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Toyohiko HIKITA

(With Text-Figures 2)

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The chinook salmon, *Oncorhynchus tschawytscha,* is one of the most valuable resources in the Columbia River and in many other rivers along the coast of the State of Washington in America as well. In Japan, little is known of the distribution of this species in her mainland. But they occasionally migrate off the coast around Hokkaido, especially along the Pacific side, every year.

In October of 1959 one hundred thousand eyed eggs of this salmon were presented to our hatchery on the occasion of the 80th Anniversary of the Hokkaido Salmon Hatchery through the courtesy of the Washington Department of Fisheries. The present paper deals with the result of the transplantation of this salmon in Hokkaido.

About 70,000 eggs of them were immediately transported to the Satsunai hatchery, Tokachi District, for hatching and raising until liberation. The remainders were placed in the Chitose hatchery, for hatching using the vertical incubator. The young at Chitose were reared until the following year in the rearing ponds which were prepared for experimental purpose, particularly for the study of regeneration and growth of marked fish. These marked fingerlings are ready to be released into some suitable streams after sufficient investigation.

The home river of the eggs above mentioned is the Dungeness River near Seattle, Washington, and they were received in the Dungeness State Salmon Hatchery, Department of Fisheries and kept these shipping by the airplane (after personal communication).

The author wishes to express his hearty thanks to Mr. Milo Moore, Director of Washington Department of Fisheries, for the gifts of the eggs and for the information concerned. Thanks are also due to Mr. Ernest Brennon, Superindent of the Dungeness Hatchery for his help in sending these eggs.

水産上に於いて或地域に棲息している魚種を他の地域に移すことを移殖すると云つており，移殖の結果或魚種では成功し又或魚種では不成功に終つている。移殖する時，魚種を移す以前の場所を供給地域は移殖元と呼び，移された場所を移殖先或は需要地と一般に云われ使用されているのである。今迄に移殖された魚類も種々雑多で，水産上有用種もあれば，しからざるものもあつた。移殖の方法を大きく 1）人為的移殖と 2）偶然的移殖とに分ける事が出来る。即ち前者は，当然魚種によつて異るけれども，有用種の卵或は成魚を人間が運ぶものであり，後者は主に人為的に魚類を移殖する時，特殊な場合を除き，普通は第2次的に起る事が最も多いが，移殖

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元の他種魚類が，結果として同時に運ばれる様な場合を云うのである。ここでは人為的移殖だけを主眼としたので，偶然的移殖については省略することにした。

扨て人為的移殖も国内各地域間の様に割合に距離の短い場合と，国外からのように長距離の移殖の２つがある。移殖の目的によつて便宜上更に５区分して考えるならば，（１）純淡水魚に多い食用魚の養魚用としては――コイ，フナ，ニジマス，ソウギヨ，ハクレン，及びテラピア等があり，（２）学術研究用としては――メダカなどが極く普通である。（３）資源増殖用としては――太平洋サケ及びマス類があり，（４）観賞用としては――金魚の各品種を初め現在 100 種内外にのぼる熱帯魚が包含され，それに（５）遊魚家及び内水面漁業を対称に湖沼，河川に移殖を実施している各種マス類等が，それぞれの範中に入るであろう。更に詳細に云えば，3）に含まれる資源維持増殖を実施する目的から２つの相異なる方法が考えられる。即ち（a）北海道各河川のサケ・マス資源を維持するために，或地方で魚が量的に多く捕獲された場合，その卵を他地方の量的に少ない河川に移殖して，それぞれの河川を育成する場合と（b）今迄に全く棲息しなかつた新しい魚種を新しい地域に移殖して，そこで棲息可能にして生産させる場合とがある。

次に卵を移殖する場合，卵は各種の刺戟，環境要因に敏感で，極めて弱いものであるから，生物学的及び理化学的条件を考慮して移殖を実施しなければ，十分な成果を期待する事は出来ないのである。それ故に過去に於いて未だ輸送交通機関も現在程発達して居らず，殆んど船舶，汽車等による以外なかつたため，卵の発生段階，移殖しようとする空間的距離，及びそれに要する時間等を前もつて十分検討しなければならなかつたわけである。然るに最近特に戦後の航空機の発達はめざましく，アメリカでは水産上でも遠距離の湖沼及び山間の未利用湖沼等に新しい魚種を実験的に或は遊魚を目的に移殖する場合には，時間的に極度に短縮されるから盛んに使用されているわけである。それ故に今迄は湖沼に或魚種を生産する場合，卵で持つていつて孵化させる色々の手間が必要であつたのを，現在ではその魚の稚魚或は成魚のまま運搬出来るようになつたわけである。しかしながら我国では未だ水産上に航空機を自由に使用出来る段階には至つていない。サケ・マス卵を運搬するためには，卵発生段階中刺戟に強い発眼期以後に行われるのが常識となつて居り，時間的にも短かく，動揺の少ない航空機で実施するのが最も卵に対し好適であることが，この度の移殖によつても充分証明されたと云えよう。

北海道でサケ・マスの人工孵化が事業的に開始されてから昨年（1959）で丁度 80 年になるので，北海道さけ・ます・ふ化場に於いて「鮭鱒人工孵化創立 80 周年記念式典」を行つた際，アメリカ太平洋岸ワシントン州立水産局の好意により，我国の河川では産卵溯上しない，分布上からも北海道がその南限にあり，量的にも極めて少ないと云われるマスノスケ発眼卵 100,000 粒を孵化場に寄贈されたのである。

我国ではマスノスケ卵及び稚魚に就いて井上（1937）がカナダ産サケ属稚魚の査定をしている Prichard（1934）の報告の１部を抄録紹介されて居り，又渡辺（1940）はアメリカで実験されたこの種の卵及び稚魚について記述されているだけである。

今迄に移殖された色々の魚種の供給地或はその後の経過等に就いては極く一部の魚種を除き，正確に記録されているものは殆んどない状態である。渡辺（1940）によれば在米中ワシントン州水産局に，該魚を日本に 1897，1898，及び 1917 年の３回にわたり，10 万粒づつ移殖した記録が残つているとの事であるが，移殖先である我国の記録は何も明らかではない。それ故著者は今回のマスノスケ卵を北海道に於ける最初の移殖として取扱い，更にその卵の到着時より，その後の経過等に就いて出来るだけ正確な資料として今後の参考に供するため取纒めた次第である。

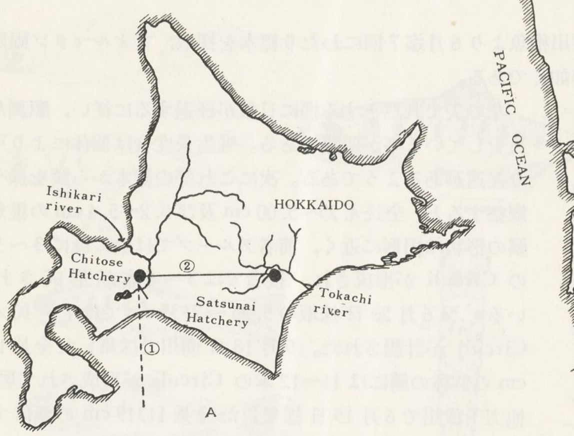
サケ・マス類は寒流性の魚類であるから，勿論棲息分布範囲内に於いては移殖可能であろうというので，1900 年代の初めにアメリカでは，これ等魚種の資源増殖を目的に，盛んに国内各州及び国外に移殖したのであるが，極く小部分を除き，殆んど不成功に終つているようである。扨て北海道は北緯 44° 附近にあり，他方シヤトルは北緯 46° 附近にあり，マスノスケ分布範囲に入るので，この種移殖に就いては充分可能性があるわけである。

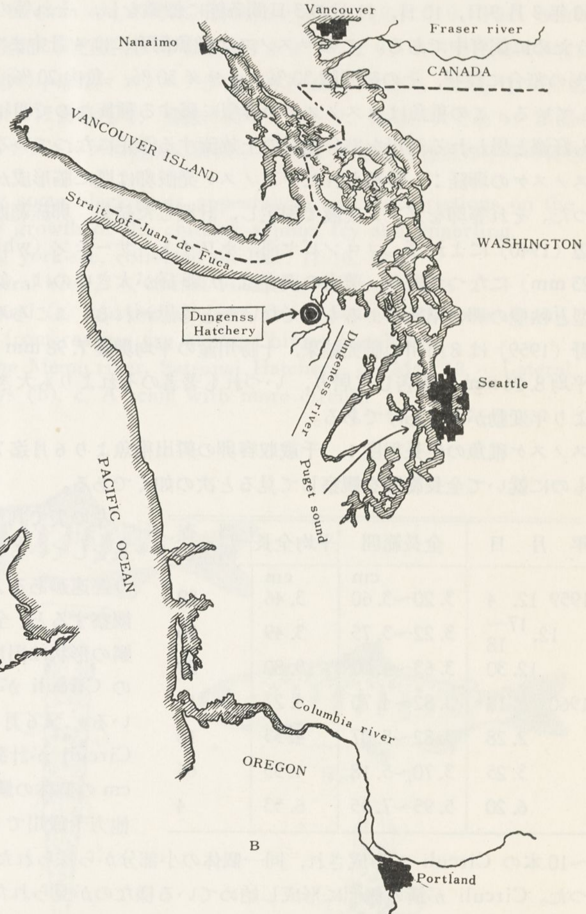
移殖経路：　今回のマスノスケ卵は全行程，輸送機で行われ，1959 年 10 月 10 日夜シヤトルを発送，12 日夕方千歳空港に到着する予定が，日本航空が多少遅れたため，12 日夜に羽田空港着，そこで１泊して翌 13 日午前 10 時に 100,000 粒を６ケのダンボール箱に入れて無事到着した。各ダンボール箱の内側はテツクス板で６方が蔽われ，定温を出来るだけ保持するよう作成されている。そのテツクス板の内側に丁度合う卵箱を４段重ねて，最上

段の卵箱に細片にした氷を入れ，卵箱内の温度が上昇しないようになつている。各ダンボール箱には約16,660粒，又各段卵箱には約5,556粒が収容されていた。千歳空港到着後直ちに千歳支場に全卵を運び，立体式孵化器に収容した。約30,000粒を千歳支場に残し，約70,000粒を十勝支場管内札内孵化場（Fig, 1, A）に収容するた

Text-Fig. 1. A and B: Maps indicating the course transplanted into Hokkaido (①-②), and the location of the State Salmon Hatchery on the Dungeness river, Washington, U. S. (modified by authur a map of Department of Fisheries)

● Transplanted hatcheries.
⊙ Parent hatchery of the Dungeness river.
… Egg transport by Japan Air Line (JAL).
— Egg transport by train.





め，アメリカからの輸送箱3ケを使用して15日午前11時20分千歳支場より本場に自動車で輸送，22時の汽車で係官附添のもとに札幌を出発，帯広駅に16日午前6時2分に到着，直ちに3輪車で札内孵化場に6時45分に到着した。本場到着より札内孵化場孵化槽に入れる迄の所要時間は大凡19時間25分であつた。汽車輸送中の列車内温度は，札幌駅19.6°C，富良野駅20.4°C及び帯広駅では17.3°Cであつた。千歳支場及び札内孵化場到着時の輸送

各段卵箱温度 ＼ 輸送箱番号	千歳支場 1	千歳支場 2	札内孵化場 1	札内孵化場 2	札内孵化場 3
上　段	5.2°C	4.0°C	4.5°C	5.4°C	4.5°C
中　段	7.2	6.5	6.2	6.2	6.3
下　段	9.1	9.3	7.2	6.9	7.0

箱内各卵箱温度を下記に列記すれば前頁下表の如くである。

卵収容後の経過： 札内孵化場到着後アトキンス式孵化器に収容，収容時の卵数は 65,072 粒（実数）であつた。収容した孵化水温は約 12°C で千歳支場のそれよりも高い。汽車輸送中の運搬害死卵数は 414 粒（実数）で，生存率は 99.36 %であつた。この運搬箱による卵輸送は極めて良好な成績である事を物語つている。孵出する迄の死卵数は 1,687 粒（運搬害を除く）で，孵出尾数は 62,791 であつた。孵出稚魚 200 尾を抽出し，その全長範囲を見ると 1.90～2.45 cm（平均 2.21 cm）であつた。次に札内孵化場収容卵の孵出その他の事項の月日を記述すると――孵出月日は 10 月 23 日～25 日，孵游は 12 月 4 日以後頃，1960 年 1 月 14日～2 月 2 日迄の間に 42,130 尾を取揚げ，この数字にもれた稚魚は河川に逃避したものと思われる。取揚げた稚魚には脂鰭と両腹鰭に標識して養魚池に放流したのである。その時の 50 尾による全長平均は 3.28 cm であつた。他方千歳支場収容稚魚は 1960 年 3 月 9 日，10 日，11 日の 3 日間各鰭に標識をし，それ等の再生度合を観察すると共に生長度等の実験を行うために飼育中である。このマスノスケ稚魚飼育には 4 月中までは大凡肝臓 70 %，他に粉乳，野菜，麦粉を 30 %の割合に混ぜ，その後肝臓 30 %，イサダ 30 %，魚肉 20 %，麦粉 15 % 及び野菜 5 %の割合に混合して投餌している。この稚魚はマスノスケの春型に属する種族なので明年（1961）まで支場の特設養魚池に飼育して，最も好適と思われる河川を充分検討の上放流する予定になつている。

マスノスケの卵経： 移殖されたマスノスケ発眼卵は既に脳形成が完了し，胎体も卵を殆んど一回転したものであつた。それ等卵をブアン氏液で固定し，計測した結果，卵経範囲は 7.3～8.0 mm（平均 7.57 mm）であつた。渡辺（1940）によれば，コロンビヤ河，ホワイト・サーモン（white salmon）産の卵経は 7.1～9.7 mm（平均 8.23 mm）になつて居り，著者の調査より卵経が大きいのは，勿論その時の親魚の大きさの相違によろうが，夏型と秋型の卵の相異によるものでないかとも思われる。こころみに北海道河川産サケ卵経と比較してみると，佐野（1959）は 8 河川の研究結果，十勝川産の平均卵経 7.98 mm となつて居り，又渡辺（1940）は西別川産では平均 8.26 mm と報告して居り，いづれも著者のそれよりも大きくなつている。勿論この卵経はサケでも河川により年変動があるわけである。

マスノスケ稚魚の生長程度： 千歳収容卵の孵出稚魚より 6 月迄 7 回にわたり標本を採取，フオルマリン固定したものに就いて全長範囲を観察して見ると次の如くである。

年 月 日	全長範囲	平均全長	調査個体数
	cm	cm	
1959 12. 4	3.20～3.60	3.46	29
12. 17～18	3.22～3.75	3.49	20
12. 30	3.63～4.00	3.80	29
1960 2. 18	3.82～4.70	4.27	11
2. 28	3.82～5.07	4.53	10
3. 25	3.70～5.18	4.55	66
6. 20	5.95～7.35	6.53	4

左の表で判然とする様に日数が経過するに従い，順調な生長をしている事が明瞭である。唯生長度合は個体により可成り遅速があるようである。次にこれ等の標本から鱗を採つて観察すると，全長 4.25～5.00 cm 及び 5.2～5.4 cm の稚魚の鱗の形状は円形に近く，前者グループでは鱗に既に 3～5 本の Circuli が形成され，後者では 3～6 本が形成されている。又 6 月 20 日採取の 5.95～7.35 cm では 7～10 本の Circuli が計測された。5 月 18 日面川で採集した全長 10.6 cm の個体の鱗には 11～12 本の Circuli が形成されて居り，他方千歳川で 6 月 15 日採集した全長 11.19 cm の個体では 7～10 本の Circuli が形成され，同一個体の小部分から採られた鱗にも若干の Circuli 本数範囲がある事がわかつた。Circuli が鱗の側面に形成し始めている様なのが見られた。これ等標本の鱗の形状ではサケ・マス類成魚の鱗に近い卵形になつている。更に面川で採集した稚魚と千歳川で採集した個体は後者の方が約 1 ケ月遅く採られたにもかかわらず，Circuli 数が僅か少ない事は水温，その他の要因によるためでないかと思われる。尚千歳支場飼育の稚魚と同河川採集の個体とを比較するならば，全長に於いて河川のものが大きいのにもかかわらず，Circuli 数は両者共，同様範囲内にあることは，河川のものは運動の場が広く，従つて餌を良く摂食するためであり，他方飼育稚魚は狭い場所に多数の稚魚を放養しなければならないので，投餌を充分にしても，運動範囲が極限されるためでなかろうかと思う。

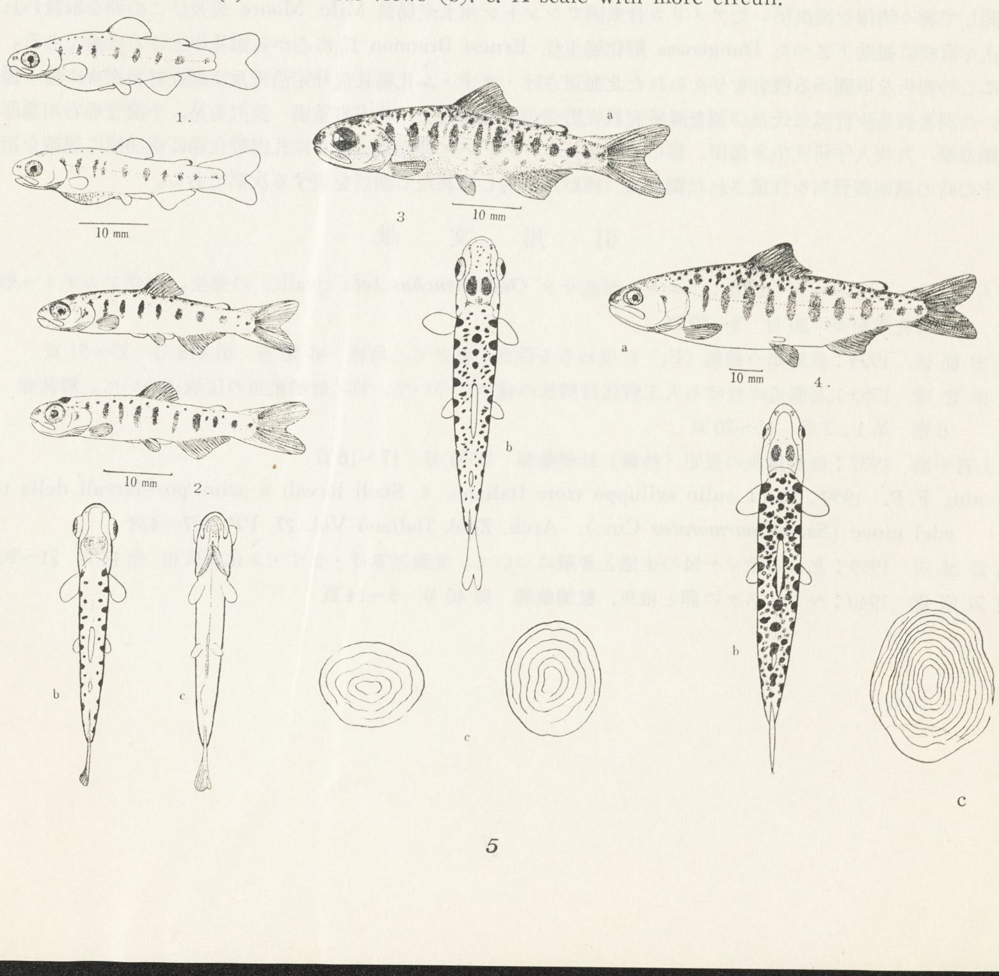
以上の事から 2 月 28 日採集の稚魚，即ち孵出後約 3 ケ月で，体が鱗に蔽われているのであるから，全長 4.25 cm になる以前に鱗が形成し始める事は明らかである（Fig. 2, C）。

マスノスケ稚魚の斑紋その他の特徴： マスノスケ稚魚の Parr mark の発現については渡辺により記述され，

著者の調査結果と殆んど一致するが，未だ卵黄吸収完了以前稚魚(Alvine)の大凡 2.5～2.8 cm の全長では既に体側に淡紫色の Parr mark が出現，個体による変異があるが，8～10 個が体側に沿つて並んで居り，背鰭前の Parr mark 背面の中間に 1 ケ至乃 2 ケの小斑点が 1 列に並ぶが， 背鰭より後方には 未だ 小斑点が出現していない。1960 年 1 月採集の稚魚では Parr mark は明らかに濃色になり体側背面の小斑点は Parr mark の間に 1 ケづつ鰓蓋後縁より尾鰭基部前まで 1 列に並んでいるが，他の黒色斑点は未だ出現していない。尚この時期の稚魚の腹部に卵黄吸収後の縫合線の皺がかすかに残つている。この小斑点はマスノスケのこの時期の特徴になるが，口部特徴は未だ出現しない。井上 (1937) の抄録の図は，この時期の稚魚であろう。2 月 28 日採集魚では Parr mark 背面の小斑点が順次拡散し始め，他に更に多くの細かい斑点が， 1 例に並んでいる小斑点の間にはさまつて出現し始め，マスノスケ独特の口部特徴の鈍形な先端を形成し始める。その上に背鰭基部の前部が黒味が強く，頭部にも若干の小黒色斑点が出現する。 面川採集の 10.6 cm のものでは，体側は全体が銀白色になり，Parr mark 及び体背部の小斑点も淡くなり，代りに体背部全面に黒色斑点が多数散在するようになり，これ等斑点は非常に明瞭になる。この時期に至れば外形特徴は外洋形の小形なマスノスケが完成されるわけである (Fig. 2,—1, 2, 3, 4)。 次に一般的外形を観察すると， Parr mark は濃紫色で，側線に沿つて大形で，体高が大であり，頭部の側線系はトツクリ状で，サケの稚魚より，むしろサクラマスの稚魚に類似している。千歳収容稚魚の生時の体色は，

Text-Fig. 2: These sketches showing some black-spots appearances and its variations on the body with the advance of growth of the chinook salmon fry and fingerling.

1. Fry with absorpting york-sac, collected on Dec. 17–18, 1959.
2. Jan. 1960… a. Lateral view, b. dorsal view, c. Ventral view.
3. Feb. 28, 1960… Lateral (a) and dorsal views (b). c. Scales with some circuli. All above sketches from rearing fry of the Chitose Hatchery.
4. A fingerling from the Memu river, Satsunai Hatchery, on May 18. … Lateral (a) and dorsal views (b). c. A scale with more circuli.



頭部より背面は暗褐色で，それに黒色小斑点が散在している。背鰭は前部で特に黒色が濃く，尾鰭両葉は橙黄色を帯びている。吻部は飴色半透明で，頭部脳室部の輪廓が緑がかつた橙赤色である。液漬標本では背鰭，脂鰭後縁及び尾鰭に黒色々素が散布して黒味がかり，体側下部にも比較的大きい淡黒色々素が分布する。マスノスケの臀鰭，胸鰭にも多少黒色々素があるが，サケ稚魚では背鰭前部を除く各鰭は白色であり，体側々線の下部腹面に黒色々素がない。

移殖供給地： マスノスケは北海道以北，ベーリング海，アラスカ，カナダ，北米合衆国にわたる北太平洋全域に分布している魚種である。マスノスケ溯上河川としては，アメリカ，ワシントン州のコロンビヤ河が有名である。又マスノスケには春型と秋型の2型があり，前者は孵出後稚魚がその年の内に降海するものの一部をのぞき，大部分は北海道に溯上するサクラマスの様に一年間河川内に棲息し，次の年に降海するものである。一方後者では孵化後稚魚はサケの如く，その年に降海する事が知られている。北海道に移殖されたマスノスケは春型に属するものである。最初著者及び孵化場係官はコロンビヤ河産の卵であると思つていたが，著者に対する水産局長の私信によつて，寄贈された卵は Juan de Fuca 海峡に面する Dungeness 河（Fig. 1, B）で，これ等卵を発生，孵化過程を取扱つたのは，ワシントン州立 Dungeness 鮭孵化場である事が判つたのである。Dungeness 河は比較的小河川で長さ約40哩，この河の水源はオリンピック山系の大凡200平方哩の地域より発している。Dungeness 水系上流には永河がある。河川の傾斜はかなり急で，河水量は秒速大凡150立方フイートから2,000立方フイートまで変動し，時にこれ等をはるかに越えることがある。Dungeness 河では6月及び7月にマスノスケ成魚（産卵群）が溯上し，ここの採卵は8月及び9月初旬に行われる。使用親魚の体重は約15～20ポンドの範囲で，各雌親魚は大体5,000粒の卵を生産するとのことである。

移殖されたこのマスノスケが産卵成魚として北海道の母川及びその周辺の河川にどれ位溯上して来るかを大いに期待しているのは，孵化場係官のみならず，ワシントン州水産局でもその成行きを見守つている事であろう。

最後に孵化場80周年記念に際し，マスノスケ卵を寄贈され，著者の質問に対しマスノスケの移殖元及び河川に関して種々情報を提供頂いたアメリカ合衆国ワシントン州水産局長 Milo Moore 氏及びこの卵を取扱われ又輸送を直接に援助下さつた Dungeness 孵化場主任 Ernest Brannon 氏に心から御礼申上げる次第である。更にこの報告を取纒める機会を与えられた北海道さけ・ます・ふ化場長荒井定治氏及び調査材料採集に種々援助頂いた調査課長佐野誠三氏及び調査課研究員坂野栄市，小林哲夫，札内事業場 長沢有晃，千歳支場石川嘉郎，倉橋澄雄，九州大学研究生多部田，修の諸氏並びにマスノスケ卵到着後直ちに札内孵化場に成功裡に運搬を担当しその時の諸観測資料を作成された調査課三浦厳氏に対し深甚なる謝意を表する次第である。

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~~G. Wedemeyer~~

Atlantic Salmon Conference
New Brunswick, Sept 1972
GW
[Intl. Symposium
1973]

THE TRUTH ABOUT SALMON FISHING

by

A. G. Huntsman

He is very anti scientist
vs. Pure scientist & academics

By "truth" is meant knowledge that works, more strictly knowledge that has worked seeing that the future is always uncertain. To me, such knowledge is science and to be contrasted with unsubstantiated imagination. I can only hope to have kept them separate.

Scientific Fishery Management

Canadian biologists started a Biological Station at St. Andrews, N.B., in 1899, under fishery auspices for the purpose of solving fishery problems. Its Board of Management consisted of biologists who wanted facilities for themselves and others that were prepared to give their services in summer for such purpose. ~1912
After 13 years and with additional stations, it became the Biological Board of Canada. In the first year of its existence, there was investigation of the local sardine fishery with a published result that made nonsense of the current three principles of fishery management, namely, hatching and planting of young to remedy depletion, protection of the young, and protection of spawners. Fishery management without scientific basis continues to this day, disregarding what the Board has discovered, reported and published.

After 35 years, the Board changed in character to become the Fisheries Research Board, whose members are now without personal interest in solving fishery problems. They hire specialists from the universities for such purpose. Over the years, the academic situation deteriorated from the practical standpoint with adulation of "pure" science and denigration of the practitioner and the engineer as well as the naturalist, as is now apparent.

But, with evident failure to improve the fisheries, the St. Andrews Biological Station selected the Atlantic salmon fishery for a special effort, beginning in 1929, primarily because it had been the fishery about which there had been most complaint at the hearings of the Royal Commission on the Maritime Fisheries of 1928. An intensive effort to solve the salmon problem was begun in 1934 on the Margaree fishery, of which there was most complaint. That problem seemed to be solved almost at once. But, there was failure to get the solution (use of artificial freshets) applied even when by 1943 its effectiveness had been well demonstrated on the Moser River fishery at low cost. Nor was any attempt made to apply the recommendations made for the management of the latter fishery as well as of that of the Apple River, the first one investigated sufficiently. Both of these were easy to deal with. All three required different treatment in accordance with local conditions. With the co-operation of fishery officials, the situation for getting application of results on the Apple fishery was explored through a local advisory committee in the early 1950's. The salmon could be used only by poaching, which was excessive, keeping the stock down. In our investigation, we had increased the stock by re-establishing a run in the east branch of the river. But, the committee would not accept remedy of the condition, wanting to make the poaching easier. All this was reported without effect.

For 6 years from 1948 to 1953, a thorough attempt was made to apply results in management of the salmon for angling in Grand (Shubenacadie) Lake near Halifax, where there were rearing ponds to help such fishery. There was no difficulty in getting the necessary science for action. But, what a situation! Management had taken no account of the local conditions. The ponds had been started under provincial auspices for rearing trout, but had been transferred to the federal government. High temperature of the water in summer killed the trout and stunted the salmon which grew no longer than about 15 inches in the ponds, and about 20 inches in the lake. Reared fish did not survive to become larger and reach legal angling size. Natural production was very low in this very rocky region with warm lake water rather than cool spring water, with the water of low fertility or even sterile for production of food for fish, and with eels preying upon the young salmon easily at such high temperatures, which slow down the latter but not the former. Attempts to remedy these adverse conditions were made or proposed, but the cost would probably be prohibitive if it were to be warranted by results. The ponds have been abandoned.

What was responsible for such failure in getting scientific management? Even the biologists showed no interest in getting application of results. The Board's Editor would not publish a long paper on management of the various fisheries that had been investigated. The Journal of Wild Life Management rejected such for publication because of a policy against "pressuring local authorities" But, was there any object in publishing what was of no interest to biologists, what did not have their backing?

The scientific situation for fisheries research was then explored. The result has been given in the 8-page folder on "Creation versus Evolution - The Fallacy of Darwinism" (Toronto, April 1972) which was an attempt to summarize what was dealt with in a document prepared for the Department of Zoology of the University of Toronto and still under consideration on "Scientific Method - The Curse of Overthinking". These show the scientific situation that has come to light.

As it happens, the St. Andrews Biological Station is in a very good position, however it has come about, to remedy the fantastic situation now revealed, that biologists in general are taught no science of what plants and animals will be where and when, nor how to get such science. This Station has a very great deal of knowledge of what fish, particularly salmon, will be where and when, whether or not such is considered by academics to be science. The main factor to determine what salmon there will be is where they go from wherever they arrive. Unfortunately, the unsubstantiated imagination that they "migrate", that is, direct their courses in going outward from their streams and back has prevented appreciation of the significance of what they can be observed to do. However, the

Station decided last year to ignore this and proceed to try to apply all its knowledge of factors determining what salmon there will be in management of the local Magaguadavic salmon fishery. As a start, Upper Trout Brook, which seems to be very good for production of the young, but which salmon do not seem to have entered, is being planted with young to establish a local stock. Since we cannot be sure of having sufficient knowledge, with the future always uncertain, this will be a test of our having the required science. That this should be done in the face of the present academic situation is remarkable. The Station has a good prospect of making history by leading in the correction of academic failure to be practical, unless the laudable desire to use new techniques for getting facts not only delays learning from facts already available, but even condemns what is so learned to block scientific advance. This last is the overweening pride of the specialists that our education produces. The everyday science of common sense is quite as valid as that of any specialist as long as it is knowledge that works.

We may now proceed to give such truth about salmon. It should not be expected that desirable data to support statements can be given in this brief account, except to a limited extent.

Is there Overfishing?

What is the situation of Canadian Atlantic salmon for recent years, which biologists without science of what salmon there will be have been unable to appreciate, and yet have ventured to judge? It varies, often greatly, from river to river to make separate consideration necessary. In the short space now available, it is only possible to deal very briefly with a few that were investigated with results that seem to have made no impression on biologists.

In the southern part of the original range of the salmon, that is, where summer temperatures are highest, and from which it disappeared in the last century, there has been no recovery. Should it be expected? That depends upon why it disappeared. For this, the Duffin Creek, Ont., experiment in the 40's (J. Fish. Res. Bd. Canada 11, 1954) showed that disappearance had been the result of intensive cultivation of the watersheds of the salmon streams with rising population, giving quick run-off of water and thus less water in the water table. This meant less cool spring water and thus more or less lethally warm water for young salmon. Each year, most of the young salmon planted were killed by the heat. Even those up near spring sources that survived and grew well had very little chance of surviving because, as the unpublished findings of later investigation showed, the temperature of the outflow of the creek, into which they would settle on descent, became too high, particularly with onshore winds. Can this be rectified?

Official action was taken this year to stop commercial capture of Miramichi and Saint John salmon of New Brunswick. I have so far been unable to learn what facts have been the basis for this action. There certainly has been the idea that decline of catch in recent years has been due, not so much to spraying of spruce forests and construction of dam reservoirs on rivers, but to overfishing to decrease the long-term yield and even endanger stocks, with the recent development of the Greenland fishery for salmon in mind. It is only imagined that such fishery affects Canadian stocks. Overfishing to reduce the long-term yield was given extensive consideration 20 years or more ago and almost no good basis was found for it. What do the facts show as to what is correlated with the course of these two salmon fisheries in recent years?

At the beginning of the Station's investigations of Maritime salmon, study of the fluctuations in the various fisheries revealed for a 60-year period a periodic scarcity at intervals of 9 to 10 years. This was in agreement with a well known periodicity in abundance of fur-bearing animals in the Canadian Northwest to indicate a common factor, perhaps climate. It proved possible to relate this scarcity to low water in summer in the streams when the young of a certain year-class were large, which is shown by salmon catches in the sea when the year-class was being caught (Trans. Roy. Soc. Can. 31, 1937). Low water acts in various ways. It is a simple illustration of the fact that you must have water to have fish. Under the existing conditions, it has been natural that salmon biologists have ignored this science. It has taken only a day's work to discover whether or not such obvious factor has been operating to affect those fisheries. There is some indication (Fig. 1) of the old periodic scarcity, but the period of time is too short for clarity. The shorter periods that were very fully studied at the beginning (Biol. Bd. Canada, Bull. 21, 1931) are not in evidence, whatever may have been the reason. But, it does seem that this basic factor of the amount of water has been dominant. Considering that low water in the critical summer months of July and August may have acted to decrease the yield and that it acts when the young salmon are in their second year of stream life and needing decidedly more room for survival, it will show up in the catches 4 years later for Miramichi salmon and 3 years later for Saint John salmon in accordance with different life histories owing to temperature. It does seem that amount of water for the young determined rises in catches to peaks in 1966 for Saint John salmon and in 1967 for Miramichi salmon and declines in catches thereafter.

In our initial study, the shortest life history (4 years) seemed to dominate fluctuations in the fisheries of the inner end of the Bay of Fundy, with small warm streams and without the deep cold sea water in summer that gives longer sea life. Also, they were peculiar, as compared with the Maritime fishery as a whole, in showing early and late highs in catches with an intermediate low during the 60 years. In accordance with their life history, the striking fluctuations were short periodicities of 2 and 4 years, that is, 2 years in the streams and 2 years after to spawning. These were more striking in the outer Minas fishery than in the inner (Shubenacadie) fishery.

The outer fishery is that at the mouth of Minas Channel which, as stated elsewhere, takes salmon of most varied origin that are concentrated there by the water circulation. In recent years (Fig. 2), its course differs markedly from that of the salmon fishery in general. It sank to a very low level in 1951 and has risen in the last 10 years, with its characteristic 2- or 4-year periodicity well shown. Tagging of the salmon in three successive years in the late 40's indicated that the extent to which they remained there, and where those that left went, was greatly influenced by rainfall. The circulation that concentrates them there is the result of mixing of fresh water with salt water.

The inner fishery is mainly that of the Shubenacadie estuary and Cobequid Bay at the head of Minas Basin where tidal action is extreme (over 50 ft. rise and fall). This permits, with very turbid water, the fish to remain to feed very well indeed in the intertidal zone. The circulation concentrates them there somewhat variously, depending upon river discharge (J. Fish. Res. Bd. Canada 15, 1958). The fishery was almost nil in 1951, the very low point for the outer fishery. It was discovered that this was correlated with very low water in the fall 4 years before, when the year-class that forms the bulk of the fishery would have been spawned. This indicated complete removal of spawners, doubtless by poaching, in 1947. Such great overfishing seems to be commonplace in these small streams when conditions are favourable. The recent course of this fishery (Fig. 3) is possibly related to the ease with which the salmon may be poached with low water in the fall. The situation should be thoroughly investigated. It seems that the absence of the 1947 year-class, giving very few fish (respawners only) to spawn in 1951, was responsible for the very low catch in 1955 in spite of there having been good water near spawning time that year (mean discharge of Rawdon River in September and October, 54 sec.-ft.). Also, it seems that, with suitably high water for spawning in 1953 and 1954 (75 and 42.6 sec.-ft.), rather low numbers of spawners gave very high numbers of fish of those year-classes, as shown by the catches of these in 1957 and 1958. Yet, with very low water for spawning in 1957 (9.8 sec.-ft.), the very high number of salmon in 1957 must have been virtually eliminated before spawning, as shown by the very low catch in 1961 when their progeny would be caught. It seems quite clear that successful spawning needs to be assured to give a steady high yield.

The Margaree salmon fishery of the Gulf coast of Cape Breton Island presents an opposite situation, that of underfishing. It was well investigated from 1934 to 1941 to assure salmon for angling. How this could be done became apparent almost at once. Again it was a matter of having the right amount of water, in this case heavy freshets, to bring the fish in through the estuary and up the river. That this would be effective was amply demonstrated on the Moser River from 1939 to 1942. But the anglers who had requested the investigation only wanted to have more nets on the coast outside the estuary eliminated. They had got them removed from the estuary first and then for half a mile on each side of the mouth of the estuary without effect that was perceptible. Tagging showed how little this effect would be. It also showed that the estuarial conditions, not only kept the fish out, but made it easy for wind movements of the water to carry more or less of the salmon away from the river in both directions along the coast for about 100 miles (Fig. 4). The course of the North Inverness fishery, of which the Margaree is the most important part, is shown in Fig. 5 for the period from 1936 to 1968. Since it was found for this river that low water in summer gave a low catch 3 years later through action on the young in their last year of river life, the summer discharge of the N.E. Margaree River from 1933 to 1965 is shown in Fig. 5. There is not very much evidence of relationship. The outstanding feature is a low level of catch from 1955 on. The records show a marked decline in the number of traps or nets from 1954 to 1958, with no recovery. It may be inferred, and can be verified, that the anglers got their objective of eliminating more of the nets. I am informed that the number of nets on the Margaree coast proper is only a fifth of what it was when we were there and that the zone free from nets on the more desirable north side of the mouth of the estuary is now one mile instead of half a mile. There seems to be no doubt that this is gross mismanagement in the face of our report on "Salmon for Angling in the Margaree River" (Bull. 57, Fish. Res. Bd. Canada, 1939).

Variable Movement Oceanward

Salmon that descend into a lake may remain there to become more or less large, to provide angling, and to return at spawning time to tributary streams. It is only imagination to assume that they are prevented from going farther by being "landlocked". It has never been shown that they differ from those that go farther in their original character, as has been imagined. Margaree salmon at the head of Lake Ainslie to some extent remain in the lake after becoming smolts, but only for a year, reaching a length of about a foot. Although free to do so, these lake salmon have not "migrated" to the ocean and back. Like zooplanktons that go down into the depths of a lake during the day, they have failed to be carried farther. As they increase in size, they require deeper water than about 40 ft. on getting about a foot long, as shown by their behaviour in lakes no deeper than that, tributary to Grand (Shubenacadie) Lake.

Salmon that descend into the 40-mile-long estuary of Cobequid Bay and Shubenacadie River at the head of Minas Basin, which is practically empty at low tide, provide a regular seasonal fishery with drift nets in this intertidal water. The nets are drifted with the inflowing and outflowing tide. These fish are large and fat for their sea age of a year or so. This is recognized by the fishermen as being due to their having exceptionally good feeding here on "ocean grub". With uniformly high temperature, they uniformly ascend their streams near spawning time only at this age as grilse. No such fish are taken in the salmon fishery in Minas Channel that connects Minas Basin with the Bay of Fundy. There is no indication whatever of "migration" to the ocean and back.

The salmon of the Saint John River, which discharges through the Reversing Falls at Saint John into the outer half of the Bay of Fundy, are caught in the sea along its evident outflow as far as the inner end of Grand Manan Island at the mouth of the Bay, but not at its outer end. In this water they have very much food, various kinds of small shrimp and small herring, with a gradation in temperature during summer of the bottom water into which they descend from the light by day, going from Saint John to

Grand Manan. Sooner or later, in accordance with this gradation in temperature, they get fat, cease feeding and roam. This may be the prelude to return to the river. It occurs at many sea ages and corresponding sizes, namely, after only a few months (no return), after a year or somewhat more, after 2 years, after 3 years, and even after periods intermediate between these. What basis could there be for belief that all these different ages have been in some distant general feeding ground in the ocean and have returned from it rather than grown locally from the very abundant local food that they are found to have in their stomachs when they cease feeding and come near the surface?

The precise and abrupt ending of transport of young salmon in the Saint John outflow just before it reaches Grand Manan is due to the outflow being mixed with deep salt water, mainly in the tidal boils of so-called "Quoddy River", that is, pollock river, a 200-ft.-deep, very rocky channel at the mouth of Passamaquoddy Bay. This remarkable phenomenon is responsible for, and the focal point of, a unique fishery for small herring to be canned as sardines. When this canning was started around the early 80's of the last century, it reduced greatly the numbers of large herring. This left more food for increase in numbers of the small herring. With no large herring to compete for this good feeding on small shrimp and small herring, the grilse and larger salmon became excessively fat by the end of the summer feeding season to make them stop feeding and roam about, which is the prelude to return to the river, in this case a year before they will spawn. It is ridiculous to call this a "spawning migration". Such fish have been found to go in through the Reversing Falls toward the end of the year with an average weight for the "grilse" (less than 2 years in the sea), which are most numerous, of 9 pounds. These fish winter in the deep water of the tidal part of Saint John River, in Kennebecasis Bay, Washademoak Lake and the Long Reach, between Saint John and Fredericton. These salmon were found in 1932 by the Station to be the basis of the capture in the river at the head of tide very early in the season by the net fishermen of York County of salmon then with an average weight of 8 pounds, which had been first observed and reported in 1885 as being a strange and peculiar species. At that time these fish were seen as being responsible for the sudden beginning in 1884 of capture of salmon by angling in the Tobique River, the northern tributary of the Saint John. In 1887, two parties landed 47 fine salmon in a few days, only fishing a few miles above the forks. In 1888, this angling had improved one half within the previous 2 or 3 years, so that the local government had leased the Tobique waters for a term of 5 years to a company for fly fishing. These fish, half way between grilse and ordinary salmon, formed the so-called Serpentine run into the Tobique River. Such science of what fish will be where and when was published by the Station in 1933 (Fig. 6). It will be realized that the origin of this run is dependent upon the salmon remaining to feed in the river outflow.

In 1932, A. A. Blair reported (MS Rept. Biol. Stas. 98) for 524 salmon taken in three different periods in the Saint John outflow in June and July that those that had been 2-year-old smolts rather than older had increased from 38.6% to 41.7% and to 58.1%. There were similar increases for 44 respawners from 12.5 to 50 and to 80%. What can this mean? For 1938, W. S. Hoar reported (MS Rept. Biol. Stas. 129) the same thing, but on the inverse basis of a decrease in those that had been 3-year-old smolts. He stated that this was in agreement with what Menzies and MacFarlane had affirmed to be "a characteristic of British rivers in general". On the basis of finding "that there are consistently more of the 3-year-smolt migrants at Saint John Harbour than at Dipper Harbour", with the intermediate Lorneville fish showing an intermediate condition, Hoar proposed that this situation represented not a "tendency of older smolts to return to the river after spending the shortest time possible" (Menzies), but to older smolts from cooler upland streams with slower growth (as found previously for the Margaree River) not going so far in the outflow. This might be expected with later descent when river discharge is lower. "A mass movement of the young salmon to a distant and specific feeding ground would not appear from this". He found (Fig. 7) that the proportions of 3-year-smolt salmon decreased through June, July and August at all three places, from over 80 to 20% at Dipper Harbour. The salmon are distributed outwards twice as far as Dipper Harbour to the inner end of Grand Manan (not to its outer end), but the fish are not sufficiently concentrated in the outer broad half to make fishing worth while. Those from outside will thus continue to enter the area of concentration. At the same time, the differences in proportion of 3-year-smolt salmon between the three places gradually disappear. This is brought about by movement of the salmon back and forth in the area in the double movement of tidal flushing out of river water as mixed with sea water in the reversing falls at the inner end of the harbour where the fishing ends. This shuttling of the salmon back and forth was shown by the salmon tagged at all three places in 1938. Of 300 fish tagged, (100 at each place), 173 were recaptured, all but one being either in the outflow or in the river. That one had joined the "lost" salmon in Minas Channel at the head of the bay.

The Margaree salmon of the inner coast of Cape Breton Island provide a marked contrast to the Saint John salmon in the extent to which they remain in the outflow. That coast, against which these salmon when roaming near the surface tend to be concentrated for easy capture, is quite straight. The salmon "fleets" or traps set at the shore to take them reveal where they are. They appear in early summer in accordance with local warming of the water, which may be a week later in a year in which the winter's ice is slow in leaving the Gulf. The outflow of the Margaree Estuary goes north along the coast, scarcely reaching Cheticamp Island, a distance of about 11 miles.

As stated in 1965 (Limnol. & Oceanogr., 10 Suppl., p. R144), it was found in examination of fish taken at different points along the outflow that fish that had been younger as smolts and that had presumably come from lower warmer parts of the river system were on the whole farther out along the outflow than those that had been older as smolts. There was also evidence that those that had been 3 rather than 2 years in the sea had been settled in deeper water that warms later, since they appeared later.

With over 30,000 Margaree salmon marked as smolts in 1938, there was a good opportunity to discover whether or nor the appearance of these fish in the catches of 1940, when they would be most numerous, would show where they had settled, if they had done so. Catches of the nets from 25 miles north to 7 miles south of the mouth of the estuary were carefully examined for marked fish. It had been found by tagging in 3 previous years (Bull. Fish. Res. Bd. Canada 57) that the salmon that appear on the coast are to a fair extent shifted away from it by winds for a distance of about 90 miles both to the north around the island and to the south along the Nova Scotia mainland.

The percentages of marked salmon in whatever catches were made by traps on various parts of the coast in each of the first 6 weeks of the fishing are shown in Fig. 8. Salmon were first taken at Cheticamp 15 miles to the north in the first week. Among 26, there were no marked fish. The next week the percentage was 0.8, and it increased rather steadily to 7.1% by the week of August 5. Farther north, at Pleasant Bay, there were fish in the second week, but no marked ones until the fourth week, and the percentage reached 7.1 the sixth week. In the two outer parts of the outflow, there were high percentages when catches were first made in the second week, but none in the next part toward the estuary, with no catches farther south. The next week they were in fair numbers on both sides of the mouth of the estuary, as if shifted there from the north by the tidal flushing of the outflow. Although the percentage just south of the estuary mouth rose rapidly from 3 in the third week to 15.3 in the ninth week, no marked fish appeared in the catches farther south at St. Rose until the seventh week and thereafter, starting with 2.1%. This is all in accordance with the prevailing winds of summer being from the southwest. The facts do seem to show that the salmon settled at least mainly in the outer part of the outflow. It seems doubtful that any settled south of the estuary mouth.

As shown in Fig. 4, some Margaree salmon that were tagged as kelts, went to all three coasts of Newfoundland even to the outer coast of Labrador, which is in accordance with their being carried in surface water driven by the prevailing southwest winds of summer. Their number is small.

Kelts that were tagged and released in Nictaux River, a branch of the Annapolis River that discharges into the head of Digby Basin on the Nova Scotian side of the Bay of Fundy opposite Saint John, showed a strikingly different pattern of recaptures from that of either the Saint John or the Margaree kelts, as shown in Fig. 9 (taken from J. Fish. Res. Bd. Canada 4, p. 105, 1938). They were all 2-sea-year salmon that returned from a second spawning after another 2 years in accordance with local temperature of the water. A little over half of them were in their river or its estuary and they were taken very early in the season as if they had gone no farther than the estuary. Several were taken on the outside Yarmouth coast the following summer, but most of them on the east coast of Newfoundland the following fall. One was taken at Ramah in northern Labrador the second summer, which was shortly after the main lot were taken in their river. Water circulation may well have taken it to the offing of Greenland for return to Canadian water at the north. This seems to be a pronounced case of failure to return from having been carried so far away. There seems to be no indication of any return of those that left the estuary. None were taken in any of the nets between the estuary and the Yarmouth coast.

Where do salmon caught in Greenland waters go? A small percentage of recaptures may be conveniently attributed to injury in capture. But 70% of the salmon tagged in the middle of the area of concentration of the fish were recaptured, but only 20% of those in the outer part, in spite of expectation that the outer ones would move inwards where fishing is more intense. They may be more apt to go out where there is no fishing, since they do go back and forth in an outflow. As reported by S. A. Horsted (Tidsskriftet Grönland, 1971, p. 257), out of 1,818 salmon tagged in Greenland waters only 4.3% were recaptured anywhere. With salmon in such demand, why were none of the 95.7% caught anywhere? Of the small number recaptured, 71.8% were again taken in Greenland waters, which was not very many, and is not indicative of an intense fishery. Again, of the small number recaptured, only 11.7%, that is, 0.5% of those tagged, were taken in Canadian waters. This gives no basis for belief that they are of any importance for us, and they may not be Canadian fish.

As reported by Horsted, out of 517,818 tagged Canadian smolts, 0.11% were taken in Greenland waters, with 0.89% retaken in Canadian waters. As reported by P. F. Elson (ICNAF Res. Doc. 69/72), out of 32,116 tagged Miramichi smolts, 0.16% were taken at Greenland and 1.34% in Canadian waters. Of the latter, the distribution was: 0.91% in the river and its outflow, 0.031% in Chaleur Bay to the north (one by river angling), 0.006% on the west coast of Newfoundland (one by river angling), 0.003% on the outer Labrador coast, 0.16% on the outer coast of Newfoundland, 0.087% on its south coast, 0.009% on the Nova Scotian coast of Northumberland Strait, 0.034% on the outer coast of Cape Breton Island, 0.028% on the outer coast of the Nova Scotian mainland, 0.04% in the Saint John outflow of the outer part of the Bay of Fundy, and 0.031% at the mouth of Minas Channel at the head of the Bay of Fundy. Does this show migration to Greenland and back? Far from it! The salmon become widely scattered, going to various shores, entering other river outflows and even ascending the rivers. This is in agreement with water circulation. The last place, at the head of the Bay of Fundy, is where drift material collects to form what is called the Cedar Swamp. In accordance with such concentration of drift material, there is a concentration there along the Kings County shore of Nova Scotia of many kinds and sizes of fish of most varied origin. The heavy weirs constructed to take them, with 30 ft. tides, are worth while mainly for the salmon they take, which are of most diverse origin, some coming from the St. Lawrence Estuary. In accordance with temperature, they cease feeding to wander and be caught, the largest near the end of May and the smallest only in August. The largest ones show that they have remained here without spawning to become larger and larger. All this is very far from being migration to Greenland and back. But, it agrees with the way in which arctic fish by the Labrador Current and tropic fish by the Gulf Stream are regularly brought to our Maritime waters to perish where these are either too warm or too cold for them.

Variable Movement Riverward

Do fat adult salmon migrate riverward through the river outflow in the sea? With warming water in early summer, they appear in the deep outer part into which they descended as smolts. They could quickly swim to the river mouth and ascend, but they do not. They become most variously concentrated in accordance with the more or less complex and variable circulation set up by mixing of fresh and salt water. They swim to and fro and are carried about by the water. This failure to migrate is the basis for their capture in nets, into which they blunder. As is well known by those on the look-out for them, they go in and out of estuaries with the tide. A narrows midway in the length of a broad shallow estuary such as the Musquodoboit, N.S., stops such movement, because they enter and hold positions in the narrows when the tide runs to make rapids there. At slack water, they roam to and fro, which permits nets close to the narrows to take them (Fig. 10, from Ecology 43, p. 554, 1962).

Variable Movement Upriver

If the Musquodoboit salmon should reach the river rapids at the head of tide, e.g., by being carried with flooding tide away from the narrows, they enter such rapids and hold positions. Since the river runs steadily, they are steadily directed upstream by it for ascent.

Do they migrate upstream when so directed? That depends upon how you define "migrate". They do not swim upstream when the going is easy. Nor do they swim up when a freshet makes ascent increasingly more difficult. They do swim slowly up after they have been stimulated to swim very fast to hold position, but only if the current declines rather sharply with subsidence of the freshet. This was observed for Margaree salmon in 1935 and later for Moser salmon with artificial freshets. It has also been seen for herring, as taken in "bar" weirs near St. Andrews (Die Fischwirtschaft, Heft 6, p. 144, 1953).

Do salmon migrate through dam reservoirs? A fishway in a dam will take them into the reservoir. What then? They have the old channel to guide them upstream if they will only swim along it, but no current to direct them. Three dam reservoirs were built along the course by which salmon ascended the Saint John River in early summer to the Tobique River and its tributary, the Serpentine River. That run is gone. Fishways did not suffice to maintain it. There has been resort to trucking the salmon up past the reservoirs, and also to large-scale rearing of smolts in a costly effort to make up for the failure of the salmon to swim homeward along a simple channel. These are the fish that people still superstitiously believe to be able to swim back home through the Atlantic Ocean from Greenland.

Basic Behaviour

If you consider the matter carefully, you will find, I feel sure, that the great part of what you do every day is automatic response to the stimuli of the moment, as contrasted with the governed action that is based upon thought. Such automatic action is what one starts with before thought develops. Without cerebral hemispheres, the salmon continues with such automatic behaviour, which becomes conditioned by experience. This is its science, that is, knowledge of the external world that works to permit its survival.

Such automatic behaviour suffices for the so-called "migration" of salmon. It is a comparatively simple matter. When salmon are up from the bottom and supported by the water, they will be carried by it wherever it goes, unless they head and swim against the current, which is rheotaxis. Even if they do this, they must swim at least as fast as the current flows or they will be carried down and out of their rivers. In the deep water of lake or sea, the same thing will happen, but it will be more difficult to observe it, the larger the salmon get. With increase in size, they go down deeper during the day.

Two species of Pacific salmon, pinks and chums, become smolts very soon after emerging from their redds, when they are quite small. Those from the Fraser River in its very turbid outflow between small islands near Vancouver Island were easy to see when I was there in 1948. They were at the very surface at dark out in Departure Bay but, during the day, they were out from shore near the ends of wharves at some distance below the surface. They could be easily seen there and were captured by using a floating seine.

Return to fresh water depends upon the salmon, when fat and vigorous, somehow reaching the turbulent discharge of the river at its mouth. How can this be seen unless the discharge is shallow? But, with large fish, will they be seen to enter a shallow discharge if they keep down from the light during the day? It was seen to happen under unusual conditions. On one occasion, the shallow discharge of the Moser River was so warm that the grilse that had reached the inner end of its shallow estuary lost their sensitivity to light and were roaming about the broad basin in a school at the very surface with their back fins sticking out in full sunlight. The school did reach the river discharge and at once dashed into and up it. As being at the surface in the river, they went to the shore and could be easily picked up.

When in the river and steadily directed upstream by the current, they ascend when suitably stimulated by the changing conditions of freshets.

The thesis that this simple behaviour is the essence of animal "migration", as typified by salmon, was advanced in Proc. XVI Intern. Cong. Zool. 2, p. 28, 1963, and in amplified form in Actual. Marins 8, p. 17, 1964.

Salmon move variously in response, not only to current and turbulence but also to light, barriers or other objects, and solutes. The responses are modified by the size, condition factor, stage or phase, and conditioning of the individual fish. They need to be taken into account.

St. Andrews, N.B.
Sept. 8, 1972

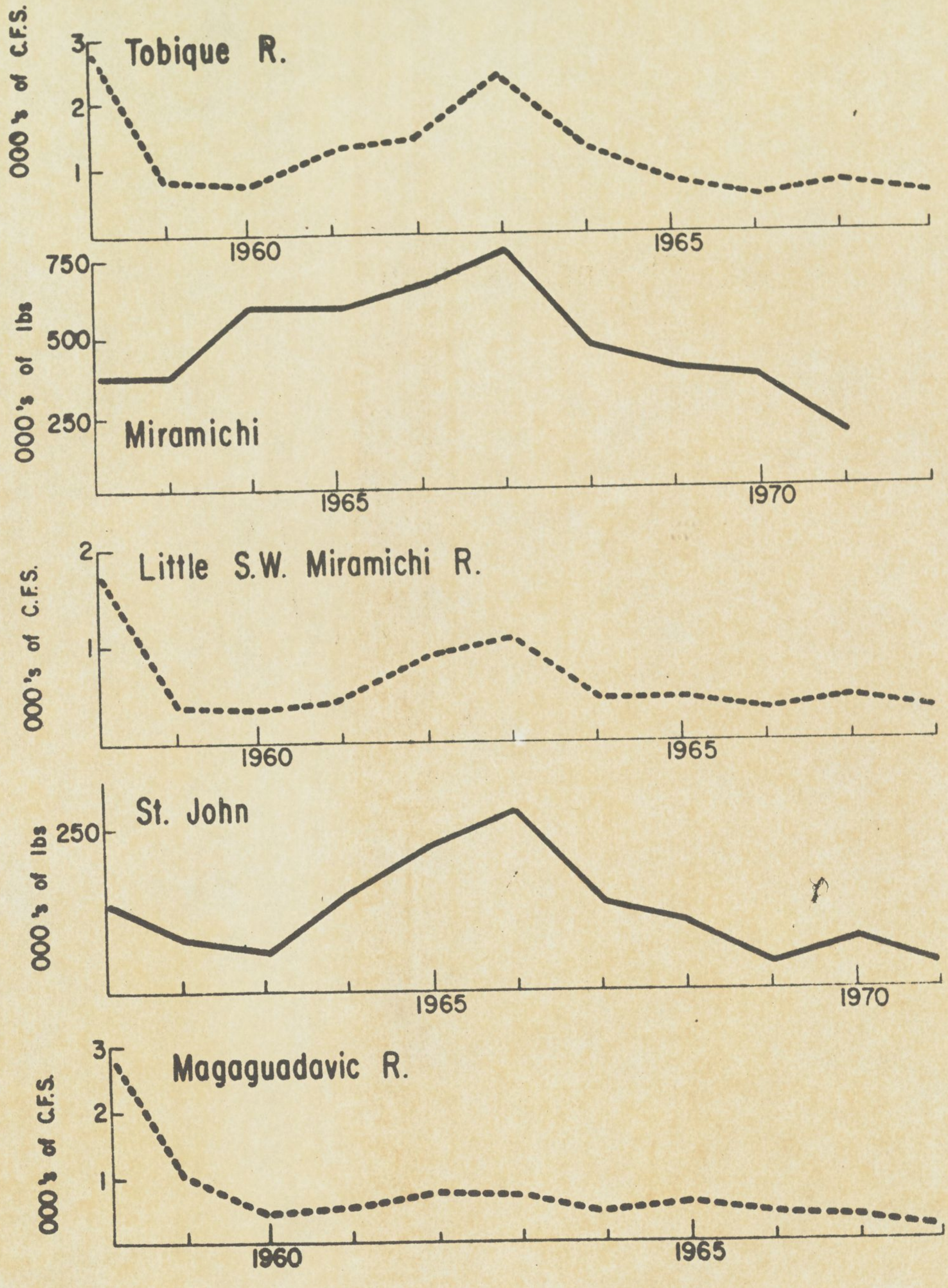

Fig. 1.

Mean discharges in July and August in successive years from 1958 to 1968 of three New Brunswick rivers in relation to catches of the St. John River salmon three years later and of the Miramichi River salmon four years later. Discharges shown with dotted lines and catches with continuous lines. See order from north to south from the top down: Discharge of Tobique River. Catch of Miramichi salmon. Discharge of Little S.W. Miramichi River. Catch of Saint John salmon. Discharge of Magagua-davic River. Discharges in thousands of cu. ft. per sec. Catches in thousands of pounds.

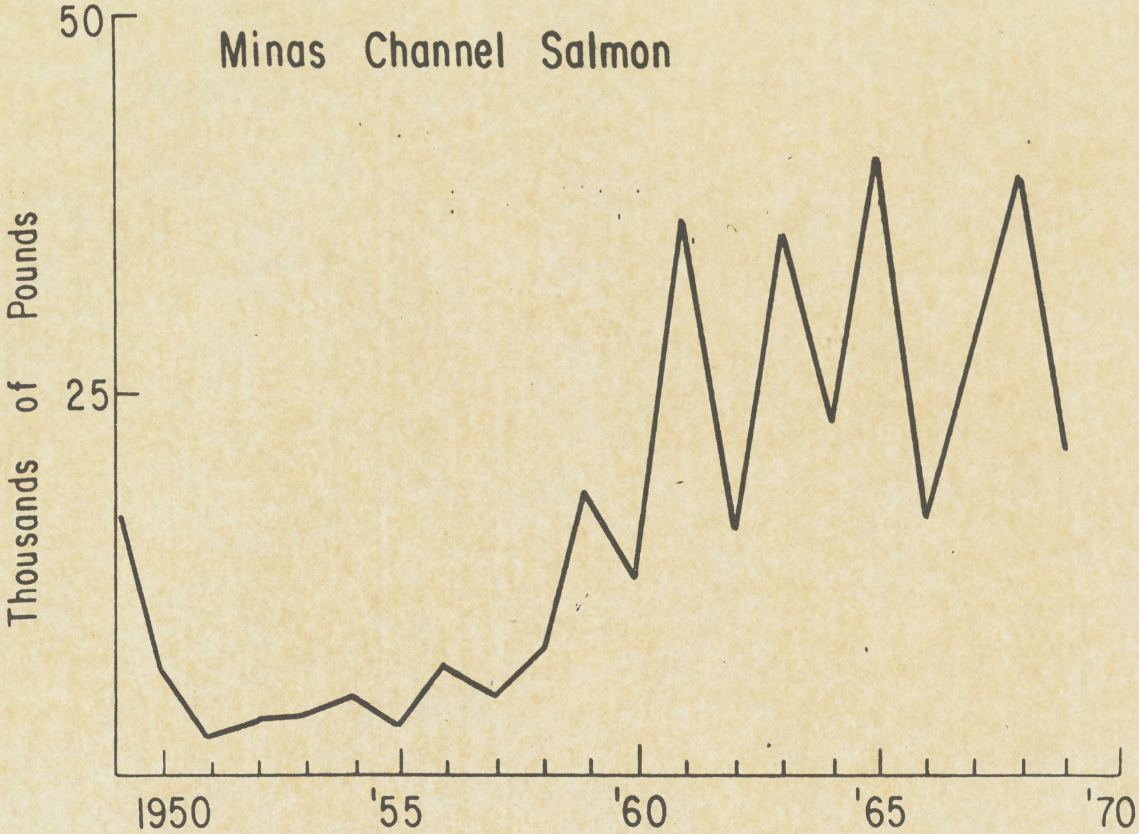

Fig. 2. Quantities of salmon taken annually on Kings Co. shore of Minas Channel from 1949 to 1970.

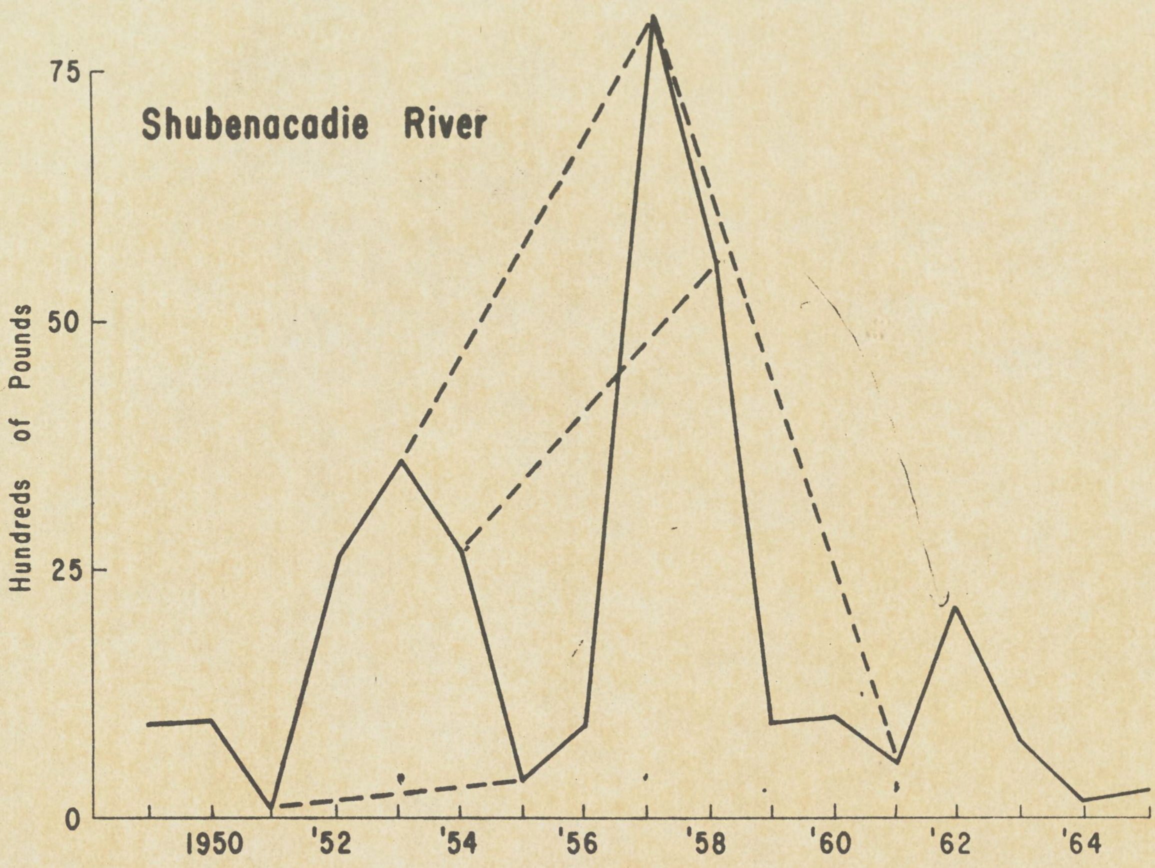

Fig. 3. Quantities of salmon taken annually in outflow of Shubenacadie River, N.S., from 1949 to 1965. Scarcely any salmon to spawn in 1951 gives low catch in 1955. High numbers to spawn in 1953 and 1954 give very high catches in 1957 and 1958. With very low water for spawning in 1957, the very high number of salmon that year were practically eliminated, as shown by the very low catch in 1961.

Fig. 4. From Publication No. 8 of the American Association for the Advancement of Science, 1939, "Migration and Conservation of Atlantic Salmon for Canada's Maritime Provinces".

Recaptures of salmon liberated as kelts in the estuary of the Margaree River. Lower left--local recaptures in the river and on the coast near the river mouth. Lower right--more distant recaptures, but within radius of 100 miles, all in Nova Scotian waters. Upper--recaptures beyond 100 miles, all in Newfoundland waters.

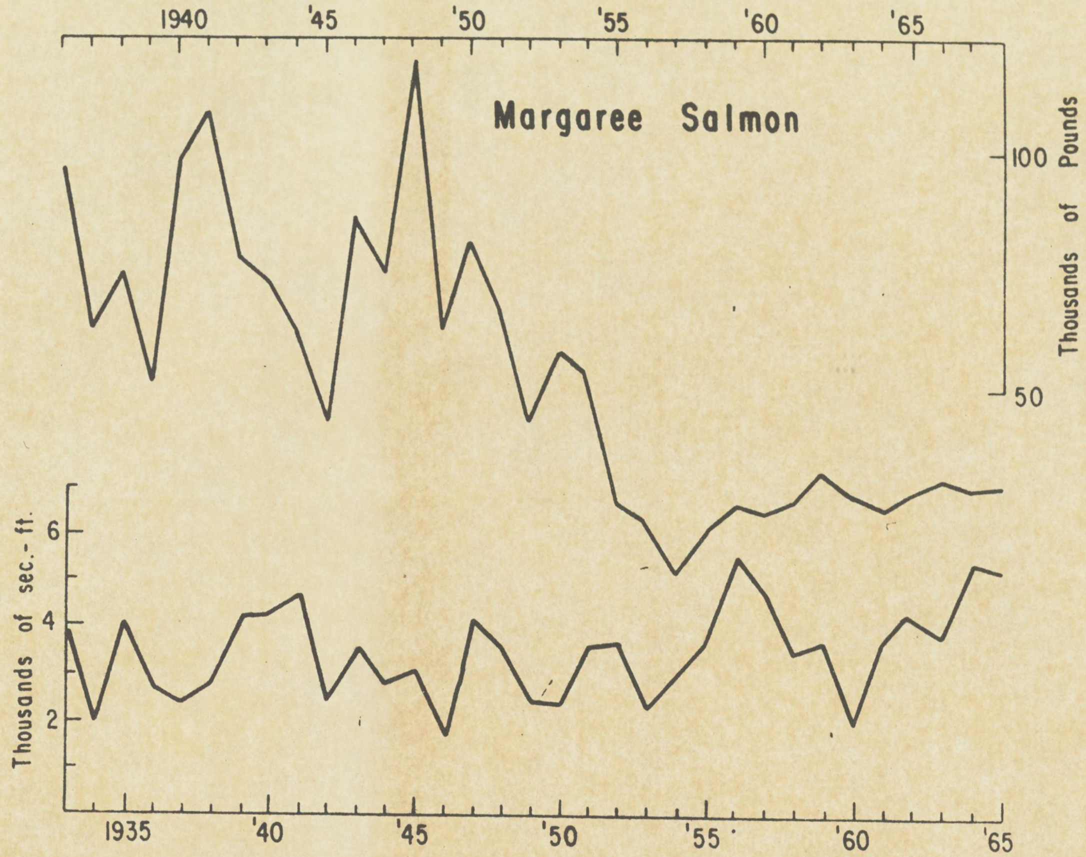

Fig. 5. Above: Quantities of salmon taken annually on North Inverness coast, N.S., from 1936 to 1968. Below: Mean discharge from June to August annually of the Northeast Margaree River.

Fig. 6. From Atlantic Biological Station, Note No. 32, 1933, "Passamaquoddy Sardine Fishing Makes Tobique Salmon Angling".

Passamaquoddy, centre for small herring (sardine factory locations shown as black circles); principal feeding ground for St. John river salmon along course of light water (fresh water mixed in at reversing falls) passing from St. John harbour toward Grand Manan island; the extensive tidal basin of the river from the reversing falls at St. John to Fredericton or somewhat farther; the non-tidal portion of the river as far up as Grand Falls; and its main branch for salmon angling, the Tobique river.

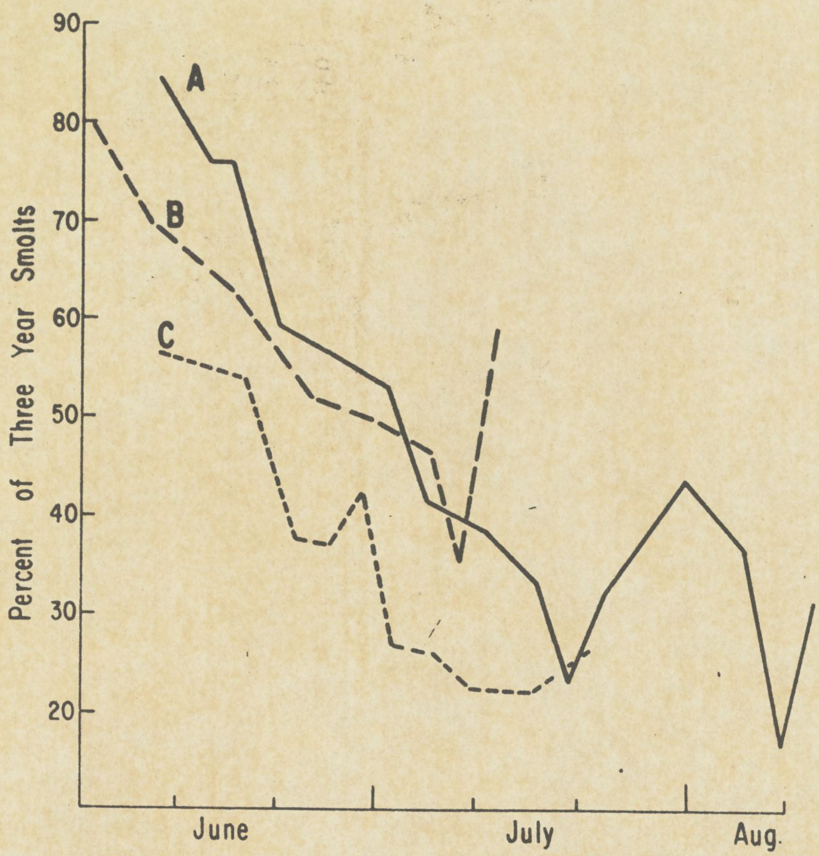

Fig. 7. Percentages of 3-year-smolt salmon in the catches in Saint John Harbour (————), off Lorneville (— — — —), and off Dipper Harbour (------) in 1938. These decrease, fluctuate and come together, as outnumbered by the dominant 2-year-smolt salmon brought riverward from outer waters.

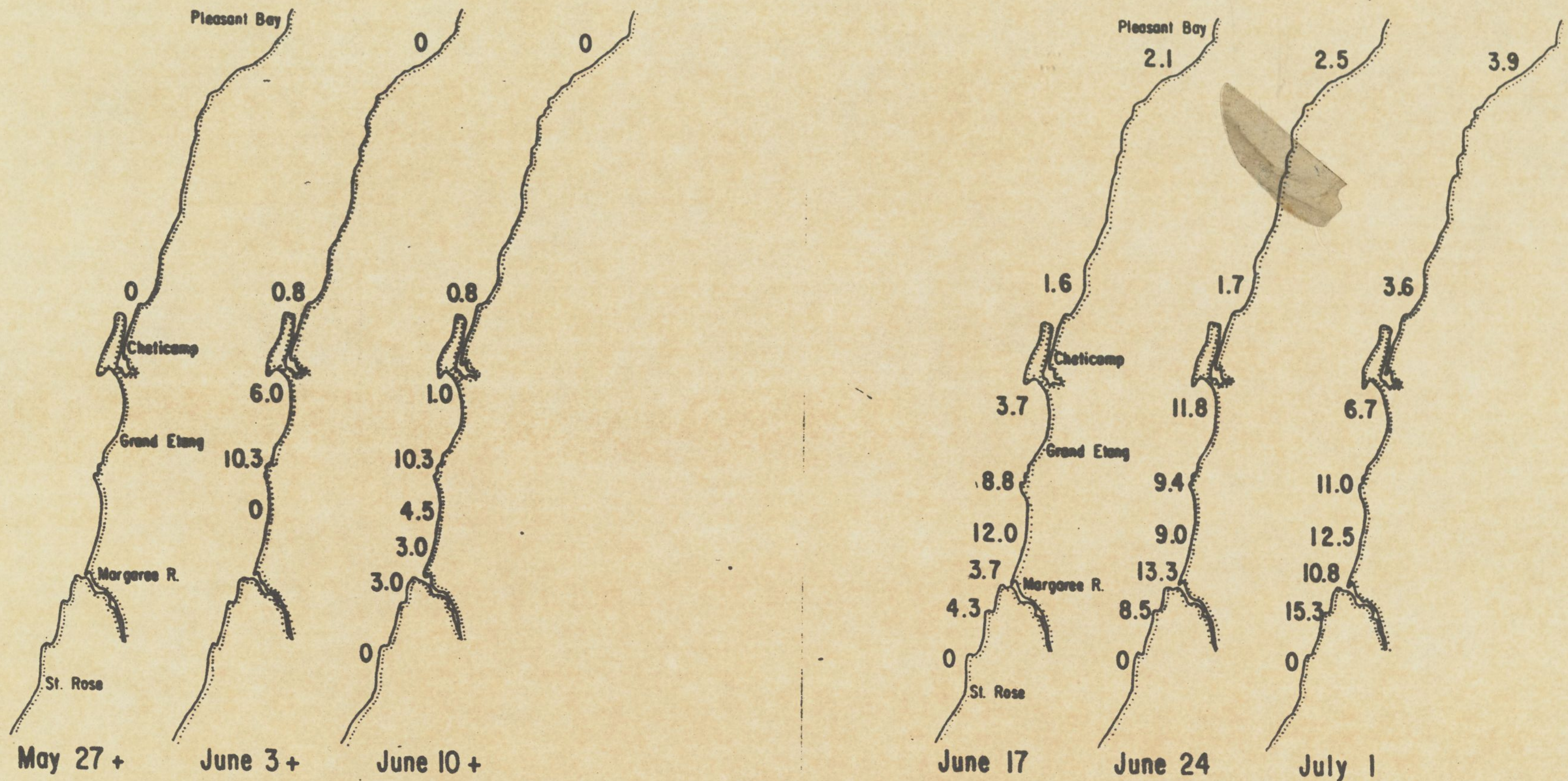

Fig. 8. Percentages of Margaree salmon marked as smolts in 1938 that were taken in the traps of the various coastal districts as shown. No figure given means no catch.

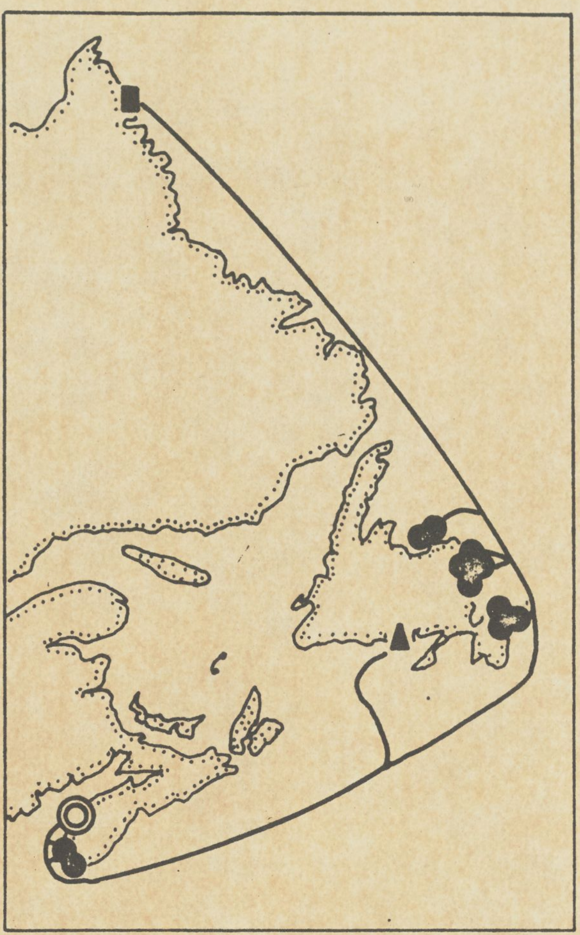

Figure 9. Annapolis River, N.S., distant recaptures of salmon. Place of liberation (double circle) of kelts in the Annapolis region, and places of recapture the following summer (solid circle) near Yarmouth, N.S., the following autumn (solid circle) on the east coast of Newfoundland, in the second summer (solid square) on the Labrador coast near Hudson Strait, and in the third summer (solid triangle) on the south coast of Newfoundland.

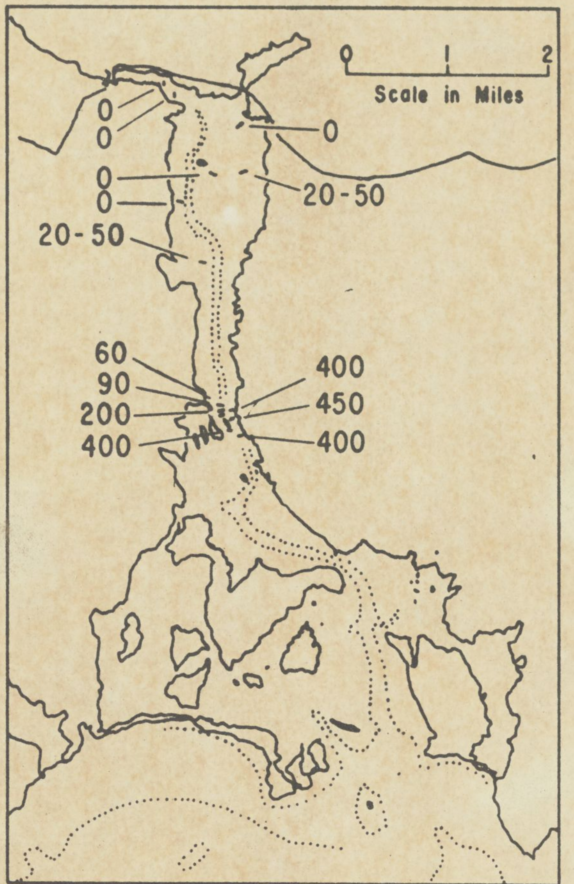

Fig. 10. The estuary of the Musquodoboit River, Nova Scotia, showing locations of salmon nets as mainly related to the Narrows, located midway in its length. The average number of pounds of salmon taken each year in recent years is indicated for each net. Dotted lines represent low tide mark and interrupted line depth of 5 fathoms.

United States
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Environmental Research
Laboratory
Corvallis, OR 97330

Research and Development

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Project Summary

Natural Variation in Abundance of Salmonid Populations in Streams and Its Implications for Design of Impact Studies

James D. Hall and Ned J. Knight

This project was an extensive literature review relating to stock size and production of salmonid populations in streams. The objective was to bring together data on the magnitude of natural variation in population size and to relate this variability to environmental conditions wherever possible. Recommendations are presented for the use of this information in designing studies to estimate the impact of nonpoint source (NPS) pollution. A partially annotated bibliography of 260 references is included in the Project Report.

A number of long-term studies, some up to 15-20 years, have provided useful data on temporal variation in population abundance. Other studies have examined spatial variation. Data from the best examples of both kinds of variation are presented. Temporal and spatial variation may be as high as several orders of magnitude in the extreme and, even at the least, are sufficient to mask significant pertubations caused by NPS pollutants. Environmental variables most closely associated with spatial variation are those relating to the quality of salmonid habitat, particularly physical characteristics such as cover in its many forms. Streamflow and food abundance have been associated with both temporal and spatial variation. In general, physical characteristics of habitat appear to be the most promising as descriptors of variability.

Considerable emphasis should be placed upon systems of rating habitat quality in attempts to minimize the effects of natural variation when evaluating the impact of NPS pollutants. First priority should be placed on the assessment of physical features. Thus far, this approach has been used mainly to explain spatial variation, but also has promise in explaining temporal variation. The other major emphasis should be in further development of systems of stream and watershed classification. The most useful of these systems devised to date take a perspective from geomorphology and focus on the potential of a stream system for biological production. As a means of more clearly separating natural variation from damage caused by NPS pollutants, more emphasis should be placed upon the study of basic processes in stream ecosystems and more extensive use should be made of paired comparisons in the design of impact studies.

This Project Summary was developed by EPA's Environmental Research Laboratory, Corvallis, OR,

to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Assessment of impacts on streams caused by nonpoint source pollutants is now receiving increasing attention. Salmonids are the principal fish species of economic importance affected by pollution in the western United States. Assessment of damage to these fish populations cannot be undertaken without some understanding of the natural variation in abundance within and between populations. Strategies of analysis must be devised that will separate natural variations from those effects due to man-made disturbances. The purpose of this review is to bring together literature and unpublished data on the natural variation in abundance of salmonid populations in streams and to attempt to relate this variation to physical, chemical and biological variables.

There are two kinds of variability to be considered, spatial and temporal. Spatial variation can be studied at several levels of resolution, ranging from microhabitat preferences to that variability occurring within and between streams. Temporal variation can occur on a diel, seasonal, or annual scale.

This report concentrates on studies of salmonid species during that part of their lives spent in the stream environment. These species include the coho salmon *(Oncorhynchus kisutch)*, chinook salmon *(O. tshawytscha)*, pink salmon *(O. gorbuscha)*, chum salmon *(O. keta)*, brown trout *(Salmo trutta)*, rainbow trout *(S. gairdneri)*, steelhead trout *(S. gairdneri gairdneri)*, cutthroat trout *(S. clarki)*, Atlantic salmon *(S. salar)*, brook trout *(Salvelinus fontinalis)*, and Dolly Varden *(S. malma)*. This review was begun with the emphasis on studies carried out on the West Coast of North America. However, it was found that most of the quantitative data on variability in resident salmonid populations came from other areas. Therefore, much of that information has been included in this report.

Much less information is available on population levels of the other fish species associated with salmonids. Though not included in this report, the importance of this element of the aquatic system should be emphasized and steps taken to fill this gap in our knowledge of fish communities.

Conclusions and Recommendations

The standing stock biomass of salmonid fishes in streams shows great natural variation, both in time and space. Reported levels of biomass vary from zero, or just above, to over 60 g/m^2. This variation is sufficient to mask large-scale perturbations caused by NPS pollutants such as those resulting from logging and agricultural practices. Among the most important causes of variation are differences in the physical characteristics of streams, including streamflow and habitat quality, particularly cover. Biological factors, such as food abundance and predation, may sometimes influence abundance. However, their mode of action is less clear and the case for their involvement more equivocal than that of the physical elements of the habitat.

Several courses of action are recommended that will help minimize the effects of this natural variation when attempts are made to evaluate impacts of a particular NPS pollutant. Habitat quality rating systems are being developed that show promise for explaining much of the spatial variation in salmonid populations in streams. These rating systems are based primarily on the assessment of physical features. They may also help to explain temporal variation caused by changes in streamflow, but other influences on temporal variation need further study. The other major approach that may aid impact assessment is the development of schemes of stream and watershed classification. One appears to be particularly promising in that it focuses upon the potential of a system for biological production, rather than a particular value of the moment and takes a biogeoclimatic perspective. Continuing emphasis on the study of basic physical and biological processes that lead to growth, mortality and production of stream salmonids is another promising approach to understanding natural variation in abundance. New approaches to the design of impact studies are suggested that may aid in more clearly separating natural variation from that caused by NPS pollutants and in monitoring the time required for biological systems to recover from perturbation.

Table 1 summarizes the advantages and disadvantages of four major approaches to watershed stream analysis. Studies may be grouped according to whether they bracketed (before-after) or followed (post) treatment. The other level of classification was based on whether detailed studies were made on one or very few streams (intensive) compared to less detailed study on many streams (extensive). This two level classification results in four categories, which are evaluated for efficiency and sensitivity of impact detection. This listing of advantages and disadvantages of each type reveals that no one design is optimum. The best approach appears to be a combination of post treatment analysis with carefully designed process studies carried out at one or more locations.

Table 1. *Summary of Advantages and Disadvantages of the Four Major Approaches to Watershed Stream Analysis*

A. Intensive Before-After (10-15 years; 5-7 years before and after treatment).

Advantages	Disadvantages
1) Possible to assess year-to-year variation and place size of impact in context of that variation.	1) No replication; results must be viewed as a case study.
2) Can assess short-term rate of recovery (ca. 5 years).	2) Results not necessarily applicable elsewhere (areas of different soils, geology, fish species, etc.).
3) No assumptions required about initial conditions.	3) Results vulnerable to unusual climatic events (e.g. high or low rainfall season(s) immediately following treatment).
4) Possible to monitor whole watershed impacts (provided substantial investment in facilities such as flow and sediment sampling wiers, fish traps).	4) Final results and management recommendations require exceptionally long time to formulate - up to 15 years after initial planning stage.
5) Long time frame provides format for extensive process studies.	5) Difficult to maintain intensity of investigation and continuity of investigators over such a long period.
	6) Must rely on outside agencies or firms to complete treatments as scheduled - considerable coordination required.

B. Extensive Before-After (2-4 years; 1 year before treatment, 1 year after).

Advantages	Disadvantages
1) Provides broader perspective across geographical area than (A).	1) Lack of long-term perspective-- little opportunity to observe year-to-year variation.
2) Larger number of streams examined lessens danger of extreme case.	2) Able to assess only immediate results, which may not be representative of longer time sequence.
3) Increased generality of results allows some extrapolation to other areas.	3) Treatment vulnerable to unusual weather (if all treatments in same year).
4) Relatively short time to achieve results (3-4 years from planning stage).	4) Must rely on outside agency (see (A) above).

C. Intensive Post-Treatment (One Watershed--Paired Sites) (4-5 years, following treatment).

Advantages	Disadvantages
1) Shorter time for results than (A).	1) Provides no strict control--requires assumption that upstream control was identical to treated area prior to treatment.
2) Moderate ability to assess year-to-year variation.	2) "Control" most logically must be located upstream of treatment. Strong downstream trend in any feature would confound analysis.
3) Provides opportunity for moderate level of effort on process studies.	3) Provides no spatial perspective--results of limited application elsewhere.
application elsewhere.	

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Table 1. (Continued)

D. Extensive Post-Treatment, 10-30 Watersheds (or more); all observations in 1-2 years (variable time after treatment).

Advantages	Disadvantages
1) Wide spatial perspective allows extrapolation to other areas.	1) No data available on pre-treatment conditions--forces assumption that control and treatment were identical (on average).
2) Long temporal perspective is possible--can assess recovery for as many years as past treatments have occurred.	2) Control predominantly upstream.
3) Provides ability to assess interaction of physical setting and treatment effects (e.g., effects of sediment input at different stream gradients).	3) Total cost concentrated in very short period--requires extensive planning.
4) Requires least time of all four designs to get results--as little as 2 years.	4) Not as effective as (A) in assessing whole watershed effects.
5) Probably most economical of all four approaches per unit of information.	5) Methods used in early treatments may not be comparable to later ones.

James D. Hall and Ned J. Knight are with the Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331.
Jack H. Gakstatter is the EPA Project Officer (see below).

The complete report, entitled "Natural Variation in Abundance of Salmonid Populations in Streams and Its Implications for Design of Impact Studies," (Order No. PB 81-163 214; Cost: $9.50, subject to change) will be available only from:

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NATURAL VARIATION IN ABUNDANCE OF SALMONID POPULATIONS IN STREAMS AND ITS IMPLICATIONS FOR DESIGN OF IMPACT STUDIES

by

James D. Hall and Ned J. Knight
Department of Fisheries and Wildlife
Oregon State University
Corvallis, OR 97331

April 1981

Project Officer

Jack H. Gakstatter
U. S. Environmental Protection Agency
200 S. W. 35th Street
Corvallis, OR 97330

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ABSTRACT

Literature on stock size and production of salmonid populations in streams has been reviewed. The objective is to bring together data on the magnitude of natural variation in population size and to relate this variability to environmental conditions where possible. Recommendations are presented for the use of this information in designing studies to estimate the impact of non-point source pollution. A partially annotated bibliography of 260 relevant references is included.

A number of long-term studies, some up to 15-20 years, have provided useful data on temporal variation in population abundance. Other studies have examined spatial variation. Data from the best examples of both kinds of variation are presented in Appendix Tables. Temporal and spatial variation may be as high as several orders of magnitude in the extreme, and even at the least are sufficient to mask very significant perturbations caused by non-point source pollutants. Environmental variables most closely associated with spatial variation are those relating to the quality of salmonid habitat, particularly physical characteristics such as cover in its many forms. Streamflow and food abundance have been associated with both temporal and spatial variation. In general, physical characteristics of habitat seem most promising as descriptors of variability.

Systems of rating habitat quality should receive considerable emphasis in attempts to minimize the effects of natural variation in the evaluation of impacts of non-point source pollutants. First priority should be placed on assessment of physical features. This approach has been used so far mainly to explain spatial variation, but has promise of explaining temporal variation as well, particularly in reference to fluctuation in streamflow. The other major emphasis should be in further development of systems of stream and watershed classification. The most useful of these devised to date take a perspective from geomorphology and focus on the potential of a stream system for biological production. More emphasis on study of basic processes in stream ecosystems and more extensive use of paired comparisons in design of impact studies are also suggested as means of more clearly separating natural variation from damage caused by non-point source pollutants.

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SECTION 1

INTRODUCTION

Assessment of impacts on streams caused by non-point source pollutants is now receiving increasing attention. Salmonids are the principal fish species of economic importance affected in the western United States. Assessment of damage to these populations cannot be undertaken without some understanding of natural variation in abundance within and between populations. Strategies of analysis must be devised that will separate natural variation from effects due to disturbance. It is the purpose of this review to bring together literature and unpublished data on the natural variation in abundance of salmonid populations in streams and to attempt to relate this variation to environmental variables--physical, chemical, and biological.

There are two kinds of variability to be considered, spatial and temporal. Spatial variability can be studied at several levels of resolution, ranging from microhabitat preferences to variability within and between streams. Temporal fluctuations in abundance can occur on a diel, seasonal, or annual scale.

This paper will concentrate on studies of salmonid species during that part of their lives spent in the stream environment. The species include the coho salmon (*Oncorhynchus kisutch*), chinook salmon (*O. tshawytscha*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), brown trout (*Salmo trutta*), rainbow trout (*S. gairdneri*), steelhead trout (*S. gairdneri gairdneri*), cutthroat trout (*S. clarki*), Atlantic salmon (*S. salar*), brook trout (*Salvelinus fontinalis*), and Dolly Varden (*S. malma*). We began this review with the intention of emphasizing studies on the west coast of North America. However, we found that most of the quantitative data on variability in resident salmonid populations came from other areas, and much of that information has been included.

Much less information is available on population levels of the fish species associated with salmonids. Though not included here, the importance of this element of the aquatic system should be emphasized and steps taken to fill this gap in our knowledge of stream fish communities.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The standing stock biomass of salmonid fishes in streams shows great natural variation, both in time and space. Reported levels of biomass vary from zero or just above to just over 60 g/m^2. This variation is sufficient to mask large-scale perturbations caused by non-point source pollutants, such as result from logging and agricultural practices. Among the most important causes of variation are differences in physical characteristics of streams, including streamflow and habitat quality, particularly cover. Biological factors, such as food abundance and predation, may sometimes influence abundance, but their mode of action is less clear and the case for their involvement more equivocal than that of the physical elements of the habitat.

We recommend several courses of action that will help to minimize the effects of this natural variation when attempts are made to evaluate impacts of a particular non-point source pollutant. Habitat quality rating systems are being developed that show promise of explaining much of the spatial variation in salmonid populations in streams. These rating systems are based primarily on assessment of physical features. They may also help to explain temporal variation caused by changes in streamflow, but other influences on temporal variation need further study. The other major approach that may aid impact assessment is development of schemes of stream and watershed classification, such as those of Platts (1974) and Warren (1979). The latter is particularly promising in that it focuses on the potential of a system for biological production, rather than a particular value of the moment, and takes a biogeoclimatic perspective. Continuing emphasis on study of the basic physical and biological processes that lead to growth, mortality, and production of stream salmonids is another promising approach to understanding natural variation in abundance. Finally, new approaches to the design of impact studies are suggestd that may aid in more clearly separating natural variation from that caused by non-point source pollutants and in monitoring the time required for biological systems to recover from perturbation.

SECTION 3

STUDIES OF VARIABILITY

Natural variability of salmonid populations in streams has been measured by two principal methods. In some streams, weirs or traps have been constructed to get reliable counts of migrating fish. Other studies have examined standing crops in the stream by electroshocking, netting, or angling.

There have been a number of important long-term studies on natural variation in abundance of anadromous and resident species, which are briefly described in Table 1. As an aid to further analysis, data from these studies and others of shorter duration that deal with spatial variation have been compiled from original sources and are included in tables in the Appendix. Further description of many studies is included in the annotated bibliography.

We performed some preliminary analyses on the data in the Appendix Tables and in other publications, in search of general patterns in variation over the species and geographical areas included. We used the range in abundance as a fraction of mean abundance for a measure of relative variability, rather than the coefficient of variation, owing to small sample sizes. Not surprisingly, the extremes of temporal variation occur in pink and chum salmon fry; their numbers may vary over several orders of magnitude. The most stable populations are those of brook trout in Wisconsin and Michigan, where the range is in the order of only one-half the mean abundance. Notably, two of the most useful analyses of variation and its causes were from these two populations (McFadden et al. 1967; Hunt 1974). Where good comparisons of both temporal and spatial variation could be made in the same stream system (Sagehen Creek, Calfiornia and Lawrence Creek, Wisconsin), spatial variation was the greater, by a significant margin. This, again, may not be a surprising result, but is one with important implications for impact studies.

It appears that inferences about natural fluctuation in abundance and its causes may best be found in detailed analyses of individual research studies, including information on as many relevant environmental variables as possible. Thus the bulk of this review is concerned with attempts to relate variation in abundance to the environmental factors with which it may be associated.

TABLE 1. LONG-TERM STUDIES OF STREAM SALMONID POPULATIONS.

Location	Species	Inclusive Dates for Data Presented	Principal Reference
Sashin Creek, Alaska	pink salmon coho salmon	1940-1959 1956-1968	Merrell (1962) Crone and Bond (1976)
Hooknose Creek, British Columbia	pink salmon chum salmon	1947-1956	Hunter (1959)
Carnation Creek, British Columbia	coho salmon cutthroat trout steelhead trout	1970-1977 (continuing)	Narver and Andersen (1974)
Minter Creek, Washington	coho salmon	1938-1953	Salo and Bayliff (1958)
Alsea River, Oregon	coho salmon cutthroat trout	1959-1973	Moring and Lantz (1975) Knight (1980)
Waddell Creek, California	coho salmon steelhead trout	1933-1944	Shapovalov and Taft (1954)
Sagehen Creek, California	rainbow trout brown trout brook trout	1952-1961	Gard and Flittner (1974)
Lawrence Creek, Wisconsin	brook trout	1953-1970	Hunt (1974)
Hunt Creek, Michigan	brook trout	1949-1962	McFadden et. al. (1967)
Au Sable River, Michigan	brook trout brown trout	1957-1967	Alexander (1979)
Hayes Brook, Prince Edward Island	brook trout	1947-1960	Saunders and Smith (1962)
Little Codroy River, Newfoundland	Atlantic salmon brook trout	1954-1963	Murray (1968)
Shelligan Burn, Scotland	Atlantic salmon brown trout	1966-1975	Egglishaw and Shackley (1977)

SECTION 4

FACTORS AFFECTING NATURAL VARIABILITY

One approach to listing the important factors or variables in the stream environment that can affect abundance of salmonid populations is the following:

A. Physical factors

1. Streamflow
2. Habitat quality

B. Biological factors

1. Food abundance
2. Predation
3. Movement and migration

In most instances these variables may interact to influence a population, and the classification is inevitably artificial. For example, habitat preferences are often related to food availability. Under natural conditions, it is often difficult to measure the effect of one factor independently. However, the variables will be considered separately in this discussion, with an attempt to show how interactions may be involved.

PHYSICAL FACTORS

Streamflow

One of the earliest studies that attempted to relate streamflow to salmonid abundance was conducted by McKernan et al. (1950). They found that low summer flows correlated with subsequent low returns of adult coho salmon in the Siletz River, Oregon from 1924 to 1945. No relation was apparent in the Coquille River from 1923 to 1948. Scarnecchia (1978) found a significant correlation ($r = 0.68$) between total streamflow in the 17-month period of stream residence of juvenile coho and the commercial troll catch of adult salmon 2 years later. These data came from five Oregon rivers from 1942 to 1962. In addition, there was a significant correlation ($r = 0.56$) between total annual flow and catch 2 years later. Smoker (1955) obtained an even higher correlation ($r = 0.91$) in the same analysis (total annual flow vs. catch of adult coho 2 years later) for Puget Sound streams from 1935 to 1954. In Cowichan Bay, B. C., a lower availability of coho to the sport fishery was noted for year classes that experienced low summer streamflows in their juvenile stages (Neave 1949). In Nile Creek, B. C., from 1946 through 1949 the output of coho smolts varied directly with the minimum monthly rainfall during the previous summer (Wickett 1951). These studies show that streamflow during some part of the freshwater phase of coho life history can influence its level of abundance in the catch.

We carried out a similar analysis for juvenile coho salmon in two of the streams that were part of the Alsea Watershed Study in Oregon. Mean monthly and seasonal discharge were correlated with mean June-April biomass and also with the smolt count in the same period, from June 1960 through May 1968. In both streams the few significant correlations were mostly in the spring (Table 2).

TABLE 2. CORRELATIONS BETWEEN MEAN MONTHLY DISCHARGE AND ANNUAL SMOLT COUNT AND MEAN JUNE-APRIL BIOMASS FOR COHO SALMON, ALSEA WATERSHED STUDY, JUNE 1960-MAY 1969.

	Deer Cr.		Flynn Cr.	
Period	Smolt	Biomass	Smolt	Biomass
June	-0.080	-0.080	-0.307	-0.321
July	0.095	-0.442	-0.004	-0.126
August	0.050	-0.199	-0.155	-0.267
September	0.098	-0.045	-0.206	-0.221
October	0.431	0.661	-0.122	0.145
November	-0.076	-0.461	0.132	0.032
December	0.153	0.003	0.291	-0.373
January	-0.398	-0.218	0.531	-0.654
February	-0.099	-0.006	0.042	0.088
March	-0.687*	-0.426	0.099	-0.055
April	0.630	0.076	0.931**	0.936**
May	0.569	-0.162	0.714*	0.694*
June-May	-0.350	-0.507	0.150	-0.364
Nov-Apr	-0.482	-0.544	-0.209	-0.446
Jan-Apr	-0.691*	-0.448	-0.097	-0.279
Mar-Apr	-0.344	-0.352	0.518	0.385
June-Sept	-0.021	-0.125	-0.262	-0.230

* P <0.05

** P <0.01

Knight (1980) used a longer series of data on smolt abundance alone and found significant negative correlations between mean January discharge and total November-May smolt count for Deer Creek and Flynn Creek (r = -0.64 and -0.65 respectively) for the 1959-1960 through 1972-1973 seasons. We performed a similar analysis for cutthroat trout from September biomass data and mean monthly discharge data (October 1961-September 1972) for all three streams in the Alsea Watershed Study. Generally, correlations were negative, but nonsignificant, in the winter months in all three streams (Table 3).

TABLE 3. CORRELATIONS BETWEEN MEAN MONTHLY DISCHARGE AND MEAN SEPTEMBER BIOMASS IN G/M^2 FOR CUTTHROAT TROUT, ALSEA WATERSHED STUDY, OCTOBER 1961-SEPTEMBER 1972.

	Deer Cr.	Flynn Cr.	Needle Br.		
Month(s)	All years	All years	All years	Pre-logging[a]	Post-logging[b]
October	-0.119	-0.014	-0.221	0.829	0.586
November	-0.133	0.085	-0.060	-0.393	0.150
December	0.222	-0.174	-0.384	-0.382	0.292
January	-0.061	-0.139	-0.538	-0.804	-0.309
February	-0.136	-0.311	-0.269	0.645	0.686
March	0.209	0.304	-0.302	0.646	-0.144
April	0.571	0.399	-0.071	0.335	-0.256
May	0.415	0.423	0.589	0.558	0.277
June	-0.212	-0.210	-0.095	0.993**	0.720
July	-0.092	0.094	-0.158	0.335	0.465
August	-0.367	0.013	0.063	0.002	0.650
September	0.097	0.117	-0.262	0.264	0.718
Oct-Sept	0.214	0.006	-0.565	-0.906	0.336
Nov-Apr	0.195	-0.027	-0.574	-0.867	0.109
Jan-Apr	0.186	0.058	-0.711*	-0.654	-0.085
Mar-Apr	0.419	0.417	-0.249	0.669	-0.202
June-Sept	-0.173	-0.100	-0.135	0.551	0.755

[a] 1962-1965

[b] 1967-1972

* $P < 0.05$

** $P < 0.01$

In all three of these analyses the lack of consistency in the correlations was notable. Although one can attach plausible explanations to the statistically significant correlations, there were hardly more of them than might be expected due to chance in a series of that many analyses. Our conclusion is that there is no solid basis for a relationship between streamflow and abundance of coho salmon and cutthroat trout in these streams, a surprising result in the face of so much other evidence for such a relation. The small size of the streams involved and the resultant low numbers of juvenile fish may have reduced the power of the analysis, however.

In several western Oregon streams, Pearson et al. (1970) did a preliminary short-term study of the effects of streamflow on juvenile coho salmon during the summer low-flow season. From 1962 to 1965, they found a significant positive relationship between coho density (number/m^2) and minimum streamflow in McKay Creek, a tributary to the Tualatin River. They also found a significant positive relationship between mean water velocity in pools and coho density for 50 pools in five streams of the Nehalem River system. Preliminary data also indicated that streams with higher flows supported coho of larger sizes.

In streams in Maine, Havey and Davis (1970) found through multiple regression analysis of several environmental variables that rainfall in July and August, presumed to be an index of streamflow during the dry season, was the single most important factor influencing survival of Atlantic salmon from age 0+ to age 1+. Their multiple regression analysis was weakened, however, by a small sample size.

Wickett (1958) reviewed the effects of low water levels on adult migration and egg deposition by pink and chum salmon in British Columbia streams. Low flows result in excessive spawning density, leading to superimposition of redds and crowding of eggs. Adult migration is inhibited by low streamflow; other consequences include failure of egg deposition and increased predation on spawning fish crowded in shallow water.

The effects of streamflow on survival of pink and chum salmon in spawning beds were studied by McNeil (1966;1968) in streams in southeastern Alaska. Below normal streamflow, both in summer and winter, caused significant mortality of eggs and alevins in the gravel. In summer, low streamflow acted by causing low levels of dissolved oxygen in intragravel water. In winter, low streamflow led to freezing of eggs and alevins, especially in streams subject to greatly fluctuating flows. High streamflow during winter caused mortality by displacement of eggs and alevins from spawning gravel.

Studies have also been undertaken on the influence of streamflow on resident populations of salmonids. In Big Roche-a-Cri Creek, Wisconsin, brook trout biomass fluctuated greatly with streamflow. White (1975) found that from 1958 through 1966, biomass was significantly correlated with mean January-February discharge ($r = 0.867$).

Using data from Sagehen Creek, California, kindly provided by Dr. Richard Gard, we correlated mean monthly and seasonal discharge with mean annual biomass of brook, brown, and rainbow trout (Table 4). Brown trout biomass was best correlated with December flows and brook trout biomass showed the best correlation with February discharge. Neither of these was statistically significant, however. Rainbow trout biomass showed significant negative correlations with discharge in January, April, and June. Again, the total number of significant correlations among the 51 comparisons is very close to the number that would be expected by chance. However, the predominance of negative correlations for brook and rainbow trout and positive correlations for brown trout is in itself a significant result that deserves further analysis.

TABLE 4. CORRELATIONS BETWEEN MEAN MONTHLY DISCHARGE AND MEAN ANNUAL BIOMASS OF BROWN, BROOK, AND RAINBOW TROUT. SAGEHEN CREEK, CALIFORNIA, 1954-1961. DATA FROM DR. RICHARD GARD (PERSONAL COMMUNICATION).

Month(s)	Brown	Brook	Rainbow
January	0.040	-0.142	-0.806*
February	-0.174	-0.632	-0.495
March	-0.168	0.072	-0.449
April	0.067	0.023	-0.746*
May	0.183	-0.488	-0.595
June	0.123	-0.547	-0.727*
July	0.109	-0.494	-0.649
August	0.259	-0.408	-0.592
September	0.354	-0.275	-0.468
October	-0.416	-0.199	0.373
November	-0.050	-0.209	-0.127
December	0.514	0.146	0.147
Jan-Dec	0.208	-0.461	-0.294
Jan-June	0.137	-0.448	-0.305
March-June	0.151	-0.449	-0.339
March-April	0.164	-0.510	-0.454
July-Dec	0.426	-0.184	-0.080

* $P < 0.05$

Floods can have a very severe impact on salmonid and other fish populations. Wickett (1958) reported that floods are a major cause of mortality in pink and chum salmon streams in British Columbia and have often reduced the size of succeeding runs. The principal cause of mortality is scouring of eggs and alevins from the gravel. In Nile Creek, B.C., chum salmon survival was considerably reduced in years of severe floods. In 1945-46, there were no floods and the fry had a 3% survival rate. There were several severe floods in 1946-47 and 1947-48, with survival rates dropping to 0.44% and 0.38%, respectively. There was high water but no severe flooding in 1948-49 and fry survival increased to 6.0% (Neave and Wickett 1953).

In the Horokiwi stream, New Zealand, severe flooding occurred between May and October 1941. Based on studies over the previous year, Allen (1951) estimated the effects of these floods on the streambed, the benthic fauna, and the brown trout population. The bottom fauna was reduced to 40-50% of levels of the previous year. The estimated number of most age classes present in October 1941 was only 25-50% the number present of the same age in October 1940. Destruction of eggs by flooding represented 80-90%, compared to a negligible loss the year before. The reduction in bottom fauna resulted in a higher percentage of this food resource being required by the remaining reduced trout population just for maintenance. This reduction left a lower proportion of the food for growth. Thus the floods caused a reduction in the bottom fauna that limited the trout stock to a lower biomass and production. This effect occurred independently of the direct reduction in numbers of trout caused by the floods. Although the study terminated at that time, the limitation was presumed to be only temporary, with both benthos and trout populations returning to original levels in periods of normal rainfall.

In Valley Creek, Minnesota, four severe floods were recorded in 1965 and 1966. Two year classes of brook trout were nearly eliminated from the population. The older age groups were reduced as a result of changes in habitat caused by flooding (Elwood and Waters 1969). A later study showed that the brook trout population made a substantial recovery in 4-5 years. Standing crop increased from 498 fish/ha in 1966 to 10,882 fish/ha in 1969. Biomass increased from 2.5 g/m^2 in 1966 to 14.8 g/m^2 in 1970 (Hanson and Waters 1974), still somewhat lower than the average of about 25 g/m^2 from 1961 to 1965.

In Sagehen Creek, California, survival of spring-spawned rainbow trout fry increased in years following winter floods (Seegrist and Gard 1972). This increased survival of age-0 rainbow trout was presumed to be caused by reduced competition from young brook trout, a consequence of brook trout eggs being destroyed by flooding. When floods occurred in May, rainbow trout eggs were destroyed and survival of young brook trout was improved. Adult trout were less affected by flooding than were the young.

These studies illustrate the impacts that floods can have on salmonid populations. Generally, they affect the eggs and young, older fish being somewhat more resistant. The magnitude of the impact, however, can vary according to the severity of the storm, the particular species, the time of year, and the physical characteristics of the stream.

Habitat Quality

Salmonids are not uniformly distributed within a stream reach. If habitat preference or use can be defined for a species, the potential exists for prediction of spatial variation in abundance based on measurement of habitat quality. It may also be possible to relate temporal variability in abundance to seasonal changes in habitat caused by changing streamflow or other variables. A number of studies have attempted qualitative or quantitative description of habitat use by stream salmonids.

Juvenile coho salmon in their first summer prefer a pool environment. Emerging fry in Waddell Creek, California, initially utilized shallow gravel areas, particularly those near the stream margin (Shapovalov and Taft 1954). The youngest fry tended to school, but as the fish grew larger, these schools broke up and individuals took up territories, which they defended. The larger fry moved into deeper water and by July and August were mainly found in the deeper pools. Chapman (1962) further defined this territorial and aggressive behavior and related it to habitat utilization. Ruggles (1966) found that over twice as many fry remained in a pool-like environment than a riffle-like condition in stream channels in British Columbia. In Oregon streams, Nickelson and Reisenbichler (1977) described characteristics of prime habitat for juvenile coho salmon as having water depth of at least 30 cm, velocity of less than 30 cm/sec, a cobble substrate, and cover consisting of undercut banks and submerged roots.

In the South Fork system of the Salmon River, Idaho, juvenile summer chinook salmon rear primarily in the main stem. Platts and Partridge (1978) recently reported significant use of many tributaries as well. In these tributaries the juvenile salmon preferred high quality pools in the larger streams that had lower channel gradients and grassy streambanks. Yet 59% of all the salmon were found in stream reaches where less than 20% of the channel consisted of pools. This distribution was presumably the result of the fact that most of the juvenile chinook in the tributaries occupied stream reaches within 400 m of the main river, where there was naturally a low pool/riffle ratio.

In a north central Colorado stream, Stewart (1970) sampled 41 sections four times from June through September. He found mean depth and underwater, overhanging rock cover to be the most important variables determining the density of brook and rainbow trout larger than 18 cm. Undercut banks and areas of deep turbulent water seemed to be related to brook trout density, but not that of rainbow trout. He also presents useful data on spatial and temporal variation in biomass of the 41 sections, along with the physical data. Biomass of brook trout >18 cm varied from 0 to 63.9 g/m, rainbow trout 0 to 81.3 g/m, and combined trout 0 to 117.5 g/meter of stream (data on area not presented).

In Little Prickly Pear Creek, Montana, Lewis (1969) conducted a similar study involving 19 sections. He found that cover was the most important factor determining the density of brown trout. Increased stream velocity was associated with increases in density of both brown and rainbow trout per unit area of pool surface and per unit area of cover. The most stable trout populations occurred in deep, slow pools with extensive cover; brown trout showed greater stability than rainbow trout. Current velocity was the most important factor determining density of rainbow trout. Useful data on spatial variation in density are presented, but there is no information on biomass.

Use of habitat by steelhead trout was studied by Shapovalov and Taft (1954) in Waddell Creek, California. Young fry showed similar tendencies to coho fry, initially congregating in schools and later setting up territories. However, unlike coho, steelhead fry inhabited riffles in late summer rather than deep pools.

Dolly Varden fry in Hood Bay Creek, Alaska, were found in quiet water near stream banks and in small pools. The fry were usually inactive and found in or on the substrate, in contrast to the more aggressive coho fry, often found in the same habitat. The coho were actively swimming and feeding from the water surface (Blackett 1968).

Species interaction can have a strong influence on habitat utilization. Apparent preferences shown in the presence of a competing species may change if that species is absent, or if another is present, so care must be used in interpreting results from field studies of species interaction. Careful field observation coupled with experimental analysis is needed to define these interrelations.

Seasonal habitat preferences and behavior of juvenile coho salmon and steelhead trout were studied by Hartman (1965) in British Columbia. In spring and summer coho occupied pools and steelhead occupied riffles. Both were aggressive in defending their respective habitats. This behavior is similar to that observed in Waddell Creek, California, discussed earlier. In winter, however, both species inhabited pools. Low population numbers, low aggressiveness, and different microhabitat preferences were thought to be responsible for this coexistence.

Glova (1978) examined sympatric and allopatric populations of coho salmon and cutthroat trout in six British Columbia streams. In each, three habitats were defined in terms of stream velocity--pools (<8 cm/sec), glides (8-20 cm/sec), and riffles (>20 cm/sec). In sampling during 1973 in Bush and Holland creeks, where both species occurred, coho salmon dominated the salmonid biomass in pools, composing 53-91% of the combined biomass, compared to 9-47% made up by trout. In riffles trout were dominant, making up 63-88% of the combined total biomass. Glides were areas of intermediate biomass for both species, although coho also tended to dominate here, with 52-81% of total biomass. Above barrier falls, where they were found alone, cutthroat trout utilized pools more so than riffles, possibly due to the absence of coho. His analysis of diets suggested that coho were more specialized feeders, relying mainly on drifting foods, whereas cutthroat were more generalized, utilizing both drift and benthos. Glova (1978) noted that cutthroat emerged much later in the year than did coho salmon, into an environment that may already be saturated by coho fry. As a result of aggressive interaction with young coho, the trout would be largely restricted to riffle areas during summer and early fall, and this habitat type is usually less abundant than pools at this time. He concluded that production of sympatric trout may be limited by interspecific interaction, although total fish production may be greater in multi-species streams.

Glova (1978) also found that pools were more extensively utilzed by the total fish species complex than were riffles. There was a strong negative correlation ($r = -0.92$) between the biomass of all fish species combined (coho salmon, cutthroat trout, and Coastrange sculpin, Cottus aleuticus) and mean stream velocity in Holland Creek during September. Based on behavioral studies he postulated that large pools would be less densely populated by salmonids than small ones, owing to competition near the heads of pools for incoming food and resultant low densities of fish in the downstream ends of the larger pools. In support of this hypothesis, he found a significant negative correlation ($r = -0.40$) between logarithms of salmonid biomass and pool surface area, based on data from a total of 37 pools in three streams.

In British Columbia, Bustard and Narver (1975b) found in experiments that overwintering coho salmon and cutthroat trout strongly preferred side-pools with overhanging bank cover to those without such cover. Given a choice between clean rubble substrate and silted rubble, they preferred the side-pools with clean rubble. In a natural stream studied during winter, age 1+ coho and steelhead were found mainly at greater depths and in deeper water than age 0 fish of either species. As stream temperature dropped below 9° C, coho and age 1+ steelhead occupied progressively deeper water and both species moved closer to cover (Bustard and Narver 1975a). Logs and upturned roots were the most commonly used cover. Steelhead were more closely associated with the substrate than were coho.

Habitat utilization by sympatric populations of coho and chinook salmon fry was studied by Lister and Genoe (1970) in the Big Qualicum River, British Columbia. At emergence, fry of both species were found along stream margins in association with streambank cover. As the young fish grew they moved into areas of faster velocity. Spatial segregation soon occurred between the two species because chinook fry emerged about one month earlier than coho fry and grew at a faster rate. As a result chinook preferred higher current velocities than did coho fry at a given date. Somewhat different results, involving more overlap of distribution and more interspecific interaction, were noted in an Oregon river where the two species emerged more nearly at the same time (Stein et al. 1972).

Diel variability in habitat preferences of juvenile chinook salmon and steelhead trout in Idaho streams was shown by Edmundson et al. (1968). Both species tended to move inshore at night to areas of quieter and shallower water than those occupied during the day. Steelhead used areas of faster velocity during the day than did chinook. Everest and Chapman (1972) found that most age 0 steelhead trout and chinook salmon in two Idaho streams lived in water velocities of less than 0.15 m/sec during summer. However, chinook occupied areas of finer substrate and deeper water than did steelhead. There is little interaction for living space between the two species because they spawn and emerge at different times; steelhead spawn in spring and chinook spawn in early fall. The larger juveniles tend to occupy deeper water, and the size differences resulting from these different spawning periods thus reduce competition for food and space between the two species (Chapman and Bjornn 1969).

Platts (1974) conducted an extensive study of fish habitats in 291 sites in 38 streams within the upper South Fork of the Salmon River system, Idaho. Geomorphic characteristics were an important determinant of population abundance. He found the highest fish population densities in channels having 30-50% pools. Total density of the fish populations was positively correlated with width and depth of the sampled streams. Rainbow trout and chinook salmon dominated the populations. Rainbow trout were predominantly found in riffles that were combined with shallow pools. Juvenile chinook were found most abundant in high quality pools.

In the Miramichi River, New Brunswick, Keenleyside (1962) studied habitats and feeding behavior of Atlantic salmon and brook trout. Salmon fry were most abundant in the upper reaches, where rapids and riffles were common. The fry were most abundant in fast water over substrate composed of small gravel and stones. Salmon parr (1-4 years old) were also more abundant in the upper sections of the river than the lower, but were found in deeper water and over larger substrate. Brook trout were found only in the upstream areas. Fry were most common in shallow slow-moving water along the margin. Older fish were found in deeper water that was often swift or turbulent. Keenleyside (1962) noticed feeding segregation between the species. Salmon fry and parr fed on benthic fauna and surface organisms, whereas trout fed almost exclusively on surface foods, possibly because they held positions further above the substrate than the salmon.

In the Indalsalven River, Sweden, brown trout and Atlantic salmon were found together (Lindroth 1955). The young trout (age 0+) occupied shallow water near the stream margin. The trout were territorial and aggressive, actively chasing salmon fry away from these areas. In Scottish streams, Mills (1969) found varying degrees of dominance between Atlantic salmon and brown trout. In some streams he found salmon fry and parr and juvenile trout living together in the same pools and riffles. All possible combinations were noted, from predominance of trout in some streams through to predominance of salmon in others.

Additional evidence that habitat quality is an important determinant of salmonid biomass comes from efforts to improve the quality of existing stream habitat. Although much of this work has gone unevaluated, a number of careful studies have shown population response to habitat development. Among the best documented is the work of Hunt (1971) at Lawrence Creek, Wisconsin. Habitat development in one 0.7 km section of the stream in 1964 increased permanent bank cover by 416% and pool area by 289%. As a result, total brook trout biomass increased from a mean of 59 kg in 1961-63 to 110 kg in 1965-67. In a follow-up study, Hunt (1976) found the mean total biomass in 1968-70 to have increased even further, to 165 kg (21.9 g/m^2).

One of the earliest studies on habitat development in the West was conducted by Tarzwell (1938) in two Arizona streams. In Horton Creek, small log dams, deflectors, and artificial bank cover were added to one section. A section of nearby Upper Tonto Creek was left unimproved as a control. From 1932 to 1937, 25,150 brook, brown, and rainbow trout were stocked in Horton Creek and 46,190 trout were stocked in Upper Tonto Creek.

A complete creel census was conducted in both streams. In 1936 and 1937, following improvement in Horton Creek, that stream yielded more trout to the angler, and a greater weight of trout per hectare than did Upper Tonto Creek, in spite of the much heavier stocking of the latter stream.

The effects of cover manipulation on trout abundance were studied by Boussu (1954) in Trout Creek, Montana. Four inventories were carried out before alteration of habitat (June, December, March, and June); three inventories were made after the alterations (September, December, and March). Rainbow and brook trout comprised about 98% of the salmonids, the remainder being a few brown trout. Brush cover totaling 14.4 m^2 was added to four sections of the stream having a total area of 263 m^2. Following the cover addition, total trout biomass in those sections increased from 1.13 kg to 4.04 kg (4.3 g/m^2 to 15.4 g/m^2). Trout biomass in three unaltered control sections increased only 22% (from 8.5 g/m^2 to 10.4 g/m^2). When 11.9 m^2 of natural brush cover were removed from two sections with an area of 108 m^2, trout biomass decreased from 3.83 kg to 2.28 kg (35.5 g/m^2 to 21.1 g/m^2). At the same time trout biomass in a control section increased 6% (38.1 g/m^2 to 40.5 g/m^2). The third treatment involved removal of 1.4 m^2 of undercut bank from two sections totaling 80 m^2. In this case biomass decreased from 0.68 kg to 0.45 kg (8.5 g/m^2 to 5.6 g/m^2), while biomass in a control area increased 20%, from 14.4 g/m^2 to 17.3 g/m^2. In each of the three treatments the response by legal-sized fish (>18 cm) to change in cover was greater than that of smaller fish. Another result of his work not explicitly presented was the finding of a very significant spatial variation in trout biomass. In the 13 sections used for the study the pre-alteration biomass averaged 16.4 g/m^2, but ranged from 0.11 to 46.7 g/m^2. Because the data are reported as averages for four sampling dates, actual variability was undoubtedly greater. It should also be noted that these data resulted from a single pass with an electroshocker through each section blocked with stop nets, rather than from a formal population estimate.

Thirteen dams, 12 deflectors, and several covers were constructed in a 411-meter section of Hayes Brook, Prince Edward Island, in 1959. In the following year, the number of age 0 brook trout increased to 526, compared with a 13-year pre-treatment mean of 482 (Saunders and Smith 1962). Numbers of older trout increased from a mean of 348 (1947-1959) to 611 in 1960.

Many of these studies have shown great variability in habitat preferences between species, at different times of the year, for different ages of fish, and in association with other species present. Knowledge of these preferences is an important concern in the design of a sampling program.

BIOLOGICAL FACTORS

Food Abundance

There has been an enormous amount of work done on food habits and feeding behavior of stream salmonids. However, very few of these studies bear directly on the matter at issue here: can differences in abundance or availability of food account for spatial or temporal variation in salmonid biomass in streams?

The question is complicated by difficulty in defining an appropriate measure of food availability--benthos, drift, or some combination. Very few studies have focused on these important issues. A reorientation of feeding studies is required before a definitive answer to the question of food limitation is possible. Our review will concentrate on the few studies relating food abundance to variation in salmonid abundance.

A starting point is to examine the significance of invertebrate drift. Drifting invertebrates represent a potential food source of considerable magnitude, but of variable availability. Of particular importance is a strong diel periodicity, most drift occurring during darkness. Other factors that may affect the rate of drift include water temperature, current velocity, stage of the life cycle, and population density (Waters 1969). Some studies (Mason and Chapman 1965; Elliot 1973; Gibson and Galbraith 1975) have shown greater fish standing crops in stream sections with greater incoming drift. Yet other studies have shown a significant part of the diet to be made up of non-drift benthic forms. For example, Warren et al. (1964) reported the greatest food consumption in stream sections with the least drift, possibly because of a much greater abundance of benthic fauna in these sections. Other work has shown little correlation between drift and diet. One such study was conducted by Mundie (1969) on coho salmon fry in British Columbia. In seeking an explanation for the lack of correlation he postulated diel and spatial variation in drift composition, and variation in fry behavior. It is clear that there is considerable variation in the degree to which drift is utilized as food by stream dwelling salmonids.

There is evidence that food can be a limiting factor for some populations of stream salmonids. One of the strongest cases was brought forward by Mason (1976). He found that food limited the stream production of juvenile coho salmon during the summer in Sandy Creek, B.C. Through supplemental feeding, the summer biomass was increased 6-7 fold compared with previous levels. However, there was no significant increase in the number of smolts the following spring. The estimate of smolt yield under natural conditions was 212 fish, and the February population estimate was 257 ± 71 fish surviving from supplemental feeding the previous summer. Thus in this stream the winter carrying capacity appeared to be the ultimate limit to smolt production.

In the Horokiwi stream, New Zealand, Allen (1951) found evidence suggesting that the food supply of brown trout, primarily the benthic fauna, could play an important role in regulating the trout population. He found that an increase in trout abundance increased pressure on the food supply, decreasing the density of that supply. This resulted in a reduction in surplus food (the amount that could be used for growth and production). Consequently, there was a decrease in mean individual growth rate. This resulted in a feedback system that would tend to keep the population biomass relatively constant by changing growth rate in response to changes in population size.

In a later review, Allen (1969) discussed the role of the benthic fauna in regulating production of stream salmonids as a group. He suggests that fish production can be limited by the density of the bottom fauna, which in turn may be controlled by consumption by fish. This interaction provides a mechanism for stabilizing the salmonid production rate.

Ellis and Gowing (1957) examined bottom fauna and brown trout populations above and below a domestic sewage outfall into Houghton Creek, Michigan. Although the biomasses of trout were similar above and below, there were significant increases in the benthic fauna and condition of trout below the point of sewage input. They also noted that trout below the outfall relied less heavily on terrestrial foods, and concluded that trout growth was strongly influenced by the quantity and kinds of food consumed.

Symons (1971) experimented with effects of fluctuating food quantities on behavior and abundance of Atlantic salmon parr in a stream tank. He found that such fluctuations had little effect on the abundance of socially dominant parr. Socially subdominant fish, however, seemed more abundant where food was plentiful than where it was scarce. Thus total fish abundance was higher in channels where food was more abundant. Mason and Chapman (1965) studied behavior and abundance of juvenile coho salmon in two experimental stream channels. They found that one channel received about a third more volume in potential food organisms, and this was associated with about a two-thirds increase in total fish weight in that channel. However, there was no replication, and other causes may also have been involved.

Variation in food abundance was associated with spatial variation in abundance of cutthroat trout populations in the Oregon Cascades. One pair of open and shaded stream reaches was studied intensively for 4 years. Primary production and insect emergence were significantly greater in the open area compared to the forested section (Triska et al. 1980). Production, growth rate, and biomass of cutthroat trout were about twice as great in the open area (Hall et al. 1978). Murphy (1979) expanded the study to include nine pairs of open and forested sites, the openings being the results of earlier clearcuts. He found the same general relations to hold, including increased abundance of primary producers, predatory insects, and cutthroat trout in the open areas.

Predation

Although predation has been shown to cause some significant mortality in stream salmonids (Hunter 1959; Mills 1964; Tagmaz'yan 1971), there have been very few studies to support the position that variation in level of predation leads to ultimate variation in size of the salmonid population.

One of the few studies to combine stream population studies with predator manipulation was carried out over a number of years in New Brunswick. Elson (1962) reports investigations of predation on juvenile Atlantic salmon by mergansers and kingfishers from 1942 to 1953. In a sample of 117 merganser stomachs analyzed, an average of 42.1% of the number of items were salmon. These salmon comprised an average of 10.3% of the total fish numbers in the river, yielding a forage ratio of 4.1. Kingfishers also selectively fed on salmon and had a forage ratio of 3.1. Predator control was practiced from 1947 through 1950 and the abundance of mergansers and kingfishers was significantly reduced. Consumption of salmon by these two species of predators was estimated to have been reduced to about 10% of pre-control levels. Before control, smolt output ranged from approximately 1,000 to 5,000 each year. During predator control, output ranged from 14,000 to 24,000 smolts. Elson

(1962) concluded that predation by mergansers was a limiting factor on Atlantic salmon smolt production. Unfortunately, the study design was somewhat flawed by differing levels of stocking in the pre-control and control years, and by lack of data on adult returns.

One of the most detailed long-term studies on trout populations and predation has been carried out in Michigan on the North Branch of the Au Sable River (Alexander 1979). Estimates of population size of brook and brown trout were made in spring and fall each year from 1957 to 1967. Catch by anglers was determined from a statistically designed creel census in two sections of the river, one in which normal angling regulations prevailed and another in which angling was significantly restricted. Predators were collected for stomach analysis from 1960 to 1974. From these analyses Alexander concluded that the annual rate of mortality of both brook and brown trout was very high (average rates calculated by Chapman-Robson method for age groups 0-IV from his data in Tables 2-5: brook - 0.84 and 0.82; brown - 0.64 and 0.74, normal and special regulations respectively). Consumption by known predators (principally the American merganser, great blue heron, belted kingfisher, mink, otter, and large brown trout) accounted for a large fraction of this mortality; their consumption was estimated between 43 and 46% of annual production. Anglers took another 37 and 8% in the normal and restricted water respectively. Notwithstanding the sizeable mortality caused by predators, Alexander is of the opinion that reduction of their abundance, short of complete removal of all predators, would not have a significant impact on salmonid abundance, owing to a compensatory kill rate that would be demonstrated by the remaining predators. The fact that total annual mortality rates are similar for each age group in the two sections, in the face of much less angling "predation" in the special water, supports this view. More effort must be put into well-designed stream studies such as this one before a definitive conclusion on the significance of predation to population abundance of stream dwelling salmonids can be provided.

Movement and Migration

Nearly all salmonid species undergo varying degrees of movement in their lifetime. Some non-anadromous species undergo annual migrations within the same stream system for the purpose of spawning. Others remain in the same general area, undergoing local movements motivated by food, temperature, streamflow, or other factors. Movement and migration can be considered a form of temporal variability. The timing and magnitude of these movements need to be understood in order to know what age and size range of fish to expect from sampling at a particular time of the year. A comprehensive review of migratory strategies of freshwater fishes and their significance to fish production is provided by Northcote (1978).

Migrations of anadromous species are so conspicuous and generally well known that it seems unnecessary to include them in this review. One cautionary example is perhaps in order, however. Conventional wisdom for many years held that juvenile fall chinook salmon migrated to salt water shortly after emergence from the gravel, whereas juvenile spring chinook resided in fresh water for a full year before migrating to the ocean. More recent studies have indicated considerable variation from this pattern, both within and between stocks of fall and spring chinook (Reimers and Loeffel 1967; Reimers

1973; Schlucter and Lichatowich 1977). These results indicate the importance of careful studies of the migratory pattern in each stock of fish.

Most studies of resident salmonids have found their movement to be quite restricted, with the exception of some activity associated with spawning. In Kettle Creek, Pennsylvania, Watts et al. (1942) observed an upstream migration of brook trout into colder tributaries in late May and early June. Spawning took place in the fall, after which the trout moved downstream once again. Resident trout in this watershed, however, moved little between tributaries.

There have been several studies of the movements of resident brown trout. Solomon and Templeton (1976) studied a population in a 7.5 km section of a chalk stream in England, from which they recognized five life history stages with respect to movements and migration. The first was a downstream movement from hatching to nursery areas. Fish stayed in these areas for about 6 months. Then came a second movement further downstream to areas of adult growth, where the trout remained until they were about 15 months old. Following this was a period of very limited adult movement until maturation. Then came an upstream spawning migration followed by downstream movements after spawning.

In the Pine River, Michigan, Mense (1975) studied effects of varying brown trout densities on movement. Among fish >15 cm, he found no change in movement patterns in a comparison of densities of 209 and 87 trout/ha. He does not present data on biomass, but we have made a rough estimate of 3.8 and 3.3 g/m^2, based on his data for the two respective years. Both values for biomass are rather low, and the fact that the average size of fish was much larger in the year of lower density reduced the power of his test of the hypothesis.

In Convict Creek, California, Needham and Cramer (1943) found extensive downstream movement of brown trout during spring. The peak coincided with rising, but not maximum, streamflows, although flow was not felt to be a causative factor. Most migrants were sexually immature. The downstream migration may have been initiated by lack of adequate food and shelter in the upper reaches of the stream. Little migration of rainbow or cutthroat trout was noted.

Movement into and out of an intermittent tributary was shown to be an important feature in the life history of rainbow trout in Sagehen Creek, California. From 39 to 47% of the spawning adults used this tributary from 1972 to 1975. Two possible reasons were given for this high use of an intermittent stream while permanently flowing tributaries were used by only a small percentage of the spawning fish. Peak runoff from snow melt is much greater and occurs earlier in the year in the intermittent tributary. In addition, there is no competition from brook trout because they cannot spawn there in the fall owing to insufficient flow (Erman and Hawthorne 1976). The rainbow trout fry from this tributary showed a diel periodicity in downstream movement that differed between a dry and wet year. In 1973, the dry year, fry moved downstream mainly during the day. In 1974, when the tributary retained permanent flow, fry migrated downstream mainly at night. In that year many fry remained in the tributary throughout the summer (Erman and Leidy 1975).

In another population of rainbow trout, movement was not extensive. In Elder Creek, Oregon, Osborn (1967) made 755 observations of rainbow trout movement, based on recaptures of marked fish larger than 75 mm. Less than 4% of the fish had moved more than 91 m.

Several studies have indicated that resident cutthroat trout undergo relatively limited movements. In Gorge Creek, Alberta, Miller (1957) found that of 58 tagged fish recaptured, 32 (55%) were recovered in the same pool in which they were tagged. He concluded that most cutthroat in this stream had a home territory less than 18 m long. In Lookout Creek, Oregon, restricted home ranges were also found for cutthroat trout. Wyatt (1959) noticed no general downstream movement, but he did observe two periods of limited upstream movement. From October through January some trout made scattered visits to tributaries. Then from the end of March to early June there was a spawning migration, with a peak in April.

OTHER FACTORS

There are a number of other factors that may affect natural variation in abundance of salmonids. This section includes consideration of those factors that are worthy of mention but have not been studied in enough detail to warrant discussion in separate sections.

In the Pigeon River, Michigan, Benson (1953b) studied the effects of ground water on brook and brown trout populations. Spawning of brook trout occurred only in sections with considerable ground water seepage. Brown trout spawned in more widely scattered areas, but the greatest concentration of redds was located where ground water was abundant. In turn, these areas of greater spawning produced higher population estimates. In a later study in the same river system, Latta (1969) found that numbers of brook trout fry were directly correlated with ground water levels. He suggested that the relation would be stronger in lower reaches of streams than in headwaters.

Ice formation can have substantial effects on overwintering salmonid populations in high mountain streams or high latitudes. In Sagehen Creek, California, Needham and Jones (1959) noted that anchor ice, which forms underwater in riffle areas, is an important ecological factor in that it can raise the water level in pools and reduce streamflow over riffles. The breakup or melting of anchor ice can dislodge the benthic fauna, making more food available to trout. In British Columbia, Bustard (1974) found collapsing snow and subsurface ice to be two major causes of winter mortality in salmonids.

Beaver dams can significantly alter physical characteristics and carrying capacity of salmonid streams. In Sagehen Creek, California, the balance of abundance of brook, brown, and rainbow trout was shifted by the presence or absence of dams (Gard 1961).

Chemical properties of stream water may influence salmonid abundance and growth rate. In New South Wales, Lake (1957) examined brown and rainbow trout populations in 130 streams. He found a strong correlation between water chemistry and growth rate. Streams with the hardest water and highest pH had the most abundant bottom fauna and produced trout with the greatest length at a given age. Kennedy and Fitzmaurice (1971) examined over 40 streams and rivers in Ireland. They found the largest and fastest growing brown trout in streams having a high calcium content. The smallest and slowest growing ones were in lime deficient waters draining acid rocks. These results are supported by Thomas (1964) from rivers in west Wales. He found that the growth rate of brown trout in waters having a pH of 7 or more with a high ion and calcium content was greater than that in more acid waters. Brown trout populations in six streams of varying hardness in Pennsylvania were sampled by McFadden (1961a). There was no consistent difference in trout density between hard and soft water streams, yet brown trout growth rate was consistently greater in hard water streams. Fish of similar size had greater fecundity in hard water.

Stream gradient usually operates to limit distribution of salmonids, rather than abundance. However, in transitional areas, where two species are involved, consideration of gradient may help to explain variation in abundance. In the Clearwater River system, Idaho, Griffith (1972) found evidence suggesting that stream gradient may influence the relative abundance of brook and cutthroat trout in streams inhabited by both species. In some parts of Idaho cutthroat live in slow water (< 6 cm/sec) when not associated with brook trout, but they did not occupy this habitat in association with brook trout in Crystal Creek. Brook trout were found in the low gradient sections of Crystal Creek, whereas cutthroat were more abundant upstream in areas of higher gradient. The same distribution of the two species was also found in a tributary of the St. Joe River.

SECTION 5

MINIMIZING THE EFFECTS OF VARIABILITY IN IMPACT STUDIES

The temporal and spatial variability in populations of stream salmonids are clearly sufficient to mask very significant man-caused changes in these populations. This is especially true for damage done by non-point source pollutants. If we are to effectively monitor impacts of such perturbations, means must be found to minimize the effects of natural variability in detecting these effects. It now seems clear that the traditional watershed study design, with its long-term pre-treatment calibration and post-treatment evaluation, is not adequate for such analysis (Hall et al. 1978). After reviewing existing approaches to the problem, we present several interrelated ideas that may improve sensitivity of future studies.

HABITAT QUALITY RATING SYSTEMS

Models that quantitatively describe the quality of salmonid habitat promise to significantly reduce the amount of unexplained variability in population abundance. The principal stimulus for the development of many of these models has been concern about loss of water from streams caused by irrigation or other appropriation. Hence the focus has been on determination of minimum streamflow requirements and on changes in habitat quality and quantity with changing streamflow. A good review of the historical basis for this work is provided in proceedings of the Symposium on Instream Flow Needs (Orsborn and Allman 1976).

One of the early attempts to develop such a model was made by Wesche (1973), who combined hydrologic parameters, surface area, and available trout cover to define available habitat for brown trout. Continuation of this work extended the analysis to a cover rating system that provided a significant linear predictor of brown trout biomass in several stream systems (Wesche 1976).

Another early study was initiated by the Oregon Department of Fish and Wildlife, mentioned earlier. They began with an attempt to relate habitat quantity and quality to streamflow by manipulating flow in a natural stream channel through a diversion (Keeley and Nickelson 1974; Nickelson 1975). Though initial work was marred by technical difficulties in establishing the diversion, recent results have been quite promising. Two types of models are presently being developed. One describes the relation between stream habitat and rearing potential of salmonids during the low flow period. Another is designed to predict the amount of habitat for any value of streamflow (Nickelson and Reisenbichler 1977; Nickelson and Hafele 1978). Pool volume alone explained 93.5% of the variation in summer standing crop of juvenile coho salmon in 12 sections of three coastal streams. For cutthroat trout a habitat quality rating (HQR) is computed as a product of a cover value, velocity preference factor, and wetted area. The cover value is a combination of depth, escape cover, overhanging cover, turbulence, and velocity shelter. Two alternative formulations of the HQR explained 91 and 87% of the variation in cutthroat trout standing crop in 31 sections of six streams (Nickelson and Hafele 1978). A related HQR for steelhead trout, involving cover, depth and velocity, and wetted area, explained 79% of the variation in standing crop of juveniles in 23 sections of four streams. Further work is underway to validate these models.

A related approach has been taken in a follow-up of work done in Wyoming streams by Wesche (1976). Binns and Eiserman (1979) developed a habitat quality index for trout from analysis of 22 physical, chemical, and biological attributes in a sample of 36 streams. Using a multiple regression approach for selection of model attributes, they constructed an index (Model I) that produced an R^2 value of 0.955 for the initial 20 streams sampled. When this model was used to predict trout standing crop at 16 new stations, R^2 dropped to 0.594. A new model was developed for all 36 sites, based on only nine habitat attributes, all physical and chemical (late summer flow, annual flow variation, maximum stream temperature, and a food index and a cover index that are combinations of nitrate nitrogen, cover, eroding stream banks, substate, water velocity, and stream width). This new model (Model II) explained 97% of the variation in trout standing crop at the 36 sites (R^2 = 0.966). However, this analysis highlights a frequent misinterpretation of R^2 as a measure of reliability of the model (W.S. Overton, Department of Statistics, Oregon State Univ., personal communication). One value of standing crop is more than twice as large as the next largest (63.4[1] vs 28.4 g/m^2). This one point tends to inflate the value of R^2 by its large contribution to the sum of squares for standing crop. A more valid measure of the goodness of fit is the relative prediction error. The authors noted that no prediction was in error more than 5.5 g/m^2 and that an error of 5.4 g/m^2 at Sand Creek (the highest trout population) was within 9% of the measured value. However, the percent error at many stations with lower biomass was substantially higher than that, and averaged 32.4% for the 36 stations with Model I (range 0-179%) and 26.2% (range 0-157%) for Model II. Nonetheless, this approach is a very useful one that promises to increase the precision of impact evaluation.

The most extensive development of indices to habitat quality has been undertaken by the Cooperative Instream Flow Service Group of the U.S. Fish and Wildlife Service (Bovee and Cochnauer 1977, Bovee 1978). Their general approach has been to couple information on the state of several hydraulic parameters of the stream environment with a "probability of use" for a combination of these parameters. A weighted usable area is then calculated for each level of discharge for the various life history stages of each species

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[1] It is noteworthy that this estimate appears to be one of the largest ever reported for salmonid biomass in streams, especially in that it resulted from only a single pass through the study section.

of interest. This effort, focused on the effects of incremental losses of streamflow on reduction in quality and quantity of fish habitat, has been substantially influenced by the thinking of physical scientists, primarily hydrologists. The input from physical scientists has been a significant feature of the program and one that should be encouraged. Addition of the perspective of geomorphology (Platts 1974; Swanson and Lienkaemper 1978) could significantly improve the generality of the approach.

PROCESS STUDIES

Understanding of the basic physical and biological processes that lead to biological production and eventually to fish production will provide a much sounder basis for assessment than has been available through the case history approach. One particularly relevant example is found in the analysis of temperature changes following logging in the Alsea Watershed Study (Brown 1967; Brown and Krygier 1970). By developing a model of the heating and cooling process in an undisturbed stream and quantifying each element in the energy budget, Brown was able to identify direct solar radiation as the primary source of warming in streams. This procedure allowed a prediction to be made of the potential impact before timber was cut, and thereby provided a basis for planning necessary buffer strips to minimize adverse effects caused by warming of stream water. The process study provided an energy budget approach that is general enough to be applied in most watersheds.

It is probably more feasible to carry out such studies of the physical processes in streams than those of the biological components. Additional work on physical process is now underway, for example, in suspended sediment and bedload transport (Beschta 1978; Beschta and Jackson 1979). Nonetheless, studies of biological process are essential to an understanding of variability in stream salmonid populations, and further emphasis must be placed there.

Though far from complete, the work in Mack Creek carried out under the Coniferous Forest Biome Study and mentioned earlier (Triska et al. 1980) provided some evidence of the validity of this approach. Knowledge of primary production, insect abundance, and trout production provided evidence that the higher trout biomass in streams flowing through clearcut areas was a real phenomenon rather than simply the result of movement of trout in response to preference for open areas. It also provided some evidence of at least one pathway through which the increase in trout production might have been achieved. Much more work will be necessary in many more systems, however, before models of biological processes will achieve the same level of understanding and predictability now enjoyed by models of physical processes in streams.

STREAM CLASSIFICATION

It seems clear that some sort of classification of streams and their watersheds will be an essential element of future impact assessment (W.S. Overton, pers. comm.). Classification has had a long history, especially in Europe, where it has been incorporated in management schemes (cf. Huet 1959).

However, the perspective of those involved in classification has often seemed to focus on differences rather than similarities of stream ecosystems, thus leading to unmanageable complexity in the system of classification (cf. Pennak 1971).

One of the approaches most adaptable to the present problem is that of Platts (1974). His classification is based on stream order and a small number of geomorphic characteristics and provides a manageable and quantifiable system. Application to a stream ecosystem encompassing 220 km of the South Fork of the Salmon River in Idaho provided significant explanation of variability in distribution and abundance of nine fish species.

A recent synthesis by Warren (1979) forwards a more inclusive classification scheme, based on a biogeoclimatic perspective. It takes the promising approach of classification based on capacity or potential of a system rather than its present state. This potential would be indexed solely by geomorphic characteristics of the stream habitat and the watershed system within which it is imbedded. The scheme thus avoids much of the complexity inherent in measuring both taxonomic and quantitative variability in biological components within and between stream ecosystems. Further development of this concept should provide a much more solid basis for impact assessment in the future.

IMPROVED STUDY DESIGN

Another source of improvement in efficiency of detection of impacts appears available through modifications in the way in which observational data are gathered. Field observations will probably always be the major basis for impact assessment. As a consequence, much of the body of experience and theory in the field of experimental design will not be directly applicable to such analysis. A sampling perspective is more appropriate, and Overton (1978) provides a useful discussion of three levels at which sampling questions can be addressed, along with general guidelines on study design.

Eberhardt (1978) provides a valuable review of the problems of appraising variability in population studies, one that should be required reading for anyone beginning a study to assess impacts of non-point source pollution. A related article (Eberhardt 1976) provides further detail, particularly on his suggestions for handling the "single-site problem" that is often a characteristic of impact assessment. He proposes substitution of repeated observations in time or space for true replication. The ratio of population density in the affected area to that in the "control" site(s) would be the measure of impact. He is cautious, indicating potential problems and suggesting the whole approach as a "pseudodesign." Nonetheless, these two papers are a very significant contribution to the topic under review here.

A number of different approaches to field observation are possible, and appropriate combinations may lead to more fruitful results than will a single approach. These possible approaches have been classified in two ways by Hall et al. (1978). In a review of effects of watershed perturbations on streams, they grouped studies according to whether they bracketed (before-after) or followed (post-) treatment. The other level of classification was based on whether detailed studies were made on one or very few streams (intensive) compared to less detailed work on many streams, including a wide range of habitat types (extensive). This two-level classification results in four categories, which are evaluated for efficiency and sensitivity of impact detection. An expanded listing of advantages and disadvantages of each type (Table 5) reveals that no one design is optimum. The extensive post-treatment approach does have a number of advantages over the classical watershed study (intensive before-after). The best approach appears to be a combination of extensive post-treatment analysis with carefully designed process studies carried out at one or more locations.

Pairing of treatment and control is proposed to improve sensitivity of detection (Hall et al. 1978). This procedure places an upstream control very close to a treatment area on each stream. It proved to be a sensitive design to investigate changes in both predator populations and their habitat in small clearcuts in the western Cascades in Oregon (Murphy 1979; Murphy and Hall MS.). By inclusion of watersheds that had been harvested up to 35 years earlier, it also provided some insight into the rate of change of physical and biological characteristics following treatment. This approach does have the limitation that it can detect only those effects that occur in the immediate stream reach affected by the treatment. It is relatively insensitive to downstream effects or those that accumulate over the larger watershed.

A modification that would provide some insight into effects on that scale would pair watersheds, treated and untreated. However, it would often be difficult to find untreated watersheds adjacent to treated areas, and such pairs would undoubtedly be more unlike than adjacent reaches of the same stream. Nonetheless Welch et al. (1977) used a variation on this approach to document effects of forestry and agriculture on streams in New Brunswick, examining a total of 34 watersheds, all smaller than about 1000 ha.

Erman et al. (1977) used an innovative form of this approach in a study of effects of clearcutting on invertebrate populations in Northern California streams. They sampled a total of 62 streams, all in small watersheds (< 800 ha). There were two objecives: to test effects of various widths of buffer strips in preventing changes in invertebrate populations, and to examine localized effects of point disturbances such as road-related landslides. For the latter purpose their design was to sample upstream of the landslide as a control, at the disturbance point, and downstream where no visual evidence of the disturbance remained.

To evaluate the role of bufferstrips, they used a design that employed two controls for each logged section, one upstream from the treatment and another in an adjacent untreated watershed. The hypothesis tested was that if effects occurred, the two control streams should be more similar than either control and the treated section. Various measures of similarity were compared and nonparametric ranking tests were used in the statistical analysis. They found significant effects on community composition in unbuffered streams and found no significant differences between controls and streams with wide bufferstrips (Newbold et al. in press).

TABLE 5. SUMMARY OF ADVANTAGES AND DISADVANTAGES OF THE FOUR MAJOR APPROACHES TO WATERSHED STREAM ANALYSIS.

A. Intensive Before-After (10-15 years; 5-7 years before and after treatment).

Advantages	Disadvantages
1) Possible to assess year-to-year variation and place size of impact in context of that variation.	1) No replication; results must be viewed as a case study.
2) Can assess short-term rate of recovery (ca. 5 years).	2) Results not necessarily applicable elsewhere (areas of different soils, geology, fish species, etc.)
3) No assumptions required about initial conditions.	3) Results vulnerable to unusual climatic events (e.g. high or low rainfall season(s) immediately following treatment).
4) Possible to monitor whole watershed impacts (provided substantial investment in facilities such as flow and sediment sampling wiers, fish traps).	4) Final results and management recommendations require exceptionally long time to formulate - up to 15 yrs after initial planning stage.
5) Long time frame provides format for extensive process studies.	5) Difficult to maintain intensity of investigation and continuity of investigators over such a long period.
	6) Must rely on outside agencies or firms to complete treatments as scheduled - considerable coordination required.

B. Extensive Before-After (2-4 years; 1 year before treatment, 1 year after).

Advantages	Disadvantages
1) Provides broader perspective across geographical area than (A).	1) Lack of long-term perspective--little opportunity to observe year-to-year variation.
2) Larger number of streams examined lessens danger of extreme case.	2) Able to assess only immediate results, which may not be representative of longer time sequence.
3) Increased generality of results allows some extrapolation to other areas.	3) Treatment vulnerable to unusual weather (if all treatments in same year).
4) Relatively short time to achieve results (3-4 years from planning stage).	4) Must rely on outside agency (see (A) above).

TABLE 5. (Continued.)

C. Intensive Post-Treatment (One Watershed--Paired Sites) (4-5 years, following treatment).

Advantages	Disadvantages
1) Shorter time for results than (A). 2) Moderate ability to assess year-to-year variation. 3) Provides opportunity for moderate level of effort on process studies.	1) Provides no strict control--requires assumption that upstream control was identical to treated area prior to treatment. 2) "Control" most logically must be located upstream of treatment. Strong downstream trend in any feature would confound analysis. 3) Provides no spatial perspective--results of limited application elsewhere.

D. Extensive Post-Treatment, 10-30 Watersheds (or more); all observations in 1-2 years (variable time after treatment).

Advantages	Disadvantages
1) Wide spatial perspective allows extrapolation to other areas. 2) Long temporal perspective is possible--can assess recovery for as many years as past treatments have occurred. 3) Provides ability to assess interaction of physical setting and treatment effects (e.g. effects of sediment input at different stream gradients). 4) Requires least time of all four designs to get results--as little as 2 years. 5) Probably most economical of all four approaches per unit of information.	1) No data available on pre-treatment conditions--forces assumption that control and treatment were identical (on average). 2) Control predominately upstream. 3) Total cost concentrated in very short period--requires extensive planning. 4) Not as effective as (A) in assessing whole watershed effects. 5) Methods used in early treatments may not be comparable to later ones.

Although much variability will undoubtedly remain in any study of natural populations in field situations, the ideas discussed above should help to resolve some of the uncertainty that has been present in past analyses. A good deal of ingenuity and insight will be needed in making the right choices of habitat parameters and in devising methods of quantifying them. Choosing the appropriate variables for watershed classification will likewise be a formidable task. Hopefully, however, some judicious combination of these approaches should make the task of assessing and controlling non-point source pollution a more effective and rational one.

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As part of a development of strategy for analysis of impacts of non-point source pollutants on streams, we have searched the literature on population dynamics of stream salmonids. The following list is not exhaustive, but we have put emphasis on studies that report quantitative estimates of population size, and those that deal with spatial and temporal variability in such data. In addition we have included studies that may be useful in interpreting this variability. Some emphasis is placed on work on the west coast of North America, but many valuable contributions from other areas have also been included. The more important contributions in the following list are annotated; other reports of interest are listed only by title.

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A study of age 0 brook trout from the Pigeon River, Michigan, in 1962, 1964, and 1965. Magnitude and periodicity of mortality are discussed in a brief review of other studies. Mortality from starvation, in relation to water temperature, is investigated in stream aquaria. Relationships between levels of groundwater and abundance of fry are also examined. The importance of groundwater levels in regulating the carrying capacity of the stream is discussed.

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A comprehensive study of the brook trout population in Lawrence Creek, Wisconsin, from 1953 through 1957. Data are presented on population estimates, lengths, age structure, density, biomass, and natural mortality in each of four study sections for each age group of trout. Length-fecundity relationships are also examined. Angling intensity is investigated by means of a complete creel census each year. Data obtained include number of fishing trips, number, sex, size, and weight of trout caught and exploitation rates. Angler mortality is compared to natural mortality of the trout, and management options are discussed as means of keeping an adequate recruitment to the population.

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One of the earlier studies attempting to explain fluctuations in salmon population levels in Oregon. Columbia River chinook salmon catch data are presented from 1866 through 1948 and coho salmon catch data from coastal rivers are presented from 1923 to 1948. Pollution, changes in angling regulations, hatcheries, logging, streamflow, and salinity are analyzed as potential factors responsible for the observed fluctuations. In addition, the effects of the fishery, indicated by marking experiments, fishing intensity, and economic trends, are examined.

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Moring, J.R., and R.L. Lantz. 1975. The Alsea Watershed Study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part I - Biological studies. Ore. Dept. Fish Wildl., Fish. Res. Rep. No. 9. 66 pp.

A summary report, incorporating data from a number of earlier publications from the study. Three small tributaries were studied, one clearcut down to the streambank, one clearcut with buffer strips left, and the third left uncut as a control, for 15 years. The pre-logging period was 1959 to 1965 and the post-logging period was 1967 to 1973. Biological studies concentrate mainly on coho salmon and cutthroat trout, the dominant species in the streams. For adults, data include numbers, timing of migration, size, sex ratio, and fecundity. Data on juveniles include emergence, growth, biomass, production, mortality, and downstream migration. Effects of logging are reported.

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Population dynamics of brown trout in a small Danish stream were examined from 1973 through 1975. Biomass of the 1971-1975 year classes is investigated. Population size, production, mortality, length-weight relationships, and smolt yield are also discussed.

Mortensen, E. 1978. The population dynamics and production of trout (_Salmo trutta_ L.) in a small Danish stream. Pp. 151-160 _in_ J.R. Moring (ed.), Proc. wild trout - catchable trout symp. Ore. Dept. Fish Wildl., Res. Devel. Sect., Portland.

Population size, survival, growth, biomass, and production of brown trout were studied in three sections of a small Danish stream from 1974 through 1976. Variability in age group composition and biomass between the three sections is shown. Density-dependent fry mortality, density-independent mortality of older fish, and variability in production-biomass ratios between age groups are also analyzed.

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Magnitude and timing of upstream adult and downstream kelt and smolt migrations in this river are examined for both species. Marking experiments are used to determine movements, utilization, and survival. Marine survival is determined from commercial catch and escapement of marked fish.

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An extensive survey of the major streams in Newfoundland, including description, location, and certain morphometric, edaphic, climatic, and biotic characteristics. Morphometric factors examined include watershed shape, elevation, gradient, vegetational cover, runoff, and discharge. Edaphic factors include surface geology, total dissolved solids, micronutrients, acidity, conductivity, and hardness. Climatic factors examined are air temperature and precipitation. Competition, predation, fecundity, emigration, survival, and disease are the biotic factors investigated. Both fish and aquatic invertebrate populations are studied. Native salmonid species are Atlantic salmon, brook trout, and Arctic char. Pink salmon, rainbow trout, and brown trout have been introduced. In addition, the sport fishery for Atlantic salmon is examined.

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Narver, D.W. 1971. Effects of logging debris on fish production. Pp. 100-111 in J.T. Krygier and J.D. Hall (eds.), A symposium: Forest land uses and stream environment. Oregon State Univ., Corvallis.

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The initial data from a long-term study of the effects of logging on the aquatic resources of a British Columbia watershed. The study is divided into pre-logging (1970-1974), logging (1975-1979), and post-logging (after 1979) periods. In particular sampling is conducted on sections of upper and lower Carnation Creek, "C" tributary, "1600" tributary, and Useless, Frederick, Ritherdon, and South Pachena creeks. This report contains data on population estimates, density, late summer biomass, growth, length-weight relationships, and condition of both resident and anadromous salmonids. The primary species include coho and chum salmon, and rainbow, steelhead, and cutthroat trout. Data are updated for every year through 1977 by Andersen and Narver (1975) and Andersen (1978).

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A review of some chemical, physical, and biological factors that affect salmon populations in British Columbia streams. Chemical factors include dissolved oxygen and pH. Important physical factors are bottom type, particularly on spawning grounds, obstructions, streamflow, including floods, and water temperature. Predation, interspecific and intraspecific competition, and disease are important biological factors discussed. Relationships between precipitation and adult returns two years later are also analyzed.

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Needham, P.R., and A.C. Jones. 1959. Flow, temperature, solar radiation, and ice in relation to activities of fishes in Sagehen Creek, California. Ecology 40:465-474.

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A study of the brown trout populations in two sections of this stream from 1939 to 1944, one closed and the other open to angling. Reproduction, survival, seasonal weight changes, and density are analyzed in both sections. The effects of angling on these parameters are shown. The possibility of stocking the stream with more trout is discussed as a method to offset angling pressure.

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Nickelson, T.E., and R.R. Reisenbichler. 1977. Streamflow requirements of salmonids. Ore. Dept. Fish Wildl. Proj. AFS-62. 24 pp.

Northcote, T.G. 1978. Migratory strategies and production in freshwater fishes. Pp. 326-359 in S.D. Gerking (ed.), Ecology of freshwater fish production. Blackwell Scientific Publ., Oxford.

Nyman, O.L. 1970. Ecological interaction of brown trout, Salmo trutta L., and brook trout, Salvelinus fontinalis (Mitchill), in a stream. Can. Field-Nat. 84:343-350.

O'Connor, J.F., and G. Power. 1976. Production by brook trout (Salvelinus fontinalis) in four streams in the Matamek Watershed, Quebec. J. Fish. Res. Bd. Can. 33:6-18.

Four streams were examined for brook trout populations from 1971 through 1973. Biomass of each age group each year is presented as well as total biomass in the study sections. Production and production-biomass ratios in each stream are also examined. Differences in these parameters between streams are related to variations in stream cover, recruitment, and total biomass. The roles of food and cover as possible limiting factors on adult production are discussed.

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Osborn, C.E. 1967. A population study of the rainbow trout (Salmo gairdneri) in a central Oregon stream. M.S. thesis. Oregon State Univ., Corvallis. 65 pp.

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An extensive study from 1970 to 1972 on conditions influencing salmonid populations in 291 stream sites in the upper South Fork of the Salmon River watershed, Idaho. Physical and hydrologic parameters examined include climate, geological processes and types, stream channel width, depth, gradient, and order, elevation, pool-riffle ratios, and streambank vegetation and stability. Effects of these factors on the salmonid populations are analyzed. The salmonid species present include rainbow, steelhead, and brook trout, Dolly Varden, chinook salmon, and mountain whitefish.

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APPENDIX

This appendix is a compilation of examples of the best data available on temporal and spatial variation in populations of stream salmonids (reprinted here with permission of the copyright owners and publishers).

The tables are arranged geographically--north to south, west to east. A dash in lieu of data indicates "not sampled."

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Scientific Information and Publication Branch, Canada Department of Fisheries and Oceans: Tables A-3, A-29, A-30.

Pacific Biological Station, Canada Department of Fisheries and Oceans, Nanaimo, British Columbia: Table A-4.

Research and Resource Services, Canada Department of Fisheries and Oceans, St. Johns, Newfoundland: Table A-32.

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United States Department of Commerce, National Marine Fisheries Service: Table A-2.

Institute of Animal Resource Ecology, University of British Columbia: Table A-1.

Washington State Department of Fisheries: Table A-6.

The Wildlife Society: Tables A-21, A-24.

Wisconsin Academy of Science, Arts, and Letters: Table A-25.

Wisconsin Department of Natural Resources: Tables A-26, A-27.

Dr. David Au: Tables A-9, A-11, A-13.

Dr. Richard Gard: Tables A-16, A-17, A-18.

Dr. Gordon Glova: Table A-5.

Mr. Gerald Lowry: Table A-14.

TABLE A-1. POTENTIAL EGG DEPOSITION AND FRESHWATER SURVIVAL OF PINK SALMON, SASHIN CREEK, ALASKA, 1940-1959 (FROM MERRELL 1962).

Brood Year	Potential Egg Deposition[a]	Number of Migrating Fry	Freshwater Survival (%)
1940	52,858,000	3,402,830	6.4
1941	88,678,000	1,024,364	1.2
1942	81,502,000	674,672	0.8
1943	14,980,000	227,673	1.5
1944	3,904,000	104,113	2.7
1945	5,062,000	41,900	0.8
1946	736,000	1,168	0.2
1947	1,330,000	26,454	2.0
1948	516,000	9,016	1.7
1949	4,800,000	176,025	3.7
1950	86,000	(50 killed)	0.1
1951	4,062,000	379,585	9.3
1952	run destroyed	0	-
1953	1,284,000	90,219	7.0
1954	12,000	576	4.8
1955	10,286,000	1,232,872	12.2
1956	1,018,000	5,043	0.5
1957	2,587,758	588,976	22.8
1958	174,000	10,577	6.1
1959	40,379,327	5,332,468	13.2

[a] Based on 2,000 eggs per female except when actual fecundity was calculated in 1957 (1,986 eggs) and 1959 (2,021 eggs).

TABLE A-2. WEIR COUNTS OF COHO SALMON FRY AND SMOLTS, SASHIN CREEK, ALASKA, 1956-1968 (FROM CRONE AND BOND 1976).

Year	Total Count	
	Fry	Smolts
1956	-	928
1957	373	1,961
1958	2,854	1,015
1959	218	1,587
1960	9,923	1,258
1961	2,699	2,489
1962	1,209	2,865
1963	1,236	1,599
1964	44,023	334[a]
1965[b]	12,000	-
1967[b]	10,000	1,400
1968	1,665	1,440

[a] Partial count.

[b] Weir not functional. Counts are estimates from fyke net sampling. Weir damaged in 1966 - no sampling conducted.

TABLE A-3. WEIR COUNTS OF DOWNSTREAM MIGRATING PINK AND CHUM SALMON FRY, HOOKNOSE CREEK, BRITISH COLUMBIA, 1947-1956 (FROM HUNTER 1959).

Brood Year	Pink	Chum	Total
1947	33,349	108,746	142,095
1948	64,312	77,539	141,851
1949	54,061	44,463	98,524
1950	234,396	431,399	665,795
1951	242,993	269,701	512,694
1952	1,227,025	182,200	1,409,225
1953	204,250	984,504	1,188,754
1954	907,458	353,761	1,261,219
1955	86,256	49,443	135,699
1956	454,148	69,830	523,978

TABLE A-4. BIOMASS (g/m^2 IN LATE SUMMER) OF COHO SALMON AND RAINBOW AND CUTTHROAT TROUT IN STREAMS IN THE VICINITY OF THE CARNATION CREEK WATERSHED, BRITISH COLUMBIA, 1970-1977 (FROM NARVER AND ANDERSON 1974; ANDERSON AND NARVER 1975; AND ANDERSON 1978).

	Lower Carnation Cr.		Upper Carnation Cr.	Trib "C"	Trib "1600"		Useless Cr.		Frederick Cr.		Ritherdon Cr.	S. Pachena Cr.	
Year	Coho	Rainbow	Cutthroat	Cutthroat	Coho	Cutthroat	Coho	Cutthroat	Coho	Rainbow	Cutthroat	Coho	Rainbow
1970	2.72	1.21	-	-									
1971	1.89	0.92	3.46	-	-	-	-	-	1.06	0.0	5.36	1.87	1.24
1972	1.47	0.43	2.90	4.79	4.88	1.93	0.84	1.64	1.54	0.33	4.50	1.31	1.11
1973	1.46	0.59	3.97	5.64	2.45	1.97	0.19	1.66	-	-	3.07	0.74	0.42
1974	1.59	0.49	1.94	3.45	2.84	0.95	0.28	2.39	0.44	0.04	3.31	0.59	0.18
1975	1.64	0.44	1.66	3.71	4.19	0.39	0.70	2.01	1.36	0.07	2.84	1.85	0.23
1976	1.23	0.30	1.94	2.77	2.75	0.25	0.38	0.67	0.66	0.02	1.40	0.82	0.17
1977	1.62	0.32	1.08	2.47	-	-	0.53	0.85	0.95	0.09	1.38	1.40	0.37

TABLE A-5. BIOMASS (g/m^2) OF CUTTHROAT TROUT, COHO SALMON, AND SCULPIN IN DIFFERENT HABITATS OF SIX BRITISH COLUMBIA STREAMS, 1973-1976 (FROM GLOVA 1978 AND GLOVA PERS. COMM.).

Stream	Date	Habitat[a]	Mean Area (m^2)	Mean Depth (cm)	Biomass			
					Trout	Coho	Sculpin[b]	Total
Bush Creek	Sept-Oct 1973	Pools	42	16	0.3	3.3	3.2	6.8
		Glides	21	11	1.1	2.4	2.5	6.0
		Riffles	17	7	0.5	0.4	2.0	2.9
	Sept-Oct 1974	Pools	32	22	0.5	3.6	3.1	7.2
		Glides	32	12	0.5	2.0	3.5	6.0
		Riffles	22	11	1.2	1.2	1.7	4.1
	Sept-Oct 1975	Pools	45	38	0.7	2.0	3.9	6.6
		Glides	30	12	0.5	1.9	3.3	5.7
		Riffles	33	9	0.4	0.4	1.9	2.7
Holland Creek	Sept-Oct 1973	Pools	28	21	1.0	1.9	3.9	6.8
		Glides	29	11	0.8	0.8	2.0	3.6
		Riffles	13	8	1.1	0.2	1.4	2.7
	Sept-Oct 1974	Pools	23	34	0.6	1.3	4.6	6.5
		Glides	22	27	0.8	1.8	1.7	4.3
		Riffles	18	11	0.6	0.4	1.5	2.5
	Sept-Oct 1975	Pools	31	37	0.5	1.4	5.1	7.0
		Glides	49	18	0.2	0.9	2.8	3.9
		Riffles	35	12	0.3	0.2	2.3	2.8
Ayum Creek	Oct 1975	Pools	40	41	1.2	2.1	5.7	9.0
		Glides	53	19	1.0	1.9	2.2	5.1
		Riffles	56	15	0.8	0.7	0.5	2.0
Shawnigan Creek	Oct 1975	Pools	71	31	1.3	0.0	0.1	1.4
		Glides	39	13	1.2	0.0	0.1	1.3
		Riffles	25	9	1.0	0.0	0.0	1.0
French Creek above barrier falls	Sept 1976	Pools	56	31	2.5	0.0	0.0	2.5
		Glides	54	16	1.7	0.0	0.0	1.7
		Riffles	20	11	1.2	0.0	0.0	1.2
Bings Creek above barrier falls	Oct 1976	Pools	46	36	5.4	0.0	0.0	5.4
		Glides	50	18	2.6	0.0	0.0	2.6
		Riffles	27	11	2.1	0.0	0.0	2.1

[a] Determined by water velocities - pool (<8 cm/sec), glide (8-20 cm/sec), and riffle (>20 cm/sec).

[b] Mainly _Cottus aleuticus_.

TABLE A-6. ESCAPEMENT, POTENTIAL EGG DEPOSITION, AND FRESHWATER SURVIVAL OF WILD COHO SALMON, MINTER CREEK, WASHINGTON, 1938-1953 (FROM SALO AND BAYLIFF 1958).

Brood Year	Females Released Upstream	Egg Potential	Smolt Count	Freshwater Survival (%)
1938	967	2,657,316	35,452	1.33
1940	1,393	4,577,398	32,085	0.70
1942	786	1,873,038	31,893	1.70
1943	906	2,092,860	23,177	1.11
1944	500	1,376,500	30,408	2.21
1946	500	1,097,000	41,848	3.81
1948	98	186,200	17,839	9.58
1949	114	287,964	27,781	9.65
1951	411	1,086,684	22,545	2.07
1952	753	1,929,186	31,363	1.63
1953	491	1,150,413	18,620	1.62

TABLE A-7. COUNTS OF SPAWNING COHO SALMON AND SMOLTS AT DOWNSTREAM WEIR ON GNAT CREEK, OREGON, 1954-1959 (FROM WILLIS 1962).

Brood Year	Female Spawners	Smolt Count
1955	26	2,996
1956	29	1,847
1957	67	1,013
1958	40	1,061
1959	45	3,226

TABLE A-8. ESCAPEMENT, POTENTIAL EGG DEPOSITION, AND FRESHWATER SURVIVAL OF COHO SALMON, DEER CREEK, OREGON, 1959-1971 (FROM KNIGHT 1980).

Brood Year	Female Escapement	Egg Potential[a]	Smolt Count	Freshwater Survival (%)
1959	21	43,197	1,917	4.44
1960	19	44,156	2,210	5.00
1961	28	67,620	2,775	4.10
1962	18	42,030	2,082	4.95
1963	27	62,964	2,368	3.76
1964	44	104,940	1,836	1.75
1965	24	55,176	2,245	4.07
1966	56	141,798	2,461	1.74
1967	23	52,815	2,160	4.09
1968	39	80,301	1,484	1.85
1969	8	15,484	738	4.77
1970	10	22,119	1,072	4.85
1971	36	73,134	1,923	2.63

[a] Calculated from regression equation (Koski 1966), $Y = -3{,}184 + 7.81\ X$, where X = average length in mm (from unpublished data) and Y = individual fecundity. Total fecundity equals Y times the number of female spawners.

TABLE A-9. ESTIMATED BIOMASS (g/m^2) OF JUVENILE COHO SALMON, DEER CREEK, OREGON, 1959-1968 (FROM CHAPMAN 1965 AND AU 1972). DATA ARE INTERPOLATED FOR THE BEGINNING OF EACH MONTH INDICATED, FROM POPULATION ESTIMATES MADE LESS FREQUENTLY THROUGHOUT THE YEAR.

	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
June	4.8	2.7	2.1	5.9	4.2	2.1	4.8	5.0	8.7	2.3
July	4.0	2.5	2.5	3.6	3.7	2.1	5.9	4.3	7.2	3.0
Aug	3.1	2.3	3.0	3.0	3.4	2.1	4.3	3.8	6.2	3.7
Sept	2.9	2.3	3.2	4.0	3.1	2.6	3.2	3.6	5.9	4.4
Oct	3.1	2.5	3.4	4.7	2.5	3.1	2.9	3.8	6.1	5.0
Nov	3.6	2.7	3.4	5.1	2.4	3.5	2.8	4.0	6.3	5.3
Dec	3.6	2.0	3.2	4.0	2.4	3.7	2.7	4.1	6.1	5.1
Jan	3.8	2.0	3.8	4.5	2.5	3.6	3.0	4.2	4.4	4.1
Feb	4.0	2.0	1.7	4.5	2.5	2.8	2.9	4.2	3.5	2.9
Mar	4.2	2.0	1.7	3.6	2.4	1.9	2.4	3.7	3.2	2.2
Apr	1.8	1.3	1.3	2.1	1.6	1.5	0.8	1.9	1.9	1.4
May	0.5	0.4	0.6	0.5	-	-	-	-	-	-

TABLE A-10. ESCAPEMENT, POTENTIAL EGG DEPOSITION, AND FRESHWATER SURVIVAL OF COHO SALMON, FLYNN CREEK, OREGON, 1959-1971 (FROM KNIGHT 1980).

Brood Year	Female Escapement	Egg Potential[a]	Smolt Count	Freshwater Survival (%)
1959	8	17,368	875	5.04
1960	26	66,742	776	1.16
1961	51	131,427	1,354	1.03
1962	2	4,644	565	12.17
1963	20	44,220	736	1.66
1964	10	24,020	663	2.76
1965	11	26,565	968	3.64
1966	55	138,050	616	0.45
1967	10	23,130	430	1.86
1968	19	38,931	207	0.53
1969	5	9,625	140	1.45
1970	5	13,745	330	2.40
1971	18	37,404	404	1.08

[a] Calculated from regression equation (Koski 1966), Y = -3,184 + 7.81 X, where X = average length in mm (from unpublished data) and Y = average individual fecundity. Total fecundity equals Y times the number of female spawners.

TABLE A-11. ESTIMATED BIOMASS (g/m^2) OF JUVENILE COHO SALMON, FLYNN CREEK, OREGON, 1959-1968 (FROM CHAPMAN 1965 AND AU 1972). DATA ARE INTERPOLATED FOR THE BEGINNING OF EACH MONTH INDICATED, FROM POPULATION ESTIMATES MADE LESS FREQUENTLY THROUGHOUT THE YEAR.

	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
June	4.1	2.9	2.1	8.3	1.3	2.2	4.1	4.0	6.0	1.1
July	3.3	2.8	2.0	3.0	1.7	1.7	1.7	2.8	3.9	1.3
Aug	3.0	2.7	2.1	2.3	2.0	1.5	1.4	2.6	2.9	1.8
Sept	3.1	2.6	2.3	2.6	2.2	1.7	1.6	2.9	2.1	2.3
Oct	2.9	2.5	2.5	3.4	2.4	1.8	1.7	2.8	1.8	2.5
Nov	2.9	2.5	2.5	3.8	2.2	2.0	1.7	2.6	1.7	2.3
Dec	2.4	2.0	3.5	4.5	2.0	1.9	1.7	2.4	1.7	1.8
Jan	2.2	1.9	2.1	4.1	1.8	1.9	1.7	2.5	1.8	1.1
Feb	2.2	1.7	2.0	4.1	1.6	1.7	1.6	2.5	1.7	0.9
Mar	2.6	1.8	1.8	3.8	1.4	1.7	1.1	2.1	1.6	0.8
Apr	1.5	1.7	1.6	2.6	1.1	1.3	0.4	0.9	1.4	0.5
May	0.5	1.3	0.7	1.4	-	-	-	-	-	-

TABLE A-12. ESCAPEMENT, POTENTIAL EGG DEPOSITION, AND FRESHWATER SURVIVAL OF COHO SALMON, NEEDLE BRANCH, OREGON, 1959-1971 (FROM KNIGHT 1980).

Brood Year	Female Escapement	Egg Potential[a]	Smolt Count	Freshwater Survival (%)
1959	2[b]	4,471[b]	462	10.3
1960	2	4,192	223	5.32
1961	15	33,135	470	1.42
1962	4	9,632	314	3.26
1963	15[c]	33,530[d]	160	0.477
1964	25[c]	55,884[d]	286	0.512
1965	28[c]	62,590[d]	333	0.532
1966	19	46,664	277	0.594
1967	15	40,460	421	1.04
1968	17	35,088	194	0.55
1969	1	2,666	76	2.85
1970	2	5,386	113	2.10
1971	18	35,604	369	1.04

[a] Calculated from regression equation (Koski 1966), $Y = -3{,}184 + 7.81\ X$, where X = average length in mm (from unpublished data) and Y = average individual fecundity. Total fecundity equals Y times the number of female spawners.

[b] Estimated equivalents from 1,627 planted fry.

[c] Estimated from redd surveys.

[d] Estimated from mean female length (693.9 mm) from the other years of the study.

TABLE A-13. ESTIMATED BIOMASS (g/m^2) OF JUVENILE COHO SALMON, NEEDLE BRANCH, OREGON, 1959-1968 (FROM CHAPMAN 1965 AND AU 1972). DATA ARE INTERPOLATED FOR THE BEGINNING OF EACH MONTH INDICATED, FROM POPULATION ESTIMATES MADE LESS FREQUENTLY THROUGHOUT THE YEAR.

	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
June	2.3	1.4	2.1	7.2	3.5	4.0	5.0	7.6	6.9	3.1
July	1.6	1.7	1.9	3.9	3.0	2.4	3.9	4.0	9.0	3.4
Aug	1.8	2.0	1.8	3.2	2.9	1.5	3.5	3.1	7.8	3.8
Sept	1.9	2.0	1.8	2.8	2.7	1.3	3.4	3.7	6.5	4.2
Oct	2.2	2.2	1.7	2.8	2.8	1.2	3.3	4.3	6.2	4.6
Nov	2.4	2.4	1.7	2.9	2.7	1.0	2.9	4.1	3.2	4.4
Dec	2.0	2.2	1.8	2.8	2.6	0.7	2.2	4.4	3.1	3.7
Jan	1.9	2.2	1.8	3.3	2.3	0.8	1.9	4.0	3.2	2.4
Feb	1.9	2.4	1.7	3.1	2.3	0.9	1.3	3.1	3.9	1.7
Mar	2.4	1.5	1.4	3.1	1.5	1.0	0.8	1.5	2.6	0.4
Apr	2.4	1.1	1.8	2.1	1.0	0.8	0.4	0.4	0.2	0.1
May	0.9	0.3	0.7	0.9	-	-	-	-	-	-

TABLE A-14. BIOMASS (g/m^2 IN SEPTEMBER) OF CUTTHROAT TROUT, ALSEA WATERSHED STUDY, 1962-1973 (FROM LOWRY 1964 AND UNPUBLISHED DATA)

Year	Deer Cr.	Flynn Cr.	Needle Br.
1962	5.07	5.82	3.89
1963	2.93	3.54	3.41
1964	1.90	4.04	3.16
1965	2.93	2.72	2.97
1966	2.05	2.73	1.09
1967	3.29	4.26	0.68
1968	2.15	2.71	1.65
1969	2.80	3.70	1.46
1970	3.83	4.01	1.14
1971	4.20	4.27	1.32
1972	4.03	4.13	1.39
1973	-	3.79	1.53

TABLE A-15. BIOMASS (g/m^2) OF SALMONID SPECIES IN THREE NORTHERN CALIFORNIA STREAMS, 1967-1969 (FROM BURNS 1971).

	No. Fork, Casper Cr.		S. Fork Yager Cr.	Godwood Cr.	
	Coho	Steelhead	Steelhead	Coho	Trout[a]
June 1967	0.18	1.09	-	-	-
July 1967	-	-	-	1.09	0.57
Aug 1967	-	-	3.22	-	-
Oct 1967	0.15	1.46	-	-	-
June 1968	0.13	1.16	-	-	-
July 1968	-	-	-	0.76	0.49
Aug 1968	-	-	4.21	-	-
Oct 1968	0.19	1.44	-	-	-
June 1969	0.61	0.98	-	-	-
July 1969	-	-	-	0.34	0.51
Aug 1969	-	-	2.94	-	-
Oct 1969	0.81	1.13	-	-	-

[a] Steelhead and cutthroat.

TABLE A-16. BIOMASS OF BROOK TROUT (g/m^2 IN MID-AUGUST) IN 10 SECTIONS OF SAGEHEN CREEK, CALIFORNIA, 1952-1961 (FROM R. GARD PERS. COMM.). SECTION I IS UPSTREAM.

	I	II	III	IV	V	VI	VII	VIII	IX	X
1952	5.15	13.90	3.75	1.48	0.39	0.80	2.01	1.06	0.24	0.01
1953	4.71	14.24	4.74	1.38	0.50	3.25	1.46	0.67	0.07	0
1954	4.85	10.12	2.17	1.28	0	1.29	1.01	1.60	0	0
1955	4.48	6.87	2.45	0.41	0.01	0.74	0.06	1.31	0	0
1956	2.47	6.65	1.80	0.96	0.18	0.55	0.41	0.13	0.01	0
1957	4.56	3.67	1.88	1.49	0.25	0.80	0.18	0.19	0	0
1958	2.24	2.91	1.23	0.25	0.53	1.14	0.96	1.84	0	0
1959	-	7.40	2.31	0.85	0.35	1.78	0.24	0.19	0.01	0
1960	4.63	2.32	1.95	0.19	0.54	1.64	0.86	0.75	0	0
1961	3.36	2.50	0.86	1.12	0.55	2.85	1.56	0.40	0	0

TABLE A-17. BIOMASS OF BROWN TROUT (g/m^2 IN MID-AUGUST) IN 10 SECTIONS OF SAGEHEN CREEK, CALIFORNIA, 1952-1961 (FROM R. GARD PERS. COMM.). SECTION I IS UPSTREAM.

	I	II	III	IV	V	VI	VII	VIII	IX	X
1952	0	0	0	0	0	0	0.63	8.56	1.99	0.40
1953	0	0	0	0	0	0.08	6.34	1.18	1.18	0.78
1954	0	0	0	0	0	0	1.69	1.47	2.03	0.67
1955	0	0	0	0	0	0.01	3.96	1.66	4.18	0.45
1956	0	0	0	0	0	0	1.48	1.06	2.54	0.11
1957	0	0	0	0	0	0.44	0.91	0	2.95	0.01
1958	0	0	0.54	0	0	0.08	0	0.13	4.11	0.16
1959	-	0	0	0	0	0.02	1.30	1.97	2.82	0
1960	0	0	0	0	0.06	0	1.30	0.37	2.93	0
1961	0	0	0	0	0	0.02	1.51	0.16	1.74	0.01

TABLE A-18. BIOMASS OF RAINBOW TROUT (g/m^2 IN MID-AUGUST) IN 10 SECTIONS OF SAGEHEN CREEK, CALIFORNIA, 1952-1961 (FROM R. GARD PERS. COMM.). SECTION I IS UPSTREAM.

	I	II	III	IV	V	VI	VII	VIII	IX	X
1952	0	1.12	1.45	4.69	0.75	1.01	0.99	0.54	0.21	0.07
1953	0	1.27	4.30	4.78	0.77	1.20	1.46	0.99	0.28	0.03
1954	0	1.42	2.31	3.89	0.37	1.73	2.42	0.45	0.01	0
1955	0	1.04	2.82	4.07	0.31	2.26	1.43	0.77	0	0.12
1956	0	0.41	1.30	2.21	0.45	1.75	0.41	0.06	0	0
1957	0	1.09	1.23	3.45	0.44	2.93	1.82	0.64	0.15	0
1958	0	1.12	0.91	2.35	1.43	3.55	1.79	0.75	0.59	0.07
1959	-	1.04	0.54	4.02	0.37	5.30	2.50	0.91	0	0
1960	0	0.37	0.83	4.60	0.83	4.29	1.54	0.11	0.49	0
1961	0	0.41	0.36	5.91	0.89	6.67	1.64	0.96	0	0

TABLE A-19. ESCAPEMENT, POTENTIAL EGG DEPOSITION, AND FRESHWATER SURVIVAL OF COHO SALMON, WADDELL CREEK, CALIFORNIA, 1933-1940 (FROM SHAPOVALOV AND TAFT 1954).

Brood Year	Female Escapement	Egg Potential	Smolt Count	Freshwater Survival (%)
1933	222	560,690	3,573	0.64
1934	309	725,014	4,911	0.68
1935	59	141,233	1,067	0.76
1936	157	377,352	1,926	0.51
1937	37	91,728	852	0.93
1938	56	130,074	1,740	1.34
1939	150	396,321	152	0.038
1940	115	257,886	711	0.28

TABLE A-20. DOWNSTREAM TRAP COUNTS OF STEELHEAD TROUT BY AGE GROUP, WADDELL CREEK, CALIFORNIA, 1933-1942 (FROM SHAPOVALOV AND TAFT 1954).

	0		I		II		III	
Year	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1933-34	604	19	741	24	1,657	53	112	4
1934-35	699	39	578	32	484	27	28	2
1935-36	1,365	35	1,655	42	830	21	90	2
1936-37	1,875	53	1,191	34	451	13	11	a
1937-38	1,946	57	1,015	30	410	12	19	1
1938-39	691	11	3,699	60	1,720	28	77	1
1939-40	2,239	64	945	27	292	8	7	a
1940-41	3,306	59	2,049	36	251	4	9	a
1941-42	2,009	35	2,834	50	843	15	33	1

a < 1 percent.

TABLE A-21. BIOMASS (g/m^2) OF BROOK, RAINBOW, AND BROWN TROUT, TROUT CREEK, MONTANA, 1950-1951 (FROM HOLTON 1953). SECTION 1 IS UPSTREAM.

Section	1				2					3					4			
Date	Aug. 24 1950	Nov. 18 1950	May 20 1951	Aug. 12 1951	July 25 1950	Sept. 14 1950	Nov. 19 1950	May 30 1951	Aug. 4 1951	Aug. 9 1950	Sept. 14 1950	Nov. 4 1950	June 3 1951	Aug. 11 1951	Aug. 1 1950	Oct. 28 1950	May 17 1951	Aug. 5 1951
Brook	13.0	34.9	12.4	10.8	3.8	8.0	3.7	2.1	5.3	2.2	2.1	3.4	1.3	2.1	2.1	1.4	1.1	0.2
Rainbow	2.0	3.0	0.9	0.9	3.6	6.5	5.0	6.6	8.1	4.9	5.0	5.8	6.9	5.7	3.9	6.4	3.0	6.2
Brown	0	0	0	0	0.4	0.8	4.6	6.7	8.4	0.5	0.5	10.6	0.1	0.3	0.6	9.7	4.1	0.7

TABLE A-22. BIOMASS (g/m^2) OF BROWN, RAINBOW, AND BROOK TROUT IN 11 SECTIONS OF LITTLE PRICKLY PEAR CREEK, MONTANA, SUMMER 1966 (FROM ELSER 1968). SECTION 1 IS UPSTREAM

Section	1A	1	2	3	4[a]	5	6[a]	7	8[a]	9	10[a]
Area (m^2)	2388	1093	1862	2266	2995	2630	3157	2145	1740	1255	3238
Mean width (m)	5.5	2.7	5.5	7.3	7.6	8.2	8.8	7.3	6.4	7.6	13.4
Brown	1.57	3.14	12.9	16.7	3.36	17.6	4.37	17.1	10.4	11.1	1.57
Rainbow	4.70	5.04	5.60	5.72	0.90	6.39	2.02	7.85	1.91	5.94	4.04
Brook	1.01	10.8	3.81	2.02	0.22	0.45	0.11	0.34	0.67	0.22	0.11
Total trout	7.28	19.0	22.3	24.4	4.48	24.4	6.50	25.3	13.0	17.3	5.72

[a] Altered sections.

TABLE A-23. NUMBER OF CUTTHROAT TROUT TRAPPED, AND NUMBER REMAINING IN STREAM AFTER TRAP WAS REMOVED,[a] ARNICA CREEK, YELLOWSTONE PARK, WYOMING, 1950-1958 (FROM BENSON 1960).

Year	Date trap removed	Age-group 0		Age-group I		Age-group II		Total		Grand Total
		Trapped	In Stream	Trapped	In Stream	Trapped	In Stream	Trapped	In Stream	
1950	Sept. 28	9,556	-	300	-	95	-	9,951	-	9,951
1951	Oct. 6	5,240	-	365	-	39	-	5,644	-	5,644
1952	Sept. 21	502	-	792	-	242	-	1,536	-	1,536
1953	Sept. 28	1,332	708	763	407	82	67	2,177	1,182	3,359
1954	Sept. 14	4,151	-	943	-	47	-	5,141	-	5,141
1955	Sept. 24	4,182	244	340	15	7	0	4,529	259	4,788
1956	Sept. 13	4,268	612	386	56	132	5	4,786	673	5,459
1957	Sept. 25	2,850	405	121	270	5	3	2,976	678	3,654
1958	Aug. 31	36	1,950	9	30	1	15	46	1,995	2,041

[a] Data not available on number of fish in stream after dismantling of trap for 1950, 1951, 1952, and 1954.

TABLE A-24. BIOMASS (g/m^2) OF BROOK TROUT, LAWRENCE CREEK, WISCONSIN, 1953-1957 (FROM McFADDEN 1961b). SECTION A IS UPSTREAM.

	Section A	Section B	Section C	Section D	Total	Mean
Sept. 1953	10.30	9.81	8.40	5.52	34.03	8.51
Sept. 1954	14.53	12.36	8.81	6.31	42.01	10.50
April 1955	11.18	9.64	6.82	6.60	34.24	8.56
Sept. 1955	7.11	8.25	6.10	3.02	24.48	6.12
April 1956	4.41	4.27	3.89	2.45	15.02	3.75
Sept. 1956	10.76	6.01	5.50	1.30	23.57	5.89
April 1957	14.48	6.93	5.35	3.37	30.13	7.53
Sept. 1957	26.18	10.74	6.37	4.20	47.49	11.87

TABLE A-25. SEPTEMBER POPULATION ESTIMATES OF AGES 0 AND I BROOK TROUT IN LAWRENCE CREEK AND BIG ROCHE-A-CRI CREEK, WISCONSIN, 1953-1964 (FROM WHITE AND HUNT 1969).

	Lawrence Creek		Big Roche-a-Cri Creek	
Year	0	I	0	I
1953	10,113	2,040	-	-
1954	13,523	2,749	-	-
1955	5,720	2,754	-	-
1956	10,853	816	-	-
1957	13,258	3,370	2,012	1,135
1958	4,166	4,393	6,229	474
1959	22,646	1,044	2,637	1,817
1960	8,507	3,324	9,915	1,257
1961	14,313	2,360	4,361	2,630
1962	7,611	4,523	5,632	1,609
1963	10,367	2,388	4,964	1,623
1964	9,680	4,382	7,420	1,072

TABLE A-26. BIOMASS $(g/m^2)^a$ OF BROOK TROUT BY AGE GROUP IN APRIL AND SEPTEMBER, LAWRENCE CREEK, WISCONSIN, 1960-1970 (FROM HUNT 1974).

Year	April					September					
	I	II	III	IV+	Total	0	I	II	III	IV+	Total
1960	4.00	0.375	0.542	0.0245	4.94	2.01	4.75	0.105	0.0417	0	6.91
1961	1.97	1.48	0.0245	0.0294	3.50	3.83	4.39	0.922	0.0172	0	9.16
1962	5.48	2.30	0.412	0.0049	8.20	1.70	6.08	0.507	0.0980	0	8.38
1963	2.71	4.62	0.333	0.0858	7.75	2.80	3.39	1.78	0.137	0.0392	8.15
1964	5.20	2.72	1.20	0.108	9.23	2.51	5.56	0.995	0.387	0.0319	9.48
1965	2.48	3.30	0.517	0.174	6.47	2.18	4.30	1.13	0.167	0.0294	7.81
1966	3.96	3.38	0.934	0.130	8.40	2.54	6.19	1.64	0.299	0.0392	10.7
1967	3.15	5.65	1.04	0.427	10.3	2.14	4.03	2.02	0.382	0.0613	8.63
1968	3.35	4.43	1.62	0.287	9.69	2.85	3.40	0.863	0.280	0.0686	7.46
1969	5.25	3.75	0.699	0.194	9.89	3.10	4.51	1.02	0.177	0.0809	8.89
1970	3.88	5.17	0.701	0.142	9.89	3.32	3.78	0.980	0.145	0.0466	8.27
Mean	3.77	3.38	0.729	0.146	8.02	2.63	4.58	1.09	0.194	0.0361	8.53

[a] Biomass from Appendix Table 1 has been divided by stream area of 4.08 ha.

TABLE A-27. ANNUAL PRODUCTION ($g/m^2/yr$) OF BROOK TROUT BY SECTION AND AGE GROUP, LAWRENCE CREEK, WISCONSIN, 1960-1970 (FROM HUNT 1974). SECTION A IS UPSTREAM.

Year	Section				Age Group					Stream
	A	B	C	D	0	I	II	III	IV+	Total
1960	13.0	10.1	13.4	14.0	4.1	7.7	0.3	0.4	<0.1	12.5
1961	17.2	13.5	10.2	8.0	6.8	3.9	1.1	<0.1	0.1	11.9
1962	14.0	10.0	11.1	10.8	3.8	6.2	0.9	0.2	<0.1	11.2
1963	16.5	12.0	12.9	11.5	6.4	4.0	2.2	0.2	<0.1	12.9
1964	19.8	12.8	9.8	8.6	5.2	5.2	1.2	0.5	<0.1	12.2
1965	19.5	9.8	11.0	5.4	4.3	4.2	1.9	0.2	<0.1	10.6
1966	15.2	12.6	9.8	6.3	3.1	5.7	1.4	0.4	<0.1	10.6
1967	21.7	9.4	10.9	6.7	3.8	4.5	2.4	0.5	<0.1	11.2
1968	21.3	12.0	8.9	5.1	4.5	4.0	1.9	0.6	0.1	11.1
1969	25.8	12.0	7.9	6.6	4.7	5.3	1.6	0.3	0.1	12.0
1970	20.5	13.2	10.1	7.8	5.3	4.6	2.2	0.2	<0.1	12.3
Mean	18.8	11.6	10.6	8.2	4.8	5.0	1.6	0.3	<0.1	11.7

TABLE A-28. PHYSICAL CHARACTERISTICS AND BIOMASS (g/m^2) OF BROOK, BROWN, AND RAINBOW TROUT IN SECTIONS OF THREE MICHIGAN STREAMS, 1937 (FROM SHETTER AND HAZZARD 1938).

Stream	Section	Length (m)	Mean Width (m)	Mean Depth (cm)	Velocity (cm/sec)	Relative Shade	Biomass			
							Brook	Brown	Rainbow	Total
South Branch, Pine River	Upper	29.5	7.6	24.9	22.9	Partly	0.95	0	0.35	1.30
	Middle	29.0	5.4	27.7	26.2	Densely	0.87	0	0.53	1.40
	Lower	31.5	6.7	34.8	20.7	Partly	2.40	0.27	1.82	4.49
Little Manistee River	Upper	32.5	8.5	43.7	41.8	Partly	0.21	1.92	1.75	3.88
	Middle	46.9	11.2	44.2	-	Exposed	0.12	0.73	2.54	3.39
North Branch, Boardman River	Upper	42.6	7.5	25.7	94.5	Partly	0.028	0.84	0	0.87
	Middle	29.0	8.5	29.0	46.3	Exposed	0.041	0.13	0	0.17
	Lower	37.0	9.1	23.1	51.5	Partly	0.048	0.10	0	0.15

TABLE A-29. NUMBER OF BROOK TROUT PRESENT IN SEPTEMBER IN HUNT CREEK, MICHIGAN BY AGE-GROUP (FROM MCFADDEN ET AL. 1967).

Year	0	I	II	III	IV	Total
1949	4,471	2,036	287	14	0	6,808
1950	3,941	2,013	304	13	0	6,271
1951	4,287	1,851	265	16	1	6,820
1952	5,033	1,763	261	16	0	7,073
1953	5,387	1,637	175	13	0	7,212
1954	6,325	2,035	234	13	0	8,607
1955	4,235	2,325	383	24	0	6,947
1956	4,949	1,612	392	51	1	7,005
1957	6,703	1,796	309	33	1	8,842
1958	5,097	2,653	355	26	2	8,133
1959	4,038	2,395	685	68	0	7,186
1960	5,057	2,217	473	47	1	7,795
1961	2,809	2,017	409	23	0	5,258
1962	5,052	1,589	448	52	2	7,143

TABLE A-30. MEAN ANNUAL BIOMASS (g/m^2) OF BROOK TROUT IN STREAMS IN MATAMEK WATERSHED, QUEBEC, 1971-1973 (FROM O'CONNOR AND POWER 1976).

Stream	Section Length (m)	Average Width (m)	Year	Biomass 0+	1+	2+	3+	4+	5+	6+	Total
Kaikhosru	355	6.1	1971	0.35	1.93	0.33	0.54	0.85	0.17	0	4.17
			1972	0.35	2.23	0.66	0.44	0.22	0.06	0	3.96
Gallienne	330	6.6	1971	-	2.40	2.12	0.57	0.14	0.10	0	5.33
			1972	-	2.83	1.74	0.49	0.08	0.14	0	5.28
Tchinicaman	620	15.1	1971	0.08	0.51	0.26	0.25	0.05	0.01	0.06	1.21
			1972	0.08	0.42	0.48	0.32	0.07	0.01	0.03	1.42
Sherry	215	4.2	1971	0.28	1.25	0.87	1.13	0.25	0	0	3.78
			1972	0.28	0.79	0.51	0.30	0.15	0	0	2.03
			1973	0.28	0.57	0.28	0.16	0.17	0	0	1.47

TABLE A-31. NUMBERS OF BROOK TROUT IN A 411-m SECTION OF HAYES BROOK, PRINCE EDWARD ISLAND, 1947-1960 (FROM SAUNDERS AND SMITH 1962).

Year	Age 0	Age I+	Total
1947	588	351	939
1948	729	342	1,071
1949	539	279	818
1950	321	223	544
1951	166	418	584
1952	611	372	983
1953	308	362	670
1954	468	294	762
1955	758	383	1,141
1956	580	467	1,047
1957	350	363	713
1958	481	314	795
1959	371	352	723
1960[a]	526	611	1,137

[a] After habitat development.

TABLE A-32. COUNTS OF ATLANTIC SALMON SMOLTS AND SEAWARD MIGRATING BROOK TROUT, LITTLE CODROY RIVER, NEWFOUNDLAND, 1954-1963 (FROM MURRAY 1968).

Year	Salmon	Trout
1954	12,210	-
1955	11,248	-
1956	14,772	706
1957	8,900	1,067
1958	9,341	889
1959	12,099	1,074
1960	7,829	457
1961	8,058	312
1962	8,193	698
1963	7,326	485

TABLE A-33. BIOMASS (g/m^2) OF BROWN TROUT IN TRIBUTARIES AND THE MAIN STEM OF THE UPPER RIVER TEES SYSTEM, ENGLAND, 1967-1970 (FROM CRISP ET AL. 1974).

	Maize Beck	River Tees below Cauldron Snout	River Tees above the Weel	Weelhead Sike	Dubby Sike	Mattergill Sike	Lodgegill Sike
Section Length (m)	70.9	30.5	23.4	97.5	40.8	47.2	45.7
Mean Width (m)	9.94	6.91	11.20	1.16	1.54	3.26	3.05
Section Area (m^2)	705	211	262	113	63	154	139
August 1967	3.68	3.65	-	3.21	-	5.14	-
October 1967	1.43	2.16	0.08	16.63	6.85	5.84	3.34
May 1968	0.81	1.28	-	2.81	2.55	1.03	0.32
July 1968	0.30	1.28	0.37	3.43	4.69	1.72	0.60
October 1968	0.92	2.24	0.01	4.73	3.20	11.76	5.25
May 1969	0.48	1.11	-	1.96	2.45	1.18	1.87
August 1969	0.42	1.21	-	4.44	4.09	2.68	1.21
October 1969	1.18	0.96	-	5.45	3.14	4.87	1.26
May 1970	1.05	2.05	-	1.56	1.66	1.63	0.57

TABLE A-34. MEAN (1968-1972) BIOMASS (g/m^2) OF BROWN TROUT IN FIVE TRIBUTARIES OF THE RIVER TEES SYSTEM, ENGLAND, IN MAY, AUGUST, AND OCTOBER (FROM CRISP ET AL. 1975).

		Moss Burn	Nether Hearth Sike	Trout Beck	Great Dodgen Pot Sike 'A'	Great Dodgen Pot Sike 'B'
Mean Width (m)[a]		1.9	4.1	5.6	0.9	1.6
Surface Area (m^2)[a]		254	209	205	84	115
	Minimum	0.8	0.7	1.0	3.0	1.1
May	Mean	1.19	1.14	1.45	4.55	1.85
	Maximum	1.6	1.5	1.8	6.8	2.7
	Minimum	1.4	1.8	2.4	3.5	1.6
August	Mean	2.00	2.62	3.97	5.54	3.77
	Maximum	2.9	3.8	6.2	10.1	7.1
	Minimum	1.0	1.2	1.0	5.3	2.9
October	Mean	1.87	2.02	1.47	5.41	3.88
	Maximum	2.2	2.8	1.9	8.1	5.1

[a] Based on measurements made in May 1968.

TABLE A-35. PRODUCTION (g/m^2) OF ATLANTIC SALMON AND BROWN TROUT IN THREE SECTIONS OF SHELLIGAN BURN, SCOTLAND, 1966-1968 (FROM EGGLISHAW 1970).

	Year Class						Annual	Section	Mean	Section
	1963	1964	1965	1966	1967	1968	Totals	Length (m)	Width (m)	Area (m^2)
Section 1-Upstream								30.8	4.10	126.0
1966 Salmon	0.23	1.57	1.25	4.47	-	-	7.52			
Trout	0.65	1.47	3.42	4.10	-	-	9.64			
1967 Salmon	0	0.11	0.63	2.22	7.88	-	10.84			
Trout	0	0.52	0.77	5.05	5.82	-	12.16			
1968 Salmon	0	0	0.16	0.64	2.53	8.54	11.87			
Trout	0	0	0	0.94	3.10	2.67	6.71			
Section 2								27.9	3.07	86.0
1966 Salmon	0	1.12	1.07	3.52	-	-	5.71			
Trout	0.51	2.49	4.69	2.80	-	-	10.62[a]			
1967 Salmon	0	0.03	0.18	1.92	6.59	-	87.2			
Trout	0	0	2.07	5.95	3.98	-	12.00			
1968 Salmon	0	0	0	0.43	2.51	7.28	10.22			
Trout	0	0	0	1.91	4.40	2.39	8.70			
Section 3-Downstream								27.5	3.43	94.0
1966 Salmon	0	0.51	1.03	4.69	-	-	6.23			
Trout	0.41	1.96	4.44	3.95	-	-	10.76			
1967 Salmon	0	0.30	0.52	2.87	8.59	-	12.28			
Trout	0	0.46	2.02	5.68	4.54	-	12.70			
1968 Salmon	0	0	0	0.72	2.56	7.89	11.17			
Trout	0	0	0	1.45	3.92	2.44	7.81			

[a] Includes 0.13 g/m^2 production of the 1962 year class.

TABLE A-36. BIOMASS (g/m^2) OF ATLANTIC SALMON AND BROWN TROUT AT THE END OF THE GROWING SEASON, SHELLIGAN BURN, SCOTLAND, 1966-1975 (FROM EGGLISHAW AND SHACKLEY 1977). TOTAL BIOMASS INCLUDES ± STANDARD ERROR.

Year	Salmon				Trout				Total Biomass
	0+	1+	2+	All	0+	1+	2+	All	
1966	3.5	1.0	1.5	6.0±1.9	2.5	4.0	3.2	9.8±1.1	15.8±0.9
1967	2.7	1.7	0.2	4.6±1.2	3.6	6.1	1.8	11.4±1.5	16.1±2.6
1968	2.5	1.7	0.7	4.9±0.9	1.9	3.2	0.9	6.0±1.1	10.9±2.1
1969	4.4	2.2	0.7	7.3±1.9	5.0	3.8	2.9	11.6±2.1	18.9±2.8
1970	1.9	2.5	0.3	4.7±2.3	1.9	6.0	2.1	10.1±2.5	14.8±3.9
1971	4.7	2.4	0.5	7.6±1.9	3.8	4.9	1.4	10.1±2.9	17.7±4.2
1972	2.6	4.6	0.3	7.5±2.8	3.2	6.9	0.8	10.9±3.0	18.4±4.2
1973	3.7	3.8	0.2	7.6±1.4	4.0	5.4	1.2	10.7±2.5	18.3±3.2
1974	3.2	3.4	0.0	6.6±1.2	2.5	4.5	0.4	7.4±2.2	14.0±3.2
1975	6.1	2.9	0.2	9.2±2.6	1.9	4.3	0.8	7.1±2.1	16.3±4.0
Mean	3.5	2.6	0.5	6.6±1.5	3.0	4.9	1.6	9.5±2.0	16.1±2.4

TABLE A-37. BIOMASS (g/m^2) OF BROWN TROUT IN SIX SECTIONS OF HOROKIWI STREAM, NEW ZEALAND, 1940-1941 (FROM ALLEN 1951). SECTION I IS DOWNSTREAM.

Zone Length (m)	I 3,167	IIM 2,035	IIR 1,918	III 2,719	IV 1,602	V 527	Total
July 1940	24.1	31.5	11.7	24.9	41.0	18.8	25.6
Oct. 1940	28.0	36.1	11.7	25.7	46.4	24.7	28.6
Jan. 1941	34.1	32.7	11.0	16.4	29.8	21.9	26.5
May 1941	22.8	42.8	14.9	21.3	26.0	24.4	25.8
Oct. 1941	1.8	13.7	2.5	2.7	18.7	18.5	6.5

33, 37, 49.

Ca 1982
Author Unknown

Competition and Resource Partitioning Among Stream Salmonids

Cases of interacting stream salmonids that have been investigated fall into two categories: species that evolved together and those that did not. For species that evolved together there appears to have been strong selection for mechanisms to partition resources, especially space, that is habitat or microhabitat, and the times at which different life history stages use these habitats. Space and time are two of the three major classes of resources for which animals are thought to compete (Schoener 1974). Food, the third resource class, is difficult for fish to partition in freshwater ecosystems (Finger 1982) because most fish are opportunistic and forage on food sizes that may span several orders of magnitude (Werner 1977), and because the array of sizes of fish in a population feeds on a wide range of prey that vary greatly with time.

reverse order of sentences?

All of the studies we found of interactions between species of stream salmonids that evolved together involved juvenile fish, at least one of which was an anadromous species that used streams for spawning and rearing of juveniles only. Mechanisms whereby coevolved stream salmonids minimize competition usually involve differences in life history characteristics, such as the timing of spawning and emergence, the size of fry at emergence, and the length of fry residence in nursery streams.

Good examples of juvenile salmonids that partition stream resources are available from the Pacific Coast of North America where many species of Salmo, Salvelinus, and Oncorhynchus evolved and now occur in sympatry. For instance, fall-spawning coho salmon coexist with spring-spawning steelhead and cutthroat trout (Salmo clarki) in coastal streams of

* fall spawning Dolly Varden

British Columbia. Coho fry emerge from gravel redds in March, about the time steelhead and cutthroat are spawning, which gives the coho up to a 15-20-mm size advantage over trout fry during the first summer of life. All three species prefer microhabitat in pools, but most steelhead and cutthroat fry occupy positions in riffles during summer, apparently being forced from pool positions by the salmon (Hartman 1965, Glova and Mason 1977). Thus, segregation of coho salmon and either steelhead or cutthroat trout occur both in time and space. The salmon and either trout spawn during different seasons and the fry emerge several months apart so that coho are significantly larger. As a result, the species pairs also use different microhabitats because coho salmon are larger and dominate the pools during summer, even though all species apparently prefer pool microhabitat.

Both steelhead and cutthroat trout are spring spawners and similar in ecology, but appear to segregate by spawning in different macrohabitat. Steelhead typically use medium size rivers for spawning and rearing of juveniles, whereas coastal cutthroat spawn in the small tributaries (Hartman and Gill 1968, Nicholas 1978). As a result, the two species are reproductively isolated and the juveniles coexist over a relatively narrow range of stream sizes.

Fall-spawning coho and ~~C~~chinook salmon are also re~~s~~ported to spawn in different but overlapping macrohabitats in an Oregon river (Stein et al. 1972). Chinook primarily used larger river habitat for spawning and smolted after about three months of stream residence, whereas coho spawned mainly in smaller tributaries and remained in the stream for at least one year, both similar to life histories in Great Lakes tributaries. Distribution of coho and chinook fry overlapped during spring, and coho were dominant over chinook of equal size in laboratory experiments. However, during summer when the main river temperature exceeded 20 C, coho were found only in cooler tributaries while chinook also used the main river due to their tolerance of higher water temperatures.

Conversely, Lister and Geno~~y~~e (1970) found that chinook salmon spawned earlier, emerged earlier, and were larger at emergence and through the first summer of life than coho salmon (~~70~~ 69 vs. 42 mm in mid-June) in a British Columbia stream. As a result, chinook fry moved into faster and deeper water earlier than coho, a ~~movement~~ pattern common among juvenile salmonids and suspected to be a result of the greater food supply and cover afforded by the faster and deeper water (Chapman and Bjornn 1969, Everest and Chapman 1972). Therefore, in this case chinook and coho were largely segregated along gradients of depth and velocity until chinook ~~coho~~ smolted in June.

Thus, coho and chinook salmon, which both spawn during fall, appear to minimize competition by several mechanisms. These include use of different macrohabitat for spawning and rearing, or slightly different times of spawning and emergence, and different sizes at emergence which result in use of different microhabitat by fry. Moreover, chinook leave these nursery streams after about three months and eliminate further competition with coho fry.

Chinook salmon and steelhead trout that use tributaries of the Columbia River in the interior of the Pacific Northwest for spawning occupy similar habitat as fry, but they spawn at different seasons and steelhead remain in streams for three years before smolting whereas chinook smolt after one year. In Idaho tributaries of the Columbia River, Everest and Chapman (1972) found that these differences in spawning season resulted in differences in size of 30 mm or more among cohorts of both species that served to minimize their interaction for microhabitat, because each cohort moved into progressively faster and deeper water as they grew. Although lengths of age-1 chinook and steelhead began to converge after about 12 months of stream residence, chinook smolted after about 14-15 months, thus eliminating the potential for interaction.

The length of stream residence of juvenile salmonids appears to be a mechanism to minimize competition among other anadromous salmonids as well. Pink and chum (O. keta) salmon leave nursery streams soon after emergence, and sockeye fry move downstream to use lakes for juvenile growth, so all three effectively eliminate competition with other stream-dwelling juvenile salmonids.

In rivers along the Atlantic coasts of North America and Europe, brook trout or brown trout coexist with Atlantic salmon. All three species are fall spawners and there are both resident and anadromous forms of brook or brown trout. All species use freshwater streams as nursery habitat for a minimum of several years, and are expected to prefer similar resources because of similar spawning and emergence of fry.

Randall (1982) reports that brook trout are 2-4 mm smaller at emergence than Atlantic salmon in New Brunswick streams, but the trout emerge two to three weeks earlier than the salmon and maintain a 10-15 mm size advantage through the first summer due to early growth. Brook trout are found mainly in the pools during summer, and Atlantic salmon in riffles (Gibson 1966). Atlantic salmon are more aggressive than brook trout, but do not displace trout of larger size (Gibson 1973 in Randall 1982). Thus, despite reports that brook trout use riffles as well as pools when salmon are not present (Gibson 1978), we suspect that both species prefer pools (see below for Atlantic salmon, this study for brook trout) and that the brook trout, being larger, are dominant and prevent Atlantic salmon from using the pools.

In England and Scandinavia, a similar situation occurs between juvenile brown trout and Atlantic salmon, and brown trout are known to be the dominant competitor (Kalleberg 1958, Lindroth 1955). Egglishaw and Shackley (1977) report that brown trout and Atlantic salmon are difficult to distinguish at emergence, but found that the trout emerged about 2-3 weeks earlier than salmon. As a result, trout were 10-15 mm longer than salmon through the first summer of life (Egglishaw and Shackley 1973) and would be expected to be successful competitors due to size alone. Both species prefer pools, but Atlantic salmon shift to use riffle microhabitat when brown trout are present (Kennedy and Strange 1980) and are thought to be better adapted to use areas of higher velocity because their larger pectoral fins allow them to maintain positions in swift currents (Jones 1975) as described in the Results section of our paper.

Thus, ~~with respect to coevolved stream salmonids,~~ a number of ~~potential~~ mechanisms potentially ~~combine to~~ minimize competition among juveniles of coevolved salmonids ~~stages~~ in streams: 1) use of different ~~macrohabitat for~~ spawning or ~~and~~ nursery habitat ~~rearing~~ by two species, which may be selected for when the species spawn simultaneously ~~during the same season~~; 2) different spawning seasons and, subsequently, different times of fry emergence from gravel; 3) different sizes of fry at emergence, ~~which is~~ usually related to egg size; 4) use of different microhabitat by fry, which usually results from one species being larger and more dominant as juveniles, and excluding the other species from preferred ~~micro~~habitat, which is usually ~~in~~ pools; and 5) different periods of fry residence in streams, which minimizes the time during which species interact, or eliminates contact entirely if one species smolts or migrates soon after emergence. Therefore, although the controversy about the importance of competition in the coevolution of species and in shaping the structure of communities continues (Connell 1980, Schoener 1982), stream salmonids appear to have evolved ways to minimize competition for space during the same times. Some of the mechanisms are genetically fixed, such as spawning and emergence times and lengths of stream residence for juveniles, while others are plastic, such as shifts in microhabitat use when competitors are present. However, when the latter shifts occur, the subordinate species are still able to profitably use resources available in the less preferred microhabitat. For instance, Hartman (1965) reports that when juvenile coho salmon are present and dominate the preferred pool microhabitat, steelhead fry defend positions in riffles and are able to garner enough food to grow in these areas.

In contrast to indigenous salmonid communities where competition for resources appears to be minimized, situations where non-native salmonids are introduced often result either in failure of the introduction or displacement of the native salmonid by the introduced species. Investigations of interaction among stream salmonids that did not evolve together are relatively rare. However, the cases studied so far indicate that the similarity in life history attributes are also important, in shaping interaction during the first year of life.

Griffith (1972) measured microhabitat use by native cutthroat and brook trout in small Idaho streams where brook trout were introduced in the 1940's, and behavior of both species in a laboratory stream aquarium.

Because brook and cutthroat trout spawn in fall and spring respectively, and cutthroat often not until June in high altitude streams, brook trout emerged earlier and maintained a 20-mm size advantage through the first summer. Juvenile brook trout dominated those of cutthroat trout in the stream aquarium due to this size difference, even though the cutthroat dominated brook trout when both were of equal sizes. In streams, age-0 cutthroat chose positions in shallower water than age-0 brook trout due to their size difference, which served to partially segregate the species during their first summer of life. However, microhabitat of age-I and -II trout overlapped substantially, while age-III brook and cutthroat trout appeared to show subtle differences in use of pool microhabitat.

This is separate from the problem in the Great Lakes.

Brook trout introduced throughout the Rocky Mountains since the late 1800's have displaced native cutthroat from much of its original habitat (Behnke 1979). The mechanisms responsible for displacement remain unclear, but involve ~~the~~ species differences with regard to susceptibility to angling (MacPhee 1966), tolerance to high stream gradient, age at maturity and concommittant reproductive output, as well as interspecific behavior.

Brook and brown trout ~~also~~ appear to be very similar species with regard to life history and ecology, and are suspected of ~~to~~ competing strongly in waters of northeastern North America, where brook trout are native and brown trout have been introduced (Fausch and White 1981). Both are fall spawners, and both use pools and overhead cover extensively in streams. Our research shows that young emerge and grow almost identically in Michigan streams, and that brook trout dominated brown trout of equal size in the stream aquarium. Both species preferred pools, but brown trout, the subordinate species, were unable to shift to positions in riffles and grow well, as steelhead and Atlantic salmon do in the presence of dominant competitors (Hartman 1965, Kennedy and Strange 1980). ~~Two~~ Thus brook and brown trout appear to have no mechanism to partition resources and minimize competition.

— by size - volume habitat

Vincent - Miller — small, cold st

vs.

larger

dominance gradient

sv. w/ cutts - brook - brown

rainbow

(Purdue)

1 copy for

Bob Behnke

[1984]

James W. Mullan, Project Leader
U.S. Fish and Wildlife Service
Fisheries Assistance Office
Leavenworth National Fish Hatchery
Route 1, Box 123A
Leavenworth, WA 98826

FRANK LOCKARD
Director

STATE OF WASHINGTON

DEPARTMENT OF GAME

600 North Capitol Way, GJ-11 • Olympia, Washington 98504 • (206) 753-5700

MEMORANDUM

TO: All Parties Interested in Washington's Trout Resources

FROM: Frank R. Lockard, Director

DATE: April 10, 1984

SUBJECT: A Basic Fishery Management Strategy for Resident and Anadromous Trout in the Stream Habitats of the State of Washington

The Department of Game technical staff has been working for some time on detailed methods for managing trout populations in streams. The product of this effort is reflected in the attached draft report. We would appreciate your review and consideration of the information and recommendations provided in the document. Primary emphasis is directed toward the basic conservation requirements of self-sustaining natural trout populations. An important supporting reference entitled "A Summary of Salmonid Hooking Mortality" is available upon request from any Game Department office.

We welcome your comments on this serious and complex fishery management subject. As stated in the schedule on page 2 of the draft, a number of opportunities will be provided for public input. Testimony relative to the strategy can be given at any of the regional meetings that will be held throughout the state during the month of June. A specific schedule will be provided as soon as the times and places for these meetings are firmed-up. Additional time for public testimony will be provided when the Game Commission considers the strategy at their October 10 meeting in Clarkston. Written comments on the strategy can be provided at any time.

We believe that the proposed management strategy constitutes one of the most comprehensive treatments of self-sustaining stream trout populations ever attempted. Your interest in the conservation needs of these important natural resources is certainly appreciated.

FRL:lca

Attachment

JOHN SPELLMAN
Governor

James W. Mullan, Project Leader
U. S. Fish and Wildlife Service
Fisheries Assistance Office
Leavenworth National Fish Hatchery
Route 1, Box 123A
Leavenworth, WA 98826

FRANK LOCKARD
Director

STATE OF WASHINGTON
DEPARTMENT OF GAME
600 North Capitol Way, GJ-11 • Olympia, Washington 98504 • (206) 753-5700

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[1984]

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A BASIC FISHERY MANAGEMENT STRATEGY FOR RESIDENT AND ANADROMOUS TROUT IN THE STREAM HABITATS OF THE STATE OF WASHINGTON

Prepared by the Fisheries Management Division,
Washington State Department of Game

INTRODUCTION

Stream habitats in the State of Washington present an exceptionally diverse array of trout populations that challenge skills of the professional fishery manager. Intent of the following report is development of a basic stream management plan recommendation for meeting the Washington Game Commission's Title 77 legal mandate to preserve, protect, and perpetuate the wildlife of the State of Washington, while maximizing public recreational opportunities.

A Washington Department of Game staff commitment for such a plan was initially made to the Commission in August 1983. The first section of this report will present a proposed time frame for development, consideration and adoption of this plan. This will be followed by sections dealing with unique features of stream angling, its potential in Washington and the need to separate lake management of trout from stream management. Basic population management requirements will then be presented (as contrasted to "trophy" fish management) and critical genetic/habitat concerns will be discussed. The main body of the report will deal with regulatory strategies for four "groups' of trout populations - migratory resident fish, steelhead, non-migratory resident fish, and sea-run cutthroat. The proposed mechanics of implementation will follow along with a statement of need for a stream trout catch reporting system. A separate report will deal with the specific subject of gear-induced mortalities on trout.

Supporting technical data will not be presented in a comprehensive manner but will be limited to representative examples illustrating the basic factors discussed. Where different points of view were discovered, these will also be presented regardless of whether or not they agree with recommendations contained in this report. Current regulations were given serious consideration as viable options based on their respective merits but were not accorded a "special" status because of their current use or tenure.

It will be necessary to decide on a basic fishery management strategy before specific proposals for individual waters can be developed. These processes cannot be done simultaneously. For this reason, the following sequence of events is proposed:

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TIMETABLE FOR PRESENTATION OF A BASIC
FISHERY MANAGEMENT STRATEGY FOR 1986 SEASON

February 1984	Division and Regional Fisheries Management staff put together basic goals and policies for total drainage fisheries management, incorporating resident and anadromous fish resources
March 1984	Administration reviews product
March 1984	Internal mailings of statewide fishery management strategy proposal to Regional and Division staffs, all Wildlife and Control Agents, all Fish Biologists, all hatchery installations, all Habitat Biologists, I & E
March 1984	Briefing of Game Commissioners
March-April 1984	Regional meetings (Division presents 1986 strategy proposal)
April 1984	Sports clubs', press, and individual mailing of 1986 strategy proposal
April-May 1984	Presentation of strategy proposal to presidents of organizations at quarterly meetings
June 1984	Public Meetings: Regions present 1985 season proposals and Division presents statewide 1986 strategy proposal.
August 1984	Commission hears 1985 season proposals <u>only</u>
October 1984	Presentation to Commission of statewide fishery management strategy proposal for endorsement
February 1985	Annual biologist meeting to discuss specific implementation recommendations to ensure consistency with basic fishery management strategy
March-April 1985	Develop season recommendations for 1986 based upon strategy; include other regulation changes that are needed
May 1985	Administration reviews recommendations
June 1985	Hold public review around the state on 1986 season recommendations
July 1985	Division incorporates public comment into 1986 fishing season recommendations and submits to Administration for review and approval for presentation to the Commission
August 1985	Present 1986 fishing season recommendations to the Commission. This presentation will include specific recommendations that incorporate the goals and policies for total drainage fisheries management

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THE FLOWING STREAM - A UNIQUE ANGLING EXPERIENCE

The lure of stream fishing is exemplified by the following passage from Mullan (1961):

> "To many anglers, trout fishing means stream fishing. While such anglers generally recognize the fact that bigger trout are available in ponds, and that the ponds have a better potential for producing trout fishing in this state, the lure of the streams ever calls them back. To these anglers, pond trout fishing with its implied waiting is no substitute for the charms of stream fishing. The expectation that lies just around the next bend, the feel and roar of white water, the skunk cabbage emerging from its winter sleep are but a few of the many ever-changing attractions encountered in the pursuit of trout in ocean-bent waters."

In areas where angler preference studies have been conducted, trout fishing in streams was accorded a high priority and demand typically exceeded available fishing opportunities. For example, the Idaho Department of Fish and Game (1980) states that:

> "Streams make up only one-fifth of the surface acreage of water in Idaho but they support nearly half of the fishing pressure and are preferred by nearly 60 percent of Idaho anglers." (Figure 1)

Available data indicate that Washington residents are doing a substantial amount of stream fishing in other states. For example, in four study areas on the Henrys Fork of the Snake River, non-residents comprised 60, 61, 80, and 89% of the anglers sampled (Rohrer 1983). All Idaho reports examined showed that Washington residents were the main component of their non-resident category. In spite of "losing" some stream fishing recreational benefits to other states, Washington still has an impressive volume of angler use. A 1980 national survey by the U.S. Departments of Interior and Commerce (1982) showed the following use statistics for freshwater recreational fishing:

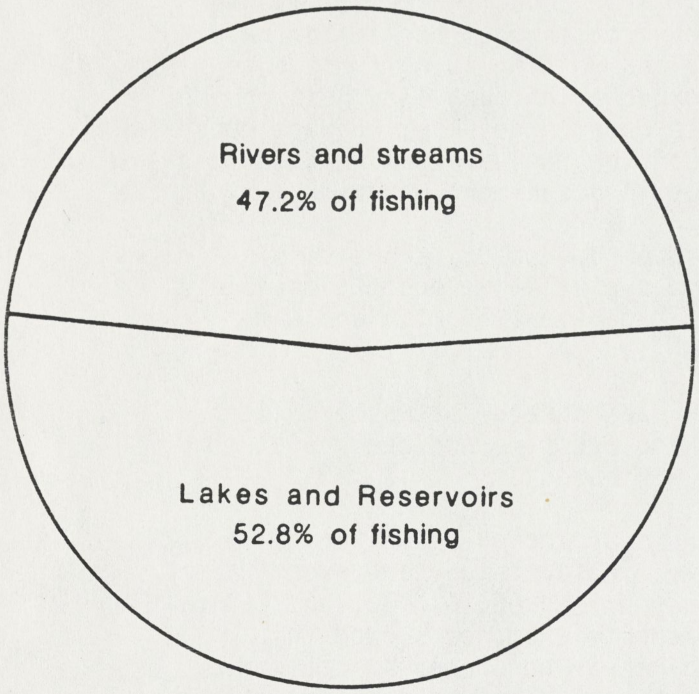
Game Department Geographic Unit	Angler Days (16 years old or more) Residents	Non-residents	Total
Region I	990,300	179,800	1,170,100
Region II	2,852,700	30,600	2,883,300
Region III	424,600	100,200	524,800
Region IV	4,410,300	114,200	4,524,500
Region V	1,599,200	130,500	1,729,700
Region VI	2,849,300	129,100	2,978,400
Total	13,126,400	684,400	13,810,800

(Note: These totals include freshwater fishing for salmon and other food fish but exclude saltwater fishing for game fish. The two categories are probably of the same order of magnitude and thus "cancel" each other out.)

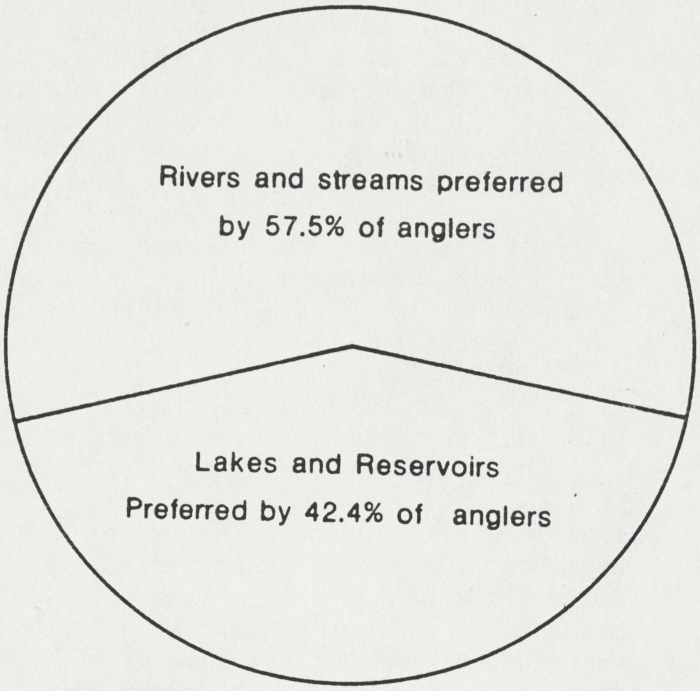
FIGURE 1

IMPORTANCE OF RIVERS AND STREAMS TO IDAHO ANGLERS

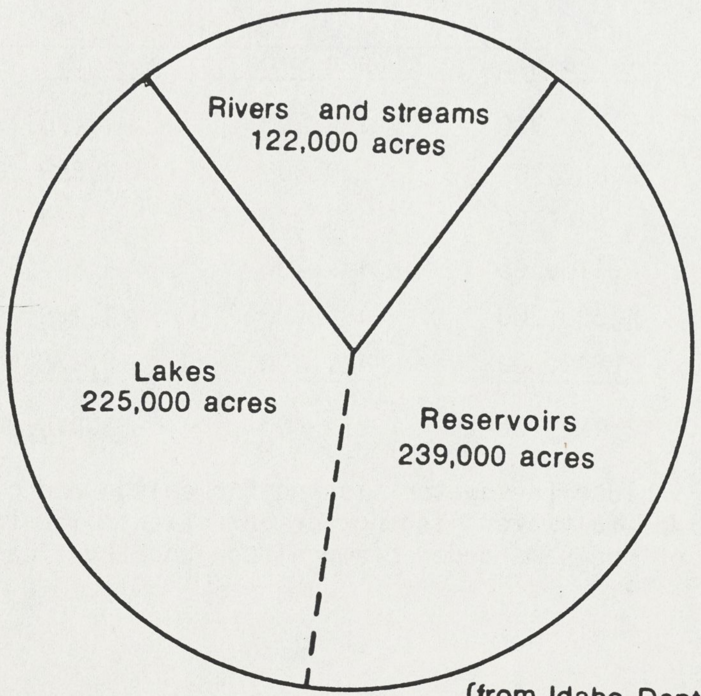
FISHING PRESSURE



FIRST PREFERENCE OF IDAHO ANGLERS



SURFACE ACRES OF WATER IN IDAHO



(from Idaho Dept. of Fish and Game 1980)

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With the addition of fishing trips by anglers less than 16 years old and a probable 3 to 5% annual rate of participation growth since 1980, current statewide trips for gamefish are at the 16 to 17 million angler trip level annually. Use by non-residents is only 5% statewide, but reaches a high of 15% in Region I. This can be attributed to the excellent lake fishing in Washington which attracts anglers from nearby Idaho. Thus, anglers are being attracted to a successful lake management program (that has been historically emphasized in Washington) but also seek the excellent stream angling currently provided in Idaho. Intent of the basic management strategy to be presented is to provide both within the State of Washington.

There is also an increasing trend of voluntary non-consumptive use for stream trout populations and this must be acknowledged in any management plan. Clark (1983) found in 1976 that anglers released 35 to 56% of the legal-sized fish they caught in sections of river restricted to fly-fishing, but released only 2% legals in sections under normal regulations. By 1979, anglers were releasing up to 85% of legal fish in the fly-only sections and as high as 25% of the legal fish in sections under normal regulations.

The reasons for recreational trout angling in streams have clearly evolved to a point where the provision of food for subsistence use can no longer be viewed as a viable fishery management objective. The results from angler interviews on Oregon's Metolius River (Griggs, MS in preparation) are typical of recent results. The top four most important reasons for fishing the Metolius were (in priority):

1. Enjoy the out-of-doors
2. Uniqueness of the area
3. Fly fishing
4. Fishing as a sport

Among the least important reasons (Number 16 in priority) was "catching a lot of fish".

A good example of high recreational benefits with a low consumptive yield is provided in the following data from Rohrer (1983) for one season in a 10.5 mile section of the Henrys Fork of the Snake River:

86,103 hours of angler effort
89,691 game fish released (required plus voluntary)
641 legal-sized game fish harvested (retained).

An angler opinion survey of the above fishery showed that 96% of sampled anglers considered fishing excellent or good. "Excellent" was the most common response (60%), while no anglers rated fishing as "poor".

Potential for Stream Fishing in Washington

Recent comments from an intra-Departmental memorandum illustrate several common points of view of WDG staff biologists:

> "...you will find that the majority of field biologists have explored their assigned areas long enough to have a good overall knowledge of what their streams are like and what they can and cannot do. Many of us have purposefully searched for streams or portions of streams to

sample in search of that bit of untouched stream where the fish are a product of their environment (old growth), not remnants from over harvest and logging. I can think of lots of streams where anglers never or seldom tread due to no access or extremely brushy, unfavorable angling conditions."

However, what this really means is that adequate protection of wild trout populations in Washington is often dependent upon the amount of fishing pressure being applied, not the regulatory controls in effect.

Many areas in Washington have favorable trout production potentials and, under proper management, could support a higher volume of recreational participation. Trout up to 20" in length were observed in North Fork Snoqualmie mainstem snorkeling transects, with a number of fish in the 16 to 18 inch range (Sweeney et al 1981). Recent measurements of rainbow trout in the Yakima River system indicate one of the best growth rates documented in North America. Thus, a common misnomer is that all Washington streams are unproductive and cannot produce resident trout.

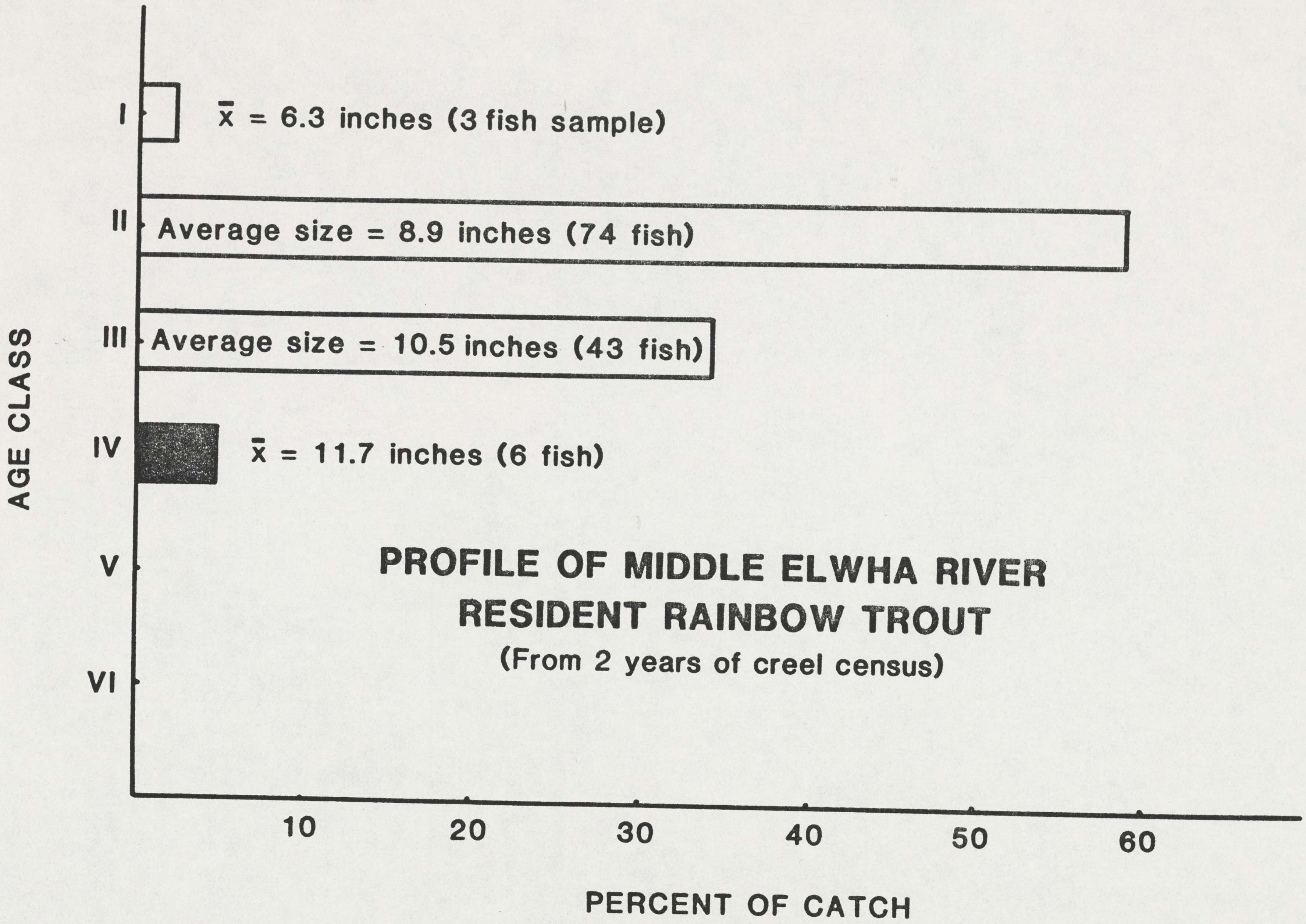
Trout populations in unproductive streams are actually more vulnerable than those in productive waters. Carlander (1969) reports that trout grow slower, live longer, and mature at an older age in unproductive streams. In addition, trout in unproductive streams typically have lower fecundity, which will provide even less resistence against effects of fishing (Royce 1975). However, success can be achieved. Three Idaho streams famous for trout fishing - St. Joe River, Kelly Creek, North Fork Clearwater River - are characterized as follows by Johnson and Bjornn (1978): "All three streams are infertile and clear."

In some cases where good standing trout populations now exist, WDG biologists express concern that the "word will get out" and the situation will be ruined by overfishing. Essentially, these populations are only being protected by this transient and unsafe approach to management. At best, this is poor resource management; at worst it is not responsive to the mandate to "preserve, protect, and perpetuate" while also "maximizing public recreational opportunities." In other stream areas, corrective action has already been taken on an individual water basis to either prevent or cure overfishing. An example of the latter case is resident rainbow in the middle part of the Elwha River system. In this instance, recent creel census work revealed all of the classic symptoms of overfishing; i.e., (1) low catch per unit effort, (2) poor angler satisfaction, (3) high annual mortality rates, (4) low overall trout population abundance, (5) lack of older age classes, and (6) a near absence of mature, spawning-age females (Figure 2).

The existing situation must be acknowledged and addressed in the same manner as recently stated by the Idaho Department of Fish and Game (1980) in their statewide plan:

> "The native species, however, are susceptible to overharvest and are sensitive to habitat alteration and many native fishes has suffered serious depletion as early as the 1930's and -40's..."
> "Since 1970, changed management philosophies have led to restoration of wild, native trout populations in a number of high quality waters through restrictive regulations."
> (Note: Title 36, Idaho code, states in part "...preserve, protect and perpetuate such wildlife.")

FIGURE 2



x̄ = 6.3 inches (3 fish sample)
Average size = 8.9 inches (74 fish)
Average size = 10.5 inches (43 fish)
x̄ = 11.7 inches (6 fish)
AGE CLASS
I
II
III
IV
V
VI
PROFILE OF MIDDLE ELWHA RIVER
RESIDENT RAINBOW TROUT
(From 2 years of creel census)
10
20
30
40
50
60
PERCENT OF CATCH

The contemporary biological data were recently reviewed by Mallet (1980), who offered the following conclusion:

> "In summary, most evidence seems to indicate that if suitable habitat is present that severe reductions in trout populations are normally caused by overfishing."

A final consideration is whether or not adequate data exist to even make the decisions required. Wright (1981) addressed this question in salmon fishery management and the same advice applies to trout populations in Washington:

> "...manager can make a serious mistake by waiting for enough evidence to protect himself. This may be a safe enough approach to ensure longevity in the business, but no decision is typically the wrong decision if overharvest in a fishery is suspected."

The basic problem is that overfished populations do not recover immediately and recreational uses dependent upon them must go through a very restrictive phase that would never have been needed in the absence of overfishing. The necessary "recovery" schedule depends mainly upon age at maturity and can be extensive. (Figure 3 illustrates the schedule for a population maturing at age V.)

SEPARATE LAKE MANAGEMENT FROM STREAM MANAGEMENT

The majority of stream fisheries in Washington are dependent upon self-sustaining wild trout populations and present a number of unique fishery management problems such as presence of several age classes and species of juvenile anadromous fish. Lakes in the state are the primary focus of WDG's major trout cultural program and many are not capable of supporting natural trout populations. Thus, the initial regulatory division that needs to be made is creation of separate basic regulations for managing trout in lakes and streams, respectively. New categories recommended are as follows:

I. <u>Trout in Lakes, Ponds, and Reservoirs</u>

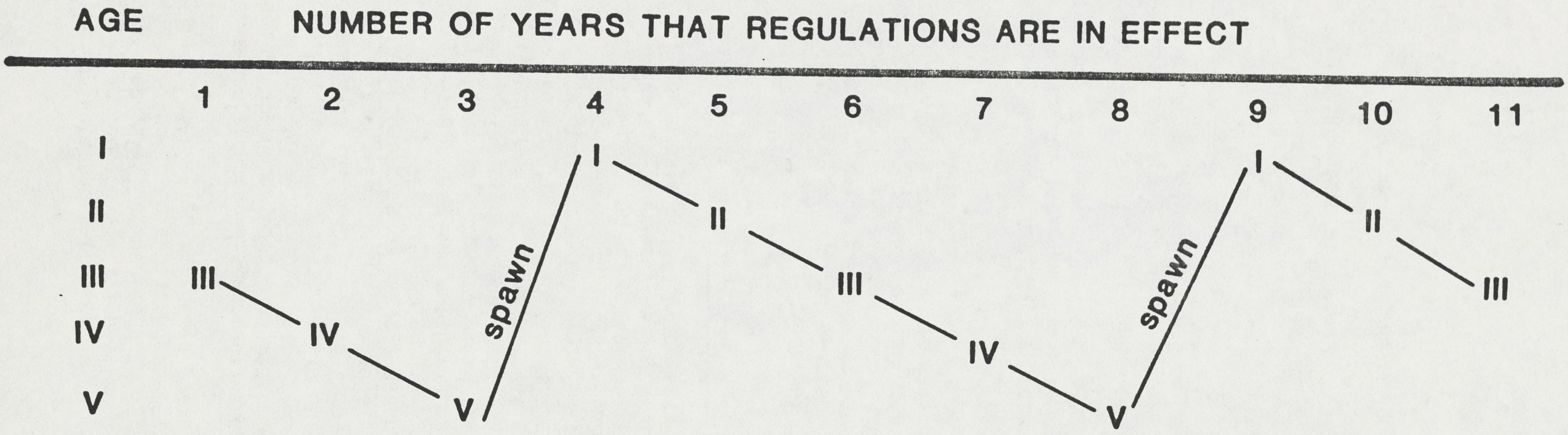
Under this category, we propose retaining the eight fish daily bag limit for licensed anglers but elimination of the 3 over 14" and 2 over 20" restrictions. The more restrictive five fish daily bag limit for unlicensed juveniles should also be retained. (Note: To properly manage game fish resources in the State, we are going to need more complex regulation, thus any non-essential <u>current</u> complexities should be dropped if at all possible). Individual lakes and reservoirs with different management needs, particularly those with important wild fish populations, would continue to be managed with "Special Regulations".

Two options for minimum size limits are (a) retention of the current six inches; or (b) the preferred alternative of no minimum size limit. In reviewing the data from other states, we could find little difference in the size distribution of fish retained under either regulation. It appears that 6" approximates or is somewhat below the difference between "desirable" and "undesirable" for the average angler.

FIGURE 3

RECOVERY SCHEDULE FOR A DEPRESSED TROUT POPULATION

SPAWNING AT AGE V AFTER IMPLEMENTATION OF EFFECTIVE REGULATORY CONTROLS



For example, Hunt (1970) reports the following for Wisconsin:

> "During the two seasons (1956-57) when there was no size limit in effect, few anglers kept trout less than six inches long. Consequently, the size distribution of the catch these two seasons was similar to that recorded when a six-inch limit was in effect in 1955 ...when there was no size limit, the proportion of successful trips was similar to that recorded when the six-inch limit applied." (Figure 4)

The distinct advantage of no minimum size (as cited by jurisdictions that use it) is that severely injured fish can be retained. Thurow and Bjornn (1973) concluded that:

> "Only 5% of the creeled cutthroat trout were less than 150 mm long." (6 inches) "Most of the anglers who kept these small fish stated that the fish had been deeply hooked and would have died if they had been released."

A potential disadvantage is that certain problems with "double-cropping" in lakes might be exacerbated and require attention in Special Regulations. However, application of a catch limit to all trout caught will actually eliminate the current situation where unlimited catch-and-release (with its associated hooking mortality) is permitted for all fish under six inches in length.

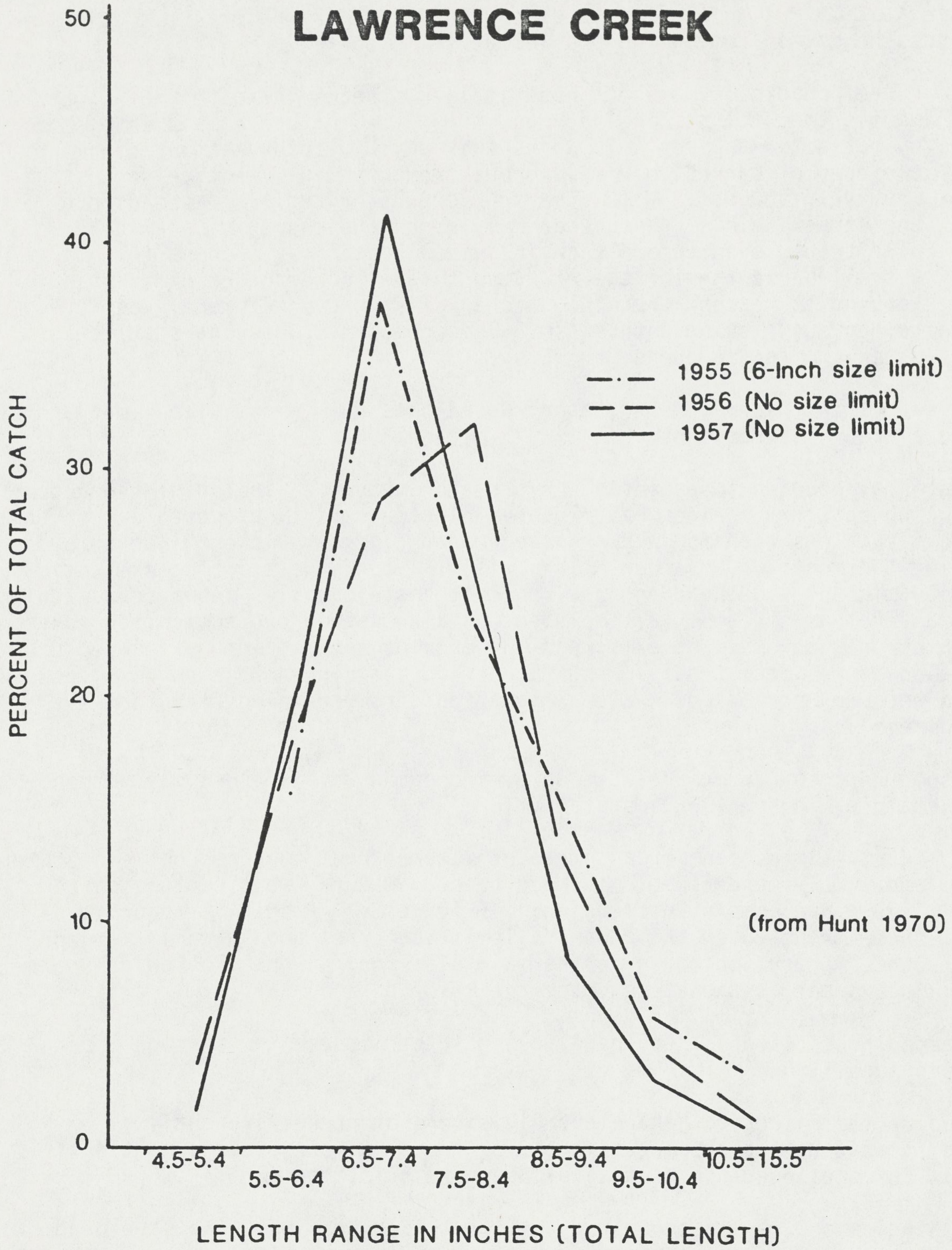
II. Trout in Rivers, Streams, and Beaver Ponds

Under this category, we also propose retaining the basic eight fish daily bag limit for licensed anglers and more restrictive five trout standard for unlicensed juveniles. However, the current three over 14" and two over 20" restrictions should be replaced with a single regulation, two over 12". Available data indicate that the aggregate number of large resident trout (over 12"), sea-run cutthroat and Dolly Varden (or bull trout) available for harvest annually on a sustained yield basis is less than the total number of steelhead available for harvest. Thus, every effort must be made to distribute the non-steelhead group among the maximum number of anglers possible. A two fish daily limit is needed.

"Designated Stream Zones Managed for Hatchery Fish" is a new proposed sub-category. Although most available hatchery production is utilized in effective lake management programs, a limited amount of stream trout planting still occurs. This is confined primarily to streams covered by formal mitigation agreements or areas of the State where alternative lake management options are poor or non-existent. These types of stream management programs provide valuable recreational benefits and should be continued. Hatchery fish management stream areas should be named in the regulation pamphlet, helping to specifically direct fishing effort toward available populations of hatchery trout. Designated hatchery zones should normally be confined to (1) stream areas where catchable trout have already been committed for mitigation; or (2) stream areas where habitat provides little or no natural production potential. (If the latter case cannot be

FIGURE 4

SIZE DISTRIBUTION OF BROOK TROUT RETAINED BY ANGLERS FROM LAWRENCE CREEK



avoided, selective fisheries for adipose-marked hatchery fish should be utilized.) The requirement to separate hatchery fish management from the needs of important wild trout populations has been documented in state after state. Mullan (1961), in describing the Massachusetts situation, states the common comingling problem as follows:

> "Creel checks of many of these smaller streams indicate that stocking spoils the quality of wild brook trout fishing previously enjoyed by but a few anglers. It works this way. With or without stocking, the crop of harvestable wild brook trout remains relatively constant from year-to-year. With stocking, crowds of anglers descend upon the stream. This pressure quickly crops the supply of available wild trout, even though each individual catch may account for but a small percentage of the wild trout take. A point of diminishing returns is reached when the hatchery fish are sufficiently depleted to depress fishing enthusiasm. This comes but a few days or weeks after the season opens."

All waters in this new sub-category would have no minimum size limit and no special gear restrictions.

A late May opening is proposed for streams statewide, including the hatchery fish sub-category. A general closure on October 31 is proposed except that stream sections open for winter steelhead angling should continue to be open during the month of November. This will (1) continue existing protection for outmigrant steelhead and sea-run cutthroat juveniles in western Washington anadromous streams; (2) implement similar needed protection for eastern Washington anadromous streams; and (3) provide some additional needed protection to resident trout during the spring spawning and/or physical condition recovery period (plus allow migrations from spawning tributaries to mainstems).

In some resident trout areas, a delayed opening until July 1 may be needed. For example, Thurow (1980) states:

> "Forty-six percent of a sample of mature trout captured between 26 May and 1 July were ripe, unspawned trout. Mature trout captured after 1 July had completed spawning." (Figure 5) Also: "A majority of these trout enter the Upper Valley tributaries and spawn in May and June. A portion spawn in the main Blackfort River. Following spawning, spent cutthroat re-enter the river."

If added protection is required, it should be implemented through Special Regulations.

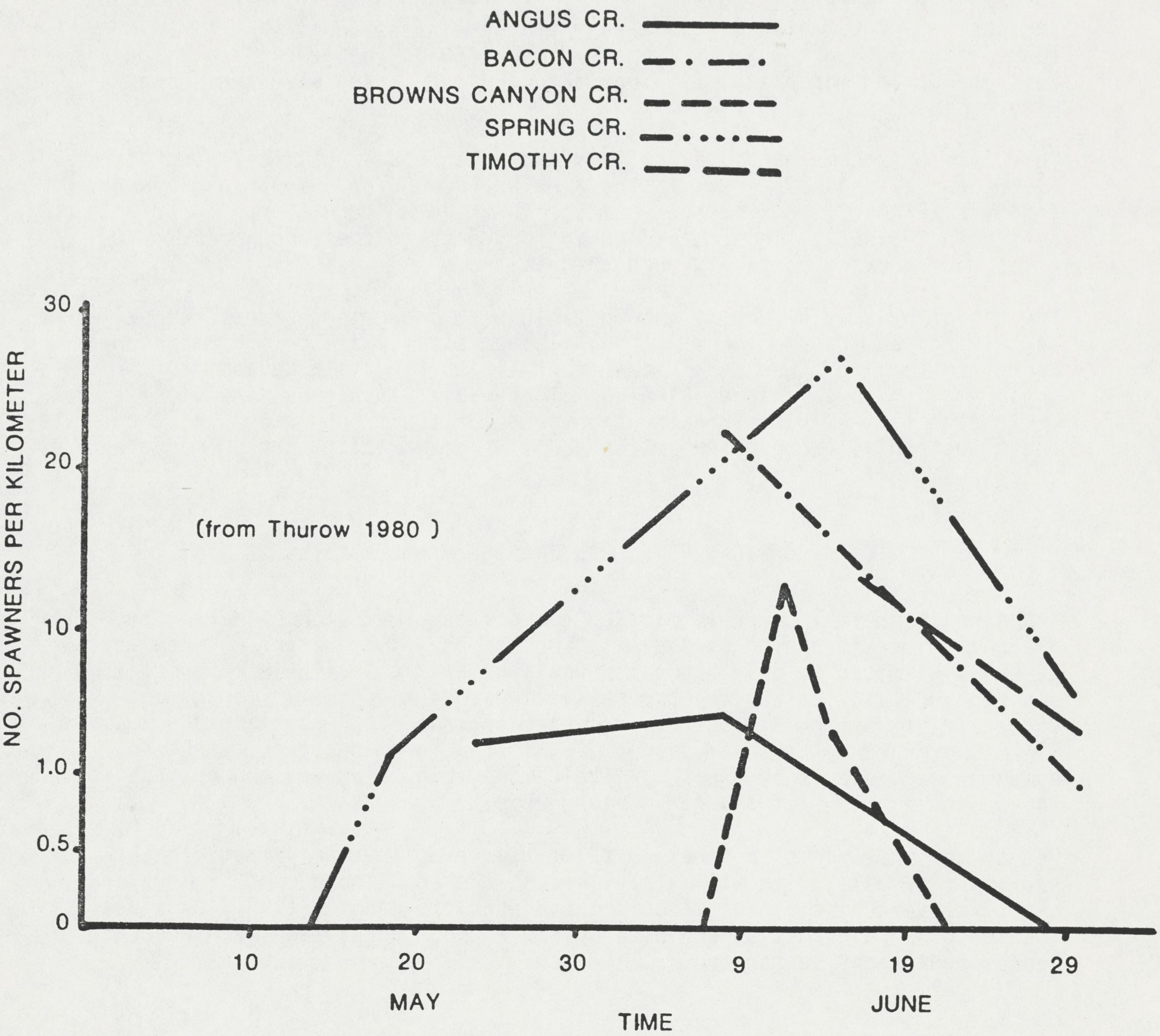
Based on the Fisheries Management Division's comprehensive analysis of studies on gear-induced mortalities for trout, we can provide no technical basis for continued use of the following restrictions:

1. Single hook restrictions for any trout fishing, including steelhead.
2. Barbless hook restrictions for any trout fishing, including steelhead.
3. Prohibition of bait for steelhead fishing.

Based on these conclusions, current SELECTIVE FISHERIES REGULATIONS should be eliminated.

FIGURE 5

OBSERVATIONS OF SPAWNING CUTTHROAT TROUT, BLACKFOOT RIVER



However, there is an equally firm technical basis for prohibiting the use of bait for general stream trout fishing. All natural production areas will have some significant degree of mandatory and/or voluntary release for several age classes of small, immature fish. A gear restriction banning the use of bait will be essential due to the high hooking mortality rate involved. The ban on bait should be coupled with an expression of daily bag limits as possession limits, not catch limits. This will have the practical effect of legalizing catch-and-release fishing in those waters so designated. In the past, a bait ban has been used sparingly in Washington under Special Regulations but it is more common in other jurisdictions. For example, current Idaho regulations ban the use of bait in 592 miles of streams and "these areas include many of the highest quality streams in Idaho" (Idaho Department of Fish and Game 1980). The general relationships between hooking mortality, fishing rates and population size are shown in Figure 6.

The Division's comprehensive analysis showed that all artificial gear types (lures and flies) would fall in the area near 0.05 (or only about 1 fish in 15 or 20 lost). Bait usage would be in the 0.30 to 0.50 range (or 3 to 5 fish in 10 lost). Thus, bait fishing produces in the order of 5 to 10 times more hooking mortality than artificials.

The use of bait is basically incompatible with management of natural self-sustaining trout populations. If no minimum size limits or minimal standards are applied, then significant mortalities can still be applied to those small fish which are released voluntarily. If higher minimum sizes are needed to meet basic conservation needs of the trout resources, then the situation is exacerbated by the addition of mortalities from mandatory release.

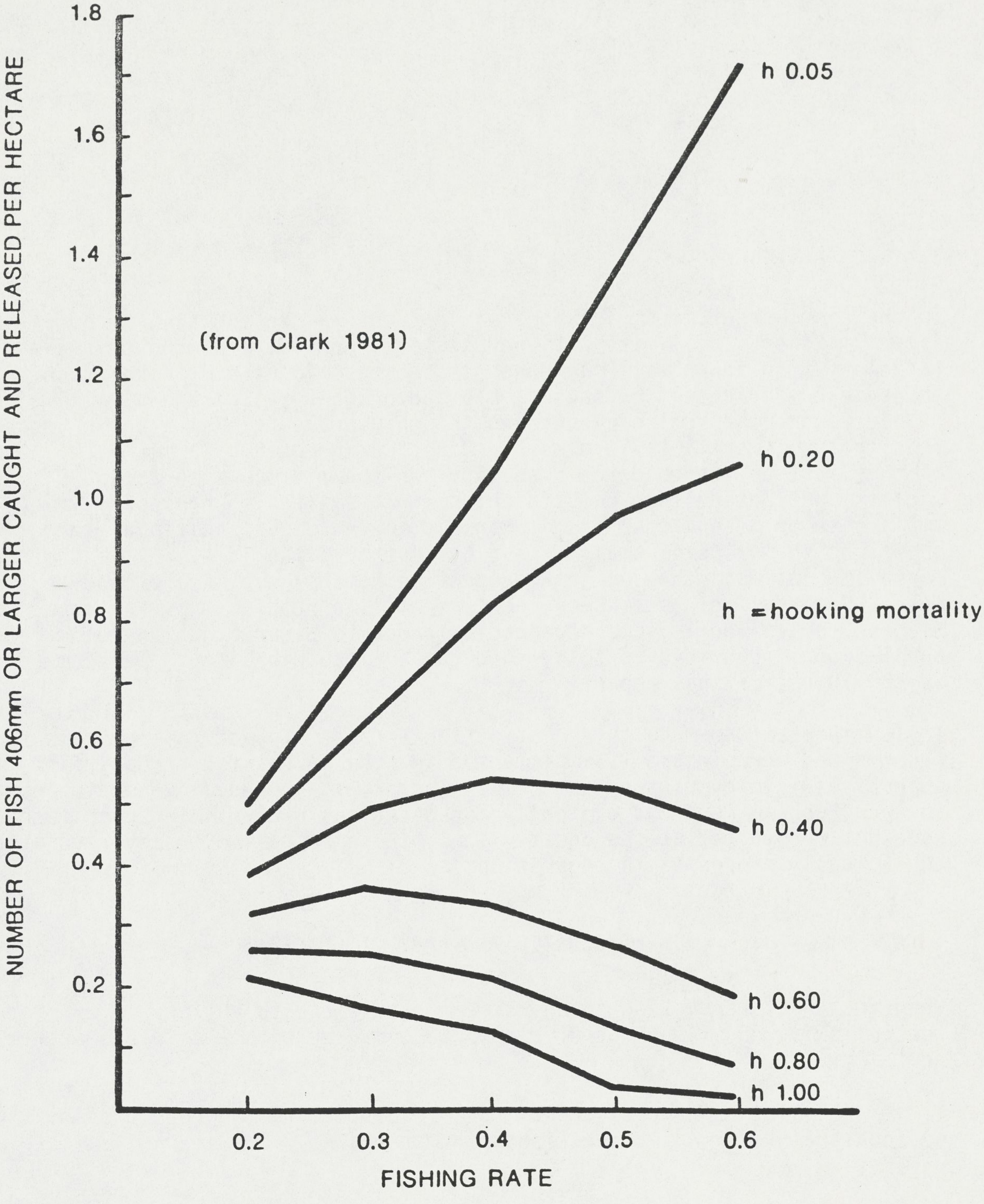
BASIC VERSUS QUALITY FISH MANAGEMENT

Areas which are deliberately managed to increase the catch of larger trout are commonly referred to as "quality" or "trophy-fish" waters. These are generally limited to only a small percentage of the available waters within a given jurisdiction and are typically viewed as a "special" management situation attracting a specific, minority segment of the angling public. Fly fishermen are the usual target of this type of management attention. Some managers view such areas as little more than necessary concessions to the political clout of a certain user group.

Due to the presence of natural mortality factors, any curtailment in the harvest of smaller fish will always reduce the total number of fish which can be harvested if recruitment is not a problem. Jensen (1981) provides the following alternative examples of how a trout population with adequate recruitment might be managed:

FIGURE 6

GENERAL RELATIONSHIPS BETWEEN CATCH, FISHING RATE, AND HOOKING MORTALITY



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Recruits	Instantaneous Fishing Mortality Coefficient	Instantaneous Natural Mortality Coefficient	Age at Entry into The Exploited Stock	Total Catch	Trophy Catch
1,000	0.50	0.70	I	417	11
1,000	0.50	0.70	II	207	19
1,000	0.25	0.70	I	263	15
1,000	0.50	0.70	I-IV (slot limit)	398	19
1,000	0.50	0.70	II-IV (slot limit)	176	31

In the cases shown, restricting age(s) of entry into the fishery by minimum size limits or slot limits will reduce total harvest even though average age (size) of fish taken will increase. A decrease in fishing rate, such as might be achieved indirectly by season, bag and/or gear restrictions, will also reduce total numerical harvest even though average fish size again increases. Thus, natural mortality is always a "cost" of producing larger fish. Some of this must be absorbed for fish to reach the minimum size acceptable to anglers, but beyond this point a balancing of values is necessary (i.e., more small fish or less larger fish). Unless the value of individual larger fish outweighs the value of smaller fish by several times (i.e., exceeds natural mortality losses), then such management cannot be justified except as a special case. However, in cases where recruitment is a problem, fishing rates must also be controlled in some dependable manner to assure that an adequate spawning population is provided to fully seed the available habitat. Basic management is the intent of this report.

It is important to make this distinction because many of the controls to be recommended were initially implemented in other areas for "trophy fish" management objectives. However, they sometimes inadvertently produce dramatic increases in trout populations and typically cured serious over-fishing conditions that were not recognized at the onset. Thus, these so-called trophy regulations are actually proper basic regulations.

GENETIC AND HABITAT CONCERNS

When the trout population in any stream accessible to anglers is examined, the following questions cannot always be answered with a complete degree of certainty:

1. Is the size and age distribution of a population the result of habitat constraints <u>or</u> selective fishing pressures?

2. Is the population abundance observed (or complete lack of fish) due to actual limitations of the habitat <u>or</u> inadequate recruitment (overfishing)?

3. Is the species composition observed reflective of habitat parameters <u>or</u> selective removal of a species more susceptible to angling pressure?

The possibility of adverse genetic consequences due to overfishing and/or gear selectivity is still being debated among trout managers. For example, in view of the strong inheritability of growth rate in salmonids, Favro, et al (1979, 1980) stated that a decline in the quality of fishing may be related to changes in the gene pool of a stock caused by selective fishing on the faster-growing individuals. A specific population, brown trout in Michigan's Au Sable River, appeared to have its growth potential reduced by selective harvest of larger fish over time. Others have characterized their findings as theoretical only, but generally agree that such changes are logical expectations. Clark et al (1980) disagree with the following conclusion:

> "But, with few exceptions, growth rates of trout in streams have remained remarkedly constant over long periods, even in heavily exploited stocks."

However, problems have been conclusively documented for closely-related species and it must be assumed that they can occur in trout populations. Any management strategy should include measures to prevent or at least minimize such long-term genetic changes.

Naiman (1982) found fishing rates of 60% and 80% on one and two ocean year Atlantic salmon, respectively and that most males (90%) are now living out their lives in freshwater and females are returning as soon as possible, sometimes after only a few months at sea. These fish are passing along their genetically controlled traits to future generations. Naiman concludes as follows:

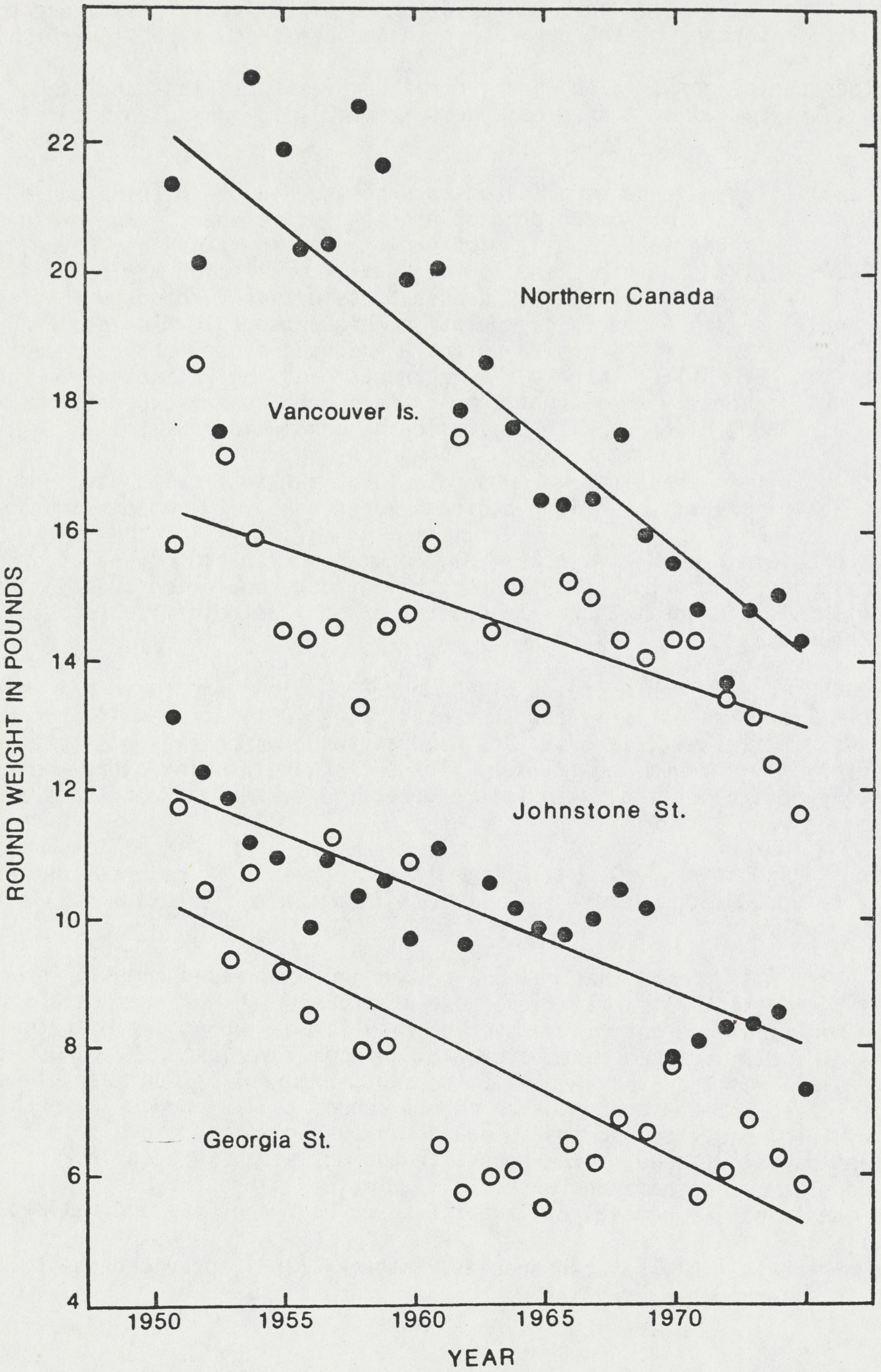
> "Eventually, in maybe 100 to 200 years, as pressure is released on the seaward populations, there will be a shift again and the fish will start going out."

Ricker (1980,1981) found that chinook salmon have decreased greatly in both size and age since the 1920's, mainly because of higher fishing rates on older fish by hook-and-line gear. The average fish is only about one-half the size of the original, unfished genetic stock. Chinook have lost 5.5 pounds in average size from the early 1950's to present (Figure 7). Odd year pinks have decreased from an average size of 5.5 pounds to 4.3 pounds and even year runs have declined from 4.6 to 3.0 pounds in average size. Coho salmon in the ocean have lost about three pounds in average size since the early 1950's. Coho and pink salmon have decreased in size mainly since the early 1950's due to the selective removal of larger fish by hook-and-line and gillnet gear.

In yet another closely-related species, Grabacki (1981) provided the following conclusions for Arctic grayling:

FIGURE 7

Sizes of Chinook salmon in four troll fishing areas



(from Ricker 1980)

"Comparisons of fish in areas of high and low accessibility to anglers, where accessibility was assumed to be proportional to fishing pressure, revealed that the average size and age, relative abundance, and individual growth rates appeared to decline as a result of fishing, while mortality rates increased. The circumstantial evidence allows the conclusion that the observed differences in population dynamics and characteristics between sections are, in fact, caused by fishing pressure."

The habitat issue is also critical since important mitigation decisions and stream protection requirements are typically based on site-specific fish population data. Any management strategy must insure that the inherent carrying capacity of available habitat is actually being utilized. Cutthroat trout are by far the most important species due to their widespread use of small streams as both anadromous and resident fish.

The initial assumptions from a paper by Burns (1971) illustrate where many habitat evaluations begin:

"Carrying capacity is defined as the greatest weight of fishes that a stream can naturally support during the period of least available habitat. It should be considered a mean value, around which populations fluctuate. Spawning salmonids in coastal streams are thought to produce enough progeny to fill streams to carrying capacity. This assumption is supported by observations of high rates of emigration and mortality of fry shortly after emergence from the spawning bed. Since a section of stream can accommodate only a limited number of territories, surplus fish are displaced... Displacement distributes fish to parts of the system remote from the spawning grounds, thus insuring that most of the area and productivity of the system is utilized. Even in the absence of excess fry production, receding summer streamflow limits habitat and practically insures that streams are filled to carrying capacity. Survival and growth of fishes in these streams are density dependent, or have density dependent components. The stream's carrying capacity limits the number and weight of salmonid smolts ultimately produced."

However, the following results proved that these assumptions were not valid and that Burn's study was measuring overfishing, not habitat capability:

"Salmonid biomass in Godwood Creek was exceptionally low, ranging from 16.68 kg/ha in 1967 to 8.48 in 1969. Prairie Creek, to which Godwood Creek is a tributary, had a salmonid biomass of 21.95 kg/ha in 1969, suggesting that Godwood Creek probably wasn't at carrying capacity. Low population densities in Godwood Creek in 1968 and 1969 apparently reduced competition, for fish attained greater average lengths than in 1969, when densities were greater. Increased growth, however, apparently did not compensate for lowered density and carrying capacity was not reached in 1968 and 1969. To test if Godwood Creek was at carrying capacity in 1969, I transplanted the salmonids captured in Prairie Creek in July into a 366-m section of Godwood Creek in sufficient numbers to increase the biomass to 27.98 kg/ha. Two months later the same section of Godwood Creek was censused to determine if the biomass had remained above the July 1969 value of 7.36 kg/ha. It was 18.08 kg/ha at the second census. This experiment demonstrated that the stream had been below carrying capacity before transplanting the Prairie Creek fish. There were no obvious reasons for the low number of salmonids in 1968 and 1969, except that young-of-the-year coho were exceptionally scarce then, suggesting that the spawning run had not seeded the stream to carrying capacity. There were no significant changes in spawning bed sediments to explain reduced survival of incubating embryos and fry."

Similar results were obtained when researchers attempted to measure the effects of logging and road building practices on Washington's Clearwater River. Such findings are relatively rare but only because very few habitat workers are able to actually test their initial assumptions about use of potential carrying capacity.

Species replacement has been documented in a number of other states and is the logical result of any mixed stock fishery where one species can support a high fishing rate and/or is less vulnerable to angling. For example, in one Ontario study, brook trout were less able to withstand angling pressure than brown trout in the same stream and differences in age composisiton of the two species were directly related to innate differences in exploitability (Marshall and MacCrimmon 1970). Mullan (1961) reached the same conclusion as follows:

> "In many streams, the German brown trout has usurped the native brook trout. This has not come about because of the cannibalistic inclination of the brown. The brown trout, merely by being harder to catch, has taken over for the brookie."

(Note: Additional data will be presented in a subsequent section of the report concerning relative susceptibility to angling).

RECOMMENDED BASIC STRATEGY

Manage Natural Trout Populations for Assured Recruitment (full utilization of existing carrying capacity)

There are only two basic methods of assuring that adequate recruitment of juvenile fish occurs on a dependable, sustained basis. The first approach is that currently utilized for steelhead, which requires that the population be quantified and actively managed to achieve a specific spawning escapement objective each season. This same approach would be technically feasible for all trout populations in the state but would entail prohibitive costs and extremely complicated emergency regulations. The same end result of assured recruitment can be achieved by making sure that one age class of mature females is allowed to spawn at least once. For fishery management purposes, this should be defined as the majority (more than 50%) of the female individuals in a given age class. The actual management process for an individual stream should parallel the following steps used by Johnson and Bjornn (1978) to determine that a 12" minimum size was the optimum solution for Idaho's St. Joe River cutthroat trout:

"The setting of a size limit can be delicate in situations where most spawners are needed to maintain an abundant population. By lowering the size limit from 13 to 12 inches, an additional 3.6% of the 1975 population would be legal-sized during the summer, but only about 5% of the cutthroat would reach the minimum size by the end of the fishing season and be available for harvest before spawning at least once. By lowering the size limit from 13 to 11 inches, an additional 8.6% of the 1975 population would be legal size during the summer, but about half of the cutthroat would reach the minimum size by the end of the fishing season and be available for harvest before spawning the first time."

If possible, it is important to avoid any size limit that "cuts across" the central or dominant portion of an age class size distribution curve. For example, if an eleven inch minimum size limit was applied to the St. Joe River cutthroat population, the resultant fishery would be strongly selective toward larger individuals of the same age/maturity class. Conversely, the remaining spawning population would be composed of smaller fish due to the prior removal of larger individuals. The general relationships are depicted in Figure 8. The fact that this actually happens is illustrated in Figure 9. It is important to distinguish between (1) a standing crop (population); (2) that portion which can be taken by certain gear; and (3) the part that can be retained under a specific regulation. Trout managers must assure adequate recruitment <u>and</u> minimize selective fishing pressures.

With the management approach described, dependence on a single age class in any one spawning cycle will usually be avoided since some significant percentage of this same age group will spawn at an earlier age. Others will survive and spawn a second time. For example, if 70% of the females spawn at age 4 and are adequately protected until that time, then the contribution from age 3 and age 5 spawners will help "buffer" any weak brood years.

The need to avoid single age class spawning success dependence (if possible) is illustrated by coho salmon data from Washington's Queets River (Figure 10). In this case, a relative constant rate of in-river fishing was being applied to a resource subjected to continually increasing ocean fishing rates. The single age class spawning dependence could not be avoided since virtually all coho salmon spawn at age 3 in the southern part of their geographic range. In this example, a single cycle became depressed in 1960 (No. 1) and was never able to recover (No.'s 2 through 6). The two other cycles took much longer to show symptoms of overfishing.

Manage with the Proper Tools

Bag limits (daily or seasonal) should be used primarily for the purpose that they are intended; i.e., to distribute the allowable harvest among anglers (the basic separation from commercial fishing). They do not provide a positive control for assured recruitment. Managers typically over-estimate the potential of bag limit reductions by (1) analyzing data on an individual angler basis versus "party" limits; and (2) calculating potential reductions as annual fish-

FIGURE 8

EFFECTS OF FISHING ON A POPULATION

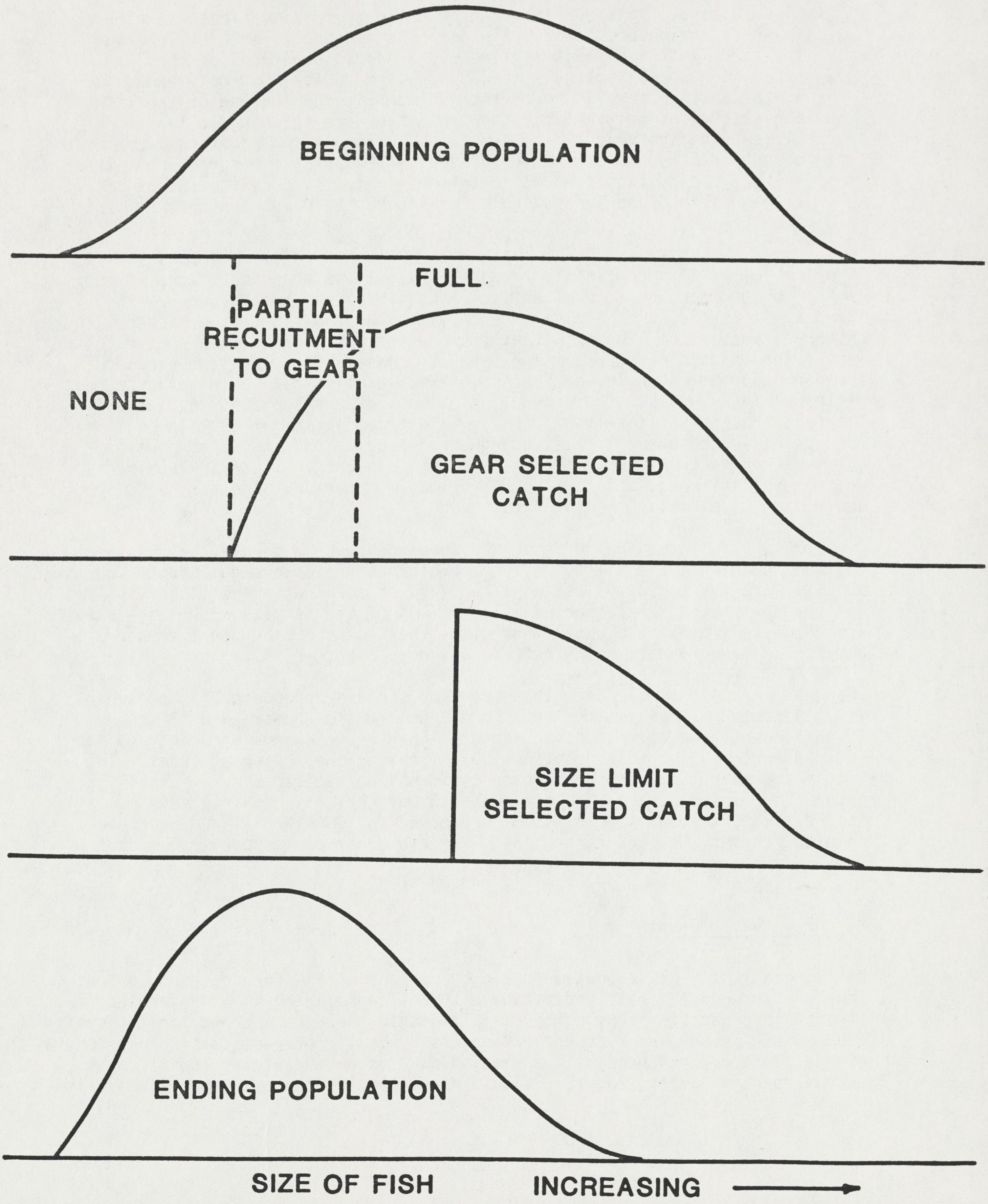


FIGURE 9

COMPARATIVE CATCHES OF CHINOOK SALMON IN THE SAME SOUTH PUGET SOUND MARINE AREA

(from Eames 1979)

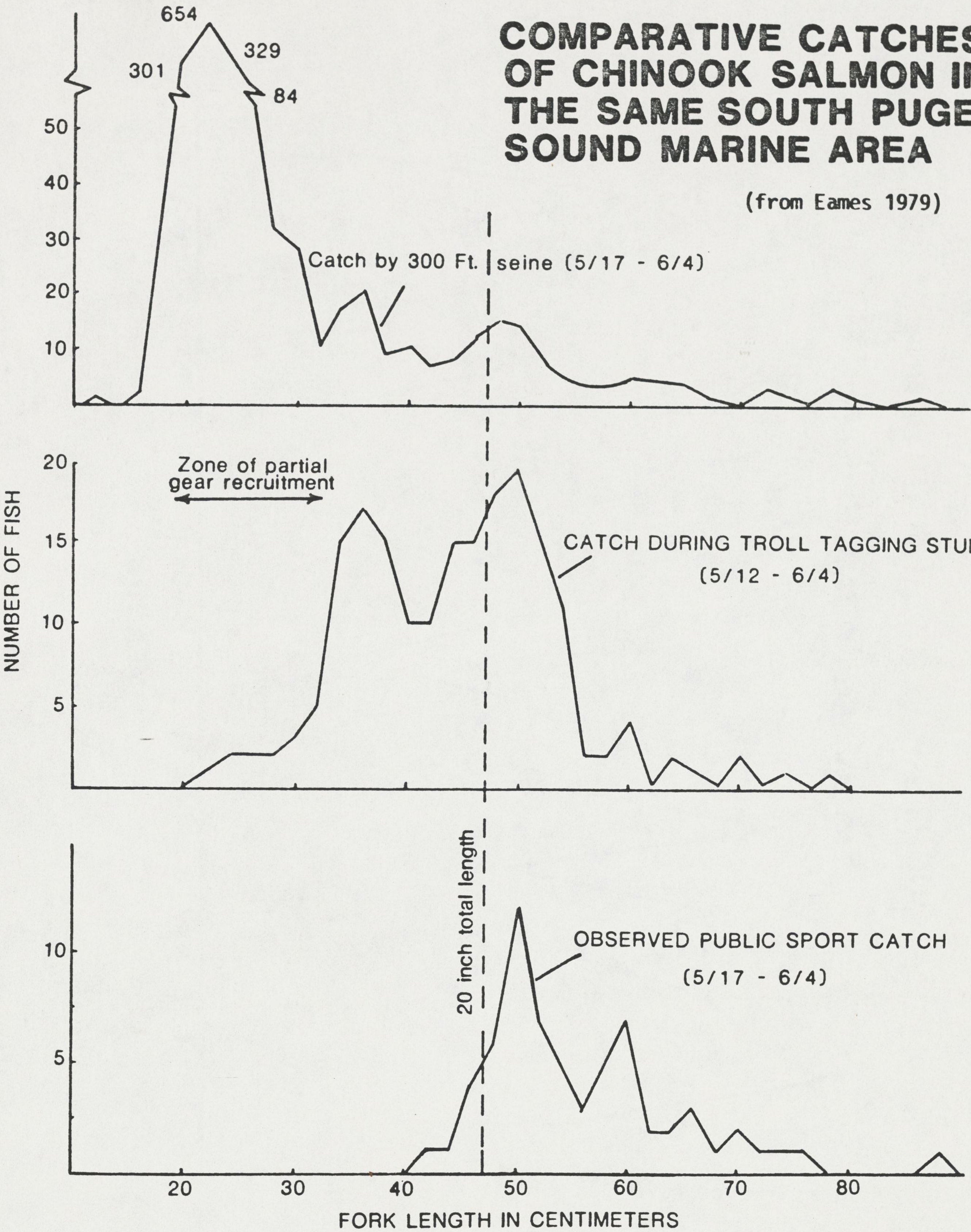
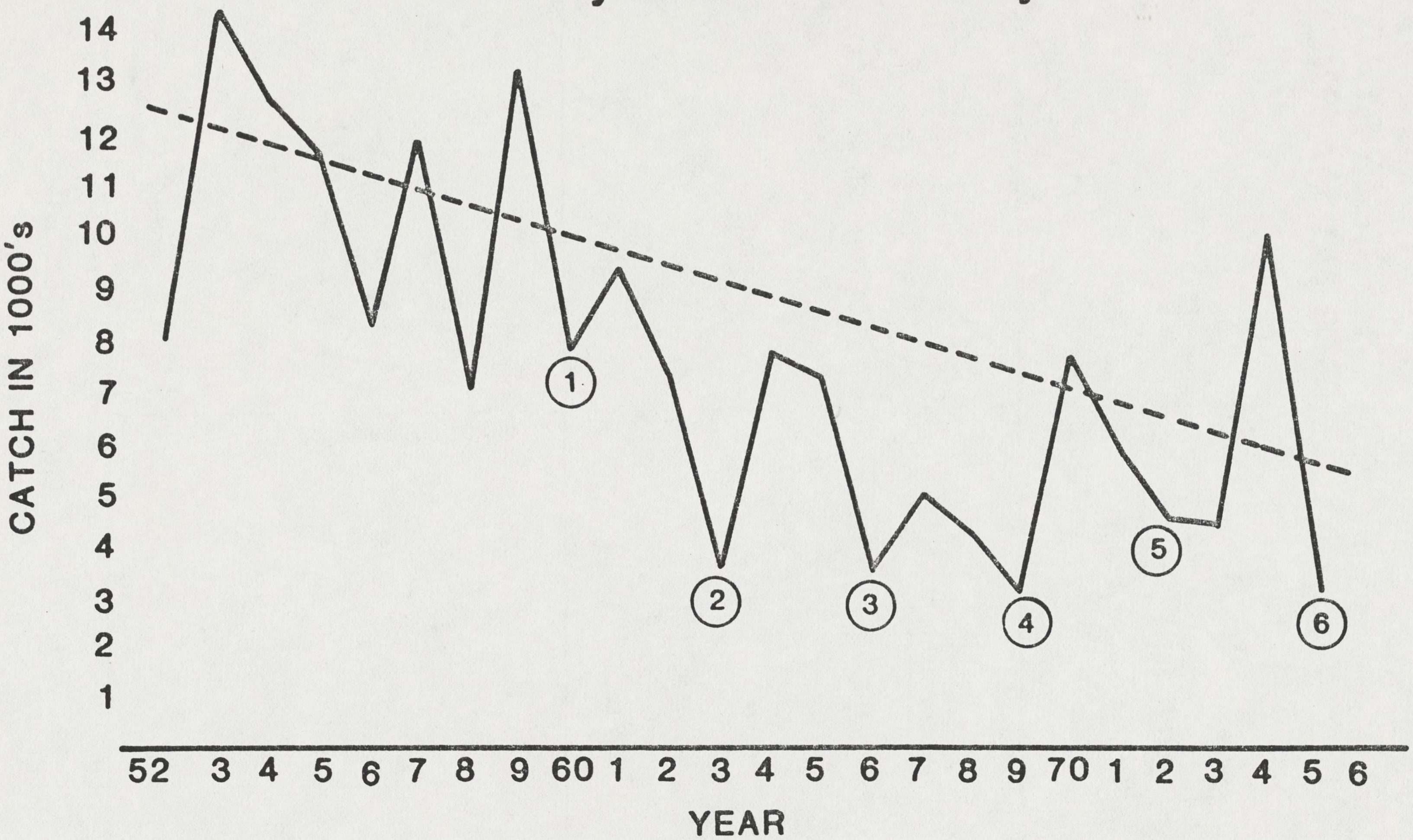


FIGURE 10

QUEETS RIVER COHO CATCHES

Treaty Indian Net Fishery



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ing rates instead of instantaneous rates. Temporary successes, even for extended periods, can be achieved by reducing instantaneous fishing rates and/or simply discouraging fishing activity. However, both of these elements can be negated by increased participation in the fishery (a workable alternative which we do not propose for general use is limited entry). In most fishery management case histories, managers have not picked-up the problem of effort increases in a timely manner and overfishing has occurred before more positive controls could be implemented.

In other cases, bag limit reductions have failed to even temporarily correct problems. Studies by Johnson and Bjornn (1978) demonstrated for westslope cutthroat that a restrictive bag limit (three fish versus the previous 15) did not protect the population until adequate numbers of females had spawned at least once and thus did not increase population size to rebuild from overfishing. Hunt (1970), in comprehensive studies with different regulations found that:

> "During all seasons and regardless of the bag limit allowed, most of the harvest was accounted for by catches of 1-3 trout/trip. ...During all seasons and regardless of the liberality of the bag and size limits, more than 50% of the anglers failed to catch a single wild brook trout."

Hunt concluded that bag limits were not effective in altering trout population structure.

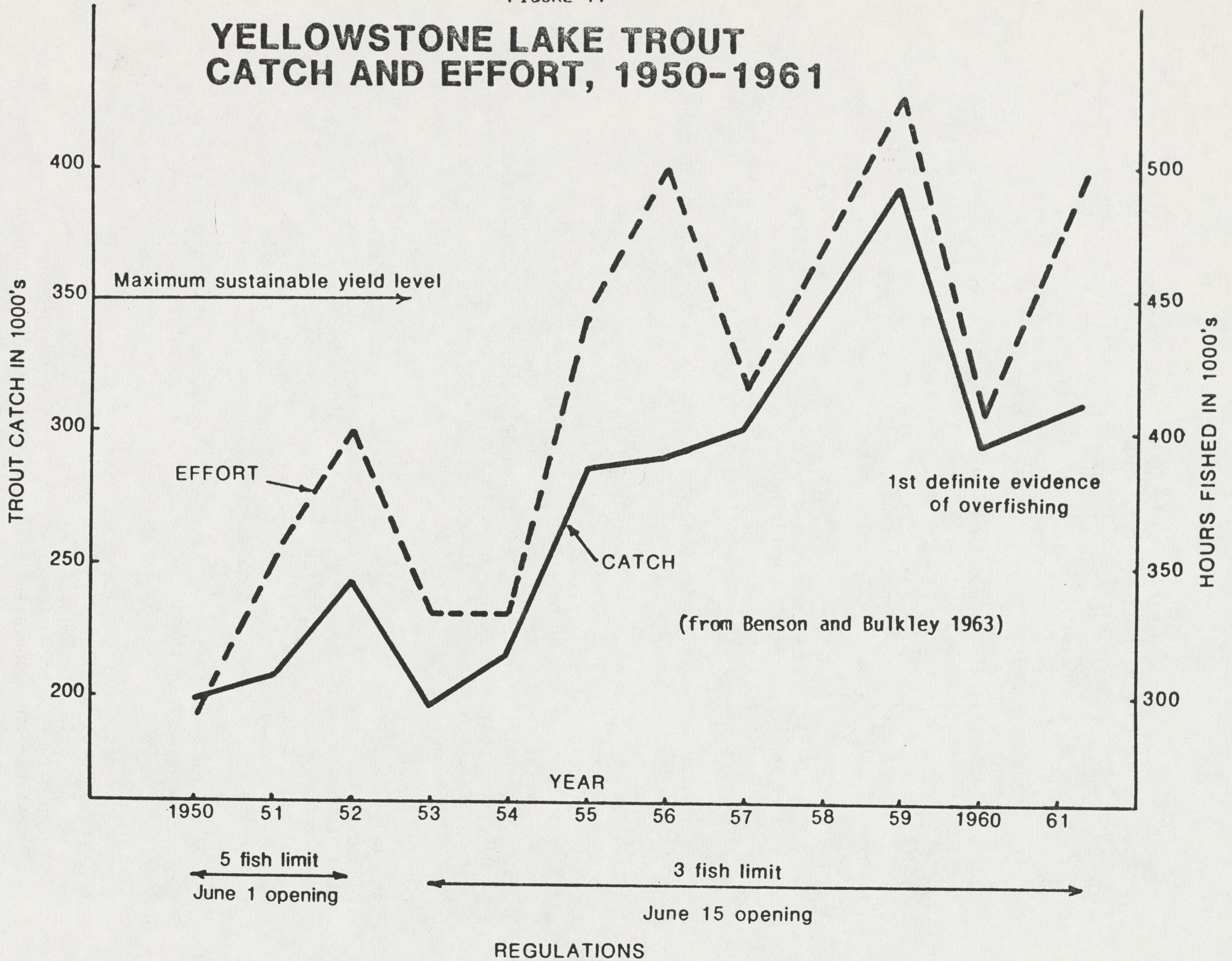
Seasons (except complete closures) also fail to provide any positive control for assured recruitment. Closed periods should be utilized primarily to protect trout populations during certain critical life history stages (such as spawning and periods of smolt concentrations). They should not be relied upon to effectively limit fishing rates by themselves. As the data on Yellowstone Lake illustrate, fishing pressure increases can negate even the combined effects of more restrictive bag limit and fishing season controls. In this instance, a temporary catch reduction was noted but the effect was completely negated by the third season after the change and overfishing soon followed (Figure 11).

The same thing can happen in streams. For example, Vincent and Clancey (1980) documented an effort increase in the Madison River (a nationally-known "blue ribbon" trout stream) from 215 angler days/mile in 1952 to 953 in 1975. Their studies showed annual recruitment rates of about 50% but much higher recent total annual mortality rates (average of 71% for four independent estimates with a range of 62 to 75). Since causes other than fishing had a background natural mortality rate of 20-25%, the harvest plus release losses could not exceed the 25-30% level on a sustained yield basis.

Two other management tools - "refuges" (closed areas) and gear - also have very limited value by themselves in effectively controlling fishing rates. Hunt (1970) characterizes these as follows:

> "As a means of providing better trout fishing, the mile-long headwater refuge was a failure. Many trout that could have been harvested or fished upon were lost to natural mortality because they did not leave the refuge....Under the conditions of fishing pressure, catch, and trout densities that prevailed at Lawrence Creek, fly fishing had no uniquely beneficial biological effects that could be detected. Changes in standing crops, survival rates, reproduction, and growth of the trout popula-

FIGURE 11



YELLOWSTONE LAKE TROUT
CATCH AND EFFORT, 1950-1961
TROUT CATCH IN 1000's
400
350
300
250
200
HOURS FISHED IN 1000's
500
450
400
350
300
Maximum sustainable yield level
EFFORT
CATCH
1st definite evidence
of overfishing
(from Benson and Bulkley 1963)
YEAR
1950
51
52
53
54
55
56
57
58
59
1960
61
5 fish limit
June 1 opening
3 fish limit
June 15 opening
REGULATIONS

tions in the two fishing zones appeared to be independent of the methods of angler harvest."

Shetter (1968) studied the fly fishing only situation in Hunt Creek, Michigan, and reached the following conclusion:

> "...provided data for assessment of the effects of a fly fishing only restriction (instead of any lure) on the brook trout population. The restriction (in effect 1955-59) did not affect the total mortality rate or the population structure of the brook trout."

Hunt (1970) goes on to describe the critical management tool as follows:

> "The size limit, if wisely applied, is the best single regulation for preventing excessive angler harvest of brook trout populations. The size limit applies to every trout caught, and it can be related to a rather stable biological parameter, growth rates of the trout populations."

When the tested regulatory "package" included a higher minimum size, work by Shetter (1968) showed the following response:

> "Total mortality and angling mortality rates for brook trout were significantly higher in the less restricted stream area."

However, regulations can only cure overfishing if it actually exists - not environmental limitations. Klein (1974), for example, reported such a failure for the Cache La Poudre River in Colorado. This high elevation stream was relatively unproductive and contained populations of slow-growing rainbow and brown trout. Management changes, including a 12" minimum size limit, did not increase the abundance of rainbow trout although the mean size increased by two inches and reversed when the minimum size limit was removed. In addition, overfishing of one species is not a sure indication of the same problem for another species. Thus, Shetter (1968) observed a positive response for brook trout but the same regulations in the same study area did not change the population structure of brown trout.

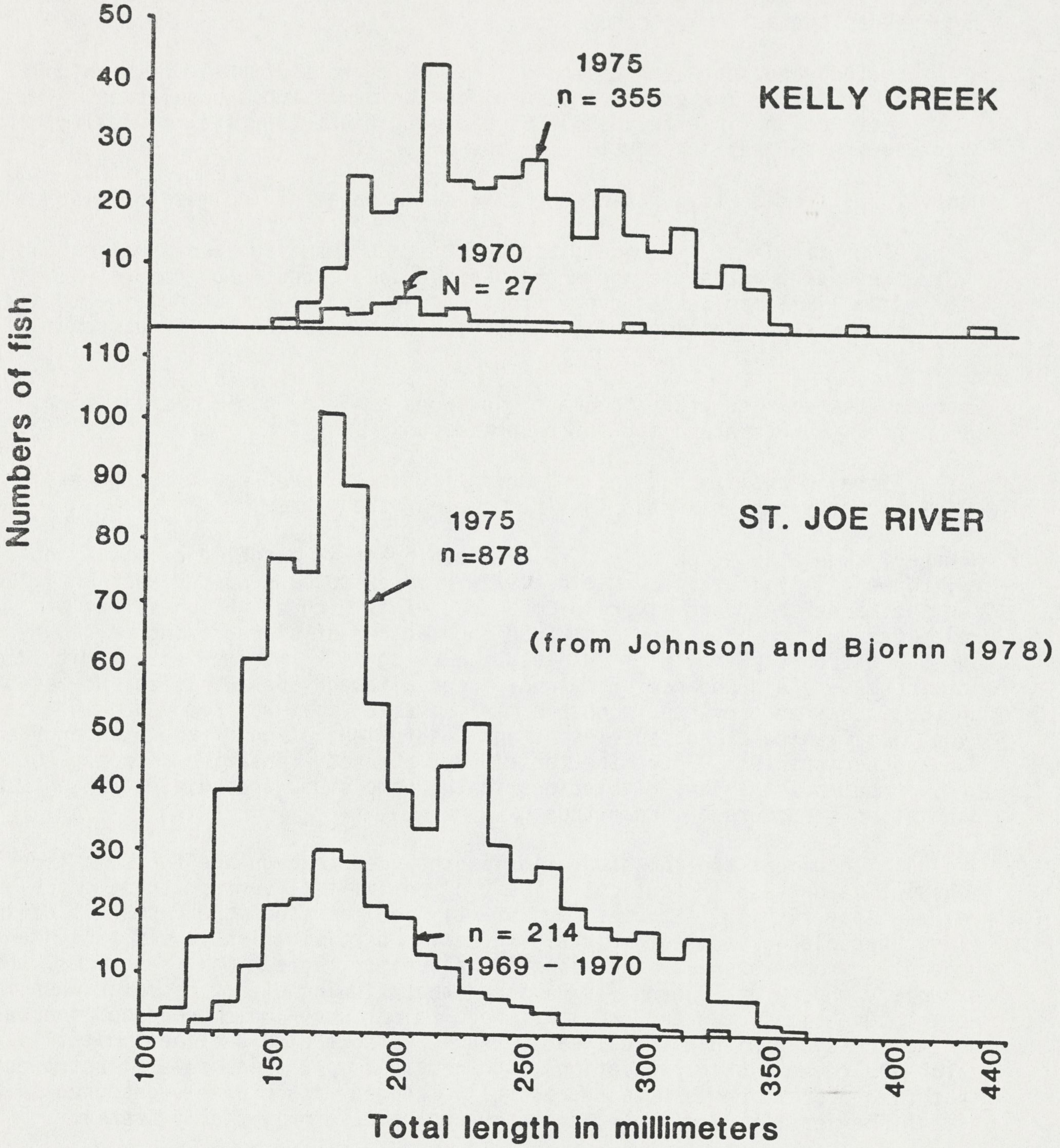
A final management tool consideration is the need to regulate for some level of consumptive harvest (retention), albeit often limited, versus strict catch-and-release only fishing. Studies consistently indicate that the former is definitely preferable in terms of maintaining angler participation levels, which are generally synonymous with the economic values for recreational resources. For example, Johnson and Bjornn (1978) found that fishing effort declined when more restrictive size, gear and bag limit regulations were implemented but increased to former levels within three years. Angler effort also declined initially with catch-and-release only regulations, but remained low. Figure 12 illustrates that fish populations can be successfully managed with properly designed selective fisheries (St. Joe River) or catch-and-release only (Kelly Creek).

Basic Management for the Needs of Cutthroat and Rainbow Trout, including Steelhead

Due to their basic life history characteristics, Dolly Varden or bull trout (at least as resident fish) are the most susceptible species to overfishing

FIGURE 12

SIZE AND ABUNDANCE OF CUTTHROAT TROUT BEFORE AND AFTER EFFECTIVE REGULATION



and are probably in a depressed status throughout most or all of the State. However, their potential and extent of distribution is much less than cutthroat or rainbow, thus Dollies (or bull trout) cannot be the focal point for basic regulations. Needed protection must be provided on a Regional or Special Regulation basis.

All applicable studies examined agreed that cutthroat trout were the most susceptible trout species in terms of catchability and must be accorded the title of most "vulnerable". Shetter and Alexander (1965) and Lantiegne (1974) found brook trout much easier to catch than brown trout and MacPhee (1966) found cutthroat trout about twice as susceptible to angling as brook trout. Under normal angling regulations, the annual rate of exploitation of cutthroat longer than 150 mm ranged from 0.70 to 0.76 or higher in Alberta (Radford 1975a, 1975b).

The gullible nature of cutthroat is aptly described by the following paragraph from Rohrer (1983):

> "Angler effort increased significantly in 1981 in Section 10 compared to previous years. However, as a result of implementation of special regulations in 1978, harvest has been greatly reduced. About 8,000 trout per 1.6 km reach were released in 1981. The population estimate for this reach was 4,500 trout per 1.6 km (1 mi). It is obvious that many trout are being caught-and-released several times." (The average trout was caught and released 1.8 times in a single season.)

Rainbow trout appeared to be somewhat less vulnerable to anglers since most relevant studies examined (i.e., comingled populations) showed a tendency for rainbow to partially replace cutthroat in the presence of heavy fishing, with a reversal occurring when cutthroat were given adequate protection from overfishing. Mullan (1961) rated hatchery brook trout more susceptible to angling than hatchery rainbow because the latter were "slower starters" in the spring due to cold water temperatures. However, the rainbow's vulnerability to anglers is perhaps best illustrated in the following passage from Pollard (1978):

> "A large proportion of juvenile steelhead trout in a stream can be removed with a moderate amount of angling. Age II steelhead are especially susceptible to angling, and 70 to 100% of those present in my 30 m study sections were removed with four man-hours of angling."

Vincent and Clancey (1980), in working with a combination of rainbow and brown trout, documented single season catch-and-release fishing rates that ranged from 83 to 101% of previous spring population estimates. This and other studies indicate that rainbow trout probably fall just below cutthroat in terms of potential for overfishing. In any case, rainbow and cutthroat are the most abundant and widespread trout species in the state, which requires that basic regulations be focused on their specific needs. Brook and brown trout angling can be liberalized by species-specific Regional or Special Regulations in some cases but their higher inherent resistence to angling pressure should not be used as a rationale for avoiding proper management of rainbow and cutthroat trout.

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Meet Resource Needs of Four Distinct Groups of Cutthroat/Rainbow Trout.

The weight of technical evidence available from the literature suggests that trout populations must be divided into at least four groups for purposes of developing a successful, statewide regulatory strategy. These groups and their needed control measures are as follows:

Migratory Resident Fish

Resident fish populations in the medium and larger-sized rivers of the state fall into this category. Typical characteristics are extensive upstream and downstream migrations plus significant mainstem and tributary interchanges. Substantial spawning often occurs in the tributaries where much of the juvenile rearing can also take place. The general situation is stated as follows by Johnson and Bjornn (1978):

> "Returns of fish tagged and released in the three study streams indicate that cutthroat trout migrated upstream into the upper drainages" (study areas) "in the spring and early summer, few cutthroat moved during the summer, and cutthroat migrated downstream to lower portions of the drainages in the fall. Downstream fall migrations of cutthroat trout probably increased their overwinter survival."

The following specifics for an individual system were provided by Thurow (1980):

> "Wild cutthroat trout exhibit the following movement patterns based on tag recoveries and trapping operations. Mature trout migrate from Blackfoot Reservoir and ascend the Blackfoot River during March, April and May. A majority of these trout enter the Upper Valley tributaries and spawn in May and June and a portion spawn in the main Blackfoot River. Following spawning, spent trout re-enter the river. Progeny of these spawners rear in tributaries of the Blackfoot River for varying periods of less than one year to two years. Juvenile cutthroat eventually enter Blackfoot Reservoir where they mature as age class III+, IV+ or V+ trout. Both juvenile and adult cutthroat migrate down the Blackfoot River in the fall to deep-water areas of the river and reservoir."

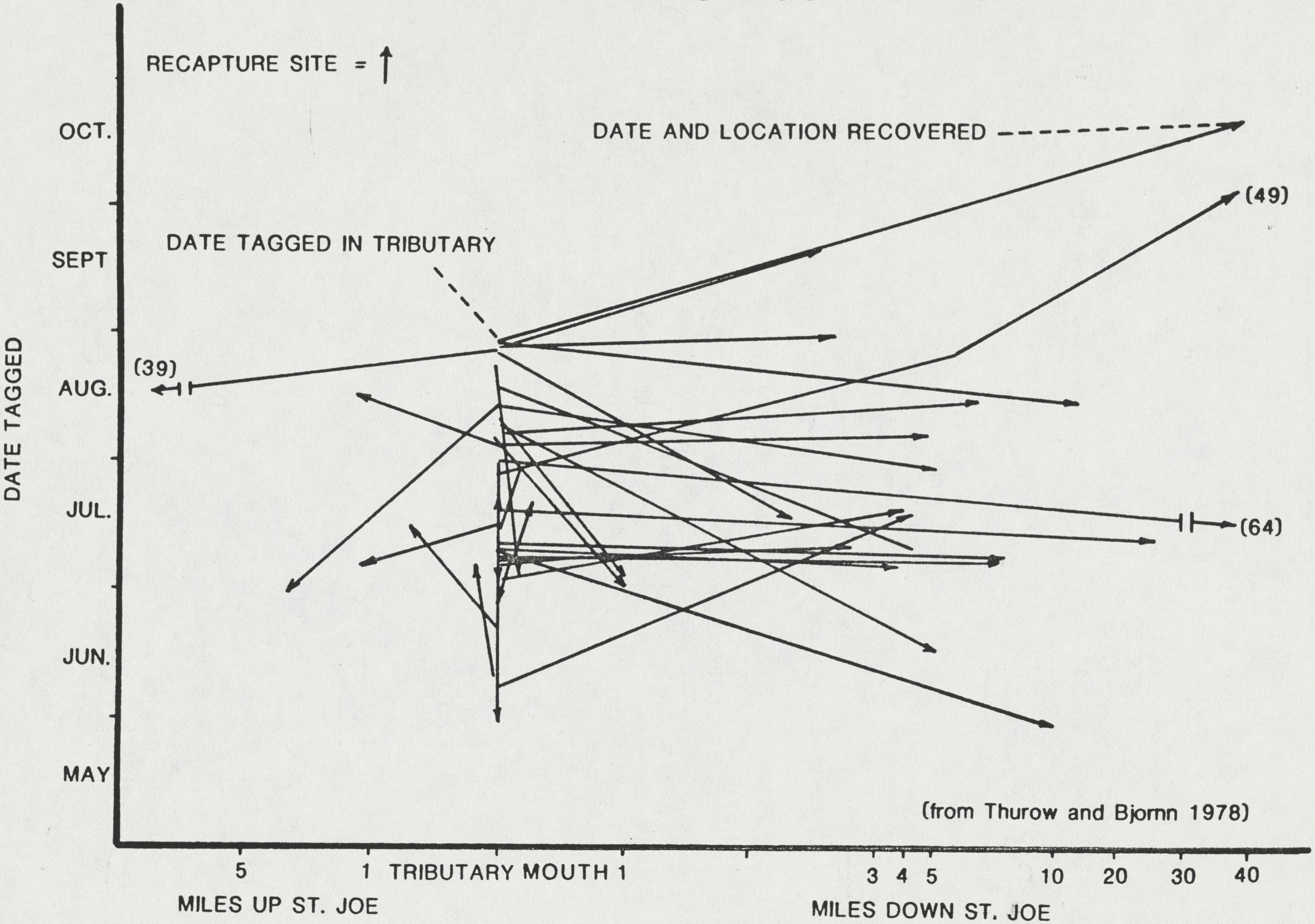
Other studies produced similar findings regardless of whether the population involved utilized a reservoir, lake or only a river mainstem. Figure 13 illustrates the extensive migration potentials for individual fish.

Homing of mature adults is strong, since Ball (1955) reports that 96.8 percent of the returns from a tagged sample of 17,836 fish were later recovered in the same stream as tagged. Homing for immatures is also strong, with Benson and Bulkley (1963) stating that 19.9 percent of 644 fin-clipped trout survived and returned to the same stream as marked and none to any other sampled stream.

These are the types of populations that have been successfully managed in other states and Canada by 12 or 13" minimum size limits in mainstem areas, including lakes and reservoirs, if applicable. These controls were initially implemented for "trophy fish" management objectives but produced dramatic increases in trout populations and typically cured serious over-fishing condi-

FIGURE 13

TWO YEARS MIGRATIONS OF TAGGED CUTTHROAT TROUT IN THE ST. JOE RIVER



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tions that were not recognized at the onset.

Johnson and Bjornn (1978) showed the following changes for cutthroat trout in the upper St. Joe River after implementation of a 13" minimum size limit:

Factor	Change
Annual mortality rates for age III+ cutthroat	Declined to a range of 0.47 to 0.56 from a previous range of 0.62 to 0.71.
Abundance of all sizes of cutthroat	Increased by 300% in road access areas, 600% in trail access areas. (NOTE: areas with good access will typically have higher losses from hooking mortality and poaching.)
Abundance of spawning cutthroat	Increased by 10 times.
Angler effort	No change.
Catch per hour	Increased to 2.5 fish from a previous 0.2 fish average.
Total catch (retained and released)	Increased by 500%.

The increases in numbers of larger fish observed during snorkeling transects is depicted graphically in Figure 14.

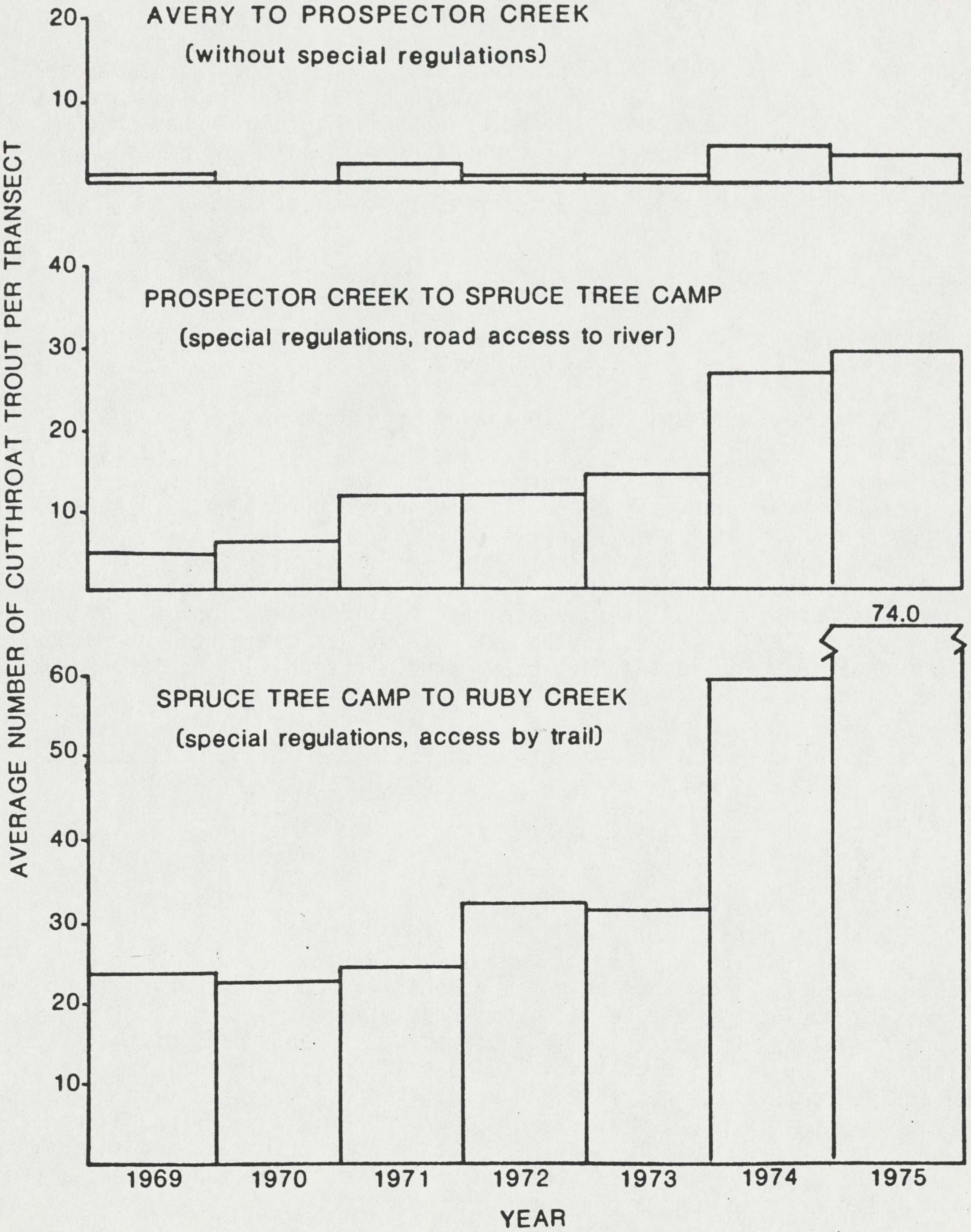
A major increase in rainbow trout abundance was recently recorded for Oregon's famous Deschutes River fishery subsequent to implementation of a 12" minimum size limit in 1979. The following data illustrate changes in abundance of fish from a 1979 low in the Neva Creek study section (Griggs 1982 and MS in preparation):

Year	Number of Rainbow Trout over 7.5"/km.
1974	812
1975	857
1979	389
1981	844
1982	2,498
1983	2,422

Fishery managers from other agencies generally recommend that controls or regulations be applied to <u>entire</u> mainstem areas utilized by a given trout population, including a lake or reservoir, if applicable. If only part of the system is protected by positive controls (such as 12 to 13" minimum size limits), the desired population response can be negated by in-system fish migrations. An example of this problem is seen in the work of Llewynsky and Bjornn (1983) on the Coeur d'Alene River. They found that some fish remained in the "special regulation" or protected areas throughout the year, but many others migrated through two or more regulatory zones.

FIGURE 14

AVERAGE NUMBER OF CUTTHROAT TROUT PER SNORKELING TRANSECT, ST. JOE RIVER



(from Johnson and Bjornn 1978)

Where data are available for individual systems, minimum size limits should be set specific to the data base in-hand so that one age class of females is allowed to spawn at least once. Where river-specific data are not available, a 12" minimum size limit has the best chance of success and should be applied to the mainstem fishery. In addition, it is necessary to protect juveniles rearing in the tributaries through their second year by an 8-inch minimum size limit or the assured recruitment objective can also be compromised. Thurow and Bjornn (1978) state the needed control measure as follows:

> "Although juvenile migratory cutthroat trout may attain lengths of 200-250 mm (8-10 inches) in tributaries, most of them migrate from tributaries at lengths of 120 to 220 mm. An 8-inch size limit would effectively reduce the harvest, since 74 percent of the harvest in Big Creek consisted of cutthroat trout less than 8 inches long."

The critical juvenile rearing area usually encompasses the lower one to three miles of larger tributaries but many exceptions can be anticipated (all of the above can only be conclusively proven by expensive, river-specific studies). Overlaps are also common as revealed by Thurow and Bjornn (1978):

> "First, two stocks of cutthroat trout (resident and migratory) are present in tributaries of the St. Joe River we studied. These stocks are partially segregated; resident trout are present throughout the streams and migratory stocks are primarily in the lower three miles of the streams."

Steelhead

Due to the existence of treaty Indian fishing virtually statewide on steelhead, there is little choice in terms of options for managing adult populations. Run sizes must be accurately quantified on a river-by-river basis and all fishing must be actively managed to achieve the proper balance between catch and spawning escapement requirements. Individual river basin plans have been developed for most of the medium-sized and larger drainages in the state and these plans have guided all recent fishery management decisions. Detailed objectives, standards and guidelines for steelhead management were developed by the WDG staff, endorsed by the Game Commission and implemented by WDG in 1983. All of the above are available to interested parties. It would be redundant and serve no useful purpose to include their contents in this report. (NOTE: The amount of space devoted to steelhead in this particular effort is definitely not proportional to their importance to the State of Washington and its recreational anglers.)

However, Washington's juvenile steelhead commonly rear for two years in freshwater and can provide major "trout" fisheries if allowed by the prevailing regulations. The magnitude of potential catches is alarming. For example, Keating (1968) estimated that 30,000 to 35,000 wild juvenile steelhead were harvested annually during the late 1960's and early 1970's from the Lochsa River above Boulder Creek. (Keating's 1966 point estimate of 38,141 steelhead from 124 km. of stream gives a value of 307 fish/km.) The breadth of the potential problem is illustrated by the following statement from Pollard (1978):

> "Many tributaries of the Snake River in Idaho are spawning and rearing areas for steelhead trout (Salmo gairdneri). Juvenile steelhead make

up a substantial part of the sport fishing harvest in these areas."

Quantitative assessments for Washington streams are quite limited but indicate relatively modest harvests. For example, a 1975 summer creel census on the mainstem of Puget Sound's Green River produced a seasonal harvest estimate of only 4,300 juvenile steelhead when the 6" minimum size limit was still in effect (Collins et al 1975).

More recently, a 10" minimum size limit has been widely used as a Special Regulation in larger streams of western Washington in conjunction with a delayed opening in late May to protect concentrations of steelhead smolts until they have migrated seaward. This approach has generally been very effective (particularily as contrasted to the Idaho situation of the early 1970's), although one problem still exists. The 10" minimum is not applied to many of the smaller streams where juvenile steelhead rearing occurs and some of these populations, despite their marginal attractiveness to the "average" angler, are exploited to provide summer and fall "trout" fisheries. In addition, a 10" minimum does not adequately protect any migratory resident fish populations (rainbow or cutthroat), including those that overlap with juvenile anadromous fish populations.

The necessary broad protection required for juvenile steelhead can, for practical purposes, be provided by a basic minimum size limit of 8" in streams. Only a very small percentage of juvenile steelhead will exceed 8" during times when trout fisheries are allowed.

Exceptions to the above generalization are some naturally-produced steelhead smolts that rear for three years in freshwater and hatchery-produced smolts that "hold-over" for an additional year of freshwater rearing. Normally, neither of these groups makes an important contribution to Washington steelhead runs. However, it has recently been determined that hold-over hatchery smolts are providing a significant component in adult returns to some upper Columbia River tributaries. Therefore, a 12" minimum size limit is recommended for the Columbia River mainstem and those tributary areas where this specific situation prevails.

(NOTE: In areas where migratory resident trout and/or sea-run cutthroat are also present, more restrictive controls must be utilized to meet their specific management needs. In addition, some lower mainstem areas that hold concentrations of smolts past mid-May will require delayed season openings through Special Regulations.)

Non-migratory Resident Fish

These diverse populations occur in hundreds of small stream sections throughout the State that are upstream from or overlap (permanently or intermittently) with both anadromous and migratory resident fish habitats. The various populations, which literally number in the thousands, are often isolated from each other by migratory barriers but recruitment from upstream populations can occur. This latter aspect was explained as follows by Michael (1981):

> "In populations of fish which exist upstream of an impassable barrier, any fish passing over that barrier is lost to the population. Unless the fish spawns prior to its downstream migration, the migratory urge is "lethal" as far as the population is concerned."

The potential for extremely limited ranges is described by Mullan (1961):

> "Contrary to some opinions, trout can and do carry out all the functions of life, including reproduction, within relatively limited areas of stream,

allowing that such an area meets the requirements mentioned. Several studies concur that such a territory generally approximates less than 200 feet of stream."

A good substantiation of this was provided by Hunt (1970) in describing why a closed area or "refuge" failed to increase numbers of fish available in adjacent open fishing areas. He states:

"Only 1% of the catch (45 of 4,695) consisted of trout that had emigrated from the refuge. During the fishing season when the refuge zone had been open to fishing, 21% of the total catch was made there. Most of the trout born in the refuge stayed there throughout their life."

In Gorge Creek, Alberta, Miller (1967) observed that many resident trout retained home ranges no larger than a single pool-riffle complex. The same situation was reported in tributaries of the St. Joe River by Thurow and Bjornn (1978). Their studies showed that only 7% of tagged cutthroat trout recovered in tributaries were 0.5 mile or more from the release site.

The fishery management problems that this multitude of separate trout populations generates is made virually impossible by highly variable growth rates. Purkett (1951) documented the following differences for rainbow trout in two sections of the West Gallatin River, Montana:

Year of Growth	Difference in Average Length
First	0.3 inch
Second	1.3 inch
Third	2.1 inches
Fourth	2.5 inches
Fifth	4.0 inches

Growth of cutthroat trout showed a similar trend with both species growing faster at lower elevations where the water was warmer. The average summer difference in early morning water temperature between the upper and lower studies sections was 9.6°F.

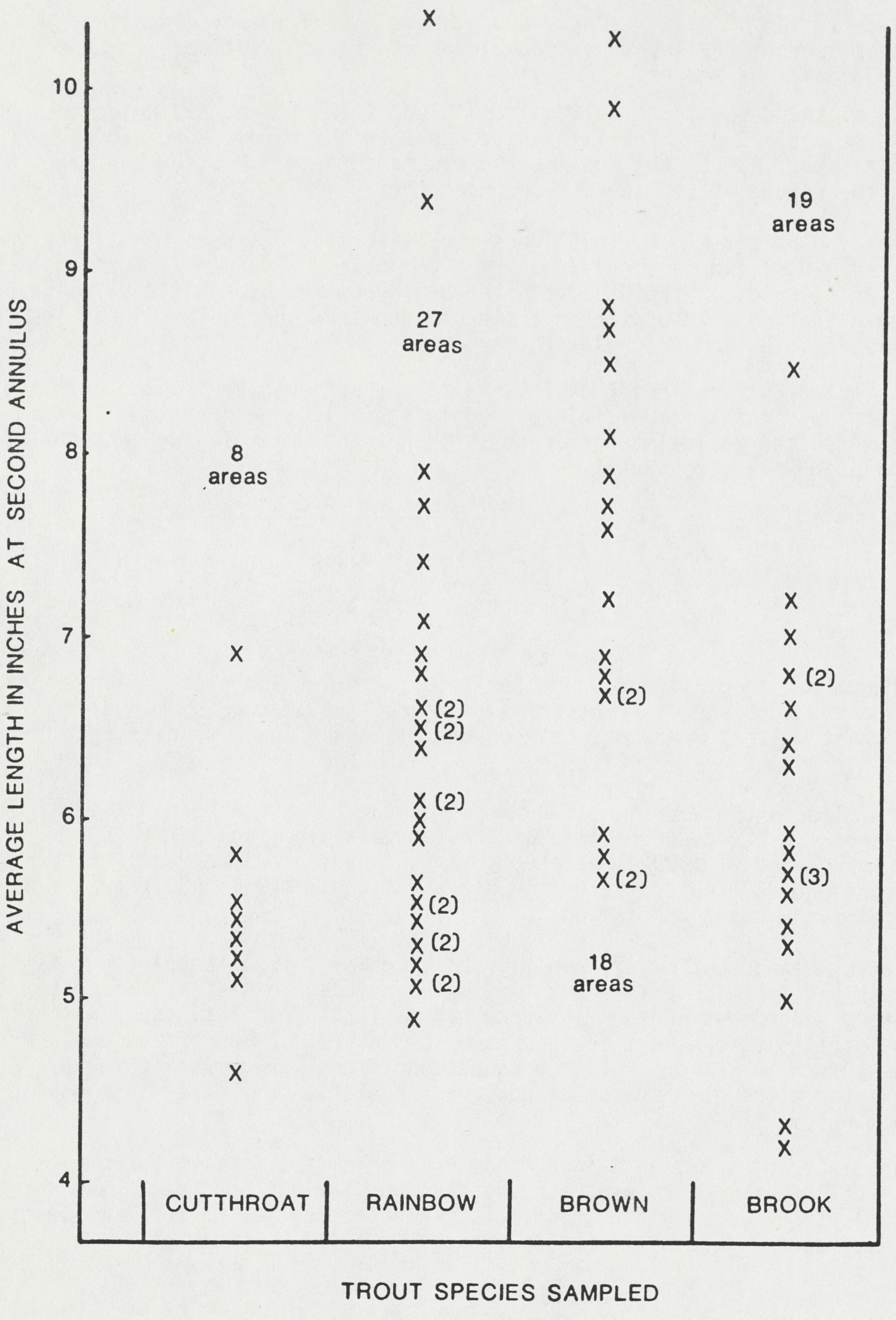
Sweeney et al (1981) checked five tributaries of the North Fork Snoqualmie River and found ranges in the average sizes of trout populations from 3.2 to 5.0 inches. Wetherbee et al (1982) reported that two study areas on Maude Creek one mile apart and 250 feet different in elevation had a 0.5 inch difference in average size of the trout population.

Proper, precise management of all non-migratory resident trout populations is simply impossible, particularly since they often overlap in distribution with juveniles from anadromous and/or migratory resident fish populations. Zones of overlap are difficult to detect in any known cost-effective manner and can change from season to season as fish passage conditions vary. As Figure 15 illustrates, there are no distinct "groups" of population size distributions to facilitate management.

However, as stated earlier, an 8-inch minimum size limit effectively protects both the juveniles from migratory resident fish populations and most juvenile steelhead. It should also yield an adequate spawning population for a majority of the non-migratory resident trout populations.

FIGURE 15

GROWTH OF TROUT IN MONTANA



(from Bailey 1961)

Many non-migratory resident trout populations will be comparable to the situation observed by Hess (1982) for cutthroat trout in lower Columbia River tributaries. Maturity data were not provided, but it is probable that most females would have spawned at the beginning of their third year. Thus, this type of population would have assured recruitment due to the protection provided by an 8" minimum size limit. However, many non-migratory resident trout populations with very small individuals have also been documented. An example is data from Parks Creek (Wetherbee et al 1982) which shows a noticeably smaller size distribution than the previous example for lower Columbia River tributaries. In spite of the small size of individual fish, the population appeared healthy with an estimated 821 trout per mile of stream. For these types of populations, no minimum size limit is needed. As earlier evidence indicated, the fish will probably receive more than adequate protection simply because they are below the preferred retention size for most stream anglers. Continuation of the current 6" minimum would provide an unnecessarily restrictive catch-and-release only situation.

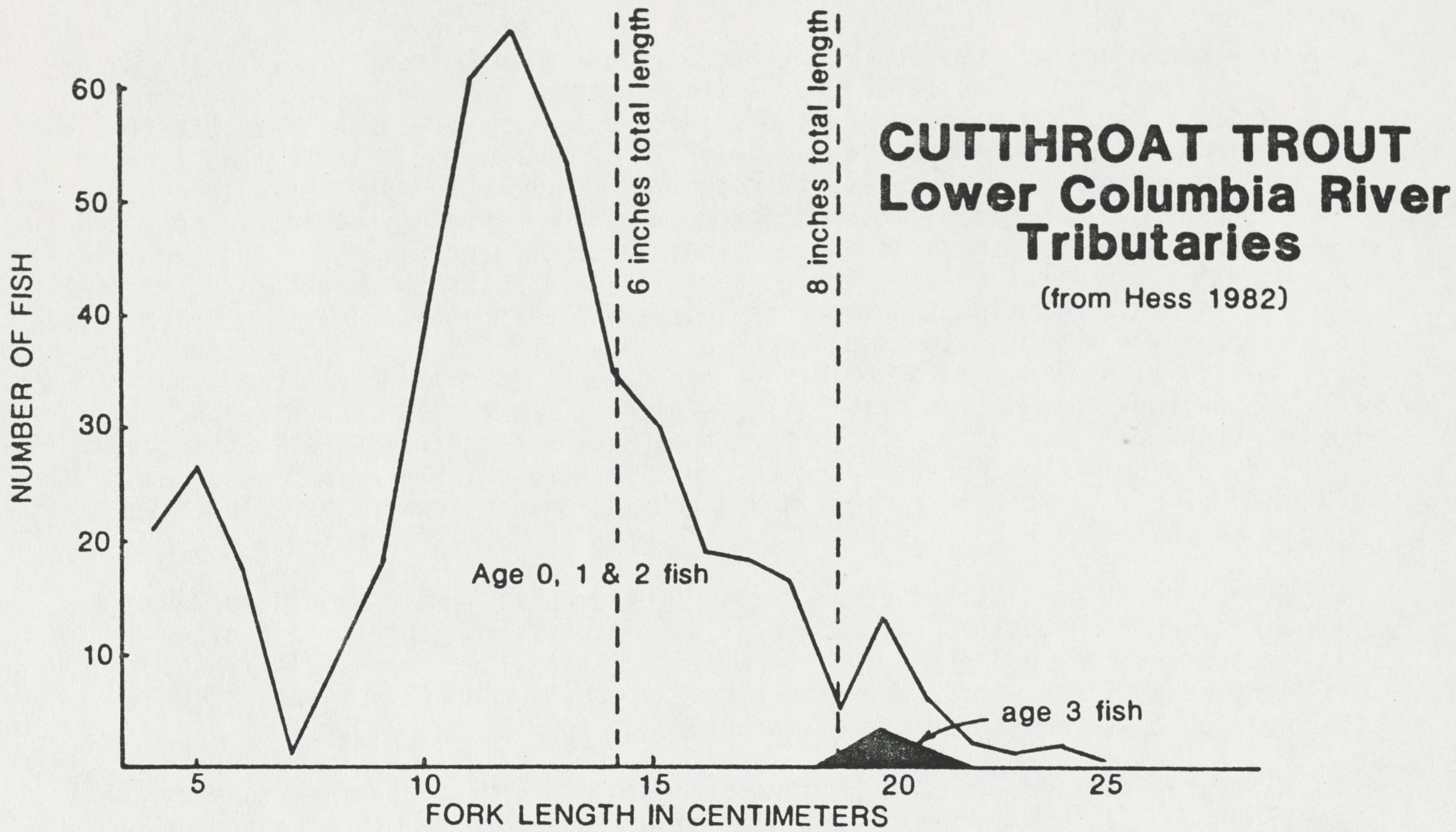
Stream trout populations requiring no minimum size limits should be managed with Special Regulations, preferably on the basis of geographic regions or "zones" rather than on individual waters. It will be impossible to accomplish very much by the latter approach since literally hundreds of interfaces and overlap zones exist for the different trout populations.

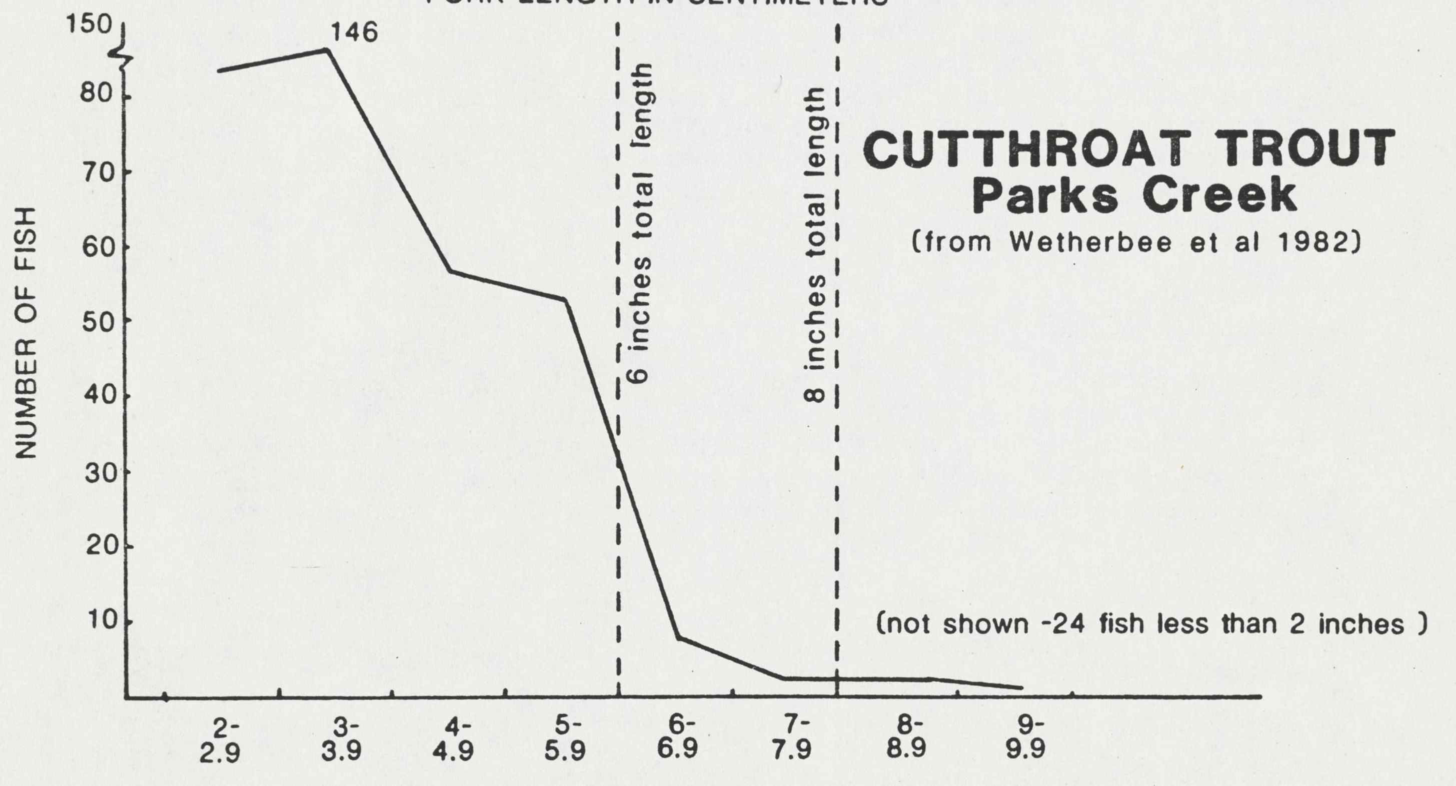
As stated earlier, it will be impossible to manage all non-migratory resident trout populations correctly and some significant degree of catch-and-release only fishing will be the practical, albeit inadvertent, consequence of the management strategy proposed. However, anadromous and migratory resident trout populations offer the greatest overall potential for recreational benefits and generally have the more restrictive conservation needs. When either of these factors are balanced against the possible over-protection of some non-migratory resident trout populations, the answer is obvious - manage for the former.

Sea-Run Cutthroat

Sea-run cutthroat, with their highly variable life history traits, seemingly present an impossible fishery management problem. However, the weight of available evidence indicates that severe overfishing has occurred, an indictment on present approaches to management. The following summarizes 1982 qualitative assessments of WDG Region IV sea-run cutthroat trout resources:

FIGURE 16


CUTTHROAT TROUT
Lower Columbia River
Tributaries
(from Hess 1982)
NUMBER OF FISH
60
50
40
30
20
10
6 inches total length
8 inches total length
Age 0, 1 & 2 fish
age 3 fish
5
10
15
20
25
FORK LENGTH IN CENTIMETERS


CUTTHROAT TROUT
Parks Creek
(from Wetherbee et al 1982)
NUMBER OF FISH
150
146
80
70
60
50
40
30
20
10
6 inches total length
8 inches total length
(not shown -24 fish less than 2 inches)
2-
2.9
3-
3.9
4-
4.9
5-
5.9
6-
6.9
7-
7.9
8-
8.9
9-
9.9
TOTAL LENGTH IN INCHES

Area	Stock	Population Status	Population Trend
Puyallup River[1]	Late entry native	remnant[2]	unknown
White River	Late entry native	remnant[2]	unknown
Cedar River[3]	Early entry native	weak[2]	unknown
Sammamish River[3]	Early entry native	weak	unknown
Snoqualmie River[1]	Early entry native	moderate	unknown
Tolt River[1]	Early entry native	weak	unknown
Raging River[1]	Early entry native	weak	unknown
Snohomish River	Early entry native	moderate	unknown
Pilchuck River[1]	Early entry native	unknown[3]	unknown
Skykomish River[1]	Early entry native	moderate	unknown
N.Fk. Skykomish R.[1]	Early entry native	moderate	unknown
Sultan River	Early entry native	unknown	unknown
Wallace River[1]	Early entry native	unknown	unknown
Stillaguamish River	Early entry native	weak	unknown
Pilchuck Creek	Early entry native	weak	unknown
N.Fk. Stillaguamish R.[1]	Early entry native	weak	unknown
S.Fk. Stillaguamish R.[1]	Early entry native	weak	unknown
Canyon Creek[1]	Early entry native	weak	unknown
Sauk River[1]	Early entry native	weak	unknown
Skagit River	Early entry native	moderate	unknown
Cascade River[1]	Early entry native	moderate	unknown
Samish River	Early entry native	moderate	declining
Squalicum Creek	Early entry native	moderate	unknown
Dakota Creek	Early entry native	unknown	unknown
Nooksack River	Early entry native	unknown	unknown
M.Fk. Nooksack R.[1]	Early entry native	unknown	unknown
N.Fk. Nooksack R.[1]	Early entry native	unknown	unknown
S. Fk. Nooksack R.[1]	Early entry native	unknown	unknown

[1] These areas are not principal harvest areas. These fish utilize small tributaries and headwaters for breeding.

[2] Insufficient numbers to attract a fishery.

[3] These may, in fact, be resident "lake-run" fish.

Note: Assessments were also made for Dolly Varden in 13 of the above areas. All population assessments were listed as "unknown".

Of the 20 areas given ratings other than "unknown", ten were rated as "weak", eight as "moderate" and two as "remnant". Perhaps most disturbing is the fact that population trends were listed as "unknown" for 27 of 28 cases.

Johnston (1981) provided the following six sea-run cutthroat life history traits that are critical for any fishery management planning:

"1) Selection of spawning and fry rearing areas in tiny headwater tributaries upstream from more dominant salmonids.

2) Age and size are greater for smolts migrating directly into the open ocean than for smolts migrating into protected inland saltwater areas.

3) Few over-winter in salt water; most return to freshwater coincidental to adult salmon migration timing.

4) In most Oregon and Washington coastal rivers (other than the Columbia), stocks are sexually mature at first return to freshwater, whereas a large percentage of Columbia River, Puget Sound, British Columbia and Alaska cutthroat females do not spawn during the winter of first return to freshwater; a migratory behavior apparently evolving from younger smolting age and historically abundant food source (salmon eggs).

5) Spawning fish home precisely to specific tributaries while non-maturing fish do not always return to their home stream to feed or when seeking an over-winter habitat.

6) Two distinct migration times in Puget Sound and Southern British Columbia: September - October for large rivers and January - February for smaller streams flowing directly to saltwater, probably an adaptation to flow conditions and food availability."

Fishery management must account for these various life history traits. However, the basic need is clear - provide assured recruitment by maintaining overall fishing rates from all sources at or below the levels necessary to provide adequate spawning populations. As stated previously, the only viable alternative for positive control would be a cost-prohibitive approach parallel to that practiced for steelhead.

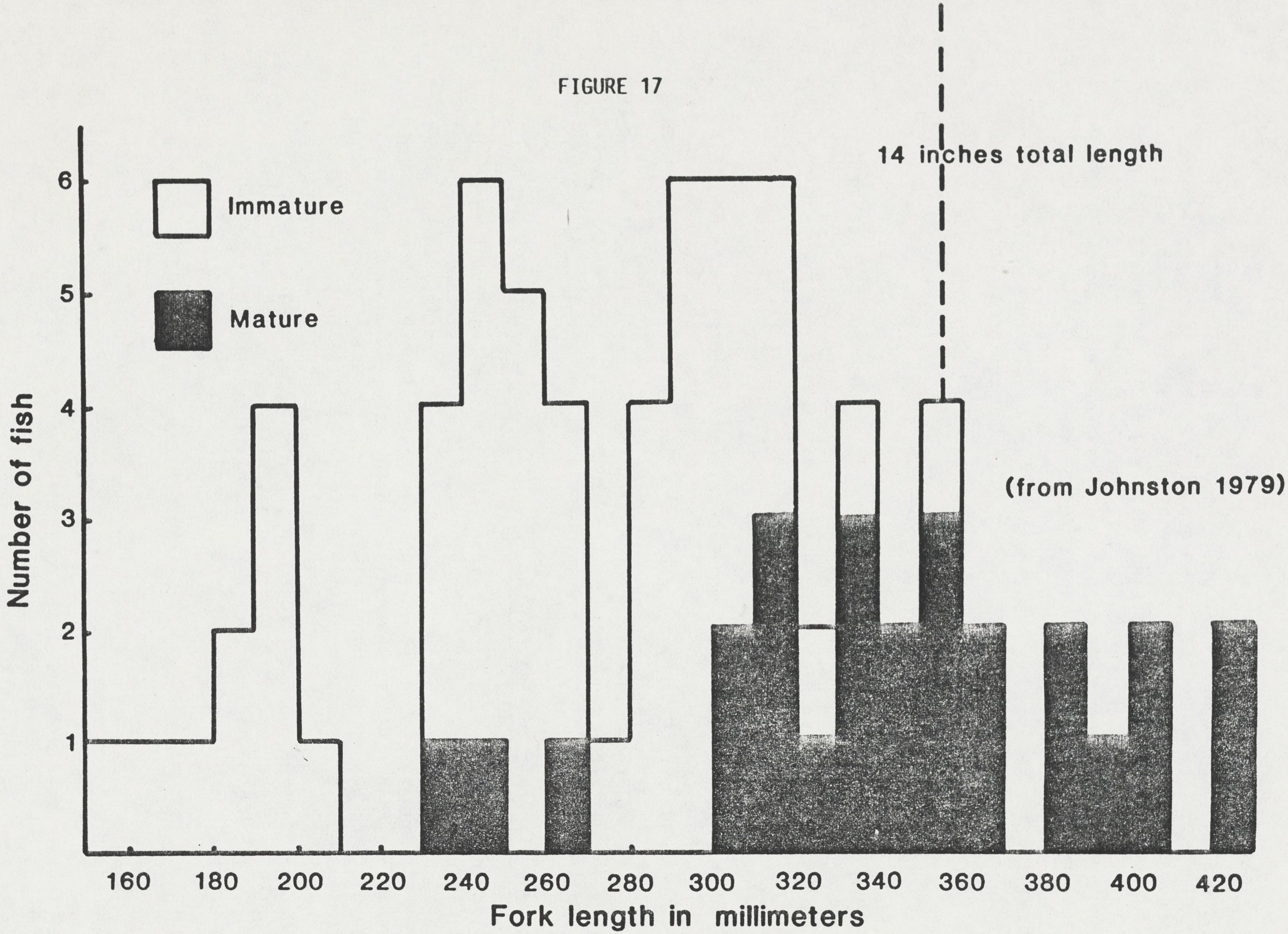
A 14" minimum size limit is the critical, direct control element needed since it would accomplish the following:

1) protect all immature females during their initial upstream migration from saltwater in Puget Sound and the Columbia River; and

2) protect an average of approximately 70% of maturing females in all areas prior to their maiden or initial spawning.

The degree of protection provided is illustrated graphically in Figure 17.

FIGURE 17



SIZE/MATURITY OF FEMALE SEA-RUN CUTTHROAT
IN THE 1978 STILLAGUAMISH RIVER CREEL CENSUS

The 14" standard should be broadly implemented by Special Regulations in medium to large-sized streams throughout most of western Washington. (NOTE: This will also meet conservation needs of any migratory resident trout populations in these same waters.) In addition, all marine waters should also be managed with a 14" minimum size limit and two fish daily bag limit. Since the primary game fish target species is sea-run cutthroat, the basic conservation needs of marine and freshwater areas are identical. This proposed change will also eliminate most regulatory and enforcement problems associated with river mouth definitions and different regulations at the major interfaces between fresh and saltwater. (NOTE: Protective measures previously described for juvenile steelhead will also adequately protect juvenile sea-run cutthroat prior to their initial migration to marine waters.)

SUMMARY OF TROUT MANAGEMENT PROPOSALS

In implementing any management strategy, basic regulations should cover the most common situation, with Special Regulations handling the exceptions. Therefore, the following regulations would be needed to implement the proposed plan:

Trout in Lakes, Ponds, and Reservoirs

Basic regulations would be simplified and liberalized by dropping the 6" minimum size limit plus the 3 over 14" and 2 over 20" restrictions. The 8 and 5 fish daily bag limits would be retained for adults/licensed juveniles and unlicensed juveniles, respectively. Bait fishing would be allowed (as in the past) but catch-and-release angling would continue to be limited to specified catch limits only. Areas with different management needs, particularily those with important wild fish populations, would continue to require attention via Special Regulations.

Trout in Rivers, Streams, and Beaver Ponds

Basic regulations would be made more restrictive by implementation of an 8" minimum size limit and a general prohibition on bait fishing in streams during the late-May through October time period. (NOTE: Bait would continue to be allowed for all winter steelhead and whitefish fisheries plus hatchery fish management zones, marine area fisheries, summer-run steelhead fisheries and non-migratory resident trout fisheries with no minimum size limits.) Basic regulations would be liberalized by use of possession limits instead of catch limits in all cases where the use of bait is prohibited. This would provide broad, new opportunities for legal catch-and-release trout fishing in streams. The 8 and 5 fish bag limits would be retained for adults/licensed juveniles and unlicensed juveniles, respectively. The 3 over 14" and 2 over 20" regulations would be replaced by a single, more restrictive standard - 2 trout over 12".

The two-day possession limit concept for steelhead management would be retained.

The basic regulations listed above would fulfill the following broad fishery resource management objectives:

- For tributary-rearing juveniles from migratory resident fish populations.
- For most juvenile steelhead.
- For most adult winter-run steelhead.

- For a majority of non-migratory resident trout populations.
- For sea-run cutthroat juveniles prior to their initial migration to saltwater.

Nine categories of Special Regulations for rivers, streams, and beaver ponds, their changes from basic regulations, and the resource management needs fulfilled would be as follows: (NOTE: Current SELECTIVE FISHERIES REGULATIONS would be eliminated.)

1. Designated Stream Zones Managed for Hatchery Fish (catch limits apply).
   - For optimum hatchery trout management (normally no minimum size limit and bait allowed).

2. Delayed season opening.
   - For use in any individual waters requiring additional protection for spawning trout, spawned-out adults and/or outmigrant smolt concentrations.

3. Bait allowed (catch limits apply).
   - For use in fisheries targeted on summer-run steelhead.

4. More restrictive regulations for Dolly Varden or bull trout (may also be implemented on a Regional basis).
   - For specific management needs of two less common trout species.

5. More liberal regulations for brook or brown trout (may also be implemented on a Regional basis).
   - For specific management needs of two less common trout species.

6. 12" minimum size limit.
   - For most migratory resident trout populations in mainstem areas, including a lake or reservoir, if applicable.
   - For large steelhead smolts in the Columbia River mainstem and applicable tributaries with "hold-overs".

7. Data-specific minimum size limit.
   - For migratory resident trout populations in mainstem areas (including a lake or reservoir, if applicable) where specific population data are available.

8. No minimum size limit and bait allowed (catch limits apply).
   - For non-migratory resident trout populations with small individual fish (preferably on a geographic basis, not individual waters).

9. 14" minimum size limit.
   - For marine waters and mainstem river areas with important sea-run cutthroat populations.
     (NOTE: Since seasons for winter steelhead fishing will continue to require Special Regulations, most of the 14" minimum size limits can be implemented by revision of current regulations, not completely new entries.)

The regulation categories described above will not address all conceivable trout management problems. Whenever different trout species or populations are comingled (top portion of Figure 18), the professional manager must determine the "target" or most important population for fishery management purposes. Fortunately, there is usually a valid technical basis for making this distinction (bottom portion of Figure 18) even if this entails different regulation zones in the same river system. In addition, other Special Regulations will continue to be required in response to the management needs of important non-trout game fish resources that also utilize Washington's stream habitats.

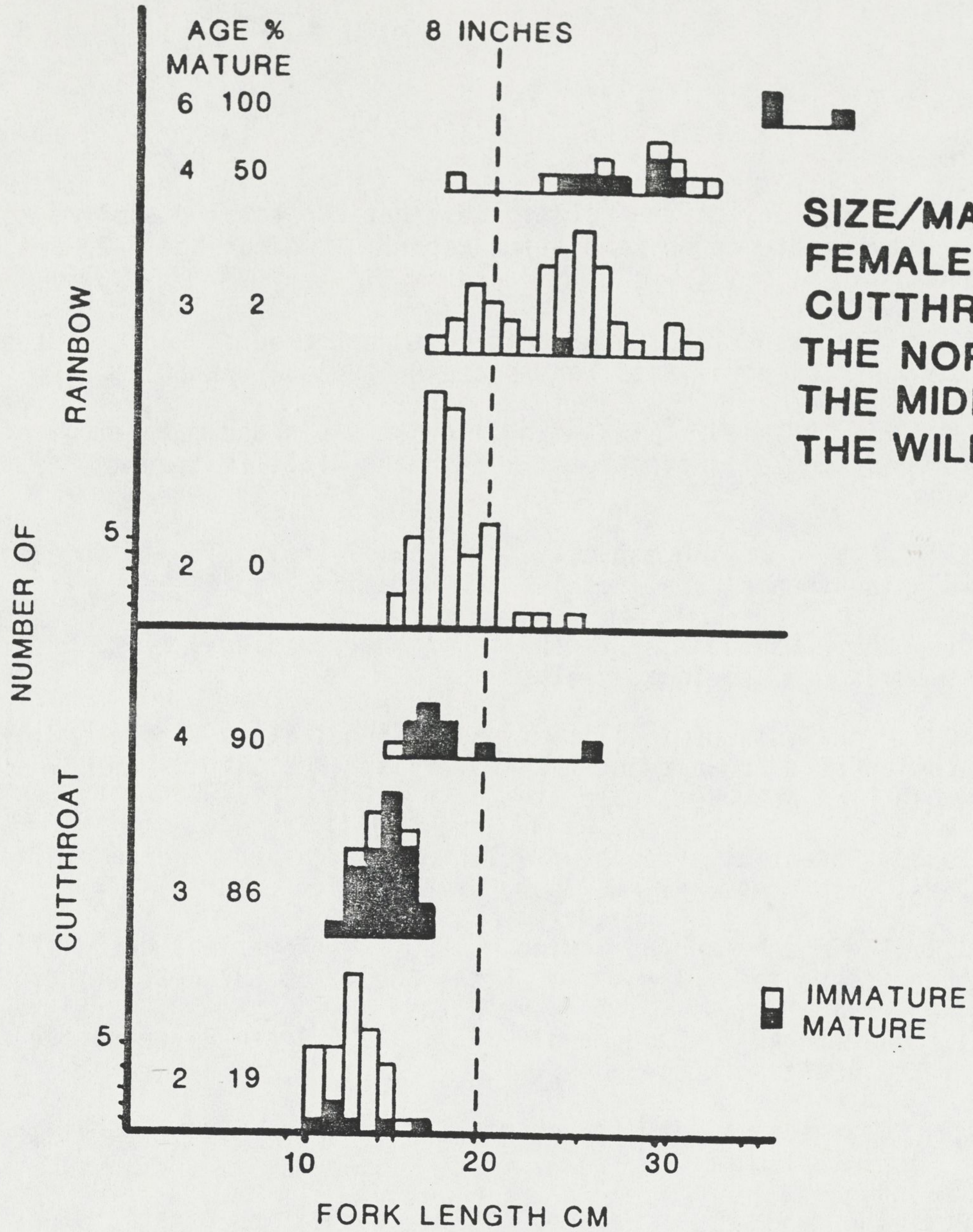
THE NEED FOR A CATCH REPORTING CARD FOR TROUT IN STREAMS

Successful long-term management of trout populations in streams requires that accurate catch statistics be provided on a permanent, consistent basis. Creel census should continue on a limited basis but only to the extent that it is needed to calibrate a report card system and meet other essential resource management objectives such as collection of size, age, sex and maturity data. Needed catch statistics for steelhead, sea-run cutthroat and migratory resident trout populations must come from the only available cost-effective alternative available - a catch reporting card for trout fishing in streams. To be workable, only fish 12 inches or larger would be recorded on the card.

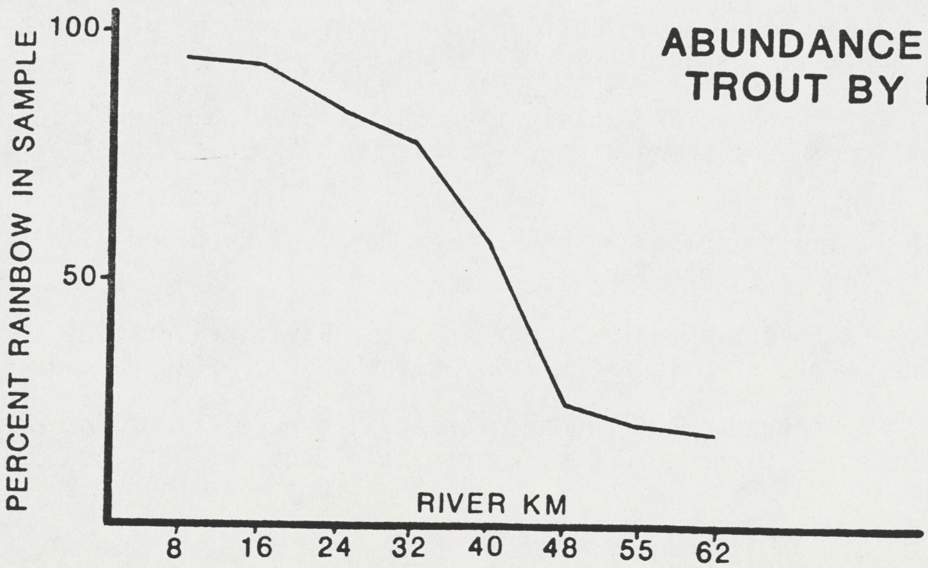
Additional recommendations are as follows:

1. A modified steelhead-type punchcard would be developed with the following codes: (1) wild steelhead, (2) hatchery steelhead, (3) resident rainbow, (4) sea-run cutthroat, (5) resident cutthroat, (6) Dolly Varden or bull trout; (7) other.
2. Only those anglers fishing for steelhead would be required to purchase a punchcard. Cards would be issued to non-steelhead stream fishermen with only a service charge.
3. Steelhead annual limits would not be altered, no other new annual limits would be established.
4. Completed (filled) cards could be exchanged for new cards at any Game Department office, including by mail.
5. Catch reporting cards would be required to fish in all stream areas except hatchery trout management zones.

FIGURE 18



SIZE/MATURITY OF FEMALE RAINBOW AND CUTTHROAT TROUT IN THE NORTH FORK OF THE MIDDLE FORK OF THE WILLAMETTE RIVER



ABUNDANCE OF RAINBOW TROUT BY RIVER AREA

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