ecologically unique in the Yakima Basin. However, guidelines for reserves for anadromous fish are only beginning to be developed (Currens et al., in review). If this reserve were really to protect genetic diversity of American River salmon, three weaknesses need to be addressed:

- The temporal and ecological dimensions of the reserve have not been defined and consequently were not protected.

- The reserve protects only one of the potentially vulnerable and distinct populations in the Yakima River Basin.

- American River spring chinook salmon have been fewer than any other populations (Fast et al. 1991) and therefore would be the most vulnerable to chance extinction (Figure 5). The reserve provides no useful purpose if the population becomes extinct.

C.4. Relative Vulnerability of Spring Chinook Salmon to Different Genetic Hazards.

The relationship between demography and chance extinction for spring chinook salmon in the Yakima River and analysis of proximate and ultimate control mechanisms of supplementation (Figure 7) both suggested that these populations are very vulnerable to extinction and loss of within population genetic diversity. The possibility that supplementation might lead to extinction has generally been ignored in Yakima Fishery Project planning documents, because it was assumed that reproductive success of hatchery fish will be greater than wild fish. Likewise, extinction may have been ignored because biologists assumed it was a lesser risk (probability) than other genetic hazards without considering

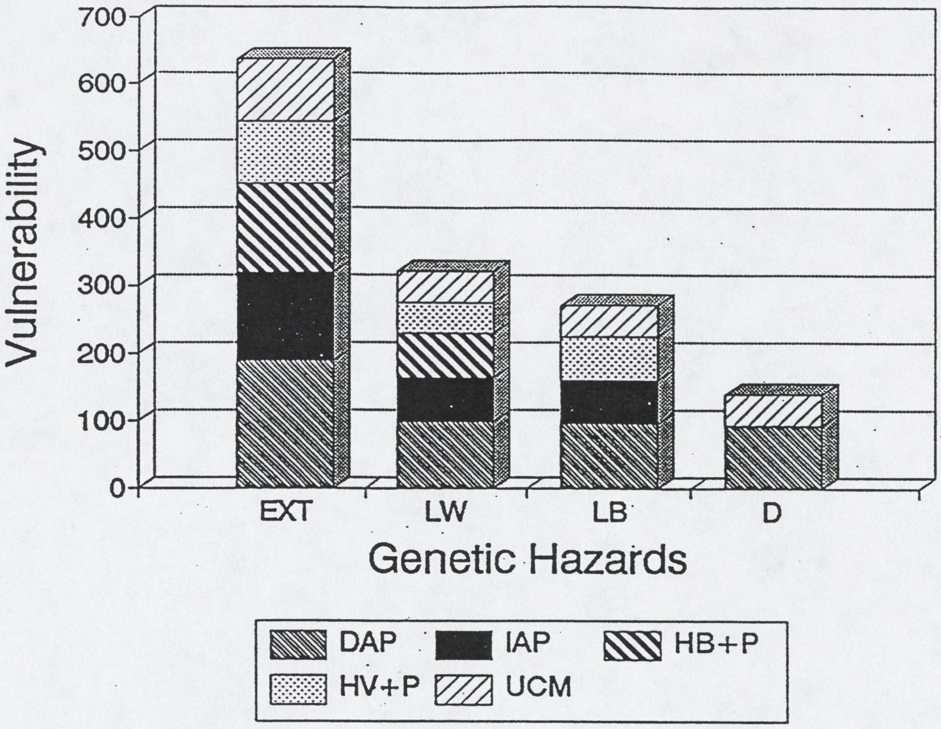

Figure 7. Relative vulnerability of Yakima River spring chinook salmon. Codes for genetic hazards are the following: EXT = extinction; LW = loss of with-in population diversity; LB = loss of among-population diversity; D = domestication or loss of fitness in the wild. Codes for components of vulnerability are these: DAP = vulnerability of directs effects of artificial propagation; IAP = vulnerability of indirects effects of artificial propagation; HB+P = vulnerability of juvenile habitat and passage management; HV+P = vulnerability of adult passage and harvest; UCM = vulnerability of genetic reserves.

differences in potential loss. The analyses in this report suggest that these assumptions should be reconsidered.

D. Vulnerability of Yakima River Summer Steelhead

D.1. Special Problems

Three major problems confront management of genetic vulnerability for summer steelhead populations in the Yakima River.

- Differences among potentially different populations have not been well described.
- Rainbow trout consisted of multiple life-history forms (including steelhead) for which the genetic basis and relationship to genetic structure are unknown.
- The potential numbers of adult steelhead available for brood stock from streams to be supplemented are low.

D.2. Extinction

For every 100 steelhead taken as brood stock in the Yakima River Basin, Yakima Fishery Project data suggested that on the average only 61 will return. This rate of return was the product of 80% pre-spawning survival of brood stock (Hagar, in prep; Yakima Fisheries Project Operations/Procedures Manual), expected mean fecundity of 2560 (Confederated Tribes and Bands of the Yakima Indian Nation et al. 1990), 50% egg-to-smolt (Confederated Tribes and Bands of the Yakima Indian Nation et al. 1990), and 0.12% smolt-to-adult survival (Yakima Fishery Project Science Team 1992). Because the Yakima Fishery Project has not collected data for different populations, these calculations were applied to all potentially different populations. Unless population growth of wild-spawning steelhead were far enough above replacement levels, supplementation of Yakima River steelhead will lead to extinction of the populations.

Under supplementation, mean growth rate of the population was reduced. Mean growth rates less than 1.0 indicated that the numbers of adult steelhead returning to reproduce were declining. For the short period from 1980 to 1992, the only years for which good data was available, mean population growth rate was 2.88. Under simple deterministic projections for supplementation, mean growth rate of Yakima River steelhead was reduced to 2.0. Assuming that mean population growth rate of steelhead over the long-term was 1, mean population growth rate under supplementation would be reduced to 0.73.

Figures 8 and 9 illustrated the relative effect of this reduction of population growth rate on the frequency of extinction. At mean population growth rate sustained by unsupplemented populations over the last 12 years, probability of extinction in 100 years or

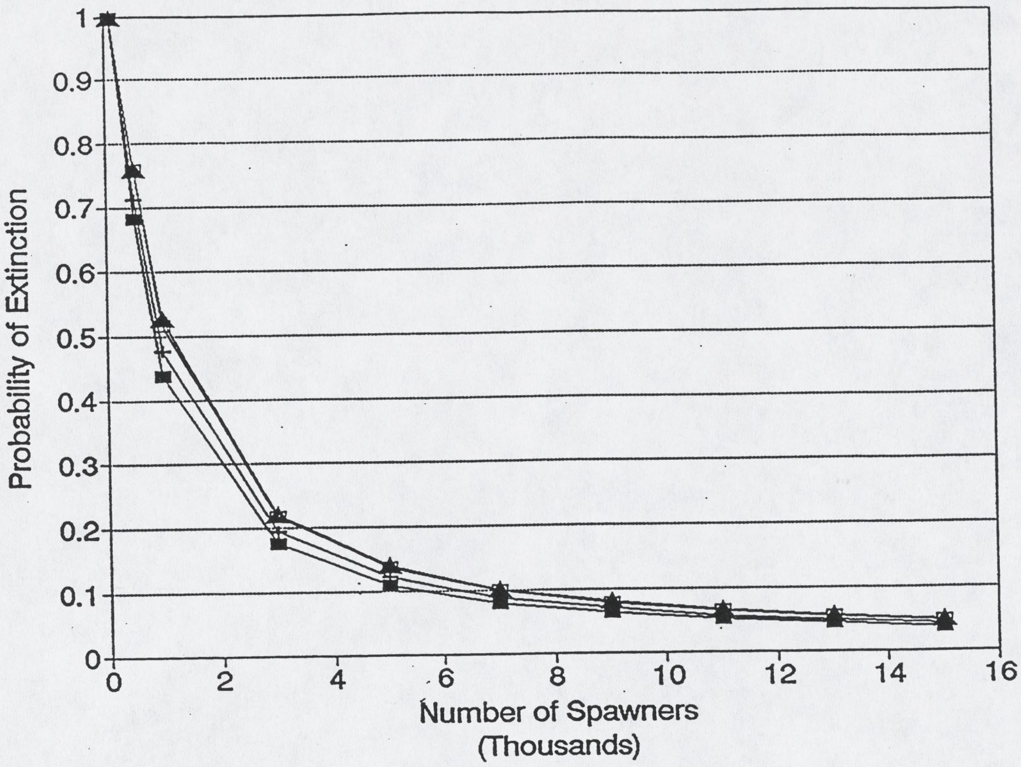

Figure 8. Relative probability of extinction in 100 years for Yakima River steelhead at different spawning population sizes with and without supplementation. Solid boxes indicate unsupplemented populations at high population growth rate; plusses are supplemented populations at high population growth rate; open boxes show unsupplemented populations at a low population growth rate; triangles are supplemented populations at a low population growth rate.

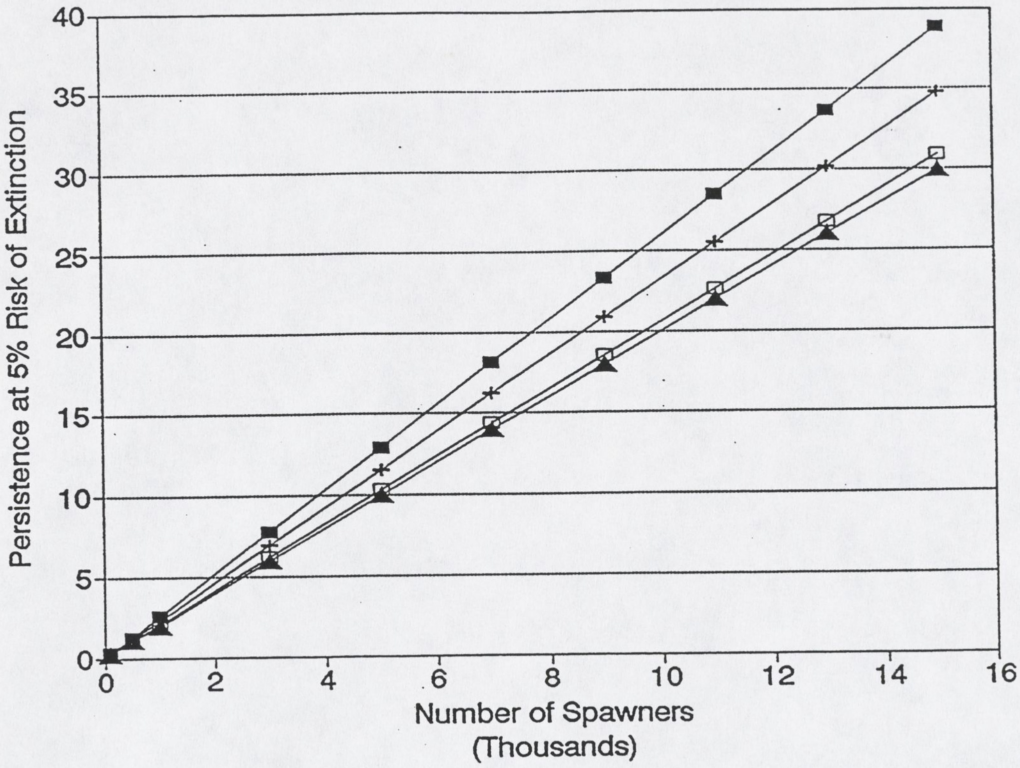

Figure 9. Relative persistence (in generations) at 5% risk of extinction for Yakima River steelhead at different spawning population sizes with and without supplementation. Solid boxes indicate unsupplemented populations at high population growth rate; plusses are supplemented populations at high population growth rate; open boxes show unsupplemented populations at a low population growth rate; triangles are supplemented populations at a low population growth rate.

Table 4. Reliability and resilience scores for proposed supplementation of Yakima River steelhead. A score of 100 indicated high reliability or resilience, whereas a score of 20 indicates low reliability or resilience. Genetic hazards are 1) extinction, 2) loss of within-population genetic diversity, 3) loss of between-population genetic diversity, and 4) domestication.

		Genetic Hazard			
Controls	Source of Hazard	1	2	3	4
Genetic stock identification	Brood stock selection	71	71	71	71
Artificial propagation	Brood stock collection	40	38	47	33
	Mating	100	47	40	44
	Rearing	38	38	38	38
	Release (direct effects)	33	33	31	38
	Percent of maximum reliability score	3.6	1.6	1.6	1.5
	Release (indirect effects)	36	36	36	100
	Percent of maximum reliability score	35.6	35.6	35.6	100
Passage and Habitat	Juvenile migration	36	36	31	100
	Percent of maximum reliability score	35.6	35.6	31.1	100
Passage and Harvest	Adult migration	40	40	38	100
	Percent of maximum reliability score	40.0	40.0	37.8	100
Genetic reserves	All of the above	53	53	53	53
	Percent of maximum reliability score	53.3	53.3	53.3	53.3

30 generations was less than it was under supplementation. This was especially true when populations are as small as they are in the Yakima River. Likewise, at 5% probability of extinction, unsupplemented populations would be expected to persist longer than supplemented populations. These differences were meaningless, however, at low numbers of spawners because the expected persistence times were so short.

D.3. Reliability and Resilience

A reliability or resilience score of 60 or greater for proximate or ultimate control of vulnerability at any given source of genetic hazard indicates that, over all, the essential components of that control mechanism were available and appropriate. For Yakima summer steelhead, the only proximate control mechanism that scored over 60 was genetic stock identification (Table 4, Appendix B). Isolated scores of 100 in Table 4 (e.g. control of extinction during mating) reflected situations where the hazard was considered inappropriate; no control mechanism scored 100 because it was perfect.

The same three major factors that contributed to low scores for supplementation of spring chinook salmon also were the main factors contributing to low scores of summer steelhead:

- Operating procedures and protocols for how conservation guidelines will be implemented did not exist, have only been superficial developed, or were inconsistent with conservation guidelines.

- Very few decision trees have been developed to indicate what the contigency plans are for failure or unanticipated results of a control mechanism.

- Planning documents indicated no intentions to provide appropriate training to avoid type I and type II error by technicians or biologists.

Unlike spring chinook, inadequate operating procedures and protocols for steelhead partially reflected difficulty in setting refined genetic objectives until distinct populations have been identified. Like spring chinook, however, lack of appropriate training for technicians and biologists was conspicous for every source of genetic hazard. As a new application of artificial propagation, supplementation has such special problems that geneticists have been hired to identify and characterize them. Assuming that technicians and field biologists already have the training to implement this technology is a major weakness. Control mechanisms of each of the potential sources of genetic hazards are discussed in detail below.

D.3.a. Genetic Stock Identification

Genetic stock identification had the highest reliability scores of any control mechanism for summer steelhead, inspite of difficulties in identifying different populations (Table 4). Every component was available and appropriate, except for absence decision trees (Appendix B). The Yakima Fishery Project has essentially postponed making a decision about the relationship of Toppenish Creek steelhead to Satus Creek steelhead, for example, until more data become available. However, at some point, decision rules will be needed to decide whether to treat Toppenish Creek as a different population, because the outcome of the decision may have an impact of the success of keeping Satus Creek as a genetic refuge. Components such as baseline data, operating guidelines, and monitoring were considered available and appropriate, but not sufficient, because Yakima Fishery Project geneticists believe that further analysis will resolve present amibiguities in describing different populations.

D.3.b. Artificial Propagation

D.3.b.(1). Brood Stock Collection

Two weaknesses were most prominent in the control of genetic hazards by brood stock collection of summer steelhead:

- Appropriate operating guidelines for hazards of loss of within-population diversity and domestication associated with proposed captive brood stock programs were lacking.

- Appropriate equipment and monitoring facilities for hazards of loss of within-population diversity and domestication associated with proposed captive brood stock programs were absent.

Because so few mature steelhead return to Toppenish Creek, Upper Yakima Rvier, and Naches River, project biologists have proposed capturing smolts from individual streams and raising them in the hatchery until they can be used as brood stock (Yakima Fishery Project Science Team 1992). Although this potentially alleviates the initial problem of having low N_e because of too few adult fish, it raises additional hazards that have not been addressed. First, no sampling guidelines existed for how to assure that collection of juvenile rainbow trout will be representative of wild adult steelhead. Potentially increased reproductive success of a non-representative sample could lower Ne and reduce within-population diversity. This is especially critical because no reliable method exists for separating sympatric resident rainbow trout and steelhead as juveniles. Likewise, no operating guidelines have been presented to control increased risk of capturing introduced, domesticated, non-native rainbow trout or their progeny, which have survived and bred with native rainbow trout (Campton and Johnston 1985). Furthermore, the special equipment and monitoring needs to collect a representative sample for captive brood stock and detect any departures from a representative sample were not indicated. If captive brood stock were not to be used, operating guidelines need to specify how minimum N_e will be achieved with so few adults.

D.3.b.(2). Mating

The reliability of controls for mating of steelhead was the best of any source of genetic hazards associated with artificial propagation (Table 4). This reflected well-developed conservation guidelines (Kapuscinski and Miller 1993), operating guidelines that are consistent with conservation guidelines (Hagar, in prep.), and monitoring procedures that are being developed. A major weakness in planning for supplementation of steelhead was the intention to spawn all populations at the Nelson Springs Hatchery (Anonymous 1992, Hagar, in prep.). Historical evidence suggested that when different populations were kept at the same facility, gametes from the different populations were often mixed (Kinunen and Moring 1978, Howell et al. 1985). This led to loss of among-population genetic diversity.

D.3.b.(3). Rearing

Control of genetic hazards during rearing of steelhead had relatively low reliability (Table 4), compared to other aspects of artificial propagation. Two major areas of weakness explained these scores:

- Operating guidelines for rearing the fish according to recommendations in conservation guidelines (Kapuscinski and Miller 1993) were missing.

- Decision trees for how to respond to unexpected emergencies that might either compromise genetic goals or experimental goals have not been developed.

Experimental hypotheses and designs have been formulated for rearing, but without operating guidelines it was difficult to determine what the actual environments of the fish in the hatchery will be and whether they are appropriate or sufficient. Similarly, if a juvenile, captive brood stock program were used for steelhead, operating guidelines need to be available for rearing the brood stock. Furthermore, it was not apparent from preliminary design reports that steelhead facilities were being designed with extensive captive brood stock rearing capacities, as well as juvenile rearing capacity (Anonymous 1990).

Decision trees are crucial for rearing. The estimated 50% egg-to-smolt survival rate for progeny of wild steelhead in the hatchery (Confederated Tribes and Bands of the Yakima Indian Nation et al. 1990) indicated that fish health in the hatchery may often be compromised. The experience of this author in raising progeny of wild rainbow trout under different experimental environments suggested that when fish health is challenged, conflicts arise between experimental goals and conservation goals. A typical scenario was described earlier for spring chinook salmon.

D.3.b.(4). Release

Release of fish may have direct or indirect genetic impacts on target and non-target species. This was the least reliable component of any safeguard for steelhead in controlling genetic hazards. The most important weaknesses in strategies to release steelhead are the following:

- Operating guidelines were inconsistent with conservation guidelines or poorly-developed.

- Decision trees have not been developed.

- Adequate baseline data have not been collected to evaluate ecological effects of steelhead releases on resident rainbow trout populations.

An important omission from operating guidelines was whether steelhead smolts of different ages will be developed to mimic the complex structure of natural populations (Busack et al. 1991, Confederated Tribes and Bands of the Yakima Indian Nation et al. 1990) or whether they will be released as year-old fish. Kapuscinsk and Miller (1993) indicated in the conservation guidelines that considerable uncertainty exists about the appropriate release of fish. However, they did recommend that numbers of fish released be based on freshwater carrying capacity. Actual numbers of steelhead to be released, however, appeared to be based on sample sizes necessary to detect statistical significance between treatments rather than on biological criteria (Anonymous 1992).

Until careful behavioral, ecological, and genetic study is made of the aquatic communities of these drainages, it is will be impossible to estimate effects of releasing large numbers of hatchery-reared fish or to develop reliable operating guidelines for supplementation. Adequate baseline data was not available, for example, to predict how rearing and release strategies may influence steelhead progeny to become resident rainbow trout. Although release was a source of genetic hazards on non-target endpoints -- such as existing resident rainbow trout populations -- reliability scores for indirect effects were actually higher for steelhead than for spring chinook salmon (Table 3, 4). In neither case did the scores indicate that controls were available and appropriate. However, the difference between species primarily reflected Yakima Fishery Project efforts to reduce vulnerability to rainbow trout by describing and monitoring steelhead-resident rainbow trout interactions. Similar efforts were missing for other species.

D.3.c. Management of Juvenile Migration and Habitat

Reliability of managing juvenile migration and habitat as a proximate safeguard against genetic hazards is crucial. Mortality during migration in the Yakima River can be a major source of poor smolt-to-adult survival (Fast et al. 1986). Because juvenile rainbow trout do not necessarily migrate towards the ocean, but rather may stray and take up freshwater residence until they mature and spawn, proximate safeguards for steelhead must also protect against loss of among-population genetic diversity. Major weaknesses of this safeguard for steelhead were the following (Appendix B):

- Explicit conservation guidelines have not been developed.
- Operating guidelines were poorly-developed or missing.
- Decision trees or rules were missing.

First principles of conservation genetics and ecology have been applied to most other proximate controls, but specific guidelines for juvenile migrations and habitat were lacking. Operating guidelines dealing with passage, water flows, and predators were available, but some were inappropriate or untested. For example, one first principle is to protect or restore historical complexity of migratory patterns of target species (Currens et al., in review). Yet, although project returns of target species would increased by improving flows, the Yakima Fishery Project has an operating guideline of not affecting water in the Yakima Basin

(Bonneville Power Administration 1992). Similarly, no appropriate proximate controls have been tested that would protect less productive, natural populations of fish from depletion due to increased natural harvest (i.e. predation) because large numbers of predators have been attracted by an abundance of hatchery-reared fish. Finally, contigency plans and decision rules have not been developed for problems associated with juvenile migration (or the lack of it) and habitat.

D.3.d. Management of Adult Migration and Harvest

Two principal weaknesses in management of adult migration and harvest explained low reliability of this safeguard (Appendix B):

- Conservation guidelines not were sufficiently well-developed to judge whether operating guidelines for harvest were appropriate or sufficient.

- Baseline characterization of straying rates and patterns or of geographical genetic differences among spawning aggregations have not been adequately collected to develop operating guidelines for preventing loss of among-population genetic diversity.

Unofficial documents indicated that harvest levels will be determined using a multiple-stock status-indexed harvest management that is based on protecting the less productive, reserve stocks (Yakima Fishery Project Science Team 1992). The actual critical levels that will be used were not available, however. To determine whether the values chosen are appropriate to minimize risks of extinction and loss of within-population genetic diversity, conservation guidelines need to be established. For example, although minimum N_e might be 500 for genetic reasons, this may not be an adequate number of spawners to protect against demographic risks of extinction (Figure 8, 9).

Conservation guidelines for restoring steelhead to streams where they were once abundant while preventing loss of genetic diversity among remaining anadromous and resident populations are needed to formulate appropriate operating guidelines. In addition, decision trees need to be developed. Limited allozyme data indicated that geneflow among spawning aggregations of steelhead has been more restricted than geneflow between resident rainbow trout and steelhead (Busack et al. 1991). However, inferred patterns of geneflow between resident rainbow trout and steelhead have been complicated by introduction of non-native strains of resident rainbow trout (Campton and Johnston 1985) and construction of dams that disrupted traditional migratory life-histories and reduced N_e. Operating guidelines for using a trap to prevent hatchery-reared steelhead from breeding with the Satus Creek genetic reserve population have been suggested (Yakima Fishery Project Science Team 1992) but the potential effects of such a facility on Satus Creek steelhead are unknown. Although further study may resolve some ambiguities about the relationship of steelhead spawning aggregations, it is possible that the preferred balance among resident rainbow trout and steelhead populations may be decided initially by non-genetic criteria. If so, then monitoring and decision trees will be crucial to allow biologists to respond appropriately to unexpect changes in the balance among resident rainbow trout and steelhead.

D.3.e. Genetic Reserves

A major strength of the Yakima Fishery Project has been the recognition that genetic reserves are an essential component of reducing vulnerability. Satus Creek has been designated a genetic reserve (Anonymous 1992). However, guidelines for implementing reserves for anadromous fish are only beginning to be developed (Currens et al., in review) and no general conservation guidelines existed for the Yakima Fishery Project. Two strengths of the designation of Satus Creek as a reserve deserved mention:

- The reserve was based on a genetic template.
- The reserve population, which accounts for nearly 50% of the total returns to the Yakima River Basin, will initially be protected over from overharvest and has the lowest probability of extinction.

Two weaknesses of the present status of Satus Creek as a reserve were the following:

- The temporal and ecological dimensions of the reserve protection were not well-defined and consequently were not protected.
- The reserve protects only one of the potentially vulnerable and distinct populations in the Yakima Basin.

D.4. Relative Vulnerability of Summer Steelhead to Different Genetic Hazards.

Both the relationship between demography and chance extinction for steelhead in the Yakima River and analysis of proximate and ultimate safeguards of supplementation (Figure 10) suggested that these populations are very vulnerable to extinction and loss of within population genetic diversity. The possibility that supplementation might lead to extinction has generally been ignored in Yakima Fishery Project planning documents, because it was often assumed that reproductive success of hatchery fish will be greater than wild fish. Likewise, extinction may have been ignored because biologists assumed it was a lesser risk (probability) than other genetic hazards without considering differences in potential loss. The analyses in this report suggest that these assumptions should be reconsidered.

E. Vulnerability of Yakima River Fall Chinook Salmon

E.1. Special Problems

Four special problems confront management of genetic vulnerability due to supplementation of fall chinook salmon in the Yakima River.

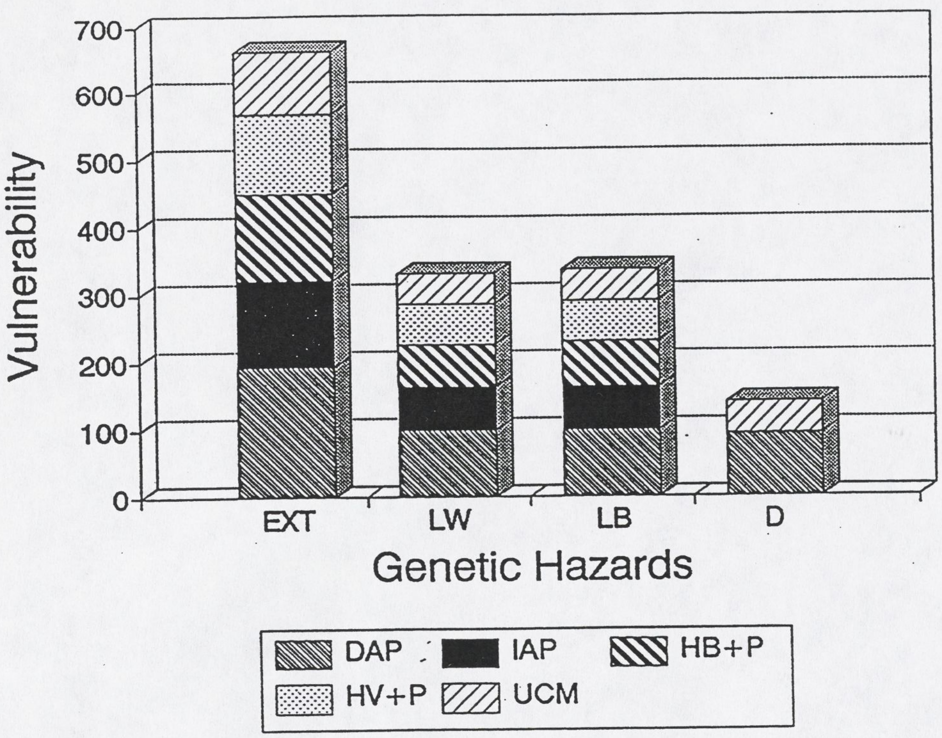

Figure 10. Relative vulnerability of Yakima River steelhead. Codes for genetic hazards are the following: EXT = extinction; LW = loss of with-in population diversity; LB = loss of among-population diversity; D = domestication or loss of fitness in the wild. Codes for components of vulnerability are these: DAP = vulnerability of directs effects of artificial propagation; IAP = vulnerability of indirects effects of artificial propagation; HB+P = vulnerability of juvenile habitat and passage management; HV+P = vulnerability of adult passage and harvest; UCM = vulnerability of genetic reserves.

- A major portion of the genetic diversity among all Columbia River upriver fall chinook salmon exists because a small, wild population has persisted in Marion Drain, an irrigation canal in the Yakima River Basin.

- To gather appropriate numbers of brood stock for supplementation of Marion Drain fall chinook, captive brood stock programs may be required.

- Supplementation has been planned for a population of hybrid fish of native Yakima River and Hanford Reach Hatchery origins.

- A large proportion of fall chinook salmon recovered in the Yakima River were strays from the Umatilla Hatchery.

E.2. Extinction

The relationship between demographics of the Yakima River fall chinook population and chance extinction with and without supplementation could not be examined because of lack of appropriate data. This was unfortunate, because if relative returns of fall chinook salmon under supplementation are not considerably better than for spring chinook salmon and steelhead, the Marion Drain population may face rapid extinction.

E.3. Resilience and Reliability

A reliability or resilience score of 60 or greater for proximate or ultimate control of vulnerability at any given source of genetic hazard indicates that over all, the essential components of that control mechanism were available and appropriate. For fall chinook salmon, the only proximate control mechanism that consistently scored over 60 was genetic stock identification (Table 5, Appendix C). Isolated scores of 100 in Table 5 (e.g. control of extinction during mating) reflect situations where the hazard was considered inappropriate; no control mechanism scored 100 because it was perfect.

Four major factors contributed to low scores for supplementation of fall chinook salmon:

- Operating procedures and protocols for how conservation guidelines will be implemented did not exist, were inconsistent with conservation guidelines, or have only been superficial developed.

- Very few decision trees have been developed to indicate what the contigency plans are for failure or unanticipated results of a control mechanism.

- Planning documents indicated no intentions to provide appropriate training to avoid type I and type II error by technicians or biologists.

Table 5. Reliability and resilience scores for proposed supplementation of Yakima River fall chinook. A score of 100 indicated high reliability or resilience, whereas a score of 20 indicates low reliability or resilience. Genetic hazards are 1) extinction, 2) loss of within-population genetic diversity, 3) loss of between-population genetic diversity, and 4) domestication.

		Genetic Hazard			
Controls	Source of Hazard	1	2	3	4
Genetic stock identification	Brood stock selection	87	87	76	76
Artificial propagation	Brood stock collection	40	40	47	29
	Mating	100	47	36	42
	Rearing	38	38	38	38
	Release (direct effects)	38	38	36	38
	Percent of maximum reliability score	5.0	2.4	1.8	1.3
	Release (indirect effects)	31	31	31	100
	Percent of maximum reliability score	31.1	31.1	31.1	100
Passage and Habitat	Juvenile migration	36	36	100	100
	Percent of maximum reliability score	35.6	35.6	100	100
Passage and Harvest	Adult migration	44	44	38	100
	Percent of maximum reliability score	44.4	44.4	37.8	100
Genetic reserves	All of the above	20	20	20	20
	Percent of maximum reliability score	20	20	20	20

Lack of appropriate training for technicians and biologists was conspicous for every source of genetic hazard. As a new application of artificial propagation, supplementation has such special problems that geneticists have been hired to identify and characterize them. Assuming that technicians and field biologists already have the training to implement this technology correctly is a major weakness. Control mechanisms of each of the potential sources of genetic hazards are discussed in detail below.

E.3.a. Genetic Stock Identification

Genetic stock identification had the highest reliability scores of any control mechanism for fall chinook salmon (Table 5). Every component was available and appropriate, except for absence decision trees and operating guidelines for controlling loss of among-population genetic diversity and domestication (Appendix C). However, a major flaw in this safeguard was the lack of sufficient conservation guidelines, operating guidelines, and decision trees to judge whether it is appropriate to select brood stock from a hybridized population, when an important, but vulnerable, unhybridized native population occurs nearby.

E.3.b. Artificial Propagation

E.3.b.(1). Brood Stock Collection

Three major problems existed with proposed brood stock collection of fall chinook salmon (Appendix C):

- No operating guidelines, decision trees, baseline data, monitoring plans, facilities, coordination, or training were indicated to control hazards of domestication associated with using a captive brood stock program for Marion Drain or collecting brood stock from the hybridized lower Yakima River population.

- No decision trees were available to decide how brood stock collection would procede if operating procedures to prevent collection of non-target populations were unsuccessful.

- Lack of baseline data and monitoring to evaluate risks of extinction due to brood stock mining were unavailable.

Collection of established hatchery strains or hybrids of such fish native fish for brood stock, such as occur in the lower Yakima River, could not only increase risk of domestication to the progeny that will be released but also to nearby native populations with which they may breed.

Because so few mature fall chinook salmon have returned to Marion Drain, biologists have proposed capturing smolts and raising them in the hatchery until they can be used as brood stock (Yakima Fishery Project Science Team 1992). Although this potentially alleviates the initial problem of having low N_e because of too few adult fish, it raises additional hazards that have not been addressed. First, no sampling guidelines exist for how to assure that collection of juvenile rainbow trout will be representative of wild adult steelhead. Second, potentially increased reproductive success of a non-representative sample could lower Ne and reduce within-population diversity. Probability of collecting non-representative samples are increased when few adult fish occur in the donor population (Kapuscinski and Miller 1993). Baseline data to follow recommendations in Kapuscinski and Miller (1993) are also insufficient. If captive brood stock are not used, operating guidelines need to specify how minimum N_e will be achieved with so few available adults. Additionally, guidelines, decision trees, and monitoring procedures have not been well-enough developed to control possible non-random mortality of brood stock while they are being held prior to spawning. Likewise, although minimium effective population size (N_e) of natural populations should be at least 500 for genetic reasons (Lande and Barrowclough 1987), no decision rules were available for deciding how to proceed if N_e falls below 500 during supplementation or if more brood fish are being taken for brood stock than return from supplementation.

E.3.b.(2). Mating

The reliability of this safeguard for fall chinook salmon was the best of any source of genetic hazards associated with artificial propagation (Table 5). This reflected well-developed conservation guidelines (Kapuscinski and Miller 1993), operating guidelines that are consistent with conservation guidelines (Hagar, in prep.), and monitoring procedures that are being developed. However, a major weakness in planning for supplementation of fall chinook salmon was the intention to spawn all populations at the Nelson Springs Hatchery (Anonymous 1992, Hagar, in prep.). Planning documents are extremely vague about how gametes from two different populations spawning at similar times over an extended period will be kept separate. Historical evidence suggested that when different populations have been spawned at the same facility, gametes from the different populations were often mixed (Kinunen and Moring 1978, Howell et al. 1985). This has resulted in loss of among-population genetic diversity.

If a single facility is to be used for all populations, decision trees are essential. For example, what is the correct response for a hatchery biologist if sperm from several Marion Drain salmon is mistakenly used to fertilize lower Yakima River salmon? Do you accept the loss of among-population diversity, because Marion Drain fish are too valuable to waste? If so, how many mistakes will be allowed?

E.3.b.(3). Rearing

Control of genetic hazards during rearing of fall chinook salmon had relatively low reliability (Table 5), compared to other aspects of artificial propagation. Two major areas of weakness explained these scores (Appendix C):

- Operating guidelines for rearing the fish according to recommendations in conservation guidelines (Kapuscinski and Miller 1993) were missing.

- Decision trees for how to respond to unexpected emergencies that might either compromise genetic goals or experimental goals have not been developed.

Experimental hypotheses and designs have been formulated for rearing, but without operating guidelines it was difficult to determine what the actual environments of the fish in the hatchery will be and whether they are appropriate or sufficient. Similarly, if a juvenile, captive brood stock program were used for fall chinook salmon, operating guidelines need to be available for rearing the brood stock. It is not apparent from preliminary design reports that facilities at Nelson Springs Hatchery were being designed with extensive captive brood stock rearing capacities, for both steelhead and fall chinook salmon, as well as juvenile rearing capacity (Anonymous 1990).

Decision trees are crucial for rearing. The experience of this author in raising progeny of wild rainbow trout under different experimental environments suggested that when fish health is challenged, conflicts arise between experimental goals and conservation goals. One possible scenario was described earlier for spring chinook salmon.

E.3.b.(4). Release

Release of fish is both a direct and indirect source of genetic hazards. This was the least reliable component of artificial propagation for controlling hazards associated with acclimation and release (Table 5). Two components of this safeguard need work.

- Operating guidelines were absent or poorly-developed.
- Decision trees have not been developed.

Conservation guidelines recognized the uncertainty associated with time, place, and condition of releasing fish (Kapuscinski and Miller 1993). Operating guidelines have not helped resolve the uncertainty. For example, operating guidelines contain no information on acclimation of fall chinook, the relationship between freshwater carrying capacity for the two different populations and the numbers of fish that will be released, and how release of fall chinook would minimize potential predation by coho salmon (a species that is to be reintroduced into the Yakima River Basin) or other predators in the lower Yakima River. Likewise, no decision trees were available for situations involving release or the failure of release and acclimation strategies.

E.3.c. Management of Juvenile Migration and Habitat

Reliability of managing juvenile passage and habitat to control genetic hazards was greater for fall chinook salmon than for spring chinook salmon or steelhead (Table 3, 5, 6). Lack of reliability here is critical because mortality during passage through the Yakima River is a major source of poor smolt-adult survival rates (Fast et al. 1991). Three major weaknesses of this proximate safeguard were the following:

- Conservation guidelines have not been well-developed.
- Operating guidelines were absent or poorly-developed.

- Decision trees were missing.

First principles of conservation genetics and ecology have been applied to most other proximate controls, but specific guidelines were lacking for management of juvenile migration and habitat. Operating guidelines dealing with passage, water flows, and predators are certainly available, but some are inappropriate or untested. For example, one first principle is to protect or restore historical complexity of migratory patterns of target species (Currens et al., in review). Yet, although project returns of target species would increase by improving flows, the Yakima Fishery Project has an operating guideline of not affecting water in the Yakima Basin (Bonneville Power Administration 1992). Similarly, no appropriate proximate controls have been tested that would protect less productive, natural populations of fish from depletion due to increased natural harvest (i.e. predation in the lower Yakima River) because large numbers of predators have been attracted by an abundance of hatchery-reared fish. Finally, contigency plans and decision rules have not been developed for problems associated with juvenile passage and habitat.

E.3.d. Management of Adult Migration and Harvest

Management of adult migration and harvest had relatively greater reliability to protect against extinction and loss of within-population diversity than to protect against loss of among-population diversity (Table 5). The higher scores for extinction and loss of within-population diversity (Appendix A) reflect intentions to use multiple-stock status-indexed harvest management that is based on protecting the less productive stocks (Yakima Fishery Project Science Team 1992). This an unofficial document, however, and scores could change when actual operating guidelines can be evaluated.

A major conspicuous weaknesses of management of adult migration and harvest was the lack of sufficiently well-developed conservation guidelines to judge whether operating guidelines guidelines for harvest are appropriate. For example, although minimum N_e might be 500 for genetic reasons, it is not certain that this is an adequate number of spawners to protect against demographic risks of extinction. Marion Drain fall chinook most likely already have an N_e well below 500 (Craig Busack, Washington Department of Fisheries, unpubl. data).

Lower scores for loss of among-population diversity reflected both the hazard to Marion Drain fall chinook salmon of using a hybridized population as an additional brood stock within the Yakima Basin and the hazard to both Marion Drain and lower Yakima River populations of a high proportion of strays from the Umatilla Hatchery (Craig Busack, Washington Department of Fisheries, unpubl. data). Given the alternatives of supplementing only the Marion Drain population or both the Marion Drain and lower Yakima River populations, supplementation of both populations increases genetic vulnerability of the Marion Drain population to loss of among-population genetic diversity relative to the first alternative. If only Marion Drain fall chinook are supplemented the major risk of loss of among-population genetic diversity comes from straying Umatilla Hatchery fall chinook.

E.3.e. Genetic Reserves

No genetic reserves were designated for Yakima River fall chinook. Guidelines for reserves for anadromous fish are only beginning to be developed (Currens et al., in review). The situation for fall chinook salmon in the Yakima River illustrates one of the basic problems that needs to be overcome while opportunities to designate reserves are still available in the Columbia River Basin:

- Genetic reserves needed to be designated on a regional as well as local basis.

For example, both the remaining populations in the Yakima River may be inappropriate as reserves. The lower Yakima fall chinook salmon are most likely hybrid fish of native Yakima River and Hanford Reach Hatchery origins. Marion Drain, which contains most of the spawning habitat for the only wild population, is ecologically inappropriate. The amount of available habitat is minimal and it occupies a single linear gradient with little structural complexity. Limited to Marion Drain, the population would be vulnerable to demographic instability due to too few resources and correlated effects of catostrophic change in the canal. Although protecting the Marion Drain fall chinook population as a reserve may be difficult, other members of the major evolutionary group that it represents still exist in the lower Snake River and Deschutes River (Busack et al. 1991). Designing reserves for these groups may still be possible.

E.4. Relative Vulnerability of Spring Chinook Salmon to Different Genetic Hazards .

The relationship between demography and chance extinction for fall chinook in the Yakima River could not be described quantitatively because of lack of data. However, small number of spawners and low N_e for Marion Drain fall chinook suggest that the potential for extinction will be great if supplementation does not return more fish than are taken as brood stock. Based on reliability of proximate and ultimate safeguards (Table 3, 5, 6), fall chinook had higher vulnerability to extinction than did spring chinook and steelhead (Figure 7, 10, 11). The possibility that supplementation might lead to extinction has generally been ignored in Yakima Fishery Project planning documents, because it was assumed that reproductive success of hatchery fish will be greater than wild fish. Likewise, extinction may have been ignored because biologists assumed it was a lesser risk (probability) than other genetic hazards without considering differences in potential loss. The analyses in this report suggest that these assumptions should be reconsidered.

F. Vulnerability of Yakima River Summer Chinook Salmon

F.1. Special Problems

Yakima Fishery Project documents indicated that the most important special problem associated with managing vulnerability of summer chinook salmon is determining whether they still exist and in what abundance.

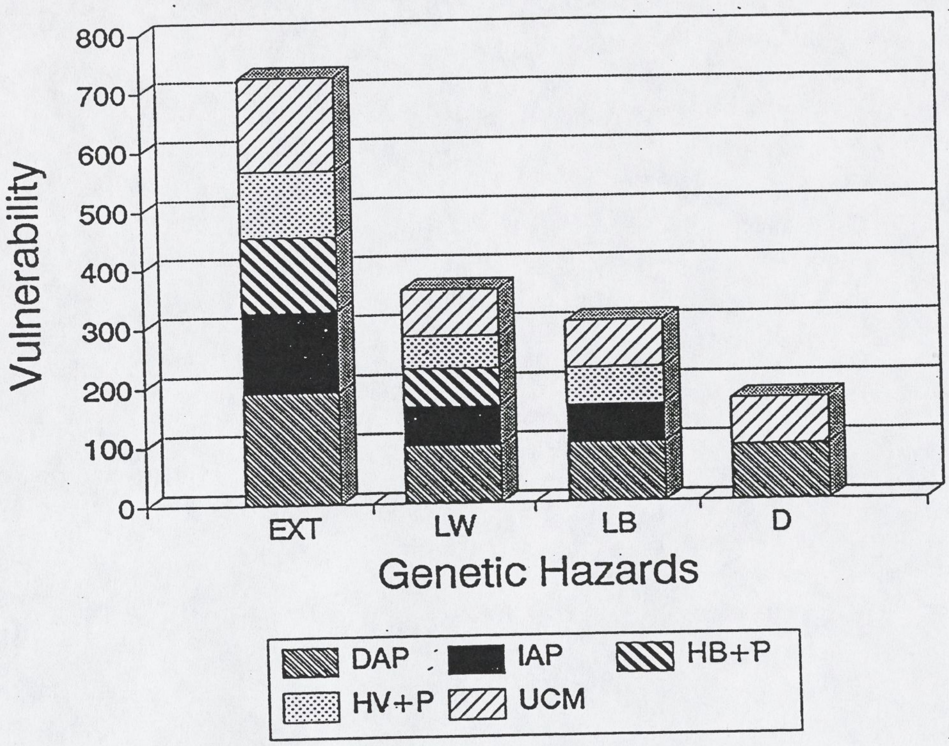

Figure 11. Relative vulnerability of Yakima River fall chinook salmon. Codes for genetic hazards are the following: EXT = extinction; LW = loss of with-in population diversity; LB = loss of among-population diversity; D = domestication or loss of fitness in the wild. Codes for components of vulnerability are these: DAP = vulnerability of directs effects of artificial propagation; IAP = vulnerability of indirects effects of artificial propagation; HB+P = vulnerability of juvenile habitat and passage management; HV+P = vulnerability of adult passage and harvest; UCM = vulnerability of genetic reserves.

F.2. Vulnerability

Little data or detailed planning exist to assess hazards of supplementation for summer chinook salmon in the Yakima River. Consequently, comparative vulnerability scores were not computed. Qualitative assessment of risks associated with reintroducing summer chinook salmon, if they are presently extinct, was provided by Busack (1990) and little has changed. However, if a remnant population of summer chinook salmon still exists in the Yakima River, the most serious hazards are extinction and loss of within-population genetic diversity. Recovery of this population will require more than supplementation.

G. Vulnerability of Yakima River Coho Salmon

G.1. Special Problems

Native coho salmon are extinct in the Yakima River. The two principal problems confront supplementation of coho salmon in the Yakima River:

- An appropriate donor population must be identified.

- Potential ecological impacts on other species need to be minimized.

G.2. Vulnerability

Little data or detailed planning exist to assess risks of reintroducing coho salmon in the Yakima River. Consequently, comparative vulnerability scores were not computed. Qualitative assessment of risks associated with reintroducing were provided by Busack (1990) and little has changed. The most important immediate hazard is the effect that coho salmon predation might have on the depleted Marion Drain fall chinook population during experimentation for supplementation.

H. Conclusions

Considered together, the results of this analysis suggest that under present plans, supplemented populations may be more vulnerable to extinction and loss of within-population genetic diversity than has been previously recognized.

- Supplementation of spring chinook salmon and steelhead in the Yakima River will generally result in fewer hatchery-reared fish returning to the wild than were taken as brood stock, unless success of the program is better than present data suggest.

- Overall, proximate safeguards for reducing vulnerability were not available and appropriate.

- Lack of decision trees, decision rules, and contingency plans were a major weakness of proximate safeguards and the ultimate safeguard of adaptive management.

- Use of genetic reserves as an ultimate safeguard to reduce vulnerability is a major strength of the Yakima Fishery Project that needs to be expanded.

- The Yakima Fishery Project was not ready for a Level II genetic risk assessment as it was defined by Northwest Power Planning Council guidelines.

A major potential conflict exists between the use of the Yakima Fishery Project as experimental opportunity to test supplementation methodologies and the goal of rebuidling natural populations of salmon and steelhead in the Yakima River **while maintaining the long-term fitness of the target population, and keeping ecological and genetic impacts on non-target populations within specified biological limits.** Experiments must be allowed to fail to gain knowledge. However, supplementation in the Yakima River must not be allowed to fail if these populations are to be rebuilt and genetic diversity of salmonids within the Columbia River Basin is to be maintained. Based on Yakima Fishery Project data, even if pre-spawning and egg-to-smolt mortality were completely eliminated, the number of returning hatchery-reared adults from the Upper Yakima population would just replace the numbers that were taken for brood stock. Consequently, fate of the whole population would depend on fitness of wild fish, just as it does now. Considerable effort has gone into the developement of experimental designs to test different methods of reducing juvenile mortality of hatchery-reared fish in the Yakima River. Lack of explicit, well-developed operating guidelines, monitoring and evaluation plans, decision trees, and contingency plans, and emphasis on the development of operating guidelines based on statistical neeeds, provide no safeguards against failure of these experiments.

I. Recommendations

- Conservation principles analogous to the genetic guidelines for hatcheries should be developed for assessing and guiding management of genetic and ecological impacts during juvenile and adult migration.

- Operating procedures and protocols for how conservation guidelines will be implemented should be fully developed to be consistent with conservation guidelines.

- Decision trees should be developed to indicate what the contingency plans are for failure or unanticipated results of a control mechanism.

- Training programs for managers, field biologists, and technicians should be developed, implemented, and evaluated to help avoid type I and type II errors.

- Monitoring and evaluation efforts must be developed to collect demographic and genetic data to evaluate the vulnerability of the populations as well as the success of different experiments. Project planners need to distinguish between evaluation of supplementation and evaluation of supplementation methodologies.

- Guidelines for designing, designating, and implementing genetic reserves that will include regional as well as local needs need to be developed.

- Genetic vulnerability of the Yakima Fishery Project should be reevaluated when operating guidelines and contingency plans have been developed. Use of the framework presented here and comparative vulnerability scores would allow evaluation of improvement.

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APPENDIX A

Table A.1. Ratings of reliability components for Yakima River spring chinook. Hazards are 1) extinction, 2) loss of within-population genetic diveristy, 3) loss of between-population genetic diversity, and 4) domestication.

RELIABILITY COMPONENTS	HAZARD SCORES			
1.1. Brood Stock Selection	1	2	3	4
1.1.1. Guidelines				
1.1.1.1. Genetic Guidelines	5	5	5	5
1.1.1.2. Operating Guidelines	5	5	5	5
1.1.1.3. Decision Trees	3	3	3	3
1.1.2. Natural Variability				
1.1.2.1. Baseline Characterization	5	5	5	5
1.1.2.2. Detection of Departures from Baseline	3	3	3	3
1.1.3. Logistics				
1.1.3.1. Equipment	5	5	5	5
1.1.3.2. Coordination	5	5	5	5
1.1.4. Technician Ability & Judgment				
1.1.4.1. Type I Error	5	5	5	5
1.1.4.2. Type II Error	5	5	5	5

RELIABILITY COMPONENTS	HAZARD SCORES			
1.2. Brood Stock Collection	1	2	3	4
1.2.1. Guidelines				
1.2.1.1. Genetic Guidelines	5	5	5	1
1.2.1.2. Operating Guidelines	1	2	2	1
1.2.1.3. Decision Trees	2	1	3	1
1.2.2. Natural Variability				
1.2.2.1. Baseline Characterization	3	3	5	3
1.2.2.2. Detection of Departures from Baseline	1	3	3	1
1.2.3. Logistics				
1.2.3.1. Equipment	2	2	2	2
1.2.3.2. Coordination	2	2	2	2
1.2.4. Technician Ability & Judgment				
1.2.4.1. Type I Error	1	1	1	1
1.2.4.2. Type II Error	1	1	1	1

Table A.1. Ratings of reliability components for Yakima River spring chinook salmon (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.3. Mating	1	2	3	4
1.3.1. Guidelines				
1.3.1.1. Genetic Guidelines		5	5	5
1.3.1.2. Operating Guidelines		2	5	2
1.3.1.3. Decision Trees		3	1	3
1.3.2. Natural Variability				
1.3.2.1. Baseline Characterization		3		1
1.3.2.2. Detection of Departures from Baseline		3		3
1.3.3. Logistics				
1.3.3.1. Equipment		2	2	2
1.3.3.2. Coordination		2	2	2
1.3.4. Technician Ability & Judgment				
1.3.4.1. Type I Error		1	1	1
1.3.4.2. Type II Error		1	1	1

RELIABILITY COMPONENTS	HAZARD SCORES			
1.4. Rearing	1	2	3	4
1.4.1. Guidelines				
1.4.1.1. Genetic Guidelines	5	5	5	5
1.4.1.2. Operating Guidelines	1	1	1	1
1.4.1.3. Decision Trees	1	1	1	1
1.4.2. Natural Variability				
1.4.2.1. Baseline Characterization	3	3	3	3
1.4.2.2. Detection of Departures from Baseline	2	2	2	2
1.4.3. Logistics				
1.4.3.1. Equipment	2	2	2	2
1.4.3.2. Coordination	2	2	2	2
1.4.4. Technician Ability & Judgment				
1.4.4.1. Type I Error	1	1	1	1
1.4.4.2. Type II Error	1	1	1	1

Table A.1. Ratings of reliability components for Yakima River spring chinook salmon (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.5. Release (direct genetic effects)	1	2	3	4
1.5.1. Guidelines				
1.5.1.1. Genetic Guidelines	3	3	5	5
1.5.1.2. Operating Guidelines	2	2	1	1
1.5.1.3. Decision Trees	1	1	1	1
1.5.2. Natural Variability				
1.5.2.1. Baseline Characterization	3	2	1	3
1.5.2.2. Detection of Departures from Baseline	3	2	2	2
1.5.3. Logistics				
1.5.3.1. Equipment	2	2	2	2
1.5.3.2. Coordination	2	2	2	2
1.5.4. Technician Ability & Judgment				
1.5.4.1. Type I Error	1	1	1	1
1.5.4.2. Type II Error	1	1	1	1

RELIABILITY COMPONENTS	HAZARD SCORES			
1.6. Release (indirect ecological genetic effects)	1	2	3	4
1.6.1. Guidelines				
1.6.1.1. Ecological Genetic Guidelines	3	3	3	
1.6.1.2. Operating Guidelines	2	2	2	
1.6.1.3. Decision Trees	1	1	1	
1.6.2. Natural Variability				
1.6.2.1. Baseline Characterization	2	2	2	
1.6.2.2. Detection of Departures from Baseline	1	1	1	
1.6.3. Logistics				
1.6.3.1. Equipment	2	2	2	
1.6.3.2. Coordination	2	2	2	
1.6.4. Technician Ability & Judgment				
1.6.4.1. Type I Error	1	1	1	
1.6.4.2. Type II Error	1	1	1	

Table A.1. Ratings of reliability components for Yakima River spring chinook salmon (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.7. Juvenile Migration	1	2	3	4
1.7.1. Guidelines				
1.7.1.1. Genetic Guidelines	1	1		
1.7.1.2. Operating Guidelines	2	2		
1.7.1.3. Decision Trees	1	1		
1.7.2. Natural Variability				
1.7.2.1. Baseline Characterization	3	3		
1.7.2.2. Detection of Departures from Baseline	2	2		
1.7.3. Logistics				
1.7.3.1. Equipment	2	2		
1.7.3.2. Coordination	2	2		
1.7.4. Technician Ability & Judgment				
1.7.4.1. Type I Error	1	1		
1.7.4.2. Type II Error	1	1		

RELIABILITY COMPONENTS	HAZARD SCORES			
1.8. Adult Migration	1	2	3	4
1.8.1. Guidelines				
1.8.1.1. Genetic Guidelines	2	2	1	
1.8.1.2. Operating Guidelines	3	3	3	
1.8.1.3. Decision Trees	3	3	1	
1.8.2. Natural Variability				
1.8.2.1. Baseline Characterization	3	3	3	
1.8.2.2. Detection of Departures from Baseline	3	3	3	
1.8.3. Logistics				
1.8.3.1. Equipment	5	5	2	
1.8.3.2. Coordination	3	3	1	
1.8.4. Technician Ability & Judgment				
1.8.4.1. Type I Error	1	1	1	
1.8.4.2. Type II Error	1	1	1	

Table A.2. Rating for components of reliability for Yakima River spring chinook salmon.

CRITERIA FOR EVALUATING POTENTIAL RESILIENCE FROM RESERVES	SCORE
1. Availability No genetic or ecological reserves identified = 1 Reserve identified but not implemented = 3 Reserve identified and implemented = 5	3
2. Appropriateness Scoring: Neither of the criteria below apply = 1 One of the two criteria apply = 3 Both criteria apply = 5 • Genetic structure is template for identifying the reserve. • Reserve represents ecological, aquatic diversity of area targeted for supplementation.	3
3. Sufficiency Scoring: None of the criteria below apply = 1 One of the criteria apply = 2 Two or three of the criteria apply = 3 Four criteria apply = 4 All criteria apply = 5 • Probability of extinction of target species in the reserve is less than 5% in 200 years. • Reserve is regional. • Harvest management goals protect reserve. • Management goals (e.g. harvest, interagency agreements about habitat, water flows, migratory corridors, artificial propagation) are defined within a temporal hierarchy, beginning with the goal that the reserve should function for at least 200. • Reserve protects or restores historical complexity of migratory patterns of target species.	2

APPENDIX B

Table B.1. Ratings of reliability components for Yakima River steelhead. Hazards are 1) extinction, 2) loss of within-population genetic diveristy, 3) loss of between-population genetic diversity, and 4) domestication.

RELIABILITY COMPONENTS	HAZARD SCORES			
1.1. Brood Stock Selection	1	2	3	4
1.1.1. Guidelines				
1.1.1.1. Genetic Guidelines	5	5	5	5
1.1.1.2. Operating Guidelines	3	3	3	3
1.1.1.3. Decision Trees	2	2	2	2
1.1.2. Natural Variability				
1.1.2.1. Baseline Characterization	3	3	3	3
1.1.2.2. Detection of Departures from Baseline	3	3	3	3
1.1.3. Logistics				
1.1.3.1. Equipment	3	3	3	3
1.1.3.2. Coordination	3	3	3	3
1.1.4. Technician Ability & Judgment				
1.1.4.1. Type I Error	5	5	5	5
1.1.4.2. Type II Error	5	5	5	5

RELIABILITY COMPONENTS	HAZARD SCORES			
1.2. Brood Stock Collection	1	2	3	4
1.2.1. Guidelines				
1.2.1.1. Genetic Guidelines	5	5	5	5
1.2.1.2. Operating Guidelines	2	1	3	1
1.2.1.3. Decision Trees	2	1	2	1
1.2.2. Natural Variability				
1.2.2.1. Baseline Characterization	2	2	3	2
1.2.2.2. Detection of Departures from Baseline	1	3	3	1
1.2.3. Logistics				
1.2.3.1. Equipment	2	1	1	1
1.2.3.2. Coordination	2	2	2	2
1.2.4. Technician Ability & Judgment				
1.2.4.1. Type I Error	1	1	1	1
1.2.4.2. Type II Error	1	1	1	1

Table B.1. Ratings of reliability components for Yakima River steelhead (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.3. Mating	1	2	3	4
1.3.1. Guidelines				
1.3.1.1. Genetic Guidelines		5	5	5
1.3.1.2. Operating Guidelines		2	2	2
1.3.1.3. Decision Trees		3	1	3
1.3.2. Natural Variability				
1.3.2.1. Baseline Characterization		2		1
1.3.2.2. Detection of Departures from Baseline		3		3
1.3.3. Logistics				
1.3.3.1. Equipment		2	2	2
1.3.3.2. Coordination		2	2	2
1.3.4. Technician Ability & Judgment				
1.3.4.1. Type I Error		1	1	1
1.3.4.2. Type II Error		1	1	1

RELIABILITY COMPONENTS	HAZARD SCORES			
1.4. Rearing	1	2	3	4
1.4.1. Guidelines				
1.4.1.1. Genetic Guidelines	5	5	5	5
1.4.1.2. Operating Guidelines	1	1	1	1
1.4.1.3. Decision Trees	1	1	1	1
1.4.2. Natural Variability				
1.4.2.1. Baseline Characterization	2	2	2	2
1.4.2.2. Detection of Departures from Baseline	2	2	2	2
1.4.3. Logistics				
1.4.3.1. Equipment	2	2	2	2
1.4.3.2. Coordination	2	2	2	2
1.4.4. Technician Ability & Judgment				
1.4.4.1. Type I Error	1	1	1	1
1.4.4.2. Type II Error	1	1	1	1

Table B.1. Ratings of reliability components for Yakima River steelhead (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.5. Release (direct genetic effects)	1	2	3	4
1.5.1. Guidelines				
1.5.1.1. Genetic Guidelines	3	3	3	5
1.5.1.2. Operating Guidelines	1	1	1	1
1.5.1.3. Decision Trees	1	1	1	1
1.5.2. Natural Variability				
1.5.2.1. Baseline Characterization	2	2	1	2
1.5.2.2. Detection of Departures from Baseline	2	2	2	2
1.5.3. Logistics				
1.5.3.1. Equipment	2	2	2	2
1.5.3.2. Coordination	2	2	2	2
1.5.4. Technician Ability & Judgment				
1.5.4.1. Type I Error	1	1	1	1
1.5.4.2. Type II Error	1	1	1	1

RELIABILITY COMPONENTS	HAZARD SCORES			
1.6. Release (indirect ecological genetic effects)	1	2	3	4
1.6.1. Guidelines				
1.6.1.1. Ecological Genetic Guidelines	3	3	3	
1.6.1.2. Operating Guidelines	2	2	2	
1.6.1.3. Decision Trees	1	1	1	
1.6.2. Natural Variability				
1.6.2.1. Baseline Characterization	2	2	2	
1.6.2.2. Detection of Departures from Baseline	2	2	2	
1.6.3. Logistics				
1.6.3.1. Equipment	2	2	2	
1.6.3.2. Coordination	2	2	2	
1.6.4. Technician Ability & Judgment				
1.6.4.1. Type I Error	1	1	1	
1.6.4.2. Type II Error	1	1	1	

Table B.1. Ratings of reliability components for Yakima River steelhead (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.7. Juvenile Migration	1	2	3	4
1.7.1. Guidelines				
1.7.1.1. Genetic Guidelines	1	1	3	
1.7.1.2. Operating Guidelines	2	2	3	
1.7.1.3. Decision Trees	1	1	1	
1.7.2. Natural Variability				
1.7.2.1. Baseline Characterization	3	3	2	
1.7.2.2. Detection of Departures from Baseline	3	3	1	
1.7.3. Logistics				
1.7.3.1. Equipment	2	2	1	
1.7.3.2. Coordination	2	2	1	
1.7.4. Technician Ability & Judgment				
1.7.4.1. Type I Error	1	1	1	
1.7.4.2. Type II Error	1	1	1	

RELIABILITY COMPONENTS	HAZARD SCORES			
1.8. Adult Migration	1	2	3	4
1.8.1. Guidelines				
1.8.1.1. Genetic Guidelines	1	1	1	
1.8.1.2. Operating Guidelines	3	3	3	
1.8.1.3. Decision Trees	3	3	1	
1.8.2. Natural Variability				
1.8.2.1. Baseline Characterization	2	2	3	
1.8.2.2. Detection of Departures from Baseline	3	3	3	
1.8.3. Logistics				
1.8.3.1. Equipment	2	2	2	
1.8.3.2. Coordination	2	2	2	
1.8.4. Technician Ability & Judgment				
1.8.4.1. Type I Error	1	1	1	
1.8.4.2. Type II Error	1	1	1	

Table B.2. Ratings for components of resilience for Yakima River steelhead.

CRITERIA FOR EVALUATING POTENTIAL RESILIENCE FROM RESERVES	SCORE
1. Availability No genetic or ecological reserves identified = 1 Reserve identified but not implemented = 3 Reserve identified and implemented = 5	3
2. Appropriateness Scoring: Neither of the criteria below apply = 1 One of the two criteria apply = 3 Both criteria apply = 5 • Genetic structure is template for identifying the reserve. • Reserve represents ecological, aquatic diversity of area targeted for supplementation.	3
3. Sufficiency Scoring: None of the criteria below apply = 1 One of the criteria apply = 2 Two or three of the criteria apply = 3 Four criteria apply = 4 All criteria apply = 5 • Probability of extinction of target species in the reserve is less than 5% in 200 years. • Reserve is regional. • Harvest management goals protect reserve. • Management goals (e.g. harvest, interagency agreements about habitat, water flows, migratory corridors, artificial propagation) are defined within a temporal hierarchy, beginning with the goal that the reserve should function for at least 200. • Reserve protects or restores historical complexity of migratory patterns of target species.	2

APPENDIX C

Table C.1. Ratings of reliability components for Yakima River fall chinook. Hazards are 1) extinction, 2) loss of within-population genetic diveristy, 3) loss of between-population genetic diversity, and 4) domestication.

RELIABILITY COMPONENTS	HAZARD SCORES			
1.1. Brood Stock Selection	1	2	3	4
1.1.1. Guidelines				
1.1.1.1. Genetic Guidelines	3	3	3	3
1.1.1.2. Operating Guidelines	5	5	2	2
1.1.1.3. Decision Trees	3	3	1	1
1.1.2. Natural Variability				
1.1.2.1. Baseline Characterization	3	3	3	3
1.1.2.2. Detection of Departures from Baseline	5	5	5	5
1.1.3. Logistics				
1.1.3.1. Equipment	5	5	5	5
1.1.3.2. Coordination	5	5	5	5
1.1.4. Technician Ability & Judgment				
1.1.4.1. Type I Error	5	5	5	5
1.1.4.2. Type II Error	5	5	5	5

RELIABILITY COMPONENTS	HAZARD SCORES			
1.2. Brood Stock Collection	1	2	3	4
1.2.1. Guidelines				
1.2.1.1. Genetic Guidelines	5	5	5	5
1.2.1.2. Operating Guidelines	2	2	3	1
1.2.1.3. Decision Trees	2	2	1	1
1.2.2. Natural Variability				
1.2.2.1. Baseline Characterization	2	2	3	1
1.2.2.2. Detection of Departures from Baseline	1	1	3	1
1.2.3. Logistics				
1.2.3.1. Equipment	2	2	2	1
1.2.3.2. Coordination	2	2	2	1
1.2.4. Technician Ability & Judgment				
1.2.4.1. Type I Error	1	1	1	1
1.2.4.2. Type II Error	1	1	1	1

Table C.1. Ratings of reliability components for Yakima River fall chinook salmon (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.3. Mating	1	2	3	4
1.3.1. Guidelines				
1.3.1.1. Genetic Guidelines		5	5	5
1.3.1.2. Operating Guidelines		2	2	2
1.3.1.3. Decision Trees		3	1	1
1.3.2. Natural Variability				
1.3.2.1. Baseline Characterization		2	1	2
1.3.2.2. Detection of Departures from Baseline		3	1	3
1.3.3. Logistics				
1.3.3.1. Equipment		2	2	2
1.3.3.2. Coordination		2	2	2
1.3.4. Technician Ability & Judgment				
1.3.4.1. Type I Error		1	1	1
1.3.4.2. Type II Error		1	1	1

RELIABILITY COMPONENTS	HAZARD SCORES			
1.4. Rearing	1	2	3	4
1.4.1. Guidelines				
1.4.1.1. Genetic Guidelines	5	5	5	5
1.4.1.2. Operating Guidelines	1	1	1	1
1.4.1.3. Decision Trees	1	1	1	1
1.4.2. Natural Variability				
1.4.2.1. Baseline Characterization	2	2	2	2
1.4.2.2. Detection of Departures from Baseline	2	2	2	2
1.4.3. Logistics				
1.4.3.1. Equipment	2	2	2	2
1.4.3.2. Coordination	2	2	2	2
1.4.4. Technician Ability & Judgment				
1.4.4.1. Type I Error	1	1	1	1
1.4.4.2. Type II Error	1	1	1	1

Table C.1. Ratings of reliability components for Yakima River fall chinook salmon (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.5. Release (direct genetic effects)	1	2	3	4
1.5.1. Guidelines				
1.5.1.1. Genetic Guidelines	5	5	5	5
1.5.1.2. Operating Guidelines	1	1	1	1
1.5.1.3. Decision Trees	1	1	1	1
1.5.2. Natural Variability				
1.5.2.1. Baseline Characterization	2	2	1	2
1.5.2.2. Detection of Departures from Baseline	2	2	2	2
1.5.3. Logistics				
1.5.3.1. Equipment	2	2	2	2
1.5.3.2. Coordination	2	2	2	2
1.5.4. Technician Ability & Judgment				
1.5.4.1. Type I Error	1	1	1	1
1.5.4.2. Type II Error	1	1	1	1

RELIABILITY COMPONENTS	HAZARD SCORES			
1.6. Release (indirect ecological genetic effects)	1	2	3	4
1.6.1. Guidelines				
1.6.1.1. Genetic Guidelines	3	3	3	
1.6.1.2. Operating Guidelines	1	1	1	
1.6.1.3. Decision Trees	1	1	1	
1.6.2. Natural Variability				
1.6.2.1. Baseline Characterization	2	2	2	
1.6.2.2. Detection of Departures from Baseline	1	1	1	
1.6.3. Logistics				
1.6.3.1. Equipment	2	2	2	
1.6.3.2. Coordination	2	2	2	
1.6.4. Technician Ability & Judgment				
1.6.4.1. Type I Error	1	1	1	
1.6.4.2. Type II Error	1	1	1	

Table C.1. Ratings of reliability components for Yakima River fall chinook salmon (Continued).

RELIABILITY COMPONENTS	HAZARD SCORES			
1.7. Juvenile Migration	1	2	3	4
1.7.1. Guidelines				
1.7.1.1. Genetic Guidelines	1	1		
1.7.1.2. Operating Guidelines	2	2		
1.7.1.3. Decision Trees	1	1		
1.7.2. Natural Variability				
1.7.2.1. Baseline Characterization	3	3		
1.7.2.2. Detection of Departures from Baseline	3	3		
1.7.3. Logistics				
1.7.3.1. Equipment	2	2		
1.7.3.2. Coordination	2	2		
1.7.4. Technician Ability & Judgment				
1.7.4.1. Type I Error	1	1		
1.7.4.2. Type II Error	1	1		

RELIABILITY COMPONENTS	HAZARD SCORES			
1.8. Adult Migration	1	2	3	4
1.8.1. Guidelines				
1.8.1.1. Genetic Guidelines	2	2	1	
1.8.1.2. Operating Guidelines	3	3	3	
1.8.1.3. Decision Trees	3	3	1	
1.8.2. Natural Variability				
1.8.2.1. Baseline Characterization	2	2	3	
1.8.2.2. Detection of Departures from Baseline	3	3	3	
1.8.3. Logistics				
1.8.3.1. Equipment	3	3	2	
1.8.3.2. Coordination	2	2	2	
1.8.4. Technician Ability & Judgment				
1.8.4.1. Type I Error	1	1	1	
1.8.4.2. Type II Error	1	1	1	

Table C.2. Ratings for components of resilience for Yakima River fall chinook.

CRITERIA FOR EVALUATING POTENTIAL RESILIENCE FROM RESERVES	SCORE
1. Availability No genetic or ecological reserves identified = 1 Reserve identified but not implemented = 3 Reserve identified and implemented = 5	1
2. Appropriateness Scoring: Neither of the criteria below apply = 1 One of the two criteria apply = 3 Both criteria apply = 5 • Genetic structure is template for identifying the reserve. • Reserve represents ecological, aquatic diversity of area targeted for supplementation.	1
3. Sufficiency Scoring: None of the criteria below apply = 1 One of the criteria apply = 2 Two or three of the criteria apply = 3 Four criteria apply = 4 All criteria apply = 5 • Probability of extinction of target species in the reserve is less than 5% in 200 years. • Reserve is regional. • Harvest management goals protect reserve. • Management goals (e.g. harvest, interagency agreements about habitat, water flows, migratory corridors, artificial propagation) are defined within a temporal hierarchy, beginning with the goal that the reserve should function for at least 200. • Reserve protects or restores historical complexity of migratory patterns of target species.	1

OREGON COOPERATIVE
FISHERY RESEARCH UNIT

OREGON
STATE
UNIVERSITY

Department of
Fisheries and Wildlife

Nash Hall 104
Corvallis, Oregon
97331-3803

Telephone
503-737-4531

Fax
503-737-3590

6 April 1993

Craig Busack
Washington Department of Fisheries
P.O. Box 43151
Olympia, Washington 98504-3151

Dear Craig:

Enclosed is the genetic risk assessment for the Yakima Fishery Project. Given where we were when we started, I believe we've made significant progress towards defining a framework for risk assessment and applying it.

There is much more I would like to do to improve the product. Ultimately, I envision a two-pronged approach to risk assessment. One emphasis would be to assess the reliability of safeguards in a project, such as I have emphasized here. The other would be to describe potential losses in genetic or demographic units, such as I did using Goodman's model.

Most of my emphasis here was on developing the framework for assessing safeguards, because that appears to be an aspect that has been ignored. I have worked from very simple criteria for judging the availability, appropriateness, and sufficiency of a safeguard, but I think these criteria could be improved by making them more explicit and thereby more repeatable and precise.

I had originally envisioned doing more genetic analyses, such as trying to estimate loss of among-population diversity under different global rates of straying and also trying to evaluate the genetic diversity protected by reserves in more of regional context. Although I still think this is important, given the amount of time available and the realization that brood stock mining may be a greater immediate hazard, I opted to use Goodman's model for the heuristic value of examining extinction. I imagine a third generation of risk assessments that would include both.

Well, good reading and let me know if you have any questions.

Sincerely,

Ken

Kenneth P. Currens

COOPERATORS:
U.S. Fish and Wildlife Service, Oregon State University and the Oregon Department of Fish and Wildlife